Mapping the Sedimentary Rocks and Crustal Structure of the Nechako Basin, British Columbia (NTS 092N, O, 093B, C, F, G), Using Teleseismic Receiver Functions

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Kim, H.S., Cassidy, J.F., Dosso, S.E. and Kao, H. (2009): Mapping the sedimentary rocks and crustal structure of the Nechako Basin, British Columbia (NTS 092N, O, 093B, C, F, G), using teleseismic receiver functions; *in* Geoscience BC Summary of Activities 2008, Geoscience BC, Report 2009-1, p. 163–170.

Introduction

This paper describes a passive-source seismic mapping project in the Nechako Basin of central British Columbia, with the goal of assessing the hydrocarbon and mineral potential of the region. Over the last decade, an explosion of the mountain pine beetle population in central BC has devastated the lodgepole-pine forest industry on which many communities depend. Mineral or energy extraction may provide an alternative economic opportunity for the region. The Nechako Basin has been the focus of limited hydrocarbon exploration since the 1930s. Twelve exploratory wells were drilled, and oil stains on drill chip samples, as well as the evidence 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 in this region. This study will utilize recordings of distant earthquakes to map sediment thickness, crustal thickness and overall geometry of the Nechako Basin. An array of seven seismic stations were deployed in September 2006 (Table 1, Figure 1) to sample a large area of the basin and two additional seismic stations were deployed in October and November 2007 (Table 1, Figure 1) due to unexpected local earthquake swarms (Cassidy et al., 2008b). This study will complement independent active-source seismic studies planned for the region by providing site-specific images and constraints on the shear-wave velocity structure. This research will also complement magnetotelluric (MT) measurements currently underway (Spratt and Craven, 2009), providing critical new information on porosity, fractures and fluids. This paper describes the methods that are being used, data collection, progress of calculation and inversion for receiver functions, some preliminary results and future work. In addition, there is an ambient noise study being conducted by the University of Manitoba (Idowu et al., 2009). It will complement the receiver function study, which provides site-specific information beneath the recording stations by generating models that average the velocity structure between pairs of stations using data from the same seismic stations as the receiver function study.

Table 1. Locations of broadband seismic stations in the Nechako Basin. Stations ALRB, CLSB, FLLB, RAMB, SULB, TALB and THMB were deployed in September 2006; stations UBRB and FPLB were deployed in October and November 2007.

Seismic Station Location	Code	Latitude	Longitude	Elevation (km)
Anahim Lake, BC	ALRB	52.510	-125.084	1.237
Cack lake[1] seismic station, BC	CLSB	52.759	-122.555	0.792
Fletcher Lake, BC	FLLB	51.739	-123.106	1.189
southwest Quesnel, BC	RAMB	52.632	-123.123	1.259
south of Vanderhoof, BC	SULB	53.279	-124.358	1.171
Tatla Lake, BC	TALB	52.015	-124.254	1.127
Thunder Mountain, BC	THMB	52.549	-124.132	1.126
upper Baezaeko River, BC	UBRB	52.890	-124.083	1.243
Fishpot Lake, BC	FPLB	52.954	-123.779	1.005

[1] unofficial place name

Methodologies

Receiver Function Analysis

The technique used in this study is receiver function analysis, in order to constrain the shear-wave velocity structure. In this method, locally generated P- to S-wave conversions in P waves from distant earthquakes (teleseisms; Figure 2; Cassidy, 1992, 1995; Eaton and Cassidy, 1996) are used to map major discontinuities beneath the nine three-component seismic stations deployed across the Nechako Basin

Keywords: *geophysics, Nechako Basin, seismology, S-wave velocity*

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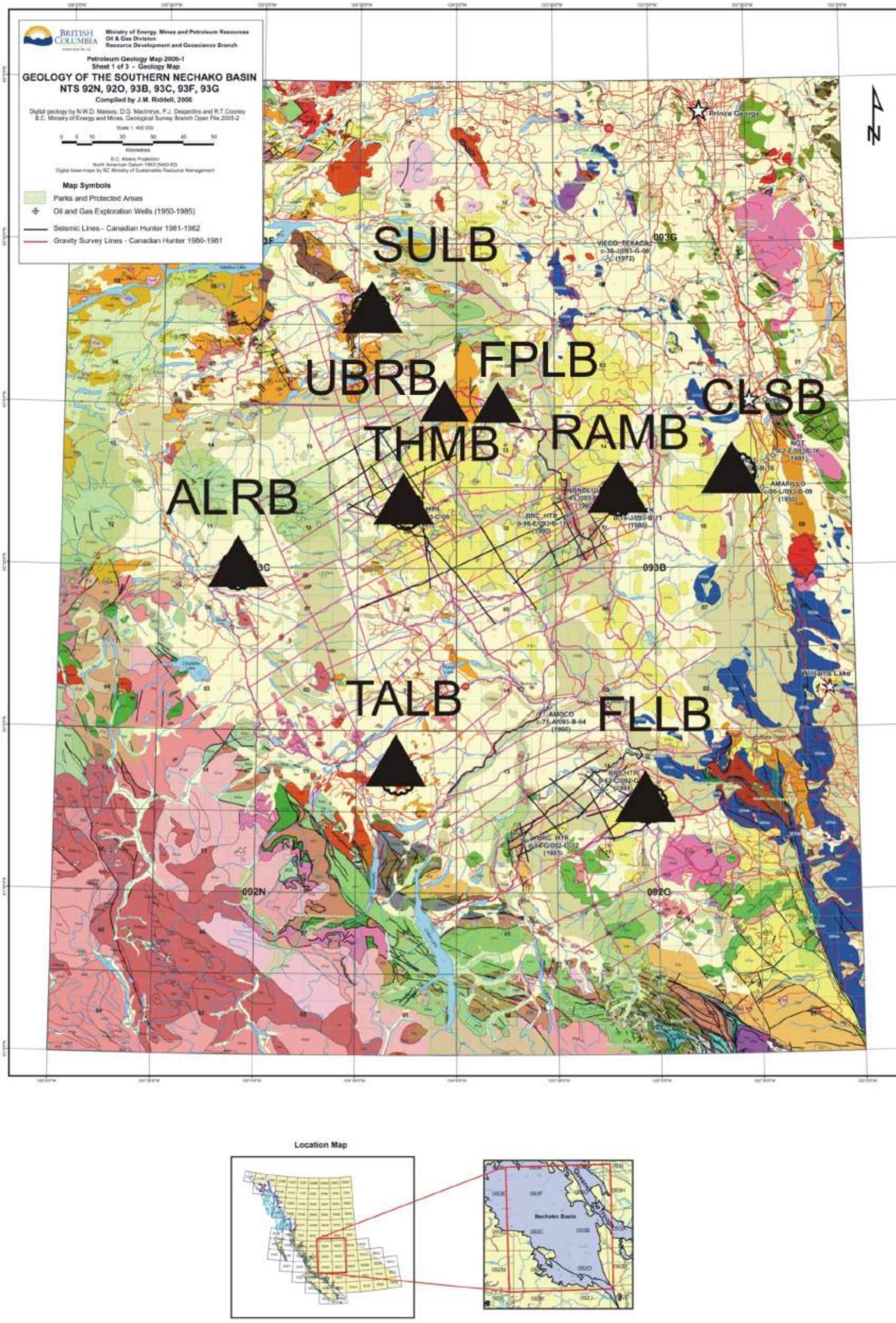

Figure 1. Location of study area. Filled triangles (and four-character station codes) indicate the locations of the nine broadband seismic stations. Base map *from* Riddell (2006).

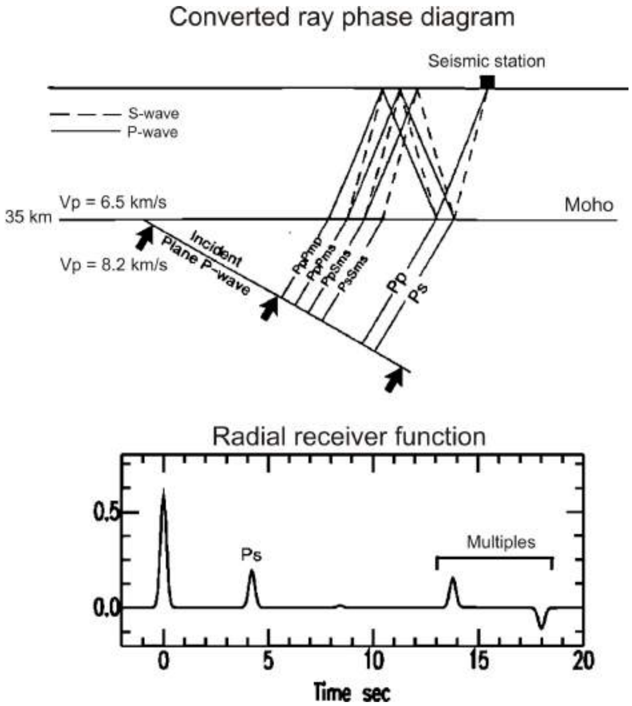

Figure 2. Schematic diagram of the receiver function method. When incident P waves from distant earthquakes encounter S-wave velocity boundaries beneath a seismic station (top), some of the energy is converted to an S wave (Ps). The amplitude and arrival time of the Ps phase, relative to the direct P wave, provides constraints on the velocity contrast and depth to the interface (Cassidy et al., 2008a).

(covering an area of approximately 33 000 km^2). The receiver functions are calculated from the recorded teleseismic waveforms by deconvolving the radial components with the corresponding vertical components. This method typically requires recording for an approximately two-year period to collect enough events 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);
- ability to determine 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, thereby providing images of both near-surface and crustal-scale structure.

Receiver functions subsequently invert for S-wave velocity structure using the neighbourhood algorithm (Sambridge, 1999a, b). This inversion approach is one of the direct search methods that is suitable for complex nonlinear problems, such as receiver function analysis.

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 (Calkins et al., 2006). This attests to the capacity of this imaging method to resolve the crustal structure in this region.

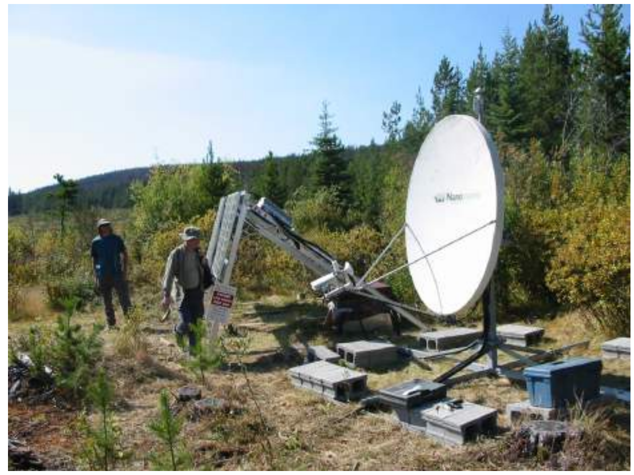

Figure 3. Photograph of Nechako seismic station RAMB, showing the typical station layout, with solar panels and a satellite dish (seismic vault is not visible).

The receiver function method has been recently applied in studies of sedimentary basins around the world. In the Bohai Bay Basin (China), Zheng et al. (2005) used receiver functions to map sedimentary thicknesses (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, seis-

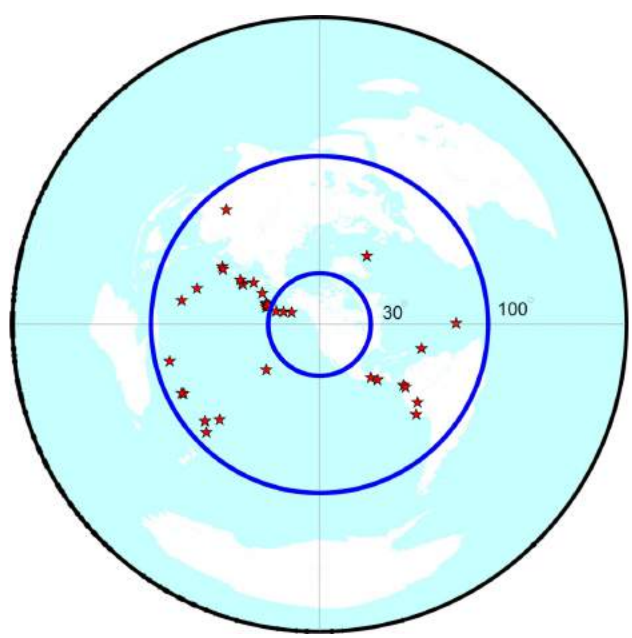

Figure 4. Distribution of distant earthquakes used in this study. Stars indicate large (magnitude >6), distant earthquakes. The map is centred on the Nechako Basin seismic array, with distances of 3360 km (30°) and 11200 km (100°) indicated. This is the useful distance range for receiver function studies.

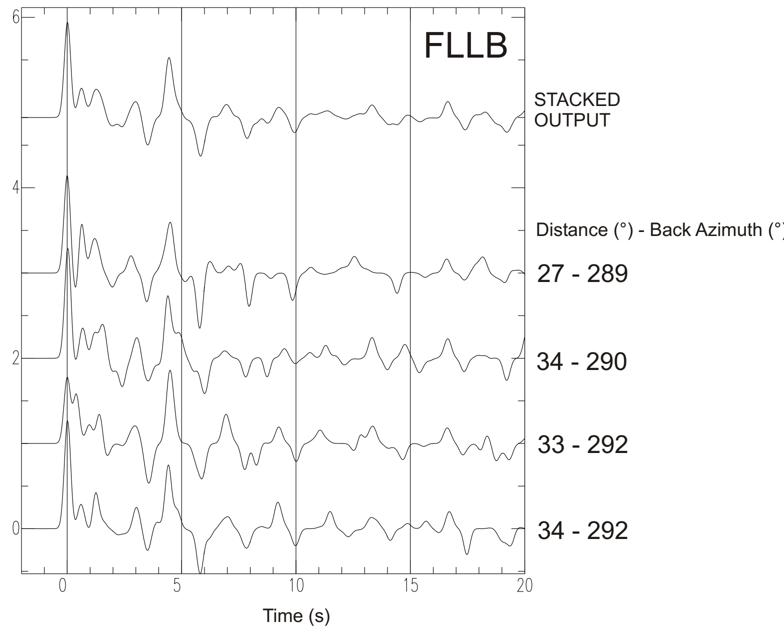

Figure 5. Weighted, stacked radial receiver function for station FLLB (top). Epicentral distances and back azimuths are indicated next to the receiver functions.

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

Data

In September 2006, seven three-component broadband seismic stations were deployed across the Nechako Basin area of central BC, and two additional stations were deployed in October and November 2007. The sites were chosen to sample a large portion of the basin and to be close to existing boreholes (Figure 1). These stations utilize solar power and satellite data transmission in order to continuously record ground shaking, transmit the data in real time and archive it at

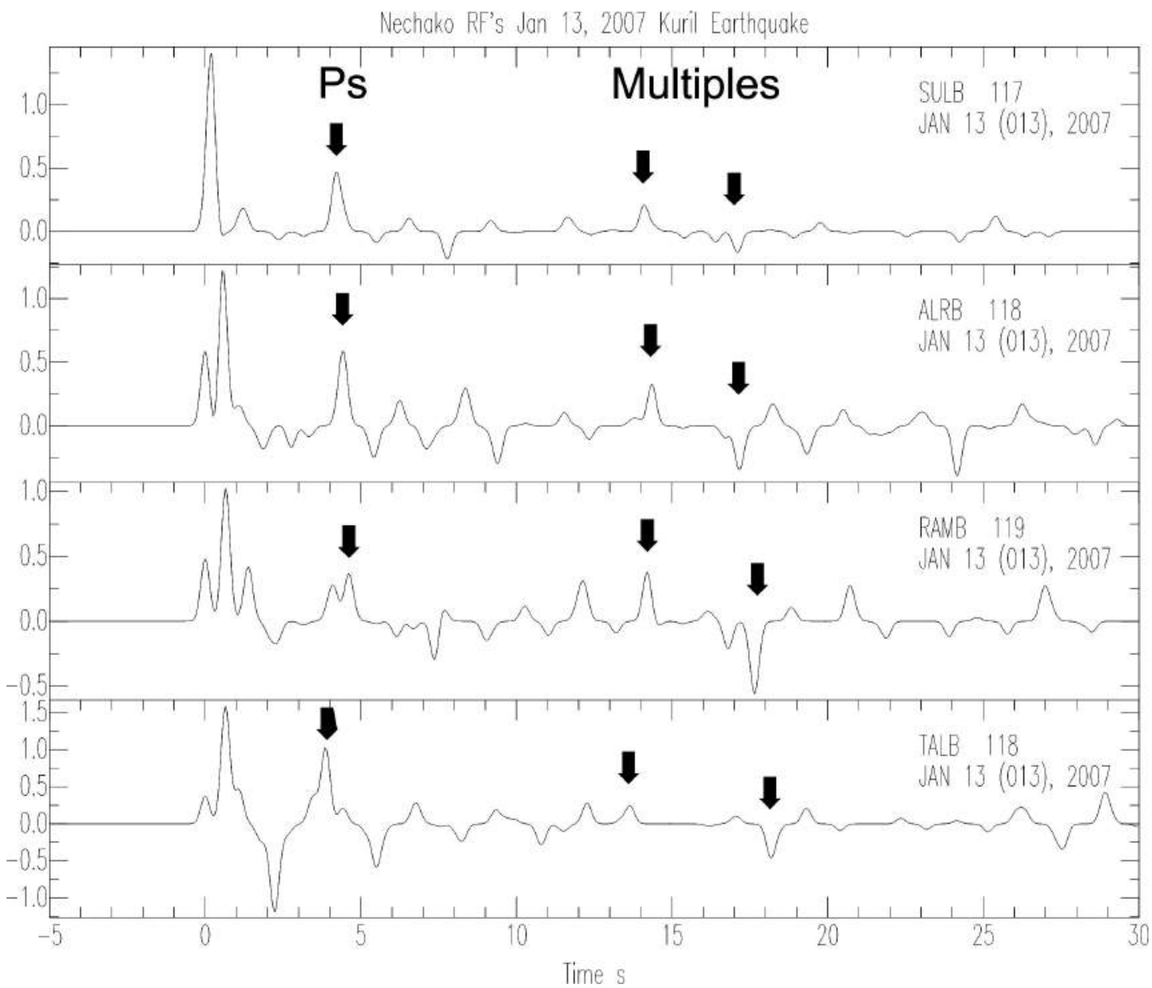

Figure 6. Sample receiver functions for select Nechako Basin stations. The large arrivals indicated by arrows are consistent with a Ps conversion from the continental Moho (near T = 4 s) and free-surface multiples of this phase near T = 12–17 s.

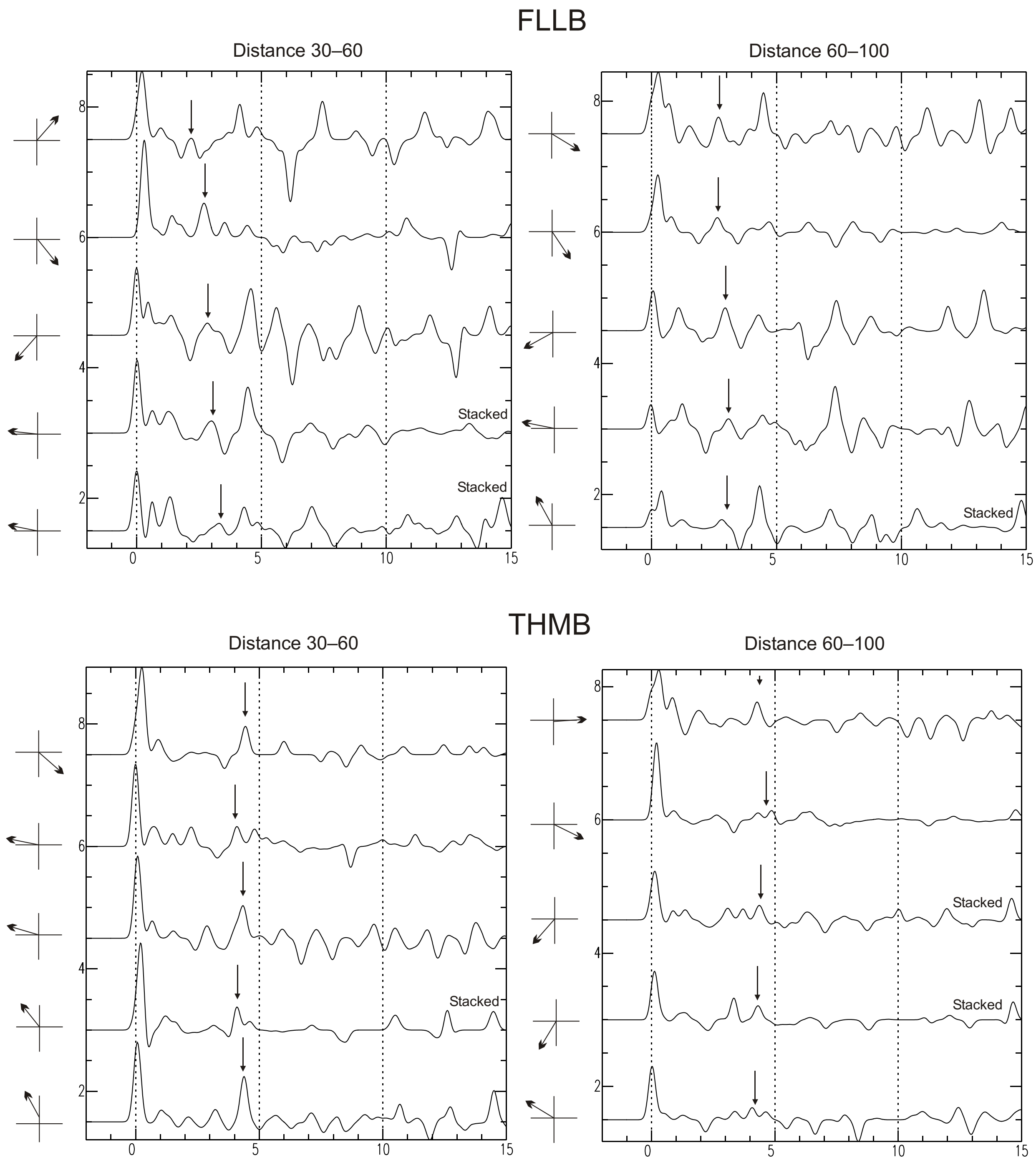

Figure 7. Receiver functions from station FLLB and THMB, ordered by back azimuths for two different distance ranges (30–60° and 60–100°). Thin arrows on the left show the back azimuth for each event. Thick arrows indicate the shifting of arrivals corresponding to the same phase. Stacked receiver functions are labelled.

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 two years of operation (September 2006–August 2008), more than 1000 intermediate to large (magnitude >5.5), distant earthquakes (teleseisms) were recorded. Among these events, 40 waveforms are the most appropriate for the receiver function analysis described above, and 25 additional waveforms may provide some information. The best 40 teleseisms for this study are shown in Figure 4. 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.

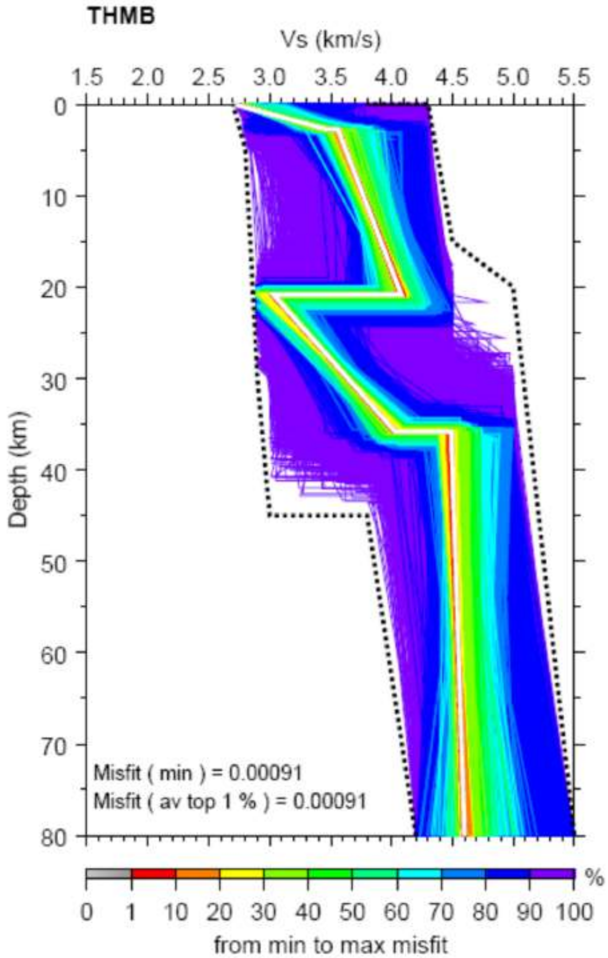

Figure 8. The S-wave velocity models for THMB. The best-fit model is in white. The black solid line shows the average of 1% models with the best data fits. Dotted lines show the minimum and maximum range of allowable models.

Receiver functions computed from the events that have similar distances and back azimuths are stacked together to identify the robust phases. By this process, the amplitude of significant arrivals associated with discontinuities add constructively and are enhanced, whereas noise is suppressed (Figure 5).

Preliminary Results

To date, receiver functions have been computed for waveforms collected over 2 years at three stations within the Nechako Basin: FLLB, THMB and SULB. These preliminary receiver functions 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. A small-amplitude arrival at T = 0, followed immediately by large-amplitude arrivals, is indicative of near-surface low-velocity sedimentary rocks. 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.

Although some arrivals indicate the same phase from the discontinuity, possibly the Moho, they may vary with the back azimuth. There is also a variation in arrival time with distance (Cassidy, 1992). Thick arrows in Figure 7 show the shifting of arrivals with the same phase.

The preliminary S-wave model indicates that the crustal thickness of the basin is about 37 km with an ~3 km thick sedimentary layer on the top and low-velocity zone at ~20–37 km depth (Figure 8). The discontinuity around 37 km depth in the model indicates the Moho.

Future Work

Receiver functions will be computed for all suitable events for remaining stations. These will be also stacked into distance and azimuth bins and modelled for S-wave velocity structures for all stations within the Nechako Basin. Amplitudes and arrival times will be used to constrain the S-wave velocity contrast and depth of the boundary, and azimuth variations in the receiver functions will help constrain the geometry of the interfaces. This research is a work in progress, being conducted by a University of Victoria M.Sc. student (H. Kim). The expected completion date of the study is August 2009.

Acknowledgments

The authors gratefully acknowledge the financial support of the BC Ministry of Energy, Mines, and Petroleum Resources, the Geological Survey of Canada and Geoscience BC in deploying and operating this seismic network. Thanks go to J. McCutcheon of the University of Manitoba, and S. Williams of the Geological Survey of Canada for their assistance in deploying this seismic array, and to I. Al-Khoubbi, I. Asudeh and the POLARIS team for maintaining these instruments. G. Rogers and R. Currie are thanked for providing a thorough review of this manuscript.

Geological Survey of Canada contribution 20080438.

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