Author response to "Correlation of core and downhole seismic velocities in high-pressure metamorphic rocks: A case study for the COSC-1 borehole, Sweden"

Manuscript by Kästner et al. 2019

Referee: Anett Blischke (ÍSOR Iceland Geosurvey)

General remarks and main points:

- *Interesting study that add to the borehole / core in-situ lab experiments for metamorphic rock settings, which is important for extending the global calibration database for deeply buried metamorphic rocks and their understanding.*

- *This aim was however (as first stated in the introduction) to improve the imaging of thrust zones and the understanding of the deeper orogenic processes and tectonic evolution? How does the manuscript relate to that project objective? I think this needs a small revision of the introduction to fit the study that in itself has a good closure.*

- *I bring in quite a few suggestions, but hope they help to make this a good paper and contribution.*

- *Looking forward to see the revised manuscript.*

We thank the reviewer for the comprehensive review of our submitted manuscript, giving a number of comments and suggestions for improvements. In the following, we attempt to respond to each of the comments and amendments, and, where applicable, we propose our changes for the revised manuscript. We feel that the presented changes will greatly improve our submission in order to provide it in a format acceptable for publication within this Journal.

Abstract:

Has all the info, still possibly sort the sentences.

- *Where?*
- *What objective?*
- *Doing What?*
- *How?*
- *Resulting?*
- *What didn´t work?*
- *What did?*
- *Why are the study results important?*

Please re-arrange specifically this passage, I am getting confused what are the results that didn't work and what did. Always better to end on the results that did work:

"The core and downhole velocities deviate by up to 2 km/s. However, velocities of mafic rocks are generally in close agreement. Seismic anisotropy increases from about 5 to 26 % at depth, indicating a transition from gneissic to schistose foliation. We suggest that differences in the core and downhole velocities are most likely the result of microcracks mainly due to depressurization. Thus, seismic velocity can help to identify mafic rocks on different scales whereas the velocity signature of other lithologies is obscured in core-derived velocities. Metamorphic foliation on the other hand has a clear expression in seismic anisotropy."

To avoid any confusion, we have re-arranged the abstract paragraph accordingly, as proposed by the reviewer:

"[…] For some intervals of the COSC-1 borehole, the core and downhole velocities deviate by up to 2 km/s. These differences in the core and downhole velocities are most likely the result of microcracks mainly due to depressurization. However, the core and downhole velocities of the intervals with mafic rocks are generally in close agreement. Seismic anisotropy measured on laboratory samples increases from about 5 to 26 % at depth, correlating with a transition from gneissic to schistose foliation. Metamorphic foliation on the other hand has a clear expression in seismic anisotropy. These results will aid in the evaluation of core-derived seismic properties of high-grade metamorphic rocks at the COSC-1 borehole and elsewhere."

Please just refer to the COSC-1 borehole consistently.

We have revised and adjusted all references to the borehole to "COSC-1".

In line 47 we change "COSC project" to "COSC-1 drilling project".

Introduction:

General, please check that references are placed, were facts and introductions are stated.

Your primary objective is to "… to improve our understanding of the deeper orogenic processes and tectonic evolution." (first paragraph)
Then follows the geophysical experiments that led to this study (REF?), specifically seismic reflection data and imaging of that thrust zone (REF?), and how does better sub-surface imaging than improve the understanding of the tectonic evolution based on core data?

See comment below.

Suggest to rephrase the primary objective that than follows well into the paragraphs (L33-39), as here it is a lithological / stratigraphic objective and not the thrust zone is described. Knowing the stratigraphy and the rocks petrophysical properties would lead to better seismic reflection data processing and imaging for example.

We agree that the objective of this particular study is not clearly separated from the primary ("long-term") objective of the COSC drilling project. As pointed out by the reviewer, the ultimate aim addressed by the COSC drilling project is the understanding of the deeper orogenic processes and tectonic evolution of the Scandinavian Caledonides. Seismic reflection data provides one tool to image subsurface and to interpret these structures (including thrust zones and nappe stacks) at depth. Especially, by knowing the physical properties of the associated rocks at depth this can help to better constrain reflections and aid the processing and interpretation of these reflection profiles.

We have modified this part of the introduction in order to clearly point out which is the long-term project aim and how our study contributes to it (objective of this study versus COSC drilling project aims). Essentially, this has required some sentences to be rephrased or moved.

If there are only 2 primary projects of this kind KTB or the CCSD, why not say so and spell them out? What about the study by Zappone et al. (2000) for the Iberian, or the Kola Borehole Kern et al. (2001)? (*Kern, H. & Popp, Till & Gorbatsevich, Feliks & Zharikov, Andrey & Lobanov, K. & Smirnov, Yu. (2001). Pressure and temperature dependence of V P and V S in rocks from the superdeep well and from surface analogues at Kola and the nature of velocity anisotropy. Tectonophysics. 338. 113-134. 10.1016/S0040-1951(01)00128-7.)*

Certainly, there are more than two studies of such kind. Our purpose was to highlight especially these two, which are of comparable geological/tectonic setting with a similar high core recovery.

We agree, however, we have added additional references in order to provide a more concise overview of the related literature and background.

We therefore have explicitly named these projects and, furthermore, added the following references:

- Golovataya, O. S., Gorbatsevich, F. F., Kern, H. and Popp, T.: Properties of some rocks from the section of the Kola ultradeep borehole as a function of the P-T parameters, Izv. Phys. Solid Earth, 42(11), 865–876, doi:10.1134/S1069351306110012, 2006.
- Sun, S., Ji, S., Wang, Q., Xu, Z., Salisbury, M. and Long, C.: Seismic velocities and anisotropy of core samples from the Chinese Continental Scientific Drilling borehole in the Sulu UHP terrane, eastern China, J. Geophys. Res. Solid Earth, 117(B1), n/a-n/a, doi:10.1029/2011JB008672, 2012.
- Kern, H., Schmidt, R., Drilling, T. P.-S. and 1991, U.: The velocity and density structure of the 4000 m crustal segment at the KTB drilling site and their relationship to lithological and microstructural, Sci. Drill., 2, 130–145, 1991.
- Elbra, T., Karlqvist, R., Lassila, I., Haeggström, E. and Pesonen, L. J.: Laboratory measurements of the seismic velocities and other petrophysical properties of the Outokumpu deep drill core samples, eastern Finland, Geophys. J. Int., 184(1), 405–415, 2011.

L48-51: *This sentence I would suggest moving up front to follow with the supporting role of this project to better understanding of thrust zone and metamorphic settings.*

Moved sentence up to line 35.

L53-58: *Isn't this better placed in the methods section?*

In order to give the reader short agenda and an idea of the following sections, we have briefly introduced the applied methods. We think this is a worthwhile extension of the introduction.

Section 1.1: *This is a good concise overview but using the geological map and cross-section with the COSC-1 borehole projected on it, would really help to get the borehole's geological settings placed in the reader's head, especially if one isn't that familiar with the area. This gives an option to show that main subdivisions described by Lorenz et al. (2015a) that leads well into the smaller scale core-based experiment.*

We agree and have added an additional subfigure to get the reader more familiar with the regional setting. See also comment in the figures subsection further below.

L75: *What type of deformations (fracturing / folding / cataclastic)?*

Rocks of the COSC-1 borehole predominantly exhibit ductile shear deformation with signs of mylonitic deformation and micro-folding.

Amended sentence: "[…] (2) an extensive (ductile shear) deformation zone prevails between […]"

<u>Data and methods:</u>

Please be more specific in describing what downhole logging data in the intro, you have them in Table 1. It would be good to briefly just state that these included short-spaced sonic and zero-offset VSP in the text with the appropriate referencing and reference to Figure 2, this way it's clear from the start of reading this chapter.

We have rephrased the sentence to: "[...] from a multi-sensor core log (MSCL) and downhole data from the COSC-1 borehole including short-spacing sonic log and zero-offset VSP".

L98: *see Table 2 and Appendix A1. I am a bit missing a Figure that shows the known geology with the core section and sample location. This is a preference for people that prefer to see the graphic setup of the borehole samples. Just a suggestion, but this way it would be easier to follow who measured what at sample depth, with higher and lower reflectivity zone based on VSP, etc.?. This could even be part of Appendix A1 if the number of figures has to stay. Please see Figures 2 by Zappone et al. (2000).*

We understand the reviewers suggested to show the geology of the samples in a figure. We have referred to Figure 10, where the lithological units, and the depth of the samples is shown.

L104-107: *Could you indicate this in Figure 4, there would be enough space for the Core MSCL image, indicating the xyz structural axis to the foliation plane. Please see Figure 4 by Zappone et al. (2000).*

We agree that it is useful for the reader to understand the relation between the structural axes and the core plug measurements. Indicating this in Figure 2, however, next to the Core MSCL picture might give a wrong impression that the core/borehole is always perpendicular to the foliation plane, which is not always the case. Especially, with Figure 2 we intend to provide the more general case highlighting only the different scale and measurement conditions. Thus, we prefer to rather implement the structural coordinate system in another figure together with a raw data example (see comment on Figure 5 and L224).

Good explanation of the Figure 3 and the method.

L131-133: *What temperature was at the 2500m? T_{2500m} = (20 °C/km * 2,5 km) + 6,4 °C = 56.4°C? I am just wondering as Table 2 indicates a depth range 400-2460m, which in turn would indicate a general linear in-situ temperature range between 14,4-55,6 °C. So why is room temperature acceptable, or has it been shown that temperature does not affect the measurements. If so please state and reference that.*

For this study, of highly consolidated metamorphic rocks, thermal effects on velocity and anisotropy can be neglected (e.g., Kern 1990). Especially, for the investigated depth and temperature range these effects are small compared to pressure effects (compare with Zappone et al. (2000)). The following paragraph clarifies this.

We have added the following paragraph, for clarification:
"Generally, seismic velocities decrease with temperature (e.g., Schön (1996), Motra and Stutz (2018)). However, at very low temperatures (< 100 °C), like we observe in the COSC-1 borehole, this effect can be neglected (Kern (1978)). Moreover, the measured pressure to temperature increment (about 1.5 MPa/K) in the COSC-1 borehole is sufficiently high to prevent thermal microcracking (Kern (1990))."

Based on lab work by Mobarek (1971), would the Vp values be slightly low based on temperature increase. Of course, those tests were done on dry sandstone, and it would be good at least to describe how temperature would affect the lab results.

We agree that the seismic velocity measurements can show thermal effects depending on the investigated rock types. In particular, this effect is more pronounced in highly porous rocks as described in the work by Mobarek (1971). However, as we described above, for low-porous, consolidated rocks at lower crustal depths and low geothermal gradient the effect is outweighed by the effect of pressure as demonstrated by the extensive work of Kern. For completeness, we have added a short description of the general effect as shown in the above paragraph.

Possibly use ranges from similar studies in comparison (e.g. Iberian Peninsula)?

See comment to L131-133 above.

Motra, Hem & Stutz, Hans. (2018). Geomechanical Rock Properties Using Pressure and Temperature Dependence of Elastic P- and S-Wave Velocities. Geotechnical and Geological Engineering.

10.1007/s10706-018-0569-9.

We addressed the thermal effect in the above mentioned paragraph and we have added the reference to the manuscript.

L144-154: *So what are you saying, are you applying this method or not? It's just the explanation and reasoning – the data trend measured vs. empirical looks convincing – perhaps just rephrase slightly to be clear.*

We have rephrased this paragraph for clarification as follows:
Amend L144: "We used the relationship derived by Ji et al. (2007) to calculate velocity-pressure curves for each of our 10 core plugs (Fig. 5)."

Amended L149: "Wenning et al. (2016) used a slightly different relation for their six samples, proposed by Wepfer and Christensen (1991)."

Removed L151-153: "However, based on [...]"

Rephrased L150-154: "For most applications aiming to determine the linear high-pressure part and intrinsic anisotropy both relations give consistent results. However, the inherent zero-boundary condition of Wepfer and Christensen's relation may lead to errors in the extrapolation of the non-linear low-pressure part, why we used the relationship by Ji et al. (2007) instead."

L156: *Different in what?*

We have added the following sentence, for clarification:
"These representations are generally based on a fractional difference of the maximum and minimum measured velocities but distinguish in the applied denominator."

Section 2.2: *As you do not reference the setup anywhere in this section, either add a figure explaining this as in Figure 3 for the lab setup or point to the appropriate reference that one can go to for understanding the setup. Is this your method, then state this, or refer to the method shown as a reference? You have done that for your lab setup and the VSP.*

As this is not our method we have added the following references that describe the applied method:

- "Breitzke, M. and Spieß, V.: An automated full waveform logging system for high-resolution P-wave profiles in marine sediments, Mar. Geophys. Res., 15(4), 297–321, doi:10.1007/BF01982387, 1993."
- "Weber, M. E., Niessen, F., Kuhn, G. and Wiedicke, M.: Calibration and application of marine sedimentary physical properties using a multi-sensor core logger, Mar. Geol., 136(3–4), 151–172, doi:10.1016/S0025-3227(96)00071-0, 1997."

L179: *… accordingly to what?*

This refers to the detected signal-to-noise ratio during the measurement. We have rephrased the sentence to: "[...] to ensure a good signal-to-noise ratio for the automatic picker."

L214: *… at 0,5 m spacing?*

To clarify the meaning of the different receiver spacing, we have rephrased this sentence:
"[...] which is defined by the applied receiver spacing (2 m). The distance over which the velocity is averaged is, thus, four times larger than for the downhole sonic log (with 0.5 m receiver spacing)."

L219: *I would leave this and state "used in our study". If you start mentioning "best case" than this naturally follows the question, what the low and high cases are that need explaining.*

We have corrected this by replacing "(best case)" with "(Rayleigh resolution limit)".

Results:

L224: *Here it would have been nice to see the data plotted of Table 2, as described as the applied method on Figure 5. These are the main results that all following conclusion is based on.*

We agree that by showing the raw data of Vp and AVp measured as a function of confining pressure would benefit the understanding of the applied processing and method (Figure 5). We therefore have introduced one additional figure showing a raw data example, which would integrate well with the applied method/processing part. Moreover, we have added the remaining data graphs (which the data shown in Table 2 are based on) to the Appendix. In the data example figure, we have also added the structural coordinate system as determined for each sample as suggested in the comment on L104-107. See also comment on Figure 5 in the figures section.

In Figure 5, we prefer to present a more generic depiction that outlines the applied method and derived data from the general measurements. Thus, we have slightly modified the labels, for example, using "V" for velocity instead of Vp etc. Please, see also comment on Figure 5.

At the moment the Table 2 has only the final results Vp0, VpAP, VpLP vs. build up pressure for each vector and mean, based on your measurements and calculations. Did you double check by including measurements for increased pressure that gives a step by step series measured Vp that would demonstrate with your data what was explained in Figure 5 and the methods?
Please see example here:
https://academic.oup.com/gji/article-pdf/187/3/1393/1694975/187-3-1393.pdf

We have incorporated a data example that shows the two pressure cycles in the above mentioned subfigure.

L232: *Do you mean "core plug axial measurements"?*

That is correct. We rephrased the sentence accordingly:
"[...] from the arithmetic mean of the three axial core plug measurements (x, y, and z plug). It represents [...]"

L250-261: *Here it would be good to point out that core-derived Vp relates to the whole core log measurements at surface conditions, whereas the Sonic-VSP Log are measured has the hydrostatic pressure in the borehole and the in situ rock.*

As this part of the paper describes the results we prefer not to interpret and explain the data. However, in order to explain the reader, the impact of the different measurement approaches, we could include the following sentence:
"As core-derived Vp relates to the whole core log measurements at surface conditions, whereas the sonic and VSP log are measured has the hydrostatic pressure in the borehole and the in situ rock (cf. Fig. 2), we expected the downhole measurements to show potentially higher values. Our data shows that there is neither a […] "

I would suggest to point out the depth intervals, where the logged rock velocity is opposite in the general trend of the VSP-Log data that follows the lithology changes - add density log alongside? What about fault / fracture zones that would stand out of the rock matrix investigated?

We have specified the depth intervals where the MSCL core velocity is opposite. We therefore added some examples in brackets to the observation previously made in the results section.

L262-263: *Please be specific that the reader can follow, e.g. VpAP with the core logged velocity at surface, the VpLP to the VSP-Log data.*

To avoid any confusion, we have added the abbreviations in brackets, where it is referred to.

I would suggest pointing out the samples that are outliers / slightly off, e.g. 106.1; 143.1; 243.2; 361.2; 641.5; 661.3; or 691.1
This is more specific than to negate an entire interval, as the shallow data do not miss-match that much in comparison to the deeper interval.
You are doing this for the VpAP in the next section below.

We have included the reviewer's suggestion accordingly and specified/named those samples that deviate.

L269: *Why might this be? Are those sample much fractured?*

There are different possible reasons. Most likely this points to a stronger effect of microcracks that reduces the core velocity stronger than for the other lithologies. This hypothesis is again pointed out in the discussion. Here, however, we propose to only focus on the observations of the data and results.

L290: *What do you mean with improper relationship? The matches are close/reasonable for examples B, E, F, and D, but samples A and C are consistently lower. In comparison to the lithology, is that seen along the borehole at other depths as well?*

We agree that this is not properly stated. We have removed the reasoning (L290) from the results and only point to the observation of the "lower sample velocities (VpAp)". Possible scenarios that again explain the data are part of the discussion.

L295: *Why keep working with that example if you do not show it? Is it possible to add the example to the display in Figure 11?*

The "not shown" examples have very similar results and are representative for the shown examples. We therefore have removed "not shown" and instead refer to Table 2. In order to keep the proportion and clarity of the figure, we rather prefer to show examples of the unique samples in Figure 11.

L303: *Why might this be? Please explain.*

The low core velocity is similar to what was observed for the felsic gneiss sections, and thus is a result of the gneissic texture, which may favor the development of microcracks. We have explained and discussed this result in line 381 ff. in the discussion.

L329-330: *Is that also in reference to your final figure 12? You are using 106-1 to 193-2 format for the other intervals with selected samples.*

In this paragraph, we only refer to the sample data of the laboratory measurements. Later on, these are also represented in Figure 12, where we also took the other logs into account. This is again pointed out in line 433, noting that the highlighted regions are based on the regions indicated by the anisotropy-depth profile:
"[…] lithology and are consistent with the zones indicated by the anisotropy-depth profile as discussed earlier."

Moreover, we have adjusted the description of the lithological units and added the sample names. Line 329 has been rephrased to:
"Assuming that the point measurements sufficiently represent the core, we distinguished four different zones based on the anisotropy depth profile (Fig. 8). They correspond to the following major lithological units: […]"

L346: *Just Figure 10?*
Isn´t this best displayed on Figure 12?

This is correct. We also have added Figure 12 to the reference list in here.

L365: *What about saturated micro-fractures that are measured as well within the matrix rock?*

Saturated micro-fractures such as related with secondary porosity should give a similar explanation. In case of a preferred orientation of the micro-fractures this can again affect the anisotropy behavior of the rock. Here, we do neglect the case of open micro-fractures under in situ conditions, because we consider the lithostatic pressure to be high enough to close microfractures/-cracks in the core samples.

L374: *... for X points out of X of VpLP.*

We have specified this observation and added how many and which of the measurements show this behavior.

L392: *Are you talking about the Core Log" or Vp0, VpAP, and VpLP as a group of VpLP specifically? Might be good to specify at the beginning of the paragraph, so the reader doesn´t mix up the two data sets.*

Here, we particularly refer to the core and downhole logs from MSCL and sonic, respectively. As the reviewer suggested, we have specified this as follows:
"Core and downhole velocity measurements using MSCL and sonic tools, respectively, are subject to different scales […]"

L418: *Possibly marked these 10% as depth intervals on Figure 10 and 12.*

These 10% only refers to an approximation of the cumulative number of fractures in the cores due to core transitions (artificially broken core pieces to fit the core boxes) and natural fractures detected from televiewer analysis from Wenning et al. (2017). We have specified that these refer to the raw core data measured by the MSCL:

L460: *Definitely revise your introduction to focus the study on the matrix primarily and influences of fractures / micro-fractures,*

As pointed out by the reviewer we have revised the introduction and included a part highlighting the importance of microcracks and that these may have a considerable effect on the investigated seismic properties. See comments on introduction.

<u>Figures and table:</u>

Figures and Tables are clearly structured, and features displayed well visible, still here are a few comments and suggestions.

- ***Figure 1:***

- *The figure looks too much as a copy – past. You could ask to get a GIS version / emf draft of that map and leave out all the lines and info that doesn't matter, such as roads, power lines. Just focus on the geological- and tectonic, and borehole location. Standard is – if you have something displayed on your map, you should include that in the legend.*

  As suggested we have cleaned-up the map (remove any unimportant information), and added the missing legend entries. Furthermore, we have added subfigures of the regional tectonostratigraphy and seismic profile to better describe the geological setting and location of the COSC-1 borehole. The colors are organized in a way that one can easily depict the different tectonic units throughout the subfigures (e.g., orange colors refer to Seve Nappe Complex, etc). See figure below.

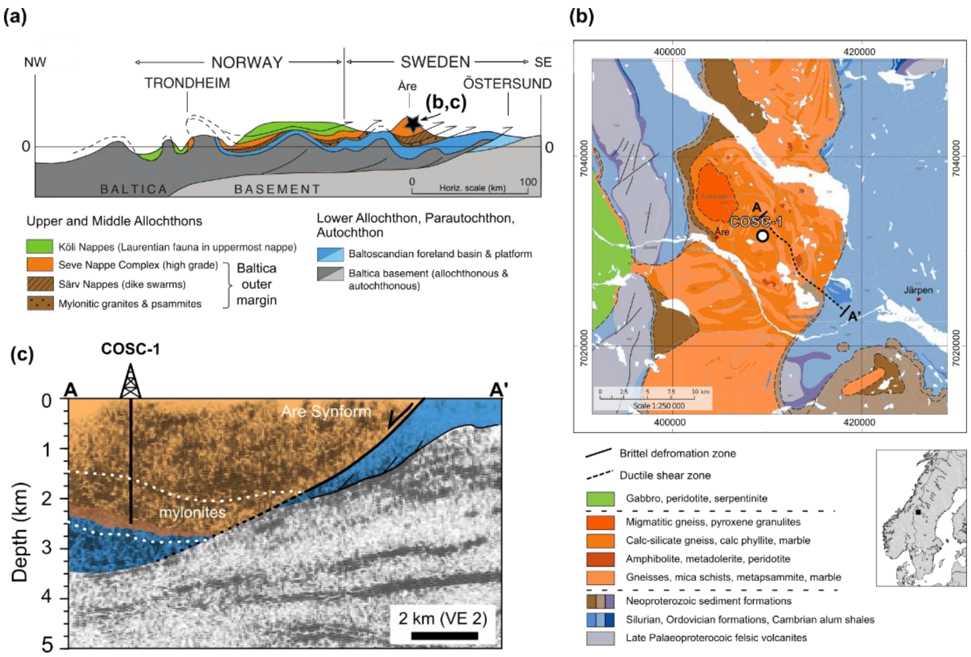


Figure 1: Overview of the regional setting and study area. (a) Tectonostratigraphic division of the central Scandinavian Caledonides (Gee et al. (2010); Lorenz et al., 2015); (b) Bedrock map with location of the COSC-1 borehole (colors modified; SGU Map Service; Strömberg et al., 1994); (c) Seismic cross-section indicated in (b), showing a part of the COSC seismic profile (Hedin et al., 2012) with the COSC-1 borehole penetrating the highly reflective Lower Seve Nappe (adapted from Juhlin et al., 2016).

- *Is there any profile section available to show how the borehole is placed and intersects the thrust zone? There are quite a few references listed that show that this should be available (Gee et al., 1985a,b; 2008, 2010; or Hedin et al., 2014, 2016, etc.).*

  Yes, there is. We have included it as described above.

  You state in the abstract "Previous seismic investigations of the Seve Nappe Complex have shown indications for a strong but discontinuous reflectivity of this thrust zone, which is only poorly understood." Seeing this, as the reader I would expect a section / profile that shows that for the introduction.
  It's just nicer to know really where the borehole is located and the general stratification that has been worked out already (Lorenz et al., 2015a,b, 2019; Krauss et al., 2017; Wenning et al, 2017; etc.)

  Please, see comment above.

- *Legend text, would be good to use emf-format; include reference to the map as a publication. The geological survey maps do in general have a publication reference.*

  We were not able to find any explicit map reference on the SGU webpage. However, the map is likely based on several mappings in the area over several years by different people (Lorenz, personal comm.). With respect to Gee et al. (2010, Fig. 8) the map is most likely based on the geological map from Strömberg et al. (1994). We have therefore added Strömberg et al. (1994) to the figure references. Please, see also general comment to Figure 1, further above.

- ***Figure 2:***
  - *Please add referencing for the Downhole-logging data input.*

    Figure 2 is a generic explanation just to show the integration of the three methods (core, downhole logging and VSP) related to a specific physical parameter used in this study, namely the compressional wave velocity (Vp). We used velocity, because it was the common physical parameter for all three methods. This same method can be applied using other types of physical properties (e.g., density). So we prefer to not add additional references.

  - *Could you indicate this in Figure 4, there would be enough space for the Core MSCL image, indicating the xyz structural axis to the foliation plane. Please see Figures 2 by Zappone et al. (2000).*

    We have indicated the core plug orientations and structural coordinates in Figure 2 as suggested. The figure capture text has been adjusted accordingly as shown below. Please also refer to comment on L104.

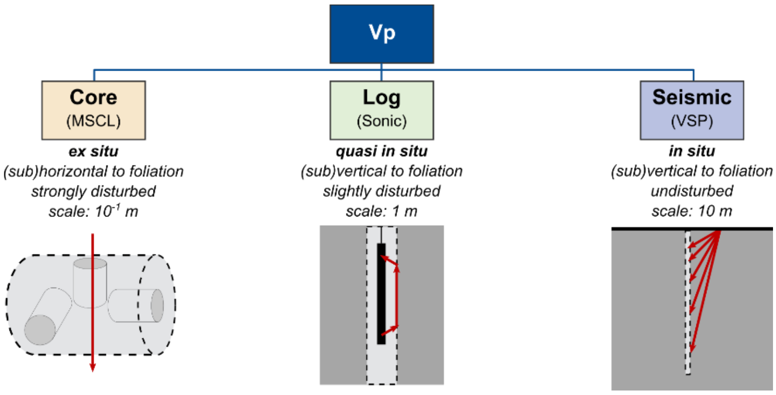


Figure 2. Schematic depicting the different environmental and measurement conditions of the core, log, and borehole seismic (VSP) P-wave velocity (Vp) measurement. Arrows indicate the direction of seismic wave propagation.

- ***Figure 4:***
  - *Please add reference for density log data source.*

    Yes, we have add and referred to:
    "Lorenz et al. (2015): COSC-1 operational report - Operational data sets GFZ Data Services."

- ***Figure 5:***
  - *Please add the reference that the method used is after Ji et al. (2007).*

    We have included the reference to Ji et al. (2007) and adjusted the labels inside the figure as described in the comment on L224.

In addition, we have introduced a new figure showing a real data example used to derive the results as listed in Table 2. For all other samples we have added the graphs in the Append. The new figure is shown below:

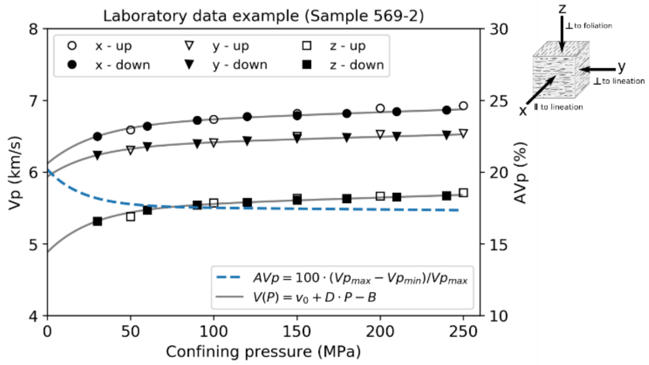


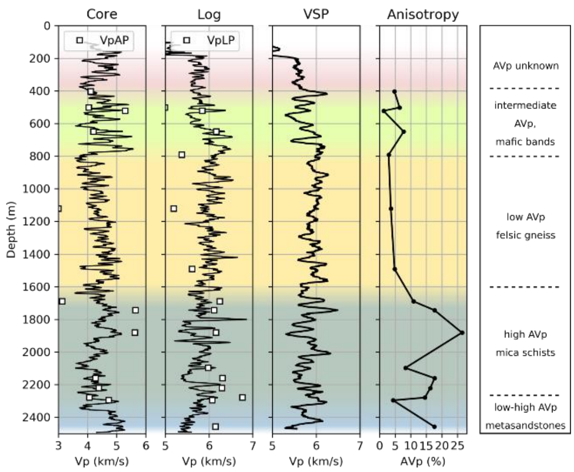
Figure X: Data example showing confining pressure versus P-wave velocity (Vp) and anisotropy (AVp) for sample 569-2 (see Table 2). Open symbols refer to measurements during pressurization and filled symbols to measurements during depressurization. Different markers indicate the velocities measured on the respective x, y, and z core plugs along the corresponding structural axes (see also Fig. 5 and text for details).

- ***Figures 10 & 11:***
  - *Please increase text size in Figures 10 and 11 similar to Figure 12*

    We have increased the text size of Figure 11.
    For Figure 10, we would prefer to keep the current text size to prevent overlapping labels. We will keep this in mind for the later publication process and will again check and optionally change it.

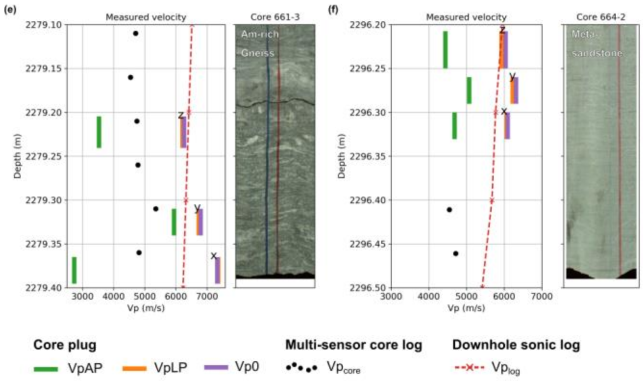
- ***Figure 12:***
  - *Please add the VpLP results to the plot.*

    We have added the mean VpAP as well as the VpLP results as small markers to the core and downhole log column, respectively, in Figure 12. See amended figure below:



- *If it is not too much trouble, please add the legends on each figure, there is enough space.*

  Yes, we have added an additional legend to Figure 11. See figure below (cropped):



Elsewhere, we proved the legends that are included in the figure or, where more suitable, designated in the figure cation (Fig. 7, Fig. 8).

- ***Table 1:***
  - *Please add references to all downhole logging data that were not part of this study but used. This helps to keep this separate, what is new data and what is part of this study.*

    Yes, we have added the following reference:

    “Lorenz et al. (2015): COSC-1 operational report - Operational data sets GFZ Data Services.”

A few first questions that came to mind:

Some questions stated by the reviewer are discussed below. Where applicable we have briefly incorporated these descriptions into the Discussion of the manuscript.

- *How does the metamorphic facies Vp results compare to other similar projects (e.g. good comparison studies doi:10.1029/2006JB004867, 2007 or doi:10.1144/GSL.SP.1998.136.01.9, 1998)*

  Ji et al. (2007): Focused predominantly on mafic/ultramafic rocks and orthogneisses from the CCSD project from the Dabie-Sulu ultrahigh pressure metamorphic terrane. They also showed a strong effect of microcracks cause by depressurization of the cores.

  Moreover, one can find a similar facies classification in terms of seismic velocities and anisotropy, where granitic gneisses exhibit lower Vp and AV values than the ultramafic rocks. However, a direct comparison is only limited because they do not investigate lower grade metamorphic such as mica schists. We think that our study provides a valuable extension to the data base of rock properties from different metamorphic facies.
  In general, prograde metamorphism develops paragneisses with progressively higher densities, with mineral aggregates that are more and more anhydrous the higher the metamorphic facies, up to the limit that eclogite and granulite facies (ultra-high pressure and temperatures respectively) are fully anhydrous and show average densities well above 3.2 g/cm3. The density, in turn, is in positive relation with the P-wave velocity (thus, higher density relates with higher velocities).

- *Uncertainty analysis is listed in references, but how was it implemented?*

  The uncertainty analysis was calculated based on a basic error propagation theory including the error of the sample specification for the velocity error. For the anisotropy uncertainty we propagated the model error of the regression coefficients to estimate the error. The uncertainty analysis was implemented using the python programming language, based on the fundamental equations described, e.g., by Taylor (1997). As being out of scope of this publication we kept the description of the error analysis to a sufficient limit in the submitted manuscript (see Methods). We prefer therefore to exclude too technical details (such as governing equations) that are, however, suitable for another more methodological publication.

- *As a connection to structural changes of the rock is mentioned as the primary reason for anisotropy, why not mark main structural intervals on Figure 10, if fractures have been analyzed?*

  We assess the structural interpretation in further below, at Figure 12. The main aim of figure 10 is to rather present results of the different log data yet without interpretation any lithological/structural differentiation.

  To understand who is driving the anisotropy, detailed analysis of the core samples has already been performed. XRD and microprobes analyses have been performed to understand if the mineralogical composition and structure can influence the anisotropy. This is the subject of the second paper. The manuscript will be submitted by the spring. The samples were also selected away from main fractures or veins that would have influenced the results of our analysis.

- *What is similar / different to the Chinese CCSD borehole experiment or the southern Iberian Peninsula? If dissimilar, are local settings governing the results? Just to mind the statement that this method would be a good tool for similar cases.*

  The study on the Iberian Peninsula, actually limited the two main metamorphic complexes (Nevado Filabride and Alpujharride) was an attempt to reconstruct a transect across a continental crust (from upper/middle to lower levels) sampling representative lithologies of various composition and metamorphic facies from outcrops. The exposed crust in that region of Southern Spain, from Marbella to Ronda, show a great variability of rock types and mainly an abundant component of high-temperature metamorphic rocks (up to migmatites). In contrast to the COSC-1 study, the Iberian study was conducted on outcrops, the rocks were as fresh (not weathered) as possible but went through an exhumation history up to exposition to atmospheric conditions (not the case in COSC-1); most of the transect of the Alpujharride was representative of continental lower crust at the transition to the upper mantle, while in COSC-1 the rocks are of middle to crustal levels (only a few samples of the Veleta and Calar Alto units are compatible with the metamorphic conditions of the Seve nappe).

  Please also see the comment about CCSD, further above.