Solid Earth Discussions

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Reply on RC1

Michael J. Schmidtke et al.

Author comment on "Elastic anisotropies of rocks in a subduction and exhumation setting" by Michael J. Schmidtke et al., Solid Earth Discuss., https://doi.org/10.5194/se-2021-3-AC1, 2021

Response to:

Review of Schmidtke et al.: Elastic anisotropies of rocks in a subduction and exhumation setting

In this paper, the authors measured the crystallographic preferred orientation of the minerals from a variety of metamorphic rocks in the Lago di Cignana area, NW Alps. These data were subsequently employed to calculate the seismic velocities and velocity ratios of different rocks, including eclogite, blueschist, amphibolite, greenschist, micaschist and gneiss. The knowledge of elastic data as provided in this study is very important when we try to distinguish different rock types at depths using seismic methods. The content of the paper is appropriate for the journal, but the current version has still large room to improve. Below are my detailed comments for this paper.

- **Thank you for the constructive comments on this manuscript. These have greatly improved the quality of this submission.**
- **The responses to the comments are listed below in bold type. All references to specific lines are made to the "changes tracked"-version of the manuscript.**
- **References mentioned in this response are listed at the end of this document.**

Major comments

Probably the most critical issue in the paper is the representativeness of the studied samples. As I can see, especially for the metabasic rock types, i.e., eclogite, blueschist, amphibolite and greenschist, each rock type has only one sample. Considering large variations of the deformation structure and mineral modal composition even in the same rock type, which has been frequently observed by other researchers, it is therefore difficult to reach a meaningful comparison of the elastic properties between different rock types by solely taking the few samples in this study. I suggest the authors to incorporate more elastic property data from other studies and compare them in a larger data set.

- **This is indeed a very valid argument. In order to better ensure comparability further studies and their respective elastic properties have been added to the discussion. To give the reader an overview of the data presented in this study in comparison to other studies table 3 has been added to the manuscript. In it all referred to studies are mentioned, as well as the methods used to acquire the elastic properties listed therein.**

Some single crystal elasticities that the authors used in this study may not be very suitable. I suggest the authors to choose the more appropriate ones with respect to the mineral compositions. In this sense, some substitutes that the authors used are not necessary. Below are some references to the latest single-crystal elasticities.

- **The new single crystal data has proven to be a valuable addition to the manuscript and as many samples contained chlorite, all of these samples have been recalculated with the single crystal constants provided in the study by Mookherjee and Mainprice (2014). In the case of actinolite sample MJS36 was also recalculated with the single crystal data from Brown and Abramson (2016). In the case of omphacite we have selected to remain with those by Bhagat et al. (1992) for our calculations as we see it as an appropriate fit. Further in the case of calcite we have recalculated the samples MJS20 and MJS22 using the single crystal data by Chen et al. (2001).**

I think the elastic properties of rocks in this study were calculated using the singlecrystal elasticities measured at the ambient condition, therefore, the effects of pressure and temperature need to be evaluated or at least discussed. This is important for different rocks that are stable at different metamorphic P-T conditions.

- **This is a good point, which is now addressed in section 6.5 (lines 668-670).**

The elastic properties of rocks in this study were calculated using Voigt average. However, to my knowledge, such data were mostly computed using Hill average in the literature. It is okay to use either one for the calculation, but for the purpose of comparisons especially with the data from others', it is recommended to follow the most commonly used method.

- **While Hill average is more commonly used, there are also numerous studies, which apply Voigt averages (e.g. Rasolofosaon et al., 2000; Takanashi et al., 2001; Ivankina et al., 2005; Ullemeyer et al., 2006; Keppler et al., 2015; Ullemeyer et al., 2018). We chose the Voigt approximation to gain the uppermost possible P-wave velocity and avoid an overestimation as well as uncertainties concerning the values of the aijkl parameters. Furthermore, the Voigt averaging approach gives the closest agreement between CPO derived and laboratory-measured seismic velocities (e.g. Seront et al., 1989).We agree that this has to be pointed out; however, we already mention the issue both in the methods part and the discussion of common issues. We added additional statements (lines 129-131 and lines 646-650) to point this out to the reader.**

The structure of Discussion section of the paper feels a bit strange to me. I would recommend to put "CPO development" and "Elastic anisotropies" as the secondary headings, and put "Metabasic rocks", "Metasediments" and "Gneiss" as the third heading. Besides, the content of Vp/Vs ratios, is not related to the elastic anisotropies; and it can be integrated into the Results section.

- **Even so this restructuring is possible the authors of this manuscript wish to remain with the original structure for several reasons. The first of these being, that this makes orientation in the manuscript far easier, as the previous sections "4. Composition and microfabrics of the samples studied" and "5. Results" are already divided by lithology and not by the methods or other categories. Adhering to the order found in "4. Composition and microfabrics of the samples studied" allows the reader to select a specific lithology of interest and filter the manuscript for data on this lithology.**
- **Further our manuscript is divided in this way, in order to cater to different audiences. The sections attaining to CPO development are primarily intended for readers from the structural geology and tectonics field, while the elastic properties are of greater interest to geophysicists.**

The elastic properties data in the paper are presented in the formats of texts and tables; and they are often hard to follow, especially when comparisons are made. I think some figures would be needed to help readers catch the points.

- **This is a very valid point. To remedy the dry nature of all the presented numbers, figure 9 has been added, which better illustrates the differences and similarities of the rock properties by the criteria of AVp and VP/VS-ratio, which are often referred to in the discussion and throughout the manuscript (see figure 9).**

When discussing the elastic property data in the context of a subduction and exhumation setting, it would be great to combine them with the P-T data or path of the studied rocks. In this sense, the elastic property data can be presented in a P-T diagram with P-T path for the studied samples. A good example could be the Figure 11 in Park and Jung (2019).

- **We agree that this is a helpful representation of data in Park and Jung (2019). However, since we do not have PT-data for each of our samples it would not be possible to pinpoint these on an exact place on a PT loop for the Zermatt-Saas zone. This would also be beyond the scope of this manuscript, since we aim toward representative samples for a broad field within different metamorphic facies, instead of samples with a specific PT condition. However, we are thankful for the reference, which is now also included in the discussion.**

The authors need to give more details about the approach they used to estimate the volume proportions of different mineral phases, as well as their uncertainties if possible, because an accurate mineral percentage is critical for obtaining a reliable bulkrock elastic property.

- **The estimates of volume proportions were made on the basis of thin-section microscopy and then compared to the volume proportions calculated during RTA. As the later however is known to be imprecise the estimates from the thin-sections was primarily relied on. This is mentioned in section 3. Methods "The volume percentages of the phases are estimated from thin-sections and calculated in MAUD by RTA.". A paragraph mentioning the possibility of errors resulting from this approach has been added to the manuscripts discussion section.(lines 664-667)**

The descriptions of the structures and textures of different rock types appear a bit simple. I suggest the authors to add more quantitative information such as grain size and grain shape, as well as more optical photographs to show the textures of related samples described in the text.

- **In response to this comment, we have added thin-section photographs of lithologies previously not depicted. A closer analysis of grain shape was not made, as studies have found the influence of grain shape, particularly in sheet silicates, on the bulk elastic properties is limited (Vasin et al. (2013, 2014, 2017); Nishizawa & Yoshino (2001)).**

The authors used F2 index to quantify the CPO strength, which is, to my knowledge, an index not as frequently used as J- and M-indices. It would be great to also provide J- or M-indices, so that a comparison with the results from other literature would be straightforward.

- **As we preform Rietveld Texture Analysis (RTA) in MAUD (Lutterotti, 2010, Wenk et al., 2010) the F2 index is the standard index for texture strength. This index was primarily selected for comparability of the texture strengths among samples within this study. Furthermore the F2 index is also implemented in other software such as BEARTEX (Wenk et al., 1998) and MTEX (Hielscher & Schaeben, 2008).**

Minor comments

- **Minor comments within the manuscript have been addressed directly therein or in the table below.**

line	Comment	**Answer**
51-60	This part of content can be integrated into the Method section.	**As the method used is a key component of this manuscript, we wish to keep this content in the introduction. It is of course explained in greater detail in section 3.**
128-132	Here I think the authors mainly talked about the method of retrieval of CPO, rather than the calculation of elastic properties. It would be better move this part of	**This is indeed the case. The paragraphs in question have been moved to the section above concerning Rietveld Texture Analysis (RTA) in MAUD.**

	content to the paragraphs above.	
201	Is the RTA dervied CPO an equivalent to one-point-per-grain or one-point-per-pixel CPO or other else in the EBSD derived data?	**Since sample volumes are measured in neutron diffraction, the methods are difficult to compare. Depending on the grain size and the volume percentage of each mineral phase several thousands of grains are measured or more. However, one large grain weighs in as much as several smaller grains that add up to the same size, so the CPO is more comparable with point-per-pixel, or maybe "point-per-unit-of-volume".**
202	What is F2 index and its physical meaning? It is better to give a short definition in the Method section.	**The definition of this index is a very valuable addition to the methods section. A paragraph containing a brief explanation has been added to the method section. In summary the F2 texture index is OFD based. In it a completely random texture (e.g. powder sample) would result in an index = 1, while a single crystal would result in an index = (Matthies et al., 1997).**
211	It would be great to provide such data in the supplementary figures. The same for below.	**As the textures are random we have chosen not to depict these.**
217	Clinozoisite and epidotite have very similar crystallographic structures. Could you describe a bit about how you separate their CPOs using TOF neutron diffraction and RTA.	**These minerals are indeed very similar, so that a separation of their CPOs using TOF neutron diffraction and RTA is not really possible. Thin sections were used for**

		determination of mineral phase and volume percentage, and the according phase was chosen for the RTA.
245	How to separate calcite and dolomite, which have very similar crystallographic structures.	**Calcite and dolomite different d-spacings that can be clearly separated in the spectra.**
281-282	how about the S1 polarization anisotropy?	**Values have now been added to a table. They are nor discussed in detail, since anisotropies are relatively low.**
284	How did you calculate the average Vp and Vs? Please provide the formula somewhere in the text.	**The average velocities were calculated by the VRH-averaging scheme as described in section 3 (lines 125-131).**
353	Why not formed during the retrograde deformation event or during exhumation? The amphibolite appears to be the retrograde product from eclogite.	**This would also be a possibility, however as stated in the manuscript, the assumption is made due that these are prograde mineral growth. However the exact timing of mineral growth is not the topic of this manuscript and it is primarily important that this growth took place at blueschist facies conditions.**
559	How about the effects of the mineral assemblage changes with P-T condition on the elastic properties?	**This is an interesting point, however, data on single crystals at different conditions is missing for most minerals used in this study. However, we now elaborate this in the discussion.**
576-578	The key issue is whether one or several samples can turely reprenent each rock type.	**This is true, however as the samples are compared with literature data (now**

	Especially for the meta-basic rocks, eclogite, blueschist, amphibolite and greenschist.	**also listed in table 3), we feel confident in the choice of samples and that these can be seen as representative of the lithologies in question.**
591-592	Could you provide references here. To my knowledge, many elastic properties data were calculated using Hill average.	**This question is answered in detail above and has been expanded upon in the manuscript.**
598-599	But some rock types, such as greenschist, are stable at low pressure condition in which microcracks could be ubiquitious.	**You are right, at lower pressures these will become a factor. We briefly discuss this in the current issue, but there is also an elaborate discussion as well as data on microcracks in our companion paper (Keppler et al.).**

Fig. 1c. It is better to mark N-S-E-W directions in the stereonets.

- **The cardinal directions have been added to the stereonets in figure 1.**

Figs. 4-8. Please mark foliation and lineation (or x, y, z-axes) in the pole figures.

- **This is indeed a very sensible addition and said marks have been added to the mentioned figures.**

Fig. 8. Please provide labels of subfigures and use them in the text. It is hard to follow the text without a subfigure label.

- **All subfigures of figure 8 have been labeled and are now referred to by these labels throughout the text.**

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