

## Abstract

It has been suggested that processes driving crustal formation in the Archean and Proterozoic were dissimilar and produced crusts with unique bulk properties and average thicknesses. Existing models based on fractionating mantle composition or evolving mantle convection require accurate estimates of the geological and geophysical properties of crustal provinces to better understand the details of early continental formation (R. Durrheim, W. Mooney, 1991). Fifteen years of publicly accessible teleseismic data from all available Canadian seismic stations are binned in horizontal slowness and deconvolved into receiver functions. We apply a new stacking method (Bostock and Kumar, 2010) to retrieve estimates of bulk crustal velocities ( $V_p$ ,  $V_s$ ) and thickness  $H$  from these data under the assumption of 1-D structure. Bootstrap error analysis is performed for each station dataset and results are compared to the results produced from alternate methods (Zhu and Kanamori, 2000). Cross-analyzing these results with the mineral and rock seismic property database of Christensen (1996) will afford improved constraints on bulk geological composition of the Canadian landmass. These results will be used to evaluate competing models of early crustal formation.

## 1 Introduction

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### 1.1 Overview

(Overview here)

### 1.2 Geological Background

(Geological background here)

## 2 Data and method

Seismic data utilized in this study comes from 343 stations across Canada from all available networks. Of these stations 146 were used for analysis. All stations are broadband with data being used between the years 2000 and 2012. Receiver function analysis has been widely employed over many years to investigate the earth's structure. Two derivations have been used in this study, one well tested stacking approach (Zhu and Kanamori, 2000) and the other a recent method that has not yet been employed at scale (Bostock, 2010). Both methods rely on the fact that the incoming S-wave contains energy from the direct arrival as well as reflected phases resulting from sharp velocity contrasts. Deconvolution of the P-wave energy arrival, used as an estimate for the source function, from the S-wave signal produces a Green's function with energy peaks at the times of the main and reflected arrivals. For better separation of P and S wave energy all

components are rotated into radial and transverse dimensions and transformed into P, SV and SH components with a wave field decomposition transfer matrix (Bostock, 1998). Deconvolution is performed by minimizing the general cross validation function  $GCV(\delta)$  where  $\delta$  is used the regularizer (Bostock, 1998; Golub et al., 1979). This method is an  $L_2$  frequency domain deconvolution which performs quickly and makes no assumptions on the noise in the data. All deconvolved signals are filtered between 0.04hz and 3.0hz and are stacked with weights  $w_1 = 0.5$ ,  $w_1 = 0.3$ ,  $w_1 = 0.2$  for the Ps, PpPs and PpSs phases respectively. Error calculations are performed with bootstrap resampling by rerunning the processing with randomly chosen receiver functions - allowing multiples - 1024 times. The error is obtained by taking the standard deviation of the results.

## 2.1 Vp methods

The stacking approach outlined above provides estimates for the parameters  $R = \frac{V_P}{V_S}$  as well as crustal thickness  $H$  - which gives the depth of the Moho. A method which estimates  $V_P$  and  $V_S$  separately (Bostock, 2010) is also employed for select stations. This method makes use of the fact the dependence on  $H$  in the travel time equations can be removed if we divide the reflected phases by the main arrival.

$$t_{Pps}(p_i) = \frac{\sqrt{R^2 - p_i^2 V_P^2} + \sqrt{1 - p_i^2 V_P^2}}{\sqrt{R^2 - p_i^2 V_P^2} + \sqrt{1 - p_i^2 V_P^2}} t_{Ps}(p_i)$$

$$t_{Pss}(p_i) = \frac{2\sqrt{R^2 - p_i^2 V_P^2}}{\sqrt{R^2 - p_i^2 V_P^2} + \sqrt{1 - p_i^2 V_P^2}} t_{Ps}(p_i)$$

This has the advantage that no assumptions on  $V_P$  are necessary to perform the gridsearch and stack. A similar stacking method as the Zhu and Kanamori approach may be employed for  $t_{Pps}$  and  $t_{Pss}$  as long as an estimate for  $t_{Ps}$  exists. With estimates for  $R$  and  $V_P$  a simple line search along  $H$  can be made using all three undivided travel time equations.

Several methods for choosing  $t_{Ps}$  are available. Direct arrival  $t_{Ps}$  should contain the largest fraction of energy out of the other phases and the moveout, depending on Moho depth, should be in the order of 3 to 6 seconds. Given this it is trivial to define a window and select the time corresponding to maximum amplitude. Another approach is to use max amplitude estimates as data in a non-linear optimization to find the  $R$ ,  $V_P$ , and  $H$  which minimizes the residual between  $t_{Ps}$  and the data. The travel time equations are twice-differentiable so the quadratically convergent Newton's method may be employed. This approach has the advantage that noise leading to poor maximum amplitude picks are effectively collapsed onto the curve corresponding to the travel time function. A third approach which offers picks along a travel time curve but better stability than the non-linear method is to perform a gridsearch with all three travel time functions, a full Kanamori stack. With the best estimates for  $R$  and  $H$  the  $t_{Ps}$

function can be found and used as input into the Bostock method. The trade-off is that the requirement for an initial  $V_P$  estimate for the initial stack introduces secondary  $V_P$  dependence into the system.

### 3 Results

Ideas: Reliability of methods: Compare bulk properties garnered from MB to Kan Approach. Compare Kan approach values to others in literature Canada wide - Regional

The preliminary interrogation of the data set yields the observation that the bulk Canadian crust is more felsic than originally anticipated. Previous experiments show crustal averages of 0.265 (Christensen and Mooney, 1995) or have averages of at least 0.27 for shields, platforms and paleozoic units (Zandt and Ammon, 1995). The weighted average for this data set shows a Poisson' ratio of 0.258 with the weighting for each station given by the calculation of the stations inverse Voronoi cell area. At the regional scale we have values of 0.251, 0.254, 0.260, 0.275 for the Churchill, Superior, Slave and Grenville Provinces Poisson's ratios respectively. Most of the Canadian Shield stations also appear to have low Poisson values with the exception of the Grenville Province which has a high Poisson Ratio of 0.275.

The data bears out earlier results showing Proterozoic crust to have a higher Poisson's ratio than Archean crust, likely the result of a more mafic composition. The increased crustal thickness of Proterozoic crust is clearly seen in the active source data while it not visible in data from processed seismic stations. The most likely reason for not seeing the signal of thicker crust in the station data is owing to poor station coverage in Proterozoic regions.

Further work on the Bostock-Kumar stacking approach is warranted from a look at the cleanest stations. Before it can be employed in large scale analysis additional denoising methods or alternative deconvolution techniques will need to be investigated to reduce the noise in the data.

### 4 Discussion

#### 4.1 Canada

Discussion on larger - Canada wide - regions

#### 4.2 Slave Province

Discussion on Slave Province

### 5 Conclusions

Conclusions here

## References