A Teleseismic Transect across Canada: Shear-Wave Splitting and Receiver Function Analyses

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Summary

Shear-wave splitting and receiver-function analyses were performed on 9 stations from the Canadian National Seismograph Network (CNSN) using 90 events that occurred between the years 1998 and 2008. The seismic stations form a sparse transect across the Cordillera and Canadian Shield, from Vancouver Island to Baffin Island. The fast anisotropy axes measured in the Shield are similar to present-day absolute plate motion direction, with some indication of frozen anisotropy in some regions, e.g. near Edmonton. The Shield also showed a uniform average crustal thickness of about ~ 38 km except at the Hudson Bay region which showed a varying thickness that was interpreted to be the result of graben-like structures. Finally, the average Vp/Vs ratio in the Shield is ~ 1.76, which points to a felsic (granitic) bulk crustal composition. Anisotropy analysis in the Canadian Cordillera did not yield robust values, due to either the complex tectonic history and/or low signal to noise ratio in the data used. The crustal thickness in the Cordillera exhibited a varying thickness, which is interpreted to be a result of tradeoffs between thermal and Airy isostacy. The average V_p/V_s in the Cordillera is found to be ~ 1.96, which points to a mafic (basaltic) bulk crustal composition.

Introduction

Teleseismic events, i.e. seismic events observed at an epicentral distance of 30° or more, can be analyzed to obtain a wealth of information. The deployment of broadband seismometer networks has proliferated in the last decade, and a number of methods have been developed to extract Earth properties from such data. Shear-wave splitting analysis attempts to estimate seismic anisotropy of the Earth, i.e. the dependence of wave propagation velocity on the propagation direction, by estimating the delay time (δt) between the two quasi s-waves and the polarization direction of the fast quasi s-wave (ϕ). Receiver-function analysis can be used to estimate crustal thickness (H) and the V_p/V_s ratio (κ). The purpose of this study is to apply these two methods to nine stations from the Canadian National Seismograph Network (CNSN) network forming a sparse transect across Canada in order to gain insights into the tectonic structure of the continental lithosphere.

Because of Earth's anisotropy, the two orthogonal s-waves are not simultaneous, but rather, separated by some time called the delay time (δt). Figure1 (left) shows the difference in wave propagation between the isotropic and anisotropic mediums. A number of wave phases can be used to do shear-wave analysis with SKS, a s-wave entering the outer core as a p-wave and exiting as a s-wave, and SKKS, a s-wave entering the outer core as a p-wave that bounces in the outer core and exiting as a s-wave, being best. SKS and SKKS wave phases give a reliable approximation for measurements in the mantle and crust below the receiver side because the waves lose any information at the core-mantle boundary due to the conversion back from a p-wave to an s-wave (Silver & Chan, 1991). These waves travel in an almost-vertical direction near the receiver; in consequence, the anisotropy that is calculated is localized beneath the receiver.

Receiver functions (Figure 1, right) are time functions calculated from the three-component seismic data resulting from the reverberation of the converted p-wave to s-wave. The functions show the relative response of the earth near the receiver and they are calculated by eliminating the source and lower mantle propagation effects.

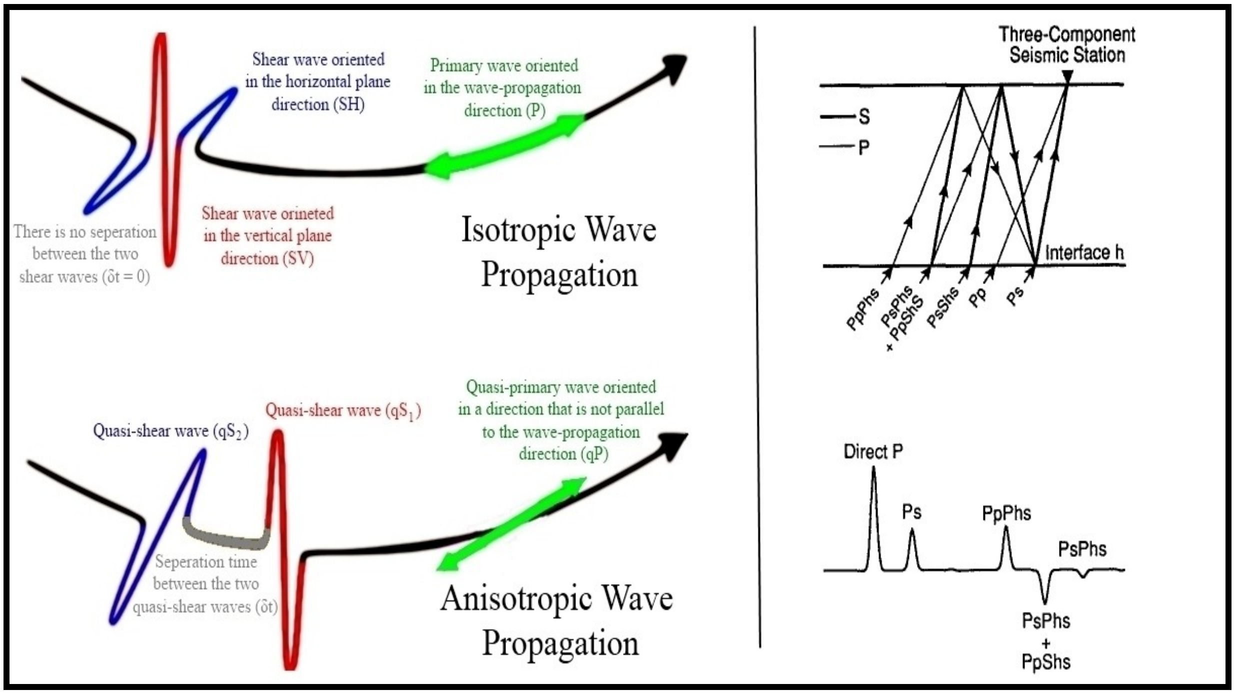

Figure 1: Wave propagation in an isotropic and an anisotropic medium (modified from Savage, 1999) (left); and a synthetic receiver function (bottom right) calculated for a receiver function diagram (top right) (Ammon, 1991) (right).

Methodology

Shear-wave splitting analysis (Figure 2) was done using the method of Silver and Chan (1991), which attempts to calculate rotating operator parameters based on several different optimization criteria.

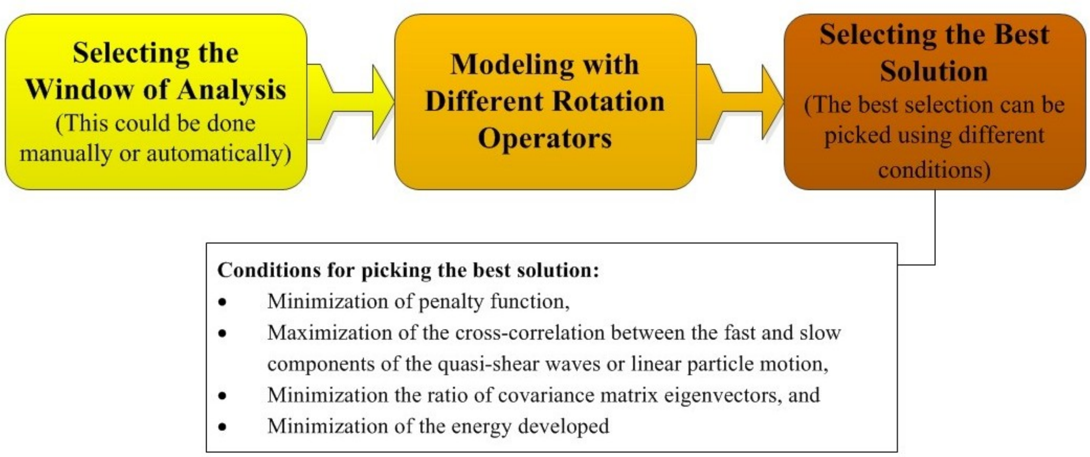

Figure 2: General workflow for shear-wave splitting analysis

The analysis is done selected time window from SKS or SKKS wave phases. In addition, a confidence interval is calculated and used to estimate error values.

Receiver-function analysis (Figure 3) was done using the method of Zhu and Kanamori (2000), as modified by Eaton *et al.* (2006), which isolates the receiver function by frequency-domain deconvolution. The crustal thickness and the V_p/V_s ratio are estimated by calculating the time difference between the arrival time of *P* and *Ps* waves (see Figure 1, right) and constructing a crustal model that fits the observed receiver function. Stacking is done in order to increase the confidence in the results.

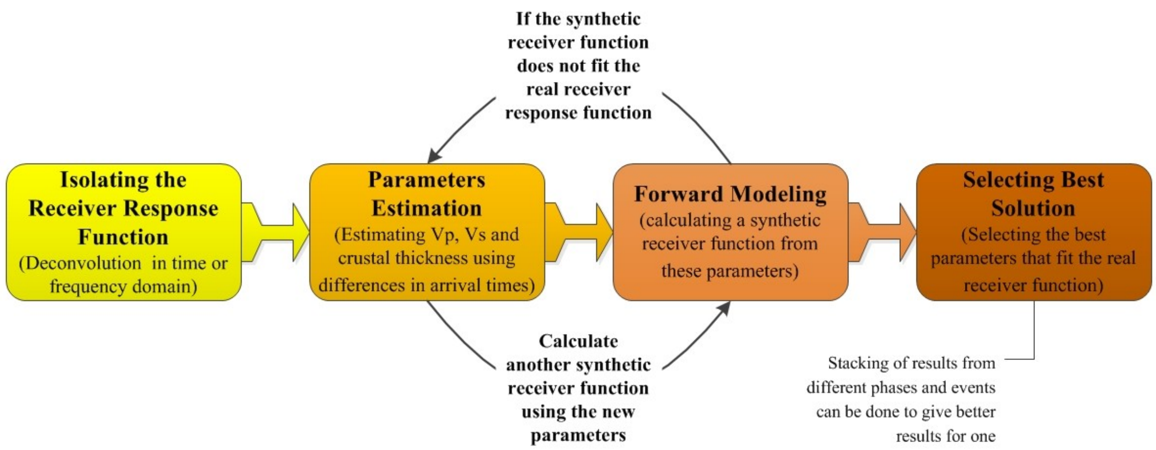

Figure 3: General workflow for receiver-function analysis

Results and Discussion

Figure 4 shows an overview of the results obtained. Shear-wave splitting results in the Canadian Shield yielded a time delay value ranging from 0.54 to 1.64 seconds and a fast polarization direction range from 31.95° to 101.61°. The Canadian Cordillera did not yield robust results. Receiver-function analysis shows a varying crustal thickness in the Hudson Bay region (stations FRB and IVKQ) and a constant thickness of ~ 38 km in other parts of the Shield. The Canadian Cordillera exhibits a varying thickness from relatively thick (stations SLEB and SHB), to relatively thin (stations LLLB and WSLR). The average V_p/V_s ratios are ~ 1.76 and ~ 1.87 for the Canadian Shield and the Canadian Cordillera respectively.

The fast splitting direction in the Canadian Shield seems to follow the general direction of present plate motion vectors, indicating the presence of a basal shear component beneath the lithosphere. A larger time delay, such as the one in the Edmonton region (station EDM), might indicate constructive interference of frozen and present day plate motion anisotropies. Crustal-thickness variations are observed in the Shield and the Cordillera. Other studies in the Hudson Bay region suggest the existence of graben-like structures which could explain the thickness variations there. Thermal isostatic equilibrium models could explain the thickness variation in the Cordillera. Finally, the average V_p/V_s ratios indicate an older felsic Shield and a younger mafic Cordillera.

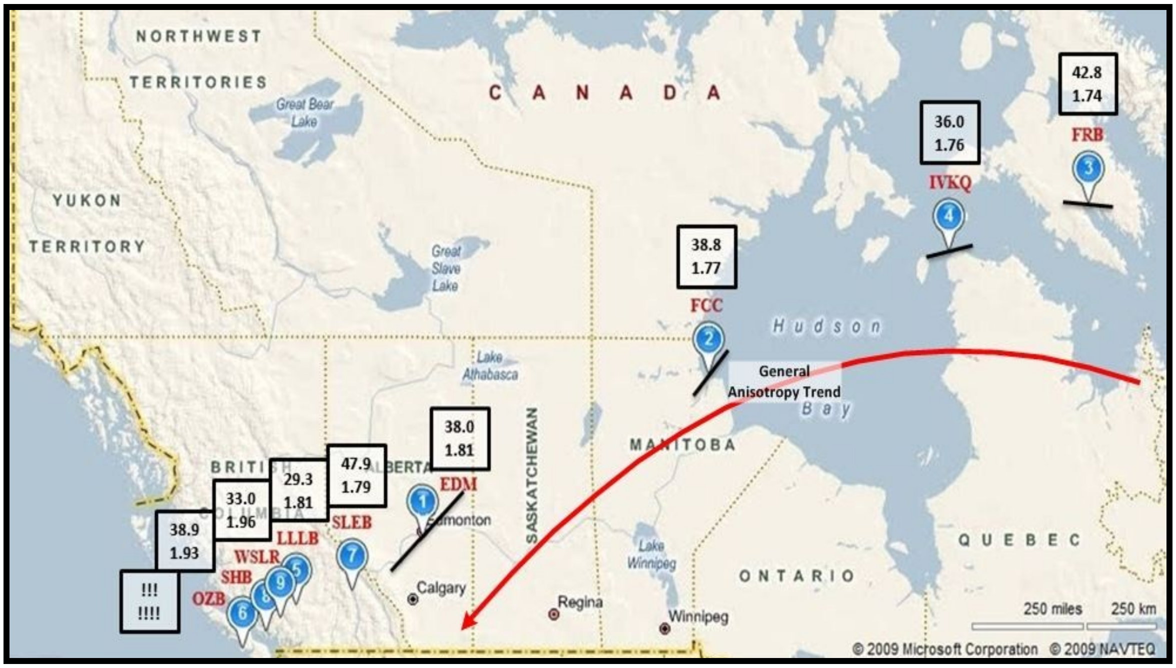

Figure 4: Analysis results for shear-wave splitting and receiver-function analysis. Black lines show the fast polarization direction for the quasi- S-wave taken from shear-wave splitting analysis using Silver and Chan (1991). Length of the lines is proportional to δt. Black boxes show H in km (top) and κ (bottom), using the semblance-weighted stacking method of Eaton *et al.* (2006).

Conclusions and Final Remarks

Teleseismic analysis can be used to obtain wealth of information about the Earth. The Canadian Shield and the Canadian Cordillera show different seismic signatures and crustal properties. This study was relatively small because of time constraints. A more comprehensive similar teleseismic study could be done through a transect across Canada using a large number of stations and a number of different methods could be used in order to obtain a better picture of the Canadian crustal mass.

Acknowledgments

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