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Interactive comment on "Permeability and seismic velocity anisotropy across a ductile-brittle fault zone in crystalline rock" *by* Quinn C. Wenning et al.

Anonymous Referee #1

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This manuscript presents the results of a very interesting experimental study on the permeability of a ductile shear zone with a brittle overprint. These data will be very useful for geothermal exploration. The paper is well written and well organised. I recommend publication in Solid Earth after the following minor comments have been suitably considered.

Page 2, line 23: Are the authors just talking about boreholes that have intersected fossil ductile shear zones? If not, there are plenty of boreholes that target faults in crystalline rock in, for example, the Upper Rhine Graben. If of use, the drilling is summarised in the following recent paper:

Vidal, J., & Genter, A. (2018). Overview of naturally permeable fractured reservoirs in the central and southern Upper Rhine Graben: Insights from geothermal wells. Geothermics, 74, 57-73.

Page 2, lines 25-26 and Page 16, line 4: Rocks from a borehole are, of course, shielded from weathering. However, rocks collected at the surface for laboratory studies typically show little to no evidence of the hydrothermal alteration that often characterises rocks sampled at depth. Perhaps ductile shear zones are less altered, but brittle fault zones are often riddled with hydrothermal alteration. If the authors agree, perhaps a subtle change in wording is in order?

Page 2, line 30: There are a couple of recently published papers that discuss geothermal energy exploitation in the ductile crust. Perhaps these could be cited here?

Violay, M., Heap, M. J., Acosta, M., & Madonna, C. (2017). Porosity evolution at the brittle-ductile transition in the continental crust: Implications for deep hydro-geothermal circulation. Scientific Reports, 7(1), 7705.

Watanabe, N., Numakura, T., Sakaguchi, K., Saishu, H., Okamoto, A., Ingebritsen, S. E., & Tsuchiya, N. (2017). Potentially exploitable supercritical geothermal resources in the ductile crust. Nature Geoscience, 10(2), 140.

Figure 1: Is Figure 1d a photograph or a scan? Some clarification would help.

Page 5, lines 4-5: Is this because short samples cannot be measured in the apparatus used, or because there are problems associated with measuring the elastic wave velocities of short samples? On that note, permeability measurements on samples with a length to diameter ratio less than 1:1 are not recommended. However, I completely understand that these borehole samples are both rare and difficult to core/prepare. Perhaps the authors could indicate which samples are below 1:1 in Table 2 (I guess these are the samples with no elastic wave velocity measurements)?

Line 14: Recent laboratory experiments have shown that thermal microcracking in granite starts at a temperature of 70 °C (see reference below). I'd recommend, in future studies, that the authors use a lower temperature to dry their samples.

Griffiths, L., Lengliné, O., Heap, M. J., Baud, P., & Schmittbuhl, J. (2018). Thermal Cracking in Westerly Granite Monitored Using Direct Wave Velocity, Coda Wave Interferometry, and Acoustic Emissions. Journal of Geophysical Research: Solid Earth.

Page 6, line 1: Impermeable means that fluids cannot pass. Please change "impermeable" to "low-permeability".

Page 6, line 3: I understand the issues associated with performing long-term permeability measurements. However, I think it would be interesting to quote the magnitude of the pressure drop used in these super low permeability measurements, to give the reader a rough idea.

Page 6, line 16: I think it's worth mentioning that the permeability measurements (at 10 MPa) were performed before the elastic wave velocity measurements (up to 260 MPa). Exposure to 260 MPa could have influenced rock microstructure.

Page 6, line 12: Is it not interesting to calculate a permeability anisotropy factor, as the authors do for their elastic wave velocity measurements? The permeability anisotropy factor could then be plotted on Figure 3.

Page 6, line 26: Are t_sample and t_rock the same?

Page 6, line 30: I guess this is the full pressure range of the apparatus? Although subtle, it might be worth clarifying this point so that people don't assume these pressures relate to borehole depths.

Page 9, lines 23 and 24: "Table", not "Tabel".

Page 10, lines 7-8: Based on comments earlier in the manuscript (that there are no microcracks) these sentences have the ability to confuse. Figure 4 shows that the elastic wave velocities increase with increasing confining pressure. So, are there microc-

racks? Intact granite can have a permeability as low as 10-22 m2 (see paper below). Perhaps there are microcracks in these rocks? Maybe grain-boundary microcracks that are difficult to see in thin section?

Meredith, P. G., Main, I. G., Clint, O. C., & Li, L. (2012). On the threshold of flow in a tight natural rock. Geophysical Research Letters, 39(4).

Page 10, line 18: I think this point should be made clearer in the methods section (Page 5, line 3). I would also be useful to see photographs/microscopic images of these cores to assure the reader that the comparison is reasonable. However, since this sample also contains a quartz-filled vein, for which the authors blame for the higher permeability perpendicular to foliation, perhaps it's best to remove this 23.6 sample altogether?

Figure 3: It should be noted somewhere in the discussion that temperature and fluid content can modify the measured elastic wave velocities. See papers by:

Griffiths, L., Lengliné, O., Heap, M. J., Baud, P., & Schmittbuhl, J. (2018). Thermal Cracking in Westerly Granite Monitored Using Direct Wave Velocity, Coda Wave Interferometry, and Acoustic Emissions. Journal of Geophysical Research: Solid Earth.

Nur, A., & Simmons, G. (1969). The effect of saturation on velocity in low porosity rocks. Earth and Planetary Science Letters, 7(2), 183-193.

Page 15, line 18: If of use, the above-mentioned Violay et al. (2017) paper provides data on the evolution of porosity during the high-pressure, high-temperature deformation of Westerly granite (and also some permeability measurements). There may also be useful information in:

Tullis, J., & Yund, R. A. (1977). Experimental deformation of dry Westerly granite. Journal of Geophysical Research, 82(36), 5705-5718.

Wong, T. F. (1982). Effects of temperature and pressure on failure and post-failure behavior of Westerly granite. Mechanics of Materials, 1(1), 3-17.

Page 15, line 27: Please give a reference for "…is dissimilar to models derived from brittle fault zones".

Page 15, line 33: Please give a reference for "velocities would be expected to decrease due to microfracturing".

Page 16, line 5: "losing", not "loosing".

Page 19, line 4: I agree that, due to the foliation, there's likely a large strength anisotropy. As the authors suggest, a large strength anisotropy has important ramifications for the design of engineering structures. There are a couple of papers on this topic, which may be of interest here:

Rawling, G. C., Baud, P., & Wong, T. F. (2002). Dilatancy, brittle strength, and anisotropy of foliated rocks: Experimental deformation and micromechanical modeling. Journal of Geophysical Research: Solid Earth, 107(B10).

Baud, P., Louis, L., David, C., Rawling, G. C., & Wong, T. F. (2005). Effects of bedding and foliation on mechanical anisotropy, damage evolution and failure mode. Geological Society, London, Special Publications, 245(1), 223-249.

Griffiths, L., Heap, M. J., Xu, T., Chen, C. F., & Baud, P. (2017). The influence of pore geometry and orientation on the strength and stiffness of porous rock. Journal of Structural Geology, 96, 149-160.

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