Constraint on Crustal Composition of the Canadian Landmass from Teleseismic Waves

B. POSTLETHWAITE[1] N. I. CHRISTENSEN[1]
M. G. BOSTOCK[1] D. B. SYNDER[2]

ABSTRACT

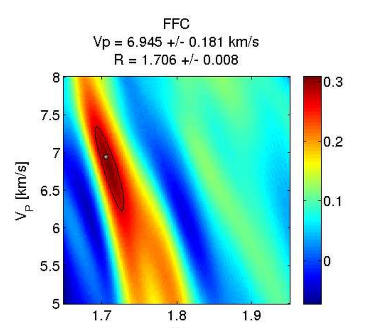
It has been suggested that processes driving crustal formation in the Archean and Proterozoic were dissimilar and produced crusts with unique bulk properties and average thicknesses. Existing models based on fractionating mantle composition or evolving mantle convection require accurate estimates of 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. A new stacking method (Bostock and Kumar, 2010) is investigated to retrieve estimates of bulk crustal velocities (Vp, Vs) and thickness H from these data under the assumption of 1-D structure. Final data analysis used in the histograms is provided by the Zhu and Kanamori (2000) stacking approach with Vp data from an active source compilation (Mooney 2012). Bootstrap error analysis is performed for each station dataset using two-standard deviation. 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 crustal formation.

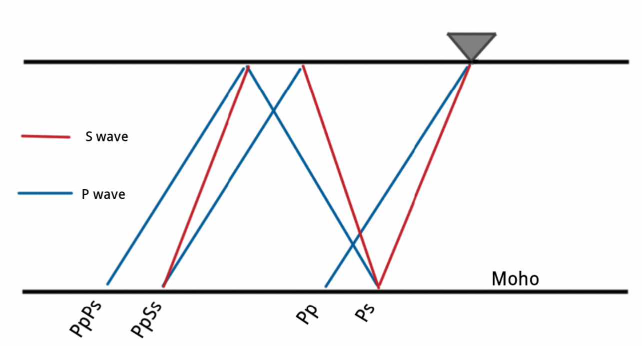
MOTIVATION

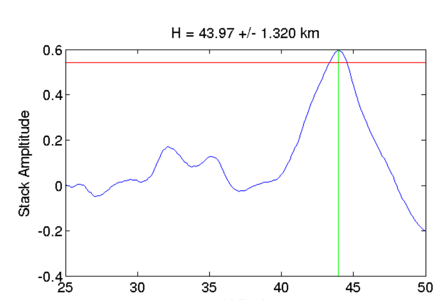
Many stacking techniques require an initial P-wave velocity value (Vp) and provide an estimate of the Vp/Vs ratio. In the 2010 paper "Bias in seismic estimates of crustal properties" by M. Bostock and R. Kumar, a fast 2D stacking approach which is not dependent on an initial Vp estimate is outlined. The algorithm returns estimates of Vp as well as the Vp/Vs ratio and - after a 1D line search - crustal thickness H. For geological regions with anomalous Vp, this approach may provide more accurate estimates of crustal parameters.

Method

Seismograms from a seismic station are deconvolved into receiver functions which, in good conditions, contain impulsive energy at the times of the phase arrivals. The phase arrivals of interest are the direct phase tPs and two distinct reflected phases tPps and tPss which have reflected off the free surface and Moho before being recorded at the seismic station. tPps spends two legs of it's journey as a P-wave while tPss spends only one leg as a P-wave, see figure below. The difference in velocity between a P-wave and S-wave allows the use these arrivals as distinct data.



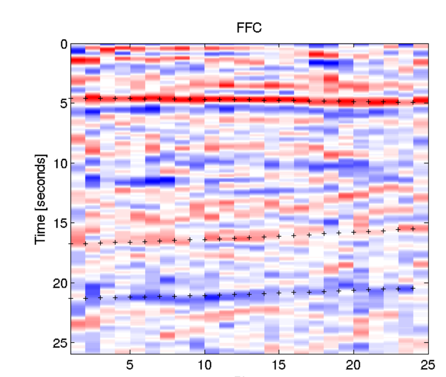


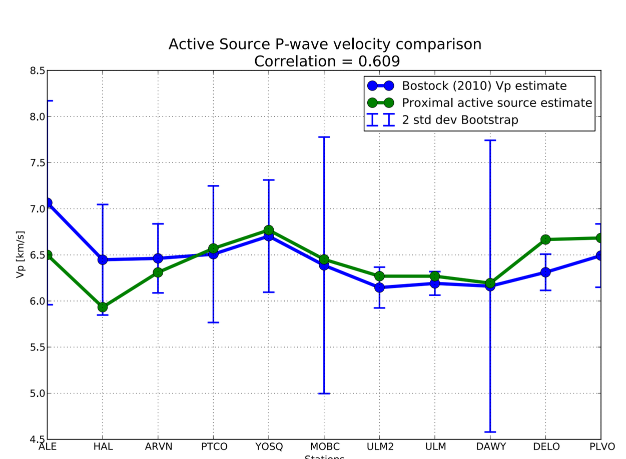


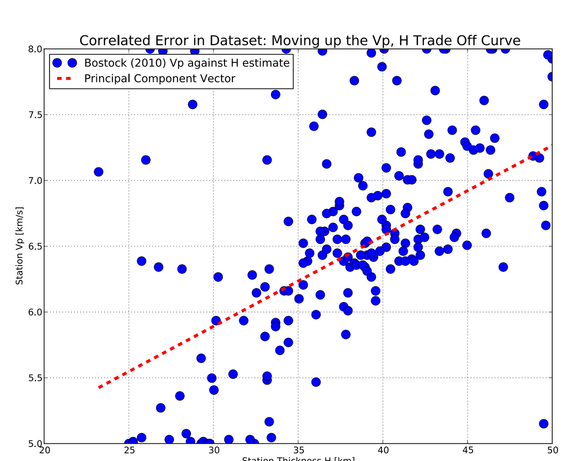
The parameter search for V_p, V_s and H is accomplished by breaking the problem into two smaller subproblems. First the reflected phase travel time equations **(2)** and **(3)** are divided by the direct arrival phase **(1)** to remove the dependence on crustal thickness H, **(4)** and **(5)**. A gridsearch over deconvolved receiver functions is performed looking for optimal values of Vp and $\frac{V_p}{V_s}$ using equations **(4)** and **(5)** and an estimate for the direct phase travel time tPs .

Second, the best estimates for VP and $\frac{V_p}{V_s}$ are chosen and used in a 1D line search using equations **(1)**, **(2)** and **(3)** for H.

These best parameter estimates are used to solve the three travel time equations **(1)**, **(2)** and **(3)** for the best estimate of a phase arrival for each receiver function and are plotted on a series of receiver functions for verification.



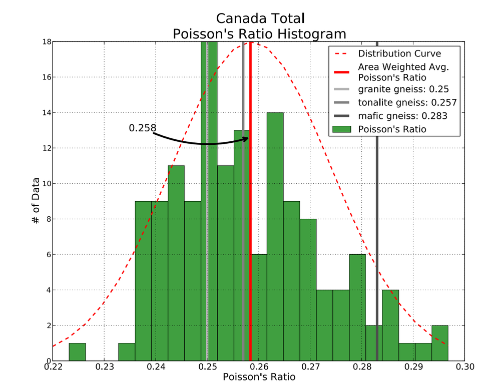


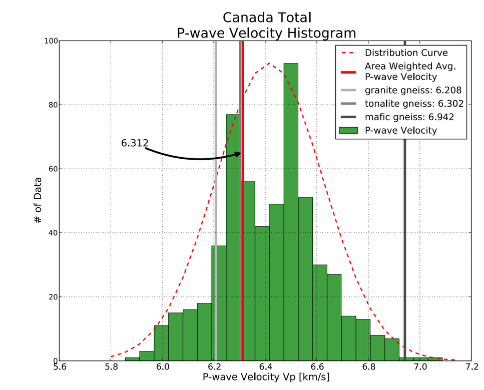


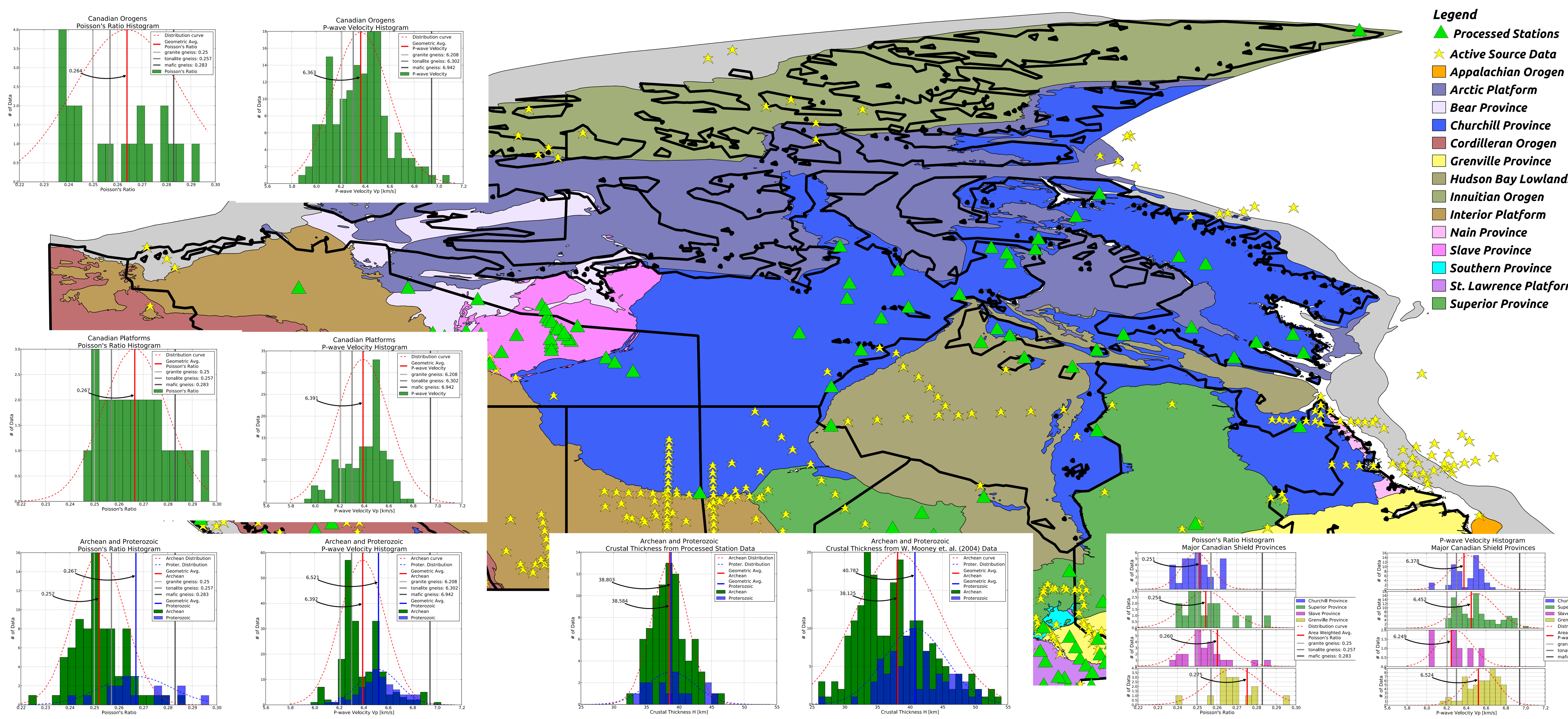
RESULTS

This preliminary look at the processed dataset compares results to existing crustal formation literature. The data which was processed using the Bostock and Kumar (2010) stacking approach shows good correlation with active source data for the cleanest seismic stations. For stations of less than optimum quality the correlation is poor and the procedure shows correlation between crustal thickness (H) and compressional wave velocity (Vp) estimates which represents a trade off in the calculations owing to low sensitivity of Vp to seismic wave travel time. For this reason active source data compiled by W. Mooney (2012) has been employed for bulk calculations instead of data calculated from the Bostock and Kumar (2010) method.

All available Canadian broadband seismic stations with sufficient data are processed using a stacking approach similar to Kanamori (2000). Of 239 seismic stations processed, 146 have clear multiples and standard deviations acceptable for use in the study. Histograms of Poisson's ratio and Vp estimates are provided for regions of interest as well as for regions associated with crustal formation in the Archean and Proterozoic. Each histogram plot also contains the geometric mean of the data or, where possible, an area weighted average computed using a Voronoi method.







REFERENCES

M. G. Bostock, M. R. Kumar, 2010. Bias in seismic estimates of crustal properties, Geophys. J. Int., 182, 403-407.
N. I. Christensen, 1996. Poisson's ratio and crustal seismology, J. Geophys. Res., 101, 3139,Äì3156,
R. J. Durrheim, W. D. Mooney, 1991. Archean and Proterozoic crustal evolution, Geology, 19, 606-609.
W. D. Mooney. 2012. Personal communication. Compiled GSC active source data for the Canada.
D.A. Thompson, I.D. Bastow, G. Helffrich, J-M. Kendall, J.Wookey, D.B. Snyder, D.W. Eaton, 2010. Precambrian crustal evolution: Seismic constraints from the Canadian Shield, Earth and Planetary Science Letters, Volume 297, Issues 3,Äì4, 1 September 2010, Pages 655,Äì666
L. Zhu, H. Kanamori, 2000. Moho depth variation in Southern California from teleseismic receiver functions, J. Geophys Res, 105, 2969-2980.

Footnotes
1. Earth and Ocean Sciences, UBC, Vancouver BC, Canada.
2. Geological Survey Canada, Natural Resources Canada, Ottawa ON, Canada.

FUTURE WORK

Continued development of the Bostock-Kumar stacking approach may yield Vp estimates for geological regions without active source Vp data. This will allow more detailed interrogation of the Canadian crust and may provide additional constraints on crustal production models.

The current data set should allow several avenues of investigation. First, certain specific seismic station Poisson's ratio anomalies appear consistent over multiple processing regimes and therefore may be analyzed within the context of their geological setting. Second, in areas with higher station density transect profiles can be built across geological features which may assist in interpretation of feature boundaries. Finally, developing ternary or quaternary plot representations with well chosen end-members could provide estimates for site specific bulk crustal composition.

CONCLUSION

The preliminary interrogation of the data set yields the observation that the bulk Canadian crust is more felsic than originally anticipated. Original global estimates provided by Nik Christensen (1996) have a Poisson's ratio of 0.265 while the weighted average for this data set shows a Poisson' ratio of 0.258. Most of the Canadian Shield stations follow this same trend except for 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.