Constraining the depth of the lithosphere-asthenosphere boundary in tectonically complex regions using locally adjusted lithological forward models and seismic velocities

by N. Liptai, D. Kalmár and I. J. Kovács

Reply to Reviewer 1

Dear Dr. Colavitti,

Thank you very much for your detailed and constructive comments. We have carefully read through your review and modified the manuscript based on your suggestions. We believe that it has significantly improved. Please find below our replies addressing your comments point by point, highlighted in blue italic.

Sincerely,
Nóra Liptai, Dániel Kalmár, István J. Kovács

Abstract

OK

1 Introduction

l. 36 "lower temperatures" it is better if you write "lower temperatures with respect to the ones expected by the 'thermal' LAB"

We modified the text as suggested.

l. 38 Consider to replace "… these are all subsolidus processes" with "all of these processes occur under subsolidus conditions"

In addition, please define very briefly what is meant by "subsolidus processes", as the term can be ambiguous (e.g., temperature and pressure below the solidus but possibly involving solid-state transformations or deformation).

We modified the text as suggested, and added the brief clarification.

This part is very clear, I was wondering if you might want to mention some P-to-S studies carried out within the Pannonian Basin, and then explain that your target is deeper, which is why you use S-to-P conversions instead.

We added a sentence referencing the P-to-S and S-to-P studies of Kalmár et al. (2021, 2023), which targeted shallower and deeper discontinuity layers, respectively. However, this part is more of a general description of the application of receiver functions, and the detailing of our goal comes later on in the manuscript.

l. 45-47 Consider to rephrase this sentence for a better clarity, for example:

“Receiver function analysis is a widely used method for determining the depth of seismic discontinuities, as seismic waves convert from shear to compressional (S-to-P) or vice versa (P-to-S) when crossing boundaries between materials with contrasting physical properties”.

We rephrased the text for better clarity based on the suggestion.

l. 49-50 This statement: “Unlike the sharp Moho interface, the LAB lacks a distinct seismological discontinuity, making its accurate determination challenging” is clear but it would be helpful if the authors could briefly explain why its determination is more challenging (e.g. temperature effects, phase changes, resolution limits, …)

Thank you for this suggestion. We have enhanced the sentence to include the main physical and methodological reasons:
“Unlike the sharp Moho interface, the LAB lacks a distinct seismological discontinuity, as it primarily reflects a gradual thermal, rheological, and compositional transition rather than a first-order velocity contrast. Temperature-dependent velocity reductions, partial melting, hydration, and anelastic effects tend to produce broad, frequency-dependent seismic gradients, which—together with limited vertical resolution—make the accurate determination of the LAB particularly challenging.”

l. 54 Please put “sensu stricto” in italic font

Done.

2. LAB depths in the Pannonian Basin

l. 79 Please replace “prepared” with “compiled”

l. 81 To avoid too many repetitions, please replace “map” with “study”

l. 87 You can delete the word “most” at the beginning of the sentence

l. 90 Replace “used” with “considered”

We applied the above suggested small changes.

3. Methods

l. 104 “… and temporary stations…” delete “and”

l. 105 just write “ Pannonian-Carpathian-Alpine Seismic Experiment - PACASE (Schlömer et al., 2024), currently within the framework of the AdriaArray initiative”.

l. 116 Replace “For the 1D velocity models, the Excel workbook of Abers and Hacker (2016) was used…” with “For the 1D velocity model construction, we adopt as a reference the work of Abers and Hacker (2016), …”

We applied the above suggested changes.

*l. 120-121 “*As significant compositional changes are not expected in the mantle of the region, it was used for the models of all stations”.

This is probably a strong assumption, please justify this constraint.

We rephrased this part, to clarify that using an average lithospheric composition for the models is justified by the fact that the xenolith compositions do not significantly differ by location.

l. 125-127 Sorry I do not understand this sentence: "Although crustal structures are considered more complex, this uniform composition represents a sufficiently realistic approximation, and calculated velocities are in good agreement with the results of Kalmár et al. (2021)"
- You say that the crustal structures are considered more complex with respect to? Mantle?
- What do you mean with "good agreement"? Can you give an example of the velocity values computed at some stations with your method and the findings of Kalmár et al. (2021)? You can put one Table or a Figure with some stations here and probably add in the Supp. Material.

We modified the sentence, adding that we mean 'more complex' in petrological sense, as opposed to the applied simplified model.

By good agreement we mean that the calculated seismic velocities are in a similar range as those provided by Kalmár et al. (2021). For example, S-wave velocities at LTVH station go from ~3.5 km/s at the top of the upper crust to ~4.2 km/s at the bottom of the lower crust (see figs 13 and 15 in Kalmár et al., 2021, and tab 2 of Table S2 in this manuscript. We used this as a confirmation that our calculations for the crustal part of the model are valid, however we do not think this warrants a separate figure as it does not represent a significant finding.

l. 136-137 Technical question: why do you use iterative time-domain deconvolution method and not frequency deconvolution?
Do you perform any quality control? Just one sentence here could be very useful.
Probably you can take a look at these works:
- Colavitti, L., & Hetényi, G., & the AlpArray Working Group. (2022). A new approach to construct 3-D crustal shear-wave velocity models: Method description and application to the Central Alps. *Acta Geodaetica et Geophysica*, 57(4), 529–562. https://doi.org/10.1007/s40328-022-00394-4.
- Hetényi, G., Plomerová, J., Bianchi, I., Exnerová, H. K., Bokelmann, G., Handy, M., et al. (2018). From mountain summits to roots: Crustal structure of the Eastern Alps and Bohemian Massif along longitude 13.3°E. *Tectonophysics*, 744, 239–255. https://doi.org/10.1016/j.tecto.2018.07.001.

Thank you very much for this excellent suggestion. We have added a sentence on quality control and included the references you mentioned. We chose the iterative time-domain deconvolution because it is more robust and better suited to handle the large dataset used in this study. Naturally, we had previously tested the differences between the two methods, and the results clearly showed that the iterative deconvolution approach (Kalmár et al., 2021) is much more applicable in the Pannonian Basin than the frequency-domain method (Kalmár et al., 2018).

l. 138 Please write one or two sentences with some characteristics about the 1D migration method described in Kalmár et al. (2023). This can be very useful for the readers.

Based on your suggestion, we enhanced the description of the 1D migration method.

4. Parameter tests

4.1 Heat flow

l. 147 Please rephrase the sentence in this way: *"*While pressure can be reliably calculated for a given depth, estimating the rate of temperature increase (the geotherm) is more challenging, as it can vary regionally depending on several factors, most notably lithospheric architecture and thermal history"

We rephrased the sentence accordingly.

l. 151-153 Probably this sentence "The high heat… of karst systems" needs at least one reference to support this statement.

We added the reference.

l. 156 What about the uncertainties of the P- and S-wave velocity profile?

I would not expect to see an error bar on the velocity profile, but it might be worth including a sentence in the main text addressing the uncertainty associated with the velocity profiles obtained for the different heat flows.

Your point is doubtlessly valid, yet it is hard to say anything specific about the uncertainties. The velocity profiles are merely calculated from available heat flow and seismic velocity data, and thus the uncertainty is inherited from these data. In fact, the main aim of the parameter tests was to see how much effect using 'wrong' data might cause.

4.2 Mantle mineral composition

OK

4.3 Pargasite

OK

4.4 Partial melt

OK

5. Results

5.1 Model set on 4 stations

l. 211 Please replace "building" with "construction"

l. 242 "… beyond the negative phase on the receiver function" probably here you can refer to one image of the RFs in the supplement.

We added the suggested modifications.

5.2 Models of rest of the stations

l. 246 For which reason, do you separate the model related to the permanent stations and to the temporary ones? Please justify your choice.

We separated the models related to permanent and temporary stations because the amount and continuity of available data differ significantly between these two station types. Permanent stations provide substantially longer recording periods, allowing us to use a much larger

number of high-quality waveforms, which results in more robust and stable receiver function (RF) estimates. In contrast, temporary stations often operate for shorter time intervals; therefore, we only accepted results from those temporary stations where a sufficient quantity and quality of RF data were available. We considered it important to emphasize—both here and as a general methodological point—that a large data volume is a key prerequisite for obtaining reliable, high-quality RF determinations.

We added a short explanation regarding this in the manuscript.

Probably you can also think to revise the current title from "Models of rest of the stations" to "Models for the other stations".

l. 256 Replace "On this figure" with "In **Fig. 7**"

We applied the suggested modifications.

6. Discussion

6.1 Comparison of LAB depth obtained with local vs. global velocity models

l. 324-326 "Our results… respectively"

consider to rephrase the sentence: "Our results are consistent with this observation. However, significant discrepancies are found only for the SOP station, where the LAB was previously estimated at 110 km depth, while migration using the global IASP91 model and the forward velocity model developed in this study yielded depths of 70 and 66 km, respectively (Fig. 9a)".

We modified the sentence.

6.2 Effect of melt beneath the LAB

l. 343 "… presence of volatiles" please specify which volatiles you mean.

We specified the volatiles (mainly H2O and C-O-H components).

6.3 Effect of metasomatism and volatile-bearing phases on seismic velocities

l. 371 Please quantify "very small volumes": this scale is even smaller with respect to the outcrop?

We slightly modified the sentence to clarify that out of many xenolith samples, only a small number were pyroxene-rich.

l. 388 "… is still a matter of debate" please mention some works related to crustal thickness and the content of hydrous minerals.

We have added reference.

6.4 Implication of surface heat flow

l. 391 Please rephrase the opening sentence with something like:

"The reliability of surface heat flow as an indicator of subsurface temperatures may be questioned".

l. 398 Replace “because” with “since”

l. 408 Rephrase like this: “Stations KOVH, MORH and A266A” represent outliers,…”

We have modified the section based on the above suggested changes.

7. Conclusions

l. 431-432 At this point: “While global models such as IASP91 provide a useful reference, they lack the resolution to capture local-scale variations in lithospheric and asthenospheric properties” you could consider adding a short remark about the potential use of 3D reference models for a potential future work, which could help capture lateral heterogeneities in the lithosphere and asthenosphere.

We added a small enhancement to the last sentence of the Conclusion about using more developed reference models.