

Interactive comment on “Electric resistivity and seismic refraction tomography, a challenging joint underwater survey at Äspö Hard Rock Laboratory” by Mathias Ronczka et al.

Anonymous Referee #1

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Dear Editor, dear authors, Ronczka et al. present a potentially interesting case study of combining electrical resistivity and seismic refraction tomography. Unfortunately, it is currently not clear, what practitioners and scientists can learn from their survey. The authors present data that was acquired under what they describe as difficult conditions, but it is unclear, what this really meant for the survey and results and what others should learn from it. Should seismics and ERT be standard methods to be used for site investigation under these circumstances or not?

In the introduction, the authors claim that they are testing geophysical methods for improving planning for infrastructure projects. Later, when discussing their results and conclusions, there is no mention of this main objective. Also, only one of the four

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fracture zones that is geologically known was found using the survey and there is only speculation, why the others are not found. Also, it is unclear, which of the shear zones would be most critical for infrastructure projects.

The introduction speaks about some of the general difficulties of site investigations and how geophysics can help. It also names quite a few studies that have tried to use different geophysical methods in environments of crystalline rock. However, the strengths and weaknesses of the different methods in conditions of crystalline rock in combination with high-conductivity water are not clearly discussed. It is also not clearly discussed why the current study is needed and what it should add, compared to the existing ones. Generally, the introduction should summarize the current state of research and discuss gaps that are addressed in the manuscript. Here, it is not clear, which gaps are being addressed and how. Furthermore, the introduction very much targets Sweden, while the study should be of more general interest to be published in an international journal.

The site description is a very short description of all the work that has been performed at the Äspö HRL. Unfortunately, information that would be important for the current study is missing:

- What have seismic surveys in the rock lab shown?
- Was no surface seismic data acquired in the region? If other surface seismic data exists: What did the surveys find? Why are they not discussed? Just a quick search finds e.g.:

J. S. Kim, Wooil M. Moon, Ganpat Lodha, Mulu Serzu, and Nash Soonawala (1994). "Imaging of reflection seismic energy for mapping shallow fracture zones in crystalline rocks." *GEOPHYSICS*, 59(5), 753-765. doi: 10.1190/1.1443633

Cosma, C., Olsson, O., Keskinen, J., Heikkinen, P., 2001. Seismic characterization of fracturing at the Äspö Hard Rock Laboratory, Sweden, from the kilometer scale

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to the meter scale. International Journal of Rock Mechanics and Mining Sciences, Application of Geophysics to Rock Engineering 38, 859–865. doi:10.1016/S1365-1609(01)00051-X

- Which seismic velocities are found in the rock lab for intact rock and how does it change in fracture zones?
- What is the electrical resistivity of intact rock and of fracture zones?
- How likely are sedimentary deposits in the region? Have other studies or evidence on land shown extensive sedimentary deposits?

For the measurement techniques, some problems are described, but not really discussed how to be solved. For example: contact resistances vary by a factor of more than 1000. What does this mean for the measurements? Should future survey be tried in similar areas, or rather not?

For the positions: electrode positions were apparently measured using differential GNSS. How did this work for the underwater survey? What was the water depth? Does an accurate bathymetry model exist? Was this bathymetry model used, or was the multi-beam echo sounder used? Was the multi-beam echo sounder used to measure 3D ocean bottom topography?

With a difference in resistivity of more than a factor of 10000 between the water and the rock, it seems very important to know the position of the interface accurately. Were electrode positions deleted because they were in the wrong place, or simply, because the GNSS positioning did not work accurately?

For seismic refraction tomography: Crystalline rock is a perfect target for reflection seismic surveys, as shown in many studies. Why is only refraction seismics being used here? Low velocity zones – especially if they are just thin fracture zones – are very difficult to image in refraction tomography from the surface. Reflection surveys in the area (see references above) have shown the great potential of seismic surveys under

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these circumstances. If the potential of geophysical methods should be addressed here, why not process the data for both reflections and refraction and compare the results?

The section on inversion is somewhat confusing and not fully consistent: For example, Equations 1a, 1b and 2 do not agree. Using eq. 2, the weighting matrix is missing in 1b. Also, according to the text, the model vector contains logarithmic resistivities. What about the slowness or velocity? Concerning the use of different norms: Most inversion schemes (and I think the one of Günther 2006b is not different) use a reweighting scheme to implement a L1 norm. This is not a true L1 inversion and should not be confused with that. The discussion of the weighting matrix and the introduction of joint inversion on P5L15-22 is confusing and not well motivated. Why should a joint inversion be attempted in the first place? What could be the advantages here? What are the difficulties with single-method inversions that could be overcome by joint inversion? The reference of Günther et al. 2010 is rather difficult to access. Why not give the actual equation here?

Synthetic study: It is interesting, but not surprising to learn from the synthetic study that 3D effects under these circumstances can be severe. The authors conclusion is that “ERT data gathered at the Äspö test site are contaminated” and that cautions should be used for the interpretation. However, if the conclusion is that the data is contaminated, the conclusion should be that one needs to take the 3D effects into account in the 2D inversion or perform a 3D survey. Simply saying that one needs to be careful in the interpretation is something one could say even without the synthetic study. I suspect that not only the island created artefacts, but also bathymetry changes in the area of the profile effect the results. A more interesting synthetic study would be to compare the current density in the rock and in the water. With a resistivity factor of more than 10000, I would suspect that only very little current flows through the rock, which directly limits the sensitivity and makes small uncertainties in the water geometry a major problem. Would it not be possible to use a 3D forward model that incorporates the 3D bathymetry

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and still invert for a 2D model along the profile? For the water, one could simply use the known water resistivity and for the rock far away from the profile, one could use the known rock resistivity. It is rather unsatisfactory to analyse a problem in a manuscript and then simply say “be careful in the interpretation”, while it is unclear what “careful” really means.

The resistivity of the water seems to be rather important for the outcome of the inversion, especially if it is kept fixed. Would it not be possible to invert for one single water resistivity value? Is the measured resistivity that at the ambient temperature, or normalized to 25 degrees? Most conductivity meters actually give the resistivity at 25 degrees and would need to be back-corrected to the much lower water temperature. It would be interesting to see how the inversion changes when the water resistivity is kept at different (higher or lower) values and how the results change when it is left to vary freely. It might be coincidental and actually makes geological sense, but the thick sediment deposit lies at the position with the greatest water depth and thus could be influenced by the water depth.

Results: The results are mostly a description of the ERT and refraction seismic results, without mentioning the previous studies in the area. How do the values compare to those expected from measurements at the HRL? How do they compare to the previous surface seismic lines? What else is known about the fracture zones?

In the introduction, boreholes and geophysics is given as the two most common ways to explore the subsurface. Here geophysical results are presented, but without incorporating ground truth from e.g. boreholes. One of the main findings is a thick sediment deposit. This would indeed be a nice result. But currently, the sediments are more a hypothesis than a result. Are there any other indications of this sediment deposit? Are any drill holes available in the area? From other studies in the area: Are similar deposits known to exist? Are they likely, given the geological history?

Overall, I judge that there is potential for a nice case study, but the current manuscript

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can only be the starting point to shape the current manuscript into a journal publication. In my opinion, the study needs to be properly embedded in the current literature, the results – especially the ERT results – need to be improved to not include 3D artefacts and the results need to be discussed in light of local geological knowledge. The 3D synthetic study shows how severe 3D artefacts are. This also means that they need to be addressed in the inversion and a warning of “being careful” is clearly not enough. For the plausibility of the sediment hypothesis, any external verification would be important. If a borehole could demonstrate the existence and thickness of these sediments, this would indeed be a very nice result!

Technical edits:

- P3L5: The abbreviation has not been previously introduced
- P3L11: should be “disposal site”
- P3L17: Remove “out”
- P3L21: On the map, all shear zones are northeast – southwest, not northwest – southeast as in the text.
- P5L16: Remove “to”.

Figure 1: There is no scale in the Figure.

Figure 2: Grid cells are partly visible, but not clearly. Either show them or remove them.

Figure 4: The red and green areas are not discussed in the caption. Why not give the resistivity values of each area in the caption?

Interactive comment on Solid Earth Discuss., doi:10.5194/se-2016-157, 2016.

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