Solid Earth Discuss., 5, C658–C666, 2013
www.solid-earth-discuss.net/5/C658/2013/

Solid Earth
Discussions

SED
5, C658–C666, 2013

Interactive comment on "Petrophysical constraints on the seismic properties of the Kaapvaal craton mantle root" *by* V. Baptiste and A. Tommasi

V. Baptiste and A. Tommasi

baptiste@gm.univ-montp2.fr

Received and published: 11 November 2013

We thank the two anonymous reviewers for their helpful contribution to improve our manuscript. In the following, the comments and questions are addressed one by one.

Comments and reply to Anonymous Referee #1

Introduction

1. "Fig. 1 is a bit unclear. The figure should include at least some geographical coordinates or an inset to help the reader. Besides, a topography map could be rather useful to get an idea about the location of the xenoliths"

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

We have added a map with geographical coordinates to Figure 1.

Method

2. "Some attention is paid to the parameters that characterize olivine anisotropy. This is reasonable; although pretty much the same information can be gathered from the previous paper by Baptiste et al. (2012). In contrast, relatively few details are provided regarding what is specifically new in this work: the estimation of the seismic properties. In particular, as the results of this work are compared to geophysical models, it would be interesting to have an estimate of the errors associated with the T, P derivatives of the elastic properties, VRH average etc. How would an uncertainty in the T estimation of, say 100 K propagate into the derived seismic velocities? In a word, what is the estimated uncertainty in the measurements provided by the authors?"

The equilibration temperature and pressure of the samples were estimated using traditional geothermometers and geobarometers for mantle rocks, which have an uncertainty of $\pm 60^{\circ}$C and ± 0.2 GPa, respectively (see Baptiste et al. 2012 for more details). This uncertainty in the estimation of the equilibration temperature results in an uncertainty in Vp and Vs of ± 0.025 and ± 0.02 km/s, respectively. The uncertainty from geobarometry results in an uncertainty on Vp and Vs of ± 0.015 and ± 0.007 km/s, respectively. As the determination of equilibration temperature and pressure are interdependent, that is an underestimation of temperature usually results in underestimation of pressure and vice-versa, the errors may add up. Thus the uncertainty in the estimation of the equilibration temperature and pressure of the samples results in a maximum uncertainty in Vp and Vs of ± 0.04 and ± 0.03 km/s, respectively. A probably larger source of uncertainty is the one related with the temperature and pressure derivatives of the elastic constants. However, in absence of more experimental data, the latter is difficult to constrain. Finally, the choice of the averaging method for calculating the sample elastic constants does affect the absolute velocities. However, it affects all velocities in the same way, and hence does not change their evolution with depth. It also does not affect the anisotropy estimation. A paragraph presenting the above discussion has been added to the revised version of the ms.

3." In equation 1 (BA index) there is no description of what the symbols P010, G100 etc. stand for."

To characterize the distribution of olivine principal axes ([100], [010] and [001]), the point (P), girdle (G), random (R) fabric type indexes are used in equation 1. They are calculated from the eigenvalues ($\lambda 1$, $\lambda 2$, $\lambda 3$) of the normalized orientation matrix for each crystallographic axis as P=$\lambda 1$-$\lambda 3$, G=2($\lambda 2$-$\lambda 3$), and R=3*$\lambda 3$. A brief description has been added to the main text.

Results

4." The discussion turns somewhat complicated to follow with the different axis and planes. A figure describing the geometrical setting would be quite useful."

Most of the studied samples are coarse-grained peridotites, where no foliation could be directly identified. To allow comparison between the samples, we rotated the CPO of these samples in a common orientation, in which the maximum concentration of orthopyroxene [001] axes and of the olivine [010] axes are parallel to the E–W and the N–S directions of the pole figure, respectively. This choice was based on the observation that [001] is the only known glide direction in orthopyroxene; plastic deformation tends therefore to align this axis in the flow direction. It is also justified by the CPO analysis presented in Baptiste et al. (2012), which shows that olivine deforms essentially by dislocation creep with dominant activation of [100](010). In the description of the seismic anisotropy patterns, we assume that the flow direction and foliation derived from CPO analysis are the real ones. The orientation of the principal structural axes has been added to figure 2 as suggested by the Referee.

5. "What is the relationship between S-wave polarization anisotropy and S1 and S2 propagation anisotropies? What would be the connection with seismic azimuthal and radial anisotropies?"

AVs is the intensity of the shear wave polarization anisotropy in one direction. AVs1 and AVs2 represent the propagation anisotropy of the fast and the slow shear waves. A connection between S-wave polarization anisotropy, AVs1 and AVs2, and seismic azimuthal and radial anisotropies can only be made if we make a hypothesis on the orientation of the foliation and of the lineation. This is what we do in Figure 7, where we make different hypothesis on the orientation of the structures in the mantle lithosphere and analyze the anisotropy that would be seen by different seismic waves.

6. “Yet, in agreement with previous studies (Ben Ismail and Mainprice, 1998), this variation is not linear: peridotites with J index>4 tend to display a weak 5 variation of the maximum anisotropy values. Coarse-grained peridotites show more variable olivine CPO intensities (J indexes range between 2–11), but their maximum seismic anisotropies are in the same range as those displayed by the sheared peridotites (Fig. 3a, b). This suggests that the modal composition has also an important effect on the seismic anisotropy of these samples.” This sentence is not clear.

The text has been corrected.

7. "How is the isotropic S-wave velocity determined?"

First, the sample anelastic tensor was calculated with D. Mainprice’s software “Anis_ctf”, using the modal composition and the elastic constants tensor of each phase as input. The isotropic velocities were then calculated with D. Mainprice’s software “VRH” using the anelastic tensor, by averaging Vs and Vp in all directions. A brief description has been added in the revised article for sake of clarity.

8. "There are a considerable number of vertical and horizontal “alignments” in Fig. 4. What is the reason for that, could it be an artifact in the determination of the petrophysical properties?"

Modal contents were derived from EBSD maps. The precision of this method do not allow us to obtain values more precise than numbers without decimals, producing the vertical alignments observed in Fig 4. The horizontal alignments are due to the fact that Vp and Vs values are rounded to two decimal places. Variations of 0.001 km/s are largely below the uncertainty of the velocity calculations (cf. the discussion on the uncertainty in these estimations in the first paragraph: the maximum uncertainty in Vp and Vs is of $\pm$0.04 and $\pm$0.03 km/s, respectively).

Fig. 5 and its discussion throughout all the text.

9. "It is repeatedly stated that variation or dispersion of Vp (and rho) is always greater than that of Vs. However, according to the relative values given by the authors, the dispersion of Vp, Vs and rho are 2.3, 3 and 1.9 % respectively. So in fact, Vs shows the greatest relative variation among the three parameters under study."

The values the referee is referring to give the percentage of variation between the highest and the lowest Vp, Vs and density. The dispersion we are describing is the variation at similar compositions. The main text has been modified for clarity.

10. "Looking at Fig. 5 a one would be tempted to interpret a bimodal distribution of Vp values with similar linear slopes but shifted intercepts (at least for the coarse-grained peridotites). A cluster analysis would be helpful here probably. Besides, the ranges of Vp, Vs and rho absolute values in Fig. 4 and Fig. 5 are rather different, what is the reason for this difference? For instance, the dispersion of rho in Fig. 4 is 3 % whereas in Fig. 5 this value is only 1.9 %. Therefore, it is not clear at all if the variation of Vp or rho are “strong” compared to Vs. In addition, if that was the case, what would be the explanation for it? Would it be an issue with the computation of the bulk modulus (as the shear modulus and rho dependency is common to Vp and Vs)?"

Although 50 samples are already a large number of samples to perform a full microstructural study, we believe our sample set is too small for a cluster analysis. The variation in the seismic velocities between Figures 4 and 5 is explained by the fact that the in figure 4, we present seismic velocities at ambient pressure and temperature, because we wanted to isolate the effect of composition on isotropic seismic properties

SED
5, C658–C666, 2013

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

and density. In figure 5, where the variation of seismic velocities with depth is plotted, the latter were calculated at the equilibration temperature and pressure of each sample. As noted by the referee, the variation in Vp is similar to the variation in Vs or in density. The text was rephrased to better express this point.

11. “At first order, the change from a “normal”100 km-thick lithosphere to a cratonic geotherm increases Vp and Vs by up to 2.8 and 3.1 %, respectively. This variation is on the same order of the one resulting from compositional heterogeneity among the Kaapvaal xenoliths (Figs. 4 and 5).” This is not, however, what Fig. 5 shows: the intervals between the cratonic and 100-km-thick crust are always quite larger than the dispersion shown by the data, particularly for Vs.

First, as explained in the answer to comment 10, the values plotted in Figure 4 and 5 were calculated in different ways. The variation of Vp and Vs in Figure 4 is only due to composition, and is indeed on the same order as the one generated by a change from a “normal” 100 km-thick lithosphere to a cratonic geotherm. The dispersion of Vp and Vs at a given depth in Figure 5, which is only due to compositional changes, is smaller. Therefore, the text has been corrected.

12. “Comparison of the velocity profiles in Fig. 5 with one-dimensional P wave velocity profiles for the Kaapvaal highlights that most P wave models show an increase of velocity with depth between 50 and 200 km depth, consistent with James et al. (2004) data, but which we do not observe (Fig. 5a).” Not entirely clear from the figure. The data seem to have an increase with depth, particularly if we consider a bimodal behaviour. In any case, the statement is too speculative.

This statement was indeed too speculative. The text has been corrected.

13. “Between 70 and 90 km, P waves velocities estimated for our xenoliths are higher than those in most seismic models. However, these depths are not well constrained in the present study because of the small number of xenoliths analyzed (2).” Could it also be related to the spinel elastic model chosen?

This variation is not related to the spinel elastic model, because we did not integrate this mineral in our calculation. Indeed, spinel is a very minor phases in all our samples (less than 1%). It is only present in kelyphite rims around garnet.

14. “If we consider a 150 km-thick homogeneous anisotropic mantle lithosphere, which is consistent with 190 km-thick lithosphere inferred from the geotherm of Baptiste et al. (2012),” Then why not just using 190 km instead?

This is exactly what we did. The crust is $\sim$40 km thick in the Kaapvaal. If the lithosphere is 190 km thick, we have to consider a lithospheric mantle thickness of 150 km. The text has been reformulated for sake of clarity.

15. To help the discussion Fig 7 could be completed with a table describing how the differ- ent cases match SKS and/or surface-wave data.

We have added a table to Figure 7, as suggested by referee 1.

16. “contrast. In addition, Peslier et al. (2010) and Baptiste et al. (2012) did measure a marked decrease in OH concentrations in olivine at depths greater than 160 km. Yet the resulting change in elastic properties is probably too weak to explain the receiver function signal.” The second sentence is too speculative. If the authors think so, they should offer some (quantitative) arguments for it.

A reference has been added to the main text.

17. “A change in the orientation of the foliation and lineation might also produce an impedance contrast, but Rayleigh waves azimuthal anisotropy does not show significant variation of the fast direction within the mantle lithosphere (Adam and Lebedev, 2012).” True, but this is likely because surface-wave data are not sensitive to that, and therefore the lithosphere is imaged nearly as a single block. For instance, Rayleigh waves at periods of 80-120 s are mostly sensitive to the depth range 100-200 km (according to the maximum in he corresponding kernel). So from that perspective, surface-waves could be averaging the hypothetical discontinuity imaged by receiver

SED

5, C658–C666, 2013

Interactive Comment

functions. What perhaps could be interesting for the discussion is to check if the authors see any trend in their samples in terms of the in situ rock anisotropy (considering, of course, that the effects of foliation and lineation, which are unknown, would be superimposed in the total, seismically measurable anisotropy). For instance, in their Fig. 6 there seems to be a change at around 140 km in the S1 velocity from something random-z axis aligned to something x axis aligned. Could this be relevant?

The change of S1 velocity pattern in Figure 6 is associated to a change of the average olivine CPO pattern due to the presence of sheared peridotites at depths greater than 140 km. However, as discussed in the main text, these rocks represent very local modifications of the lithosphere, and cannot be related to the discontinuities imaged by receiver functions.

Conclusions

18. "Vp does not show a clear trend; it is highly variable at all depths, probably reflecting a greater sensitivity to modal composition changes" This should be tested quantitatively (see my comment above). The explanation given is clearly insufficient.

As explained in answer to comment 10, we believe sample set is too small for the cluster analysis to be relevant here. However, we understand the point made by referee #1 and have corrected the main text.

19. "Models considering end-member orientations of the foliation and lineation in the sub- cratonic mantle lithosphere show that the simplest model that might produce both the coherent fast directions over large domains, but low delay times imaged by SKS studies, and the low azimuthal surface ewaves anisotropy with SH faster than SV in the subcratonic mantle lithosphere is the presence of 45 dipping foliations and lineations. Horizontal or vertical lineations both fail to explain the observed seismic anisotropy." However, one ends up with the feeling that neither of the presented cases (in Fig. 7) is able to match, at the same time, SKS and surface wave observations after reading the corresponding discussion section. What would be the geodynamic interpretation of the

authors of such an oblique fabric in the Kaapvaal lithosphere?

Such an oblique fabric is coherent with the “stack-subduction” model for the formation of the Kaapvaal craton. We have added a discussion on this matter in the main text.

REFERENCES:

Baptiste, V., Tommasi, A. and Demouchy, S.: Deformation and hydration of the lithospheric mantle beneath the Kaapvaal craton, South Africa, Lithos, 149, 31-50, 2012.

Interactive comment on Solid Earth Discuss., 5, 963, 2013.

SED

5, C658–C666, 2013

Interactive Comment