Crustal structure of Botswana from joint inversion of receiver functions and surface wave dispersion

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Introduction

Botswana consists of an amalgamation of Archean cratons and Proterozoic mobile belts. The sedimentary cover of the Kalahari desert masks the underlying basement favoring geophysical methods over geological investigation. In this study we have jointly inverted receiver functions with surface wave dispersion data from Fadel et al. (2020) to create one-dimensional shear wave velocity models below seismic stations from the Botswana Seismic Network. Here we focus on our results from eastern Botswana. Our results improve on the study by Fadel et al. (2018), who only modeled receiver functions by a single layer crust.

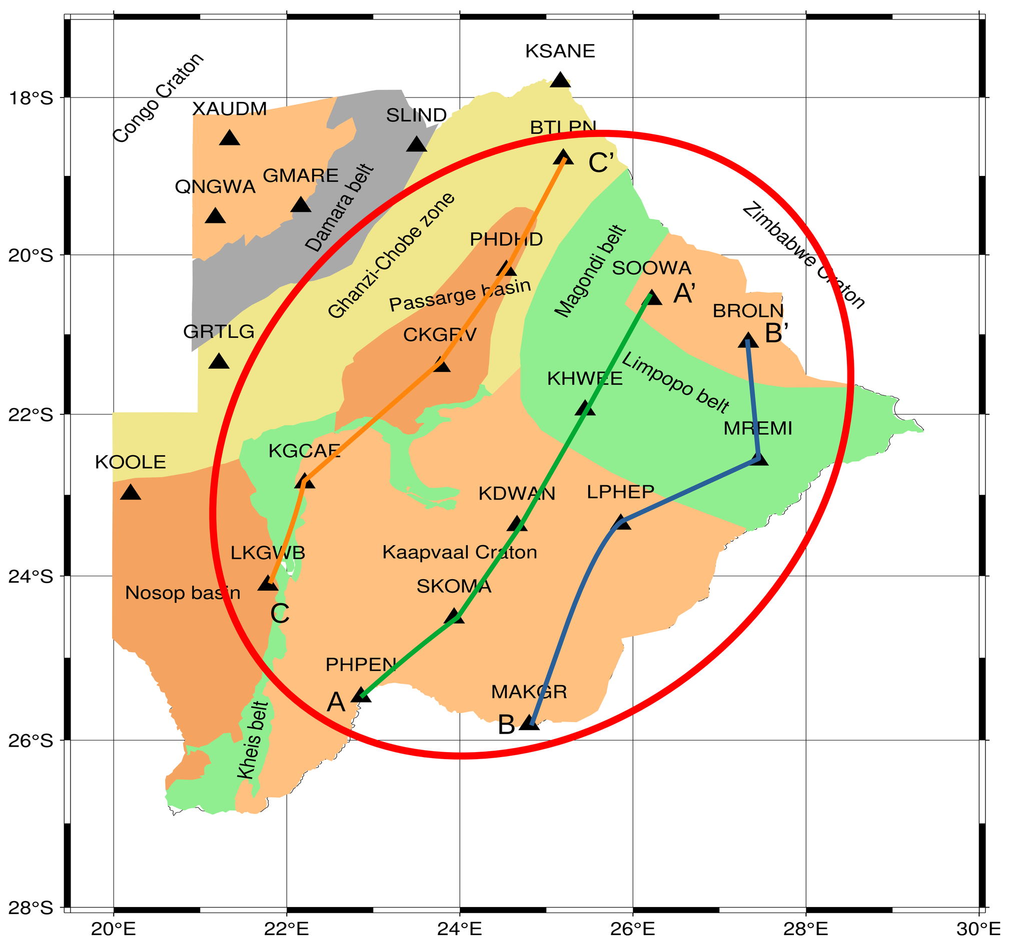

Figure 1: Tectonic map of the study area. It shows both the tectonic terrains and the locations of the seismic stations that were used. The map is based on the interpretation by Chisenga et al. (2020). The red ellipse marks the receivers that we focus on here. The three colored lines indicate the profiles shown in figure 4.

A joint inversion is chosen because receiver functions are mostly sensitive to sharp seismic discontinuities and less to absolute S-wave velocity, whereas it is the other way around for surface wave dispersion sensitivity. By using a combination of the two data sets we can better constrain the velocity structure than either data type alone could.

Methods

Receiver functions of teleseismic earthquakes are obtained by deconvolving the horizontal components from the vertical component of a seismogram. This procedure removes source effects and effects from the path through the mantle whilst making P- to S converted waves and reverberations from the crust visible. We used the method of Langston (1979) with water level stabilization and a Gaussian low pass filter. To improve the signal to noise ratio, receiver functions are stacked based on slowness and, if necessary, on back azimuth.

Phase velocity measurements are taken from Fadel et al. (2020). They obtained these from ambient noise tomography for periods of 3-35 s and Helmholtz tomography using teleseismic earthquakes for periods of 30-120 s.

Joint inversion of the receiver functions and phase velocity dispersion curves was performed with the BayHunter code (Dreiling et al., 2019). This code is based on the transdimensional Bayesian approach by Bodin et al. (2012). This means that all the results are presented as probability distributions. The advantage of this approach is that this allows us to estimate the model uncertainty.

Results

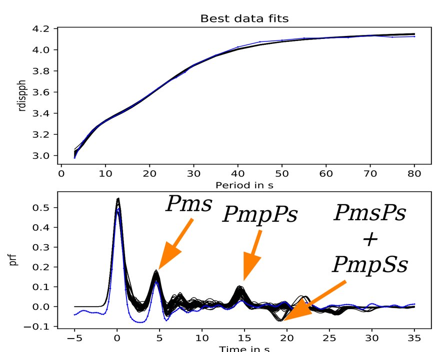

Figure 2: Top: Phase velocity fit for station KHWEE with the data in blue and the synthetics for the best 50 models in black. Bottom: Same as the top figure but now for the inverted receiver function stack.

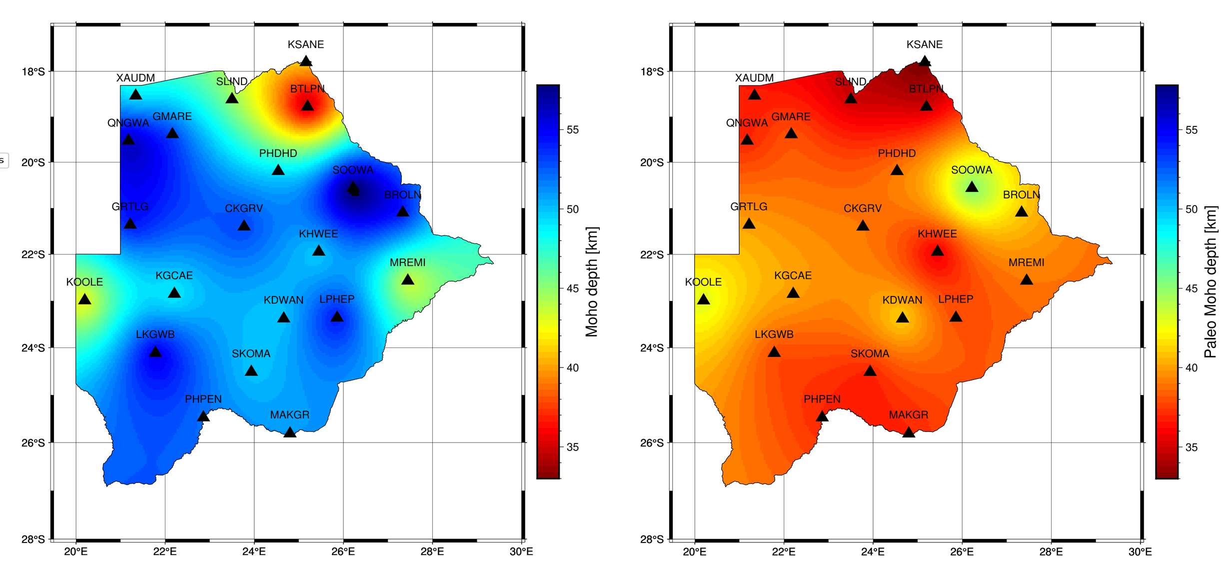

Figure 3: Interpolated crustal thickness maps of Botswana based on the mean and mode velocity models as shown in figure 4. The left map shows the Moho depth (35-58 km) defined as the depth where the shear wave velocity exceeds 4.5 km/s. The right map shows the depth where the shear wave velocity exceeds 4.2 km/s (35-45 km). Measurements at stations XAUDM and MREMI were excluded in the right map because the depth of the discontinuity was ambiguous.

Results

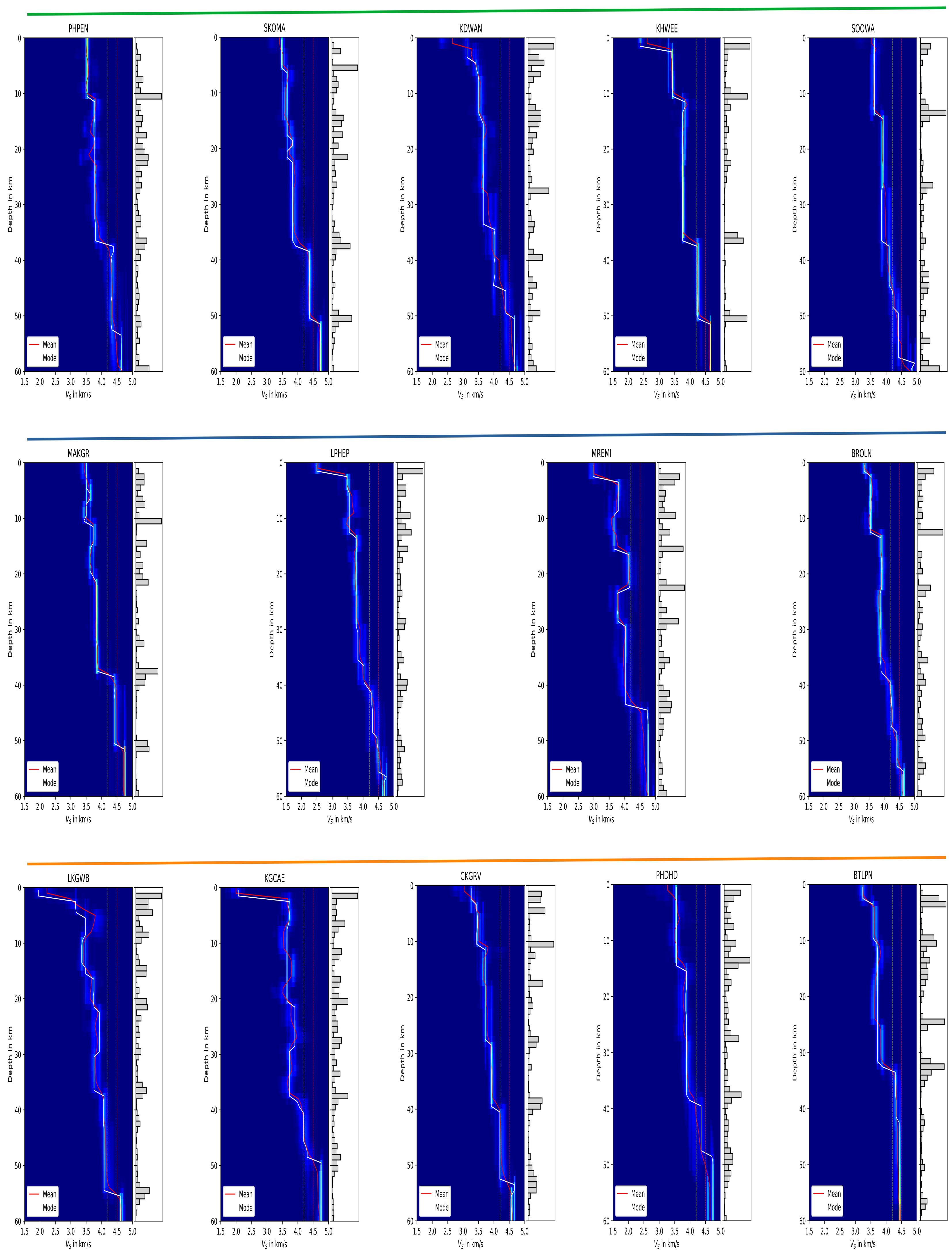

Figure 4: Crustal shear wave velocity models at the seismic stations. The mean (red) and mode (white) models are presented in the posterior distribution. The vertical red and yellow dashed lines indicate the 4.2 km/s and 4.5 km/s thresholds respectively. The right panel histograms represent the probability of a discontinuity being at a specific depth. The results per row correspond to the profiles indicated in figure 1. The upper row corresponds to the profile from A to A', the middle row corresponds to the profile from B to B' and the lower row corresponds to the profile from C to C'.

There are several features that can be recognized in the models:

- In some models, there is a low velocity uppermost layer that can be associated with sediments from the Kalahari desert.
- Many of the models have a discontinuity between 10 and 15 kilometers depth.
- Most of the models have two discontinuities in the lower part of the model domain. One at approximately 35 kilometers and one at approximately 50 kilometers.

Interpretation & Conclusions

- The discontinuity at 10 to 15 km is interpreted as a mid crustal discontinuity from a felsic upper crust to a more intermediate middle crust. A discontinuity at similar depths is observed globally.
- We tentatively interpret the discontinuity where the velocity exceeds 4.2 km/s as a Paleo Moho and the discontinuity where the velocity exceeds 4.5 km/s as the current Moho. The velocity in the layer between these discontinuities is approximately 4.4 km/s. We interpret this layer as a layer of mafic material due to magmatic underplating.
- The crust in the Zimbabwe craton appears to be significantly thicker than the crust in the Kaapvaal craton. This could be related to the intrusion of the Okavango dyke swarm causing crustal thickening in this area.
- The Moho in northern Botswana is shallow compared to the rest of the country. This can be related to recent rifting in the Okavango rift zone causing crustal thinning.

References:

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