Author response to review 2:

We thank the referee for his careful review of the manuscript and the many useful suggestions and constructive comments, which helped us to improve the manuscript. In the following, we discuss these comments and document the associated changes we applied to our manuscript.

Thomas Doe, Referee # 2 Received and published: 28 January 2020

Comment 1) 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.

Author response: The electrical logs exhibit considerable uncertainty and thus a clear link to the mineralogy of alteration products is difficult, especially in zones of fault breccia which are accompanied by severe borehole enlargements. The fault breccia of the GBF shows epithermal-style mineralizations consisting of quartz including microcrystalline varieties of chalcedony, adularia, hydrothermal clays, pyrite, marcasite, and molybdenite (Hofmann et al. 2004, Belgrano et. al. 2016). For the section of the GBF drilled in the current study, clay gouge did not play a role and matrix porosity is rather controlled by the intensity of the ductile strain (Egli et al.2018). Different types of matrix porosity are classified by their mineralogy and texture. Quartz-dominated zones are governed by inter- and intragranular porosity, with an average porosity of 0.8%, feldspar-dominated areas show solution porosity with mean matrix porosities of 1.4%, fine-grained mica (75 μm) and coarse-grained mica are governed by inter- and intragranular porosity with average porosities of 2.8% and 4.6%, respectively, whereas breccia porosity is significantly higher with an average of 22% (Egli et al. 2018). There seems to be an indication of the influence of mica on the electrical logs as illustrated in Figure A1 below.

Changes in the manuscript: A statement about the mineralization of the fault breccia has been added in the manuscript and the Appendix A now includes a brief discussion of the resistivity logs with respect to porosity and mylonites. The discussion section was substantially extended.

Comment 2) 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 Figure 10 of this paper, but 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).

Author response: In 2015, passive and pumped EM flow meter tests were performed. However, at the time of these measurements, the system was severely disturbed. Polymer drilling mud may not have been fully removed after several rounds of flushing the borehole and potentially clogged some of the flow paths. The EM flow meter tests listed in the table of the current manuscript were performed before the pumping test described in Cheng and Renner (2017) and are not included in their paper. The in- and outflow zones marked in Figure 10 and 12 are taken from Cheng and Renner (2017) based on an interpretation of their tests. The reason not to include the measurements in the current manuscript was that we deemed the data not reliable and difficult to interpret, especially the pumped EM flow meter tests. We agree with the reviewer that a more detailed flow characterization would have been beneficial. However, funding for a follow up study in 2016 to perform further flow tests, notably periodic pumping tests, was regrettably not granted.

Changes in the manuscript: We will update Figure 10 with the passive EM flow meter tests performed in 2015, although they might be not very reliable.

Comment 3) 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?

Author response: The discussion section now includes a comparison between the porosity of the different cluster groups and the porosity database of Egli et al. (2018). The corresponding paragraph was accidently commented out in the original submission of the paper. Cluster groups 3 and 4 are in the range of matrix porosity values obtained by Egli et al. (2018).

As mentioned in the paper, Archie's law is not suitable to estimate porosity from the resistivity data. To match the porosity values from the BHR measurements, cementation indices of less than 1 would be required, which is unrealistic. The data clearly plot outside the validity range of Archie's law (Figure A1) and exhibit a different functional relation between the formation factor and porosity than the simple power law of Archie. However, it should be kept in mind that the absolute values of the measurements may not be reliable due to the slotted PVC casing. Hence, in the framework of a Master project, the effect of the fluid-filled borehole and slotted PVC casing were investigated utilizing analytical corrections and numerical forward modelling in COMSOL Multiphysics. Neither of the two approaches lead to resistivity values consistent with Archie's law. One possible reason might be the influence of surface conductivity, as indicated in the paper. Interestingly, the data in the upper section of the borehole (42 – 72 m) would suggest a higher matrix conductivity than in the lower part of the borehole (105 - 120 m). The upper section contains stronger ductile deformation and thus more mylonitic zones. A recent study of electrical properties of mylonites from the Alpine fault project in New Zealand found values ranging from 675 – 75 Ohm.m (Kluge et al. 2017). To derive a reliable relationship for the resistivity logs in this study, laboratory measurements of electrical resistivity for samples of different mineralogy would be required, which is outside of the scope of the current study.

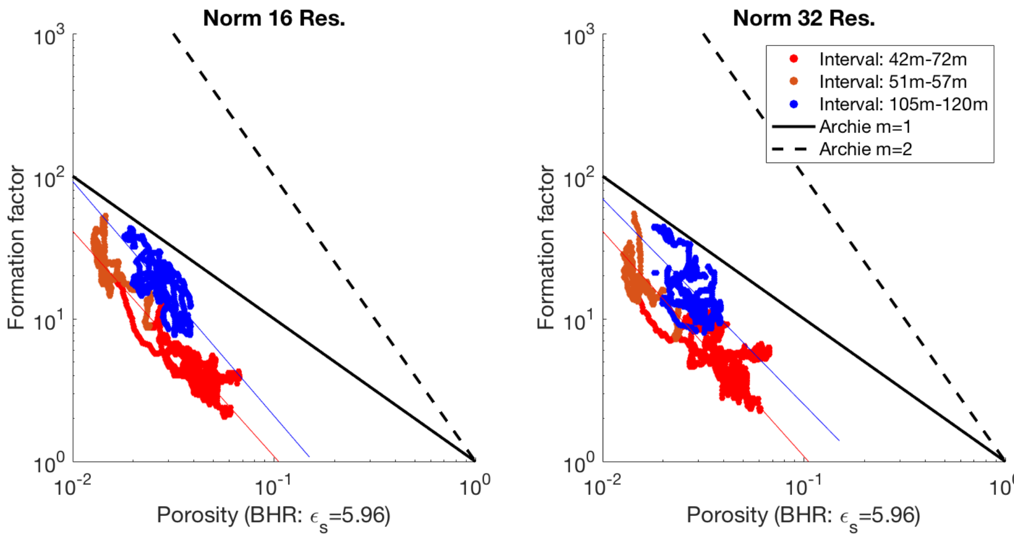

Figure A1: Formation factor vs. porosity obtained from the borehole radar for a permittivity of the solid of 5.69. The formation factor is calculated from the normal resistivity measurements 16" and 32" recorded in 2016 and the fluid resistivity obtained from the STS measurement at ambient conditions in 2016. For comparison Archie's law with a cementation factor of m=1 and m=2 is shown.

BHR measurements are not commonly utilized in oil and geothermal reservoirs since the tools are only designed to a maximum depth of roughly a 1000 m. Though dielectric propagation logs were developed for oil reservoirs and array dielectric tools are offered, for example by Schlumberger, one reason for their rare application to estimate porosity is, that in boreholes less affected by severe enlargements, Neutron-Neutron logging would be the obvious choice. BHR measurements are rather used in groundwater investigations. Frequently used set-ups in groundwater surveys to estimate porosity are vertical radar profiles (VRP) and cross hole tomography (e.g. Bradford 2008). The single-hole reflection set-up utilized in this study is more commonly used to image fractures rather than for porosity logging.

Changes in the manuscript: The discussion includes now a comparison between the porosity of the different cluster groups and the porosity database of Egli et al. (2018). Appendix A was extended and shows now the comparison of the resistivity measurements with Archie's law. The new discussion section is attached to the response of referee **# 1.**

Comment 4) 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.

Author response and changes in the manuscript: We agree that the term borehole breakout is misleading and replaced it with enlargement as a general term to describe all borehole failure encountered.

Comment 5) Line 164. By aperture does this mean open space between fracture walls or the thickness of a cataclastic zone that may have stuff inside it?

Author response: No differentiation between open space and fractures with infill has been made in the current manuscript. Aperture always refers to the thickness of the fractures. Fractures with relatively large apertures tend to have infill as evidenced by the OTV images.

Changes in the manuscript: A corresponding statement has been added to the manuscript.

Comment 6: Line 507 (Appendix) Something missing?

Author response and changes in the manuscript: Yes, there was something missing. Thanks for pointing this out. We added the missing paragraphs.