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

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 firstly 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.

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 worked 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 15 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.*"

Please just refer to the *COSC-1 borehole* consistently.

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*)

Than 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?

Suggest to re-phrase 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.

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.

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.

L53-58: Isn´t this better placed in the methods section?

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 setting´s placed in the readers 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.

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

Data and methods:

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.

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 as to stay. Please see Figures 2 by Zappone et al. (2000).

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 Figures 2 by Zappone et al. (2000).

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.

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.

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

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.

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.

L156: Different in what?

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.

L179: … accordingly to what?

L214: … at 0,5 m spacing?

L219: I would leaved 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.

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.

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 you 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

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

L250-261: Here it would be good to point out that core-derived Vp realtes 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 insitu-rock.

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?

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.

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.

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

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 consistent lower. In comparison the the lithology is that seen along the borehole at other depths as well?

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?

L:303: Why might this be? Please explain.

L-329-330: 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.

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

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

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

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 paragraphe, so the reader doesn´t mix up the two data sets.

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

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

Figures and table:

- 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.

    - Are 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.).

      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.)

    - 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.

- Figure 2:

  - Please add referencing for the Downhole-logging data input.

  - 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).

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

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

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

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

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

- 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.

A few first Questions that came to mind:

- 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)

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

- 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 analysed?

- 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.