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Solid Earth Discussions
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Interactive comment on "Characteristics of a fracture network surrounding a hydrothermally altered shear zone from geophysical borehole logs" *by* Eva Caspari et al.

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Background Comments

First, my thanks to the editors for giving an opportunity to comment on this paper. It is important work, I enjoyed reading it, and I hope I can provide some useful comments!

Fault zones are highly understudied features of our earth, despite their importance in many practical fields including geothermal energy, radioactive waste disposal, carbon sequestration, and petroleum development to mention only a few. This paper is a part of a significant multi-disciplinary effort to characterize by means of geology, hydrogeol-

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ogy, and geophysics a fault zone accessible at shallow depths in the Swiss Alps. The focus of the effort is a 125-m long, steeply inclined borehole in granitic rock, GDP-1, which intersects the core of a fault zone about two-thirds of the way down. The work also benefits from proximity to an underground research laboratory, which has been operating for several decades near Grimsel Pass.

This paper is at least the fifth in a series documenting the results of this project. It covers the borehole geophysics having been preceded by papers on vertical seismic profiling, general structural geologic and hydrothermal setting, detailed geologic description, and permeability testing. The detailed geologic paper (Egli and others, 2018) has a wealth of porosity data on both fractures and altered rock matrix.

These data confirm that despite generally held beliefs of granite being very low in matrix porosity, faults zones containing hydrothermally altered rock may have porosity values from the high single digits to greater than 20%. Understanding how this porosity affects oil and gas production from granitic rocks (yes, there are such things), as well as contaminant transport, and geothermal circulation are central issues. This project is not the first to produce such data; there are some excellent studies from the radioactive waste programs in Sweden (Ahlbom, and others, 1989, Andersson and others, 1991, Gustafsson and Andersson, 1991 to name a small part of the output). But the field is hardly saturated with respect to the need, so this paper is a very welcome addition to the literature.

I must confess as a reviewer I am a user rather than a generator of borehole geophysics data, so I am unable to comment on the technical details of log analysis and interpretation. Rather, I am acutely interested in how well logs can tell me information on porosity and permeability (especially that of altered matrix) and anything that will help identify the important fluid conducting fractures. The interest in matrix comes partly from working fractured basement oil reservoirs in SE Asia, where the flow occurs in transmissive, core-zone fractures, and the storage is in alteration-enhance matrix porosity and small damage-zone fractures. A key question for such reservoirs is how

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to avoid water breakthrough leaving a lot of oil in damage-zone storage behind.

Overall Comments on Paper

The paper overall is very well conceived and written. The selection of borehole logging tools is appropriate including relative standard methods (resistivity, gamma, neutron, SP, optical televiewer) and less common ones like full waveform sonic and borehole radar. I would have liked to have seen an acoustic televiewer, but one does have to work to a budget. The work and the analyses are well described.

So overall, I consider this paper a useful contribution to the field of fault zone studies and well worth publishing.

That said there are some areas that could be improved or enhanced.

The paper would benefit from a discussion of the mineralogy of alteration products. More needs to be discussed on what these are and how they affect the logs especially the electrical logs. More needs to be stated about what is often associated with faults breccias and gouge, like clay minerals. Looking at Egli's paper, there is not a clay gouge in this rock, though such things are important contributors to hydraulic compartmentalization. Whether or not clay is there and how the alteration products affect the logs could be enhanced.

Overall the entire Grimsel fault study project (not just this paper) appears to be diminished by not have a detailed flow characterization (or one I can find). Similar studies in Sweden used continuous logging using a 0.5-m packer straddle and more recently have employed highly sensitive flow logging tools to locate and quantity the transmissivities of conducting fractures. The Cheng and Renner (2017) well tests supporting this work do not cover the entire hole and use intervals that are relatively course. Hence is not surprising that it is hard to correlate transmissivity to log attributes (line 447). That said, Table 1 lists an EM flow meter and flowmeter tests with a reference to Cheng and Renner (2017) though I could not find that data in that paper. The data do appear in

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Figure 10 of this paper, but I assume these are passive (not pumped) as they show inflows and outflows. Are there any detailed transmissivity estimates from those flow logging tests? Correlating those to the logs is an important part of the work. Again, they appear in Figure 10, but are they relevant to the logs in Figure 12? A proper reference to the flow logging work is needed with a bit more discussion of those data (apologies if they are in Cheng and Renner and I missed it).

The methodology for determining alteration-enhanced matrix porosity from geophysical logs could be a really big contribution from this paper. The complementary porosity database from Egli's paper and the correlations such as in Figure 9 and Appendix A are a great start. Yet there is very little in the conclusions about this. This is potentially a very important contribution and should be developed more. Could one use these data to help figure out a way to use resistivity data, whose limitations are mentioned in line 297. Is Appendix B useful to that end? The discussion of getting porosity from BHR is nice, but I am not aware BHR is a common logging method in oil or geothermal reservoirs (I confess I could be mistaken). Is there a way to get insights from BHR that would help with using other more common methods?

Nit-picks

A relatively minor point that confused me was the usage of the term “breakouts”. I may have it incorrect, but wearing my rock mechanics hat, I tend to think of breakouts as stress-induced borehole failure typically creating paired spalls that run along the borehole wall 180 degrees from one another. I was expecting to see such things in this paper, until I realized breakout was being used to describe any borehole wall failure, which in this hole would involve collapse and washing out of very weak material in the brecciated fault core (unfortunately the most interesting part!). I am not sure a different word to use (washouts? enlargements?), but I would suggest the use of breakout be clarified.

Line 164. By aperture does this mean open space between fracture walls or the thick-

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ness of a cataclastic zone that may have stuff inside it?

Line 507 (Appendix) Something missing?

References

Ahlbom, K., J. Smeallie, S. Tirén, J.-E. Andersson, L. Ekman, R. Nordquist, P. Wikberg, P.Andersson, and E. Gustafsson: Characterization of Fracture Zone 2, Finnsjön Study Site, Svensk Kärnbränslehantering AB, SKB Technical Report 89-19 1989 (Also appeared in special issue of Journal of Hydrology) Andersson, J.-E., L. Ekman, R. Norquist, and A. Winberg:, Hydraulic testing and modeling of fracture zone at Finnsjön, Sweden, Journal of Hydrology, 126:45-77, 1991 Cheng, Y. and Renner, J.: Exploratory use of periodic pumping tests for hydraulic characterization of faults, Geophysical Journal International, 212, 543–565, 2017. Egli, D., Baumann, R., Küng, S., Berger, A., Baron, L., and Herwegh, M.: Structural characteristics, bulk porosity and evolution of an exhumed long-lived hydrothermal system, Tectonophysics, 747, 239–258, 2018. Gustafsson, E., and P. Andersson: Groundwater flow conditions in a low-angle fracture zone at Finnsjön, Sweden, Journal of Hydrology, 126:79-111, 1991

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