

Solid Earth Discuss., author comment AC1
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Reply on RC1

Ruth Keppler et al.

Author comment on "Elastic anisotropies of deformed upper crustal rocks in the Alps" by
Ruth Keppler et al., Solid Earth Discuss., <https://doi.org/10.5194/se-2021-27-AC1>, 2021

- General comments

I have read Keppler and co-workers' article various times with personal interest and attention and, in my opinion, it is adequate for publication in the Solid Earth aforementioned special issue, as it deals with a classic major nappe of the Alps Lepontine dome as well as with the use of sophisticated fabric analysis techniques, derived calculations and rock geophysical measurements applied to metamorphic rocks that record a poly- orogenic geological history.

The results of this study may also constitute relevant inputs for ongoing geophysical studies of the Alps (the manuscript mentions the AlpArray high-end seismological array experiments) and in other similar initiatives elsewhere. The text is well written and organized in general, and the figures that illustrate the manuscript are correct and appropriate. For these reasons I would recommend acceptance of the article, though there are some items that, in my opinion, should be clarified and improved previously, all this requiring a minor/moderate revision. I explain below my comments and suggestions in a long section 2 dealing with specific comments and a short section 3 including a few technical corrections.

Thank you very much for this very detailed and elaborate review and the suggestions for additional discussion topics and references. It has largely improved the manuscript. Almost all suggestions have been implemented into the manuscript and explained in the following (answers in cursive).

- Specific comments

a. "The upper crust within collisional orogens". The authors mention several times in the abstract, conclusions and elsewhere in the MS that they are studying typical lithologies from deformed upper crustal rocks in the Alps. I am mystified by the statement since the rocks dealt with are ortho- and paragneisses that underwent intense ductile deformation coeval with amphibolite facies metamorphism under relatively high pressure conditions (or

truly high-P in the eclogite facies). It is not a surprise that the authors describe it in their texts and support it with references. However, what do they actually mean with "upper crustal rocks"? Currently they are in the upper crust, but they did not acquire their principal characteristics in this realm, but at great crustal depth. When the authors design their rock ultrasound velocity experiments at different confining pressures up to 400 MPa they are implicitly admitting at least midcrustal ambient conditions. The authors should revise what they actually mean and, if necessary, rewrite the parts of the MS where they include the label "upper crustal rocks".

With upper crust we refer to what was originally in an upper crustal position and has an upper crustal composition (granitoids and sedimentary rocks, or ortho- and paragneisses) as opposed to the typically more mafic lower crust. You are right, however, that the rocks investigated here acquired their principal characteristics at much deeper positions. Therefore, we rephrased this at several sections within the manuscript (line 26, 32-35, 114-122, 130 in manuscript with changes tracked). We keep the term "upper crust", when referring to the NFP20 profile as well as our simplified version, as we use it exactly in the sense of Schmid and Kissling (2000). That allows to directly correlate with the NFP20 profile.

b. On the point of elastic anisotropy measurement and calculations. The authors deal with seismic anisotropy directions in the Alps (with supporting citations) and rock average seismic velocities/anisotropies to support the interest of rare studies as the presented here on gneisses. However, though I can foresee, it is not clear for me (after the current text) which are the specific relationships implied or the eventual applications. On one hand, the authors report on seismic anisotropy parallel or transversal to the orogenic surface trend, but its origin (attending to the publications cited) is teleseismic wave birefringence essentially generated in the mantle. The authors mention mineral and stretching lineations of surface metamorphic rocks to support geometrical relationships (that I do not challenge at all), but their contribution to teleseismic signal anisotropy likely is very small due to the relative short tract of crustal segments compared to mantle ones in wave rays, and the still shorter of the uppermost crust (in spite of being much anisotropic). So, which is the contribution expected of crustal rock anisotropy to teleseismic wave anisotropy? Is it relevant? Would it help/hinder seismic lithological reconnaissance along profiles with different orientations? Please, explain.

The contribution of the crustal rock anisotropy to the teleseismic signal is difficult to quantify. Usually, it is neglected because of the small thickness of the crust in comparison to the mantle and because of the lithological variety as well as the large differences in crustal rock anisotropy. In contrast, for the mantle, it is usually assumed that the rock anisotropy is rather constant and hence together with its large thickness most crucial for the overall teleseismic wave anisotropy. However, when crustal thickness is large, due to, for example, stacking in an orogenic wedge, and the anisotropy is high due to strong deformation in a coherent tectonic setting, the contribution of the crustal rock anisotropy to the teleseismic signal could be much more significant (e.g., Levin and Park, 1997; Xu et al., 2007; Huang et al., 2015; Wang et al., 2016). Our data set might be a basis for a better analysis of the teleseismic signal anisotropy and its origin from either crust or mantle sources. This, however, is only one step for an improvement of the teleseismic methods and we are not able to evaluate the progress of teleseismic processing and analysis within the investigations presented here.

On the other hand, the authors concentrate of the interest of determining "average rock" geophysical properties, but it may be misleading. I wonder if a highly anisotropic medium such as de Adula nappe (with a gentle-dip layered organization of interleaved ortho- and paragneiss units meter to tens or a few hundreds of m thick, and their internal penetrative foliation/lineation fabrics) would be seismically imaged as a coherent unit, nearly transparent in reflection seismology experiments and distinguishable from over- and

underlying units in seismic refraction. In the latter case "average rock" properties might be sound. However, the actual lithological organization of the Adula nappe appears to be prone to produce several reflections. In this regard, it should be noted that, rather than the thickness of layers, the key resides in the existence of acoustic impedance contrasts across contacts, which abound between ortho- and paragneisses, and between them and scarcer marble and metabasite lenses, as described in the manuscript. As a conclusion to this item, I consider the authors should describe to what aspect of seismic studies their data and results intend to make a significant contribution.

We completely agree with this assessment. Our idea of an average crustal rock originates from discussions with seismologists within the Alp Array project (German section 4D-MB). In one of the earlier meetings we presented our data showing different VP patterns and anisotropies within our sample set. This data is generally useful to the seismologists, but some of them asked if we could provide an average value for crustal anisotropy. As a geologist, I fully support the statement that the crust is completely heterogeneous both in composition and in grade of deformation. Even within the same lithology the anisotropy is very variable, as shown by our data. However, the seismologists of 4D-MB are working on an entirely different scale. Some of them need crustal data, just so that it can be subtracted in their models to make a better estimation on seismic anisotropy of the mantle. Average values of the same suit of rocks and of the crust allow for a "best fitting" of their general and large-scale models. This is why in the current study, we present the variety of different crustal rock anisotropies, as well as an anisotropy for an average crustal rock, which of course, from a geologists' point of view is an extreme oversimplification. By presenting both, the range of different anisotropies of various crustal rocks and an average crustal anisotropy, geophysicists working at a crustal scale with higher resolution, as well as those working at a lithospheric scale and taking the crust as one coherent unit have the required data to work with.

c. The regional geology of the Adula nappe. The authors present a succinct description of this nappe and illustrate it with a simplified map and a cross section parallel to the regional lineation. In a brief bibliographic survey on the nappe I have found outstanding maps and cross sections that provide a much more precise image of the organization of the unit. I am not sure if I am allowed to include excerpts of them in this report, but in any case they can be accessed, for example, in M. Carvagna-Sani's thesis (2013, Université de Lausanne, "The Adula nappe: stratigraphy, structure and kinematics of an exhumed high-pressure nappe") and related publications on the Adula nappe. They are not cited in this manuscript and, though do not contradict the descriptions presented in this article, they are outstanding as complementary structural support that likely merits citation of consideration to redraw the Fig. 2. Complementary to this, it should be mentioned that the orthogneisses correspond to two groups of different age: Ordovician and Permian.

We now include the suggested references and protolith ages of the orthogneisses found in the Adula Nappe (line 222-223 in manuscript with changes tracked). Furthermore, we updated Figure 2 based on a map by Carvagna-Sani et al. 2014, as suggested. The map is now much more detailed and accurate and we are grateful for this suggestion.

Also, now in relation with the regional geology, in the line 173 (and then in the 281) the authors refer to the "Zapport" phase, which likely is unknown to most readers unfamiliar with Alpine geology. Please, explain what is understood as the "Zapport" phase (pervasive Alpine deformation phase in the northern part of the Adula nappe, associated with the regional foliation, isoclinal folding with approximately N-S fold axes and N-S stretching lineation associating top-to-the-North sense of shear), state its age, and (maybe as a colateral must) that there also exist younger regional phases with local names (Leis and Carassino).

We agree. The Zapport phase is regional and not all readers will be familiar with it. More information on the deformation structures formed during the Zapport phase has now been provided in the text (see line 237-240). An age for peak conditions of the UHP metamorphism has been added, which marks the beginning of Zapport phase deformation. As we state in the text, the samples were collected in the central Adula Nappe, where rocks have not been subjected to younger deformation phases, such as the Leiss phase. This is why we prefer not to introduce these in the text.

d. Comments on the cross section of the Alps (Fig. 1A), the (over) simplified Fig. 1B and the subdivision of the crust into weakly deformed isotropic upper crust and strongly deformed anisotropic Alpine upper crust (sections 2.1 and 2.2). Apart of the already discussed above on the clarification of the actual meaning of "upper crust", I suggest the authors should reconsider their writings in this section. I understand what the authors intend, but I feel it is an oversimplification not supported by the regional geology as I explain. First, consideration of the crystalline external massifs and the Adriatic basement as recorders of weak or disregarded elastic anisotropy contradicts the fact that these massifs record the imprint of pervasive orogenic deformation, metamorphism and magmatism in internal zones of the Hercynian orogen (see below some Von Raumer and co-workers' articles on the subject). Also, in several cases the evidence exists that the Hercynian chain reworked an older Cadomian orogen.

Von Raumer, J.F., Stampfli, G.M. and Bussy, F., 2003: Gondwana-derived microcontinents - the constituents of the Variscan and Alpine collisional orogens. *Tectonophysics*, 365: 7-22.

Von Raumer, J.F., Bussy, F. and Stampfli, G.M., 2009: The Variscan evolution in the external massifs of the Alps and place in their Variscan framework. *C.R. Geoscience*, 341: 239-252. DOI: 10.1016/j.crte.2008.11.007.

Von Raumer, J.F., Bussy, F., Schaltegger, U., Schulz, B. and Stampfli, G.M., 2013: Pre-Mesozoic Alpine basements – Their place in the European Paleozoic framework. *Geological Society of America Bulletin*, 125: 89-108. Doi: 10.1130/B30654.

Additionally, during Mesozoic hyperextension in the Alps, several crustal units of distal parts of the involved plate margins (e.g. the Adula nappe basement) underwent widespread ductile deformations that generated foliations, lineations, and elastic mechanical rock anisotropy (there exists also a considerable bibliographic background on this topic that the authors might know, or even articles authored). All this predated the Cenozoic Alpine orogeny, of course, but likely those units are mechanically as anisotropic as those resultant of the Alpine evolution. In my opinion, all this should be acknowledged in the relevant parts of main text, even though actually the authors arrive at their current positions on crustal organization for future modelling.

We agree. The influence of structures formed during previous orogenic events has been underrepresented in our text. We now give reference to those and advise that these need to be considered in any crustal scale seismic model of the Alps. In the Adula Nappe, all Mesozoic rifting Hercynic orogeny structures have been overprinted by pervasive Alpine ductile deformation and can therefore be neglected. However, such earlier deformation is well preserved in some other parts of the Alps. For that reason we now also refer to previous deformation and related references (lines 190-194, 201-204).

e. The authors follow a correct linear procedure in explaining how they record mineral rock fabrics and, together with experimental mechanical constant determinations available, follow calculation procedures to quantify ideal rock mechanical properties that then are compared with laboratory measurements in real rocks. This has been done previously in several occasions with peridotites and eclogites and the authors cite the relevant literature

grouped into publications dealing with calculations and others dealing with measurements. However, some of the citations contain the two types of information and their appearance in only one group might be misleading. Complementary to this, it is remarkable the contrast between eclogites and gneisses in this regard. Less than five citations relate to gneisses because there exists a real lack of such data. Notwithstanding, there are some references (classical and recent) that might be included in support of the authors' statements (both in the section 2 and in the upcoming). These include the classic works of Christensen, Fountain, Ji and co-workers, such as the listed below (from which a few might be picked) and a recent one on ortho- and paragneiss petrofabrics in a tectonic/metamorphic context similar to that of the Adula nappe (Puelles et al., 2018, J. Metamorph. Geol., 36, 225-254).

Christensen, N.I., 1965. Compressional wave velocities in metamorphic rocks at pressures to 10 kbar. *Journal of Geophysical Research*, 70, 6147-6164. Doi: 10.1029/JB084iB12p06849.

Christensen, N.I., 1979: Compressional wave velocities in rocks at high temperatures and pressures, critical thermal gradients, and crustal low velocity zones. *Jour. Geophys. Res.*, 84: 6849-6857.

Christensen, N.I. and Fountain, D.M., 1975: Constitution of the lower continental crust based on experimental studies of seismic velocities in granulite. *Geol. Soc. Amer. Bull.*, 86: 227-236.

Christensen, N.I. and Mooney, W.D., 1995: Seismic velocity structure and composition of the continental crust: a global view. *Jour. Geophys. Res.*, 100 B7: 9761-9788.

Fountain, D.M., Arculus, R. and Kay, R.W. (Eds.), 1992: *Continental Lower Crust*. Elsevier, Amsterdam: 485p. Ji, S. and Salisbury, M.H., 1993: Shear-wave velocities, anisotropy and splitting in high-grade mylonites. *Tectonophysics*, 221: 453-473.

Ji, S., Salisbury, M.H. and Hanmer, S., 1993: Petrofabric, P-wave anisotropy and seismic reflectivity of highgrade mylonites. *Tectonophysics*, 222: 195-226.

Ji, S., Wang, Q. and Xia, B., 2003a. *Handbook of Seismic Properties of Minerals, Rocks and Ores*. Polytechnic International Press, Montreal, 630 p. 4

Ji, S., Wang, Q. and Xia, B., 2003b. P-wave velocities of polymineralic rocks: comparison of theory and experiment and test of elastic mixture rules. *Tectonophysics*, 366, 165-185. Doi: 10.1016/S0040-1951(03)00094

Thank you for pointing this out. It is quite hard to pick references dedicated to measurements or to modeling only, as majority of works, starting with classical papers, e.g., [Christensen, 1965; Babuška, 1968] already discuss, at least qualitatively, the relation between the measured elastic wave velocities, and elastic properties, mineral composition and preferred orientations of minerals. We tried our best to separate works, which are mostly about ultrasonic measurements, and works, which mostly represent different models of elastic properties of rocks, also paying an attention to papers using both experiments and advanced modeling methods. However, we revised the references in lines 66 - 74 and added the following references:

Christensen, N. I.: Compressional wave velocities in metamorphic rocks at pressures to 10 kilobars. Journal of Geophysical Research, 70(24), 6147-6164, 1965.

Christensen, N. I.: Compressional wave velocities in rocks at high temperatures and pressures, critical thermal gradients, and crustal low-velocity zones. Journal of

Geophysical Research: Solid Earth, 84(B12), 6849–6857, 1979.

Christensen, N. I., and Mooney, W. D.: *Seismic velocity structure and composition of the continental crust: A global view. Journal of Geophysical Research: Solid Earth*, 100(B6), 9761-9788, 1995.

Cholach, P.Y., and Schmitt, D.R.: *Intrinsic elasticity of a textured transversely isotropic muscovite aggregate: Comparisons to the seismic anisotropy of schists and shales. Journal of Geophysical Research*, 111, B09410, 2006.

Ji, S., and Salisbury, M.H.: *Shear-wave velocities, anisotropy and splitting in high-grade mylonites. Tectonophysics*, 221, 453-473, 1993.

Ji, S., Salisbury, M.H., Hanmer, S.: *Petrofabric, P-wave anisotropy and seismic reflectivity of high-grade tectonites. Tectonophysics*, 222, 195-226, 1993.

Ji, S., Wang, Q., Xia, B.: *P-wave velocities of polymineralic rocks: comparison of theory and experiment and test of elastic mixture rules. Tectonophysics*, 366, 165-185, 2003.

Puelles, P., Ábalos, B., Gil Ibarra, J.I., Rodríguez, J.: *Scales of deformation partitioning during exhumation in a continental subduction channel: A petrofabric study of eclogites and gneisses from NW Spain. Journal of Metamorphic Geology*, 36(2), 225-254, 2018.

f. Methods. Sample preparation for ultrasonic wave measurement. I am intrigued about how the authors prepared "roughly spherical" rock samples for neutron time-of flight and ultrasonic measurements, as it is not explained in the main text (lines 183-84 and 227). Where they prepared as polyhedra with several facets cut with a discoidal saw, or were they prepared with a spherical grinding machine?

For the CPO measurements by neutron diffraction, samples were cut with a saw into roughly equiaxed polyhedral (see figure below) to ensure that the whole sample remains inside the neutron beam during the rotation in the course of experiment, and also to further minimize already small effect of absorption of thermal neutrons in the sample. The samples used in the ultrasonic measurements at increased pressures were prepared as spheres with a high precision (the error on diameter is +/- 0.1 mm) using a special machine equipped with two half-spherical cutters.



g. Sections 4.5 and 4.6. From my viewpoint, some parts of the texts included in these sections explain methods rather than results and might possibly be reorganized.

We added more details to section 5.5 (formerly 4.6) to highlight all the model assumptions. In addition we added a sentence in the methodical part in lines 292 -293.

h. Theoretical and measured densities used to estimate crack porosity (lines 433-440). In principle the approach to quantify the porosity associated to microcracks may be reasonable, but the 1.7% value appears to me excessive for these rocks. The authors should be aware that considering the actual Ca-Na relationship of gneiss feldspars instead of albite may change the result, as well as would do consideration of the experimental P and S wave data presented to calculate gneiss sample Poisson's ratios, and after it their density under different confining pressures. Since these rocks depart from perfect incompressible materials (with theoretical Poisson's ratios of 0.5), the actual volume changes due to pressurization/decompression should not be ascribed exclusively to microcrack porosity and lowers the 1.7 estimation.

Total porosity was calculated based on 1) measured density of the dried sample at ambient conditions; 2) mineral composition of the same sample refined from diffraction data coupled with mineral density values from literature. Indeed, the composition of minerals in the gneiss may differ from that in references. Due to complexity of the rock and insufficient statistics and resolution of measured diffraction patterns, we made no

attempt to refine crystal structures of mineral composing the gneiss, which would have allowed us to obtain good estimates of particular mineral densities. Also, mineral volume fractions determined in the diffraction experiment are subject to uncertainties. Therefore, even though 1.7 Vol.% crack porosity may be considered too high for a gneiss, it is a reasonable estimate judging from the experimental data we have. Measured P- and S-wave velocities are not affected, as well as the elastic anisotropy coefficients of the model (since they are ratios). Model velocities are affected in two ways. First, the square root of density enters as a factor for velocities; but here the error is expected to be < 1%, comparable to uncertainty of measured ultrasonic velocities, which is $\approx 0.5\%$ for P-waves. Second, all crack porosity is attributed to thin microcracks that greatly affect elastic constants. But for rock with thin cracks, linear elastic properties are defined by crack density, which in our case is proportional to the ratio of crack porosity and crack aspect ratio for each microcrack type.

h. Microcracks and the origin of anisotropy at low confining pressure. This is an interesting matter of debate in these rocks and I suggest to include some additional descriptions and points of view. It is out of discussion the relationship between microcracks and seismic velocity magnitude and anisotropy at low confining pressure, as well as the geometrical relationships between microcrack and mesoscopic penetrative structures. In my opinion the microcrack descriptions provided in the manuscript can be improved with the help of the microphotographs presented and, likely, with additional observations. The micrographs presented correspond to standard rock sections normal and parallel to the foliation. In them, in principle would be visible microcracks (intra- and trans-granular) normal to the three principal fabric planes. If the microcracks are narrow rather than wide, it is due to the fact that they form an angle close to 90° with the plane of the image. Alternatively, if they are wide it might be due to either they are open cracks or they are oblique to the image section (actually derived of a $30\ \mu\text{m}$ thick slice) and apparently are wider. These considerations should be borne in mind prior to discussing on crack opening estate.

We note that quantification of microcracks is very important, especially for thinner cracks, which greatly affect bulk elastic properties. Despite being much more complex than the often considered Voigt-Reuss-Hill schemes, GMS model still disregards many microstructural features, i.e., representing microcracks as ellipses, with a reasonable, but not exactly measured orientation distribution, without shape distribution, without account for possible local heterogeneities or stress concentrators. It is true that the aspect ratio of microcracks may be overestimated from microscopy on thin sections, due to cracks inclined with respect to the plane, or due to limited resolution. But again, linear bulk elastic properties are defined by crack density. For modelling, we took rather high estimates of crack density and crack aspect ratio, but the model would yield same results for lower crack density of thinner microcracks.

In several microphotographs (and the main text) the authors highlight as microcracks mica exfoliation planes and I do not find convincing evidence in support of that assignation. The reason why those planes are optically individualized by contrast with other cleavage planes can be variable (opaque mineral nanoinclusions, sheared surfaces) and the low mechanical coherence of mica basal planes contributes to it. The authors should provide clear evidence to support those planes are true microcracks. The fact that some mica grains also contain irregular microcracks normal to cleavage planes might support stress states with the plane containing the maximum and minimum stress

directions normal to mica cleavage planes. In the case of quartz (notably) the presence of microcracks usually normal to the mineral shape elongation is doubtless and likely record stress relaxation along the lineation direction. No argument against it. However, the Appendix Figure 2 provides clues on the presence of mechanical discontinuities with the same orientation normal to the lineation that parallel to, or laterally grade into fluid inclusion trails. These and other similar features can be thoroughly identified as healed microcracks and are common (though usually overlooked) in quartz-bearing rocks. They denote brittle strain accommodation and immediate crack healing in the presence of fluids under geologically low T conditions, but not as low as those prevailing at the terrain surface. This may be related with the sentence included in lines 556-558: "It is likely that another system of thinner microcracks is required to match the GMS model and experimental ultrasonic wave velocities in RK15-22 at low pressure values" and may be also relevant for the discussions raised in the lines 566-572 and 617-618. There exist a background of scientific articles dealing with these intragranular penetrative microstructures, published during the last two decades, from which the authors may be aware and that might be taken into account in the discussion section in order to explain the progressive seismic anisotropy decrease and velocity increase until stabilization at significant confining pressures (600-700 MPa, equivalent to crustal depths well above 10-15 km). All this would also apply to discussion on the effect in velocity and anisotropy of other ubiquitous mechanical coherence discontinuities with close geometrical relationships to the macroscopic rock fabric: the grain and subgrain boundaries between identical and different mineral phases. I include below some bibliographic citations that might help.

Derez, T., Pennock, G., Drury, M. and Sintubin, M., 2015. Low-temperature intracrystalline deformation microstructures in quartz. *Journal of Structural Geology*, 71, 3-23.

Kjøll, H.J., Viola, G., Menegon, L. and Sørensen, B.E., 2015. Brittle-viscous deformation of vein quartz under fluid-rich lower greenschist facies conditions. *Solid Earth* 6, 681-699.

Palazzin, G., Raimbourg, H., Stünitz, H., Heilbronner, R., Neufeld, K. and Précigout, J., 2018. Evolution in H₂O contents during deformation of polycrystalline quartz: an experimental study. *Journal of Structural Geology*, 114, 95-110.

Raghmi, E., Schrank, C. and Kruhl, J.H., 2020. 3D modelling of the effect of thermal-elastic stress on grainboundary opening in quartz grain aggregates. *Tectonophysics*, 774, 228242. Doi: 10.1016/j.tecto.2019.228242.

Richter, B., Stünitz, H. and Heilbronner, R., 2018. The brittle-to-viscous transition in polycrystalline quartz: an experimental study. *Journal of Structural Geology*, 114, 1-21. Doi: 10.1016/j.jsg.2018.06.005.

Schmatz, J. and Urai, J.L., 2011. The interaction of migrating grain boundaries and fluid inclusions in naturally deformed quartz: a case study of a folded and partly recrystallized quartz vein from the Hunsrück Slate, Germany. *Journal of Structural Geology*, 33, 468-480.

Stünitz, H., Thust, A., Heilbronner, R., Behrens, H., Kilian, R., Tarantola, A. and Fitz Gerald, J.D., 2017. Water redistribution in experimentally deformed natural milky quartz single crystals - Implications for H₂O weakening processes. *Journal of Geophysical Research, Solid Earth*, 122, 866-894. Doi: 10.1002/2016.JB013533.

Tarantola, A., Diamond, L.W. and Stünitz, H., 2010. Modification of fluid inclusions in quartz by deviatoric stress. I: experimentally induced changes in inclusion shapes and microstructure. *Contributions to Mineralogy and Petrology*, 160, 825-843.

Trepmann, C., Hsu, C., Hentschel, F., Döhler, K., Schneider, C. and Wickmann, V., 2017. Recrystallization of quartz after low-temperature plasticity – the record of stress relaxation below the seismogenic zone. *Journal of Structural Geology*, 95, 77-92. Doi: 10.1016/j.jsg.2016.12.004.

Thank you for pointing this out. The possibility of former microcracks sealed by solution precipitation has now been included as a potential additional mechanical discontinuity in our samples. This is now incorporated within in the discussion and some of the mentioned references have been added (see section 6.2. fourth paragraph).

Concerning Fig 3: It was not explicitly stated in the manuscript, which microcracks were used in modeling. For self-consistent models, we considered cracks along elongated mica grains. Figure 3 was adjusted to highlight inter- and intragranular cracks instead of mica cleavage traces.

The authors estate in the lines 530-531 that: "The CPO of quartz and mica was not necessarily formed at the same time and could represent different deformation stages", in order to explain apparent discrepancies between CPOs and experimental velocity patterns. Appart of this being difficult to support with the microstructural features described and shown in the Figure 3 (suggestive of coeval mineral fabric development), likely it is unnecessary, bearing in mind the contrasting velocity distribution patterns in the minerals considered (notably quartz and mica), controlled by their crystallography. I suggest removing the sentence.

The sentence was removed.

- Technical corrections

Line 50. Check the correctness of "is" (are) for anisotropy data.

Lines 53-54. Revise "...can be either be..."

Lines 59, 590, 671 and 726-728. The correct citation year of Ábalos et al. is 2011, not 2010. In

the reference list it is wrong, too.

Lines 191-92, 504, 595 and 672. Check the correctness of citing articles submitted to the same

journal issue or in preparation (lines 578-579).

Lines 211-212. Avoid one-sentence paragraphs.

Line 220. Check the form of presentation of citations. Should it be "e.g., Vasin et al.

(2013),..." instead as (Vasin et al., 2013; ...)?

Lines 237-270. This section describes petrographic data and likely should be presented as an

independent section prior to the "Results" section.

Line 253. "kalifeldspar" is used to explain the kfs abbreviation. Is it correct instead of the "Kfs" or "K-feldspar" terms of the usually recommended after Whitney and Evans (2010)?

Lines 239, 256, 380. Here "potassium feldspar" is used, see previous comment.

Line 311. "P-wave anisotropies ... are (instead of is) defined..."

Lines 313, 328, 329, 340, 350, 493, 494, 502, 509, 524, 535 and 653. Add "the" to "... in lineation direction".

Line 646. Add a comma (,) after "collected".

All technical corrections have been applied.