

Review Comments

The seismo-hydro-mechanical behaviour during deep geothermal reservoir stimulations: open questions tackled in a decameter scale in-situ stimulation experiment, by Amann et al

General:

This manuscript has essentially two parts to it: The first is a review of coupled seismological-hydro-mechanical processes with a focus on experimental work across scales. The second part is a fairly detailed description of a meso-scale controlled stimulation experiment conducted in a mine in the Swiss Alpes. In some ways, this is an odd combination, and I am trying to convince myself that this combination is useful for the reader. This may be more a question for the editor of the journal rather than a decision to be made by a reviewer. Here are my main comments:

1) Part 1: Literature Review of seismo-hydro-mechanical processes

I found the literature review well done and useful for a broad audience interested in EGS. Most of the relevant literature has been cited and adequately discussed. The manuscript is an interesting read for experts and non-experts in the field. I found this part of the paper acceptable for publication with some minor edits. The review culminates in a short section discussing open research questions and promoting meso-scale decameter experiments to bridge a scaled- and experimental gap existing between laboratory studies in large-scale field experiments.

2) Part 2: Description of the ISC experiment

The second part of the manuscript is a description of the meso-scale decameter ISC experiment that the authors and partners conducted in 2017 in the Grimsel Rock Lab in the Swiss Alpes. I am quite familiar with the experiment which was well designed and will down the road lead to many superb research advances. However, the description of ISC here falls short because it is largely a planning document describing the design and monitoring methods for the test, but not any results or findings. Plus, the description is at times painfully detailed (i.e., what manufacturer for sensors, which resolution, what frequency,...), leaving the reader to wonder why that these details are relevant given no results are shown. Also, the authors at times seem to be confused about the timing of writing the paper vs the timing of the test: while most text is in present tense ("The stimulation injections target natural fracture zones....", line 852) some phrases fall into past tense ("Selected stimulation intervals were isolated ...", line 900). This is confusing, in particular since there is no early "warning" in Section 3 that the ISC description would not include any results or findings. Here is what I might suggest as remedy:

- Make the second part much shorter and higher level. I like that the literature review results in making a case for meso-scale experiments, which then is followed by the detailed description of the ISC. But for the purpose of his paper, the second part should be shorter and to the point. Also make sure that

readers understand early on what to expect from the ISC section (i.e., no test results).

- Or, my preferred option, provide some selected experimental results in Section 3, and defer for any further analyses in future papers. This would make the paper much more interesting. Selected results could be linked back to the research questions given on Page 20. (As you are adding experimental results, the design description parts of the ISC section should still be shortened considerably!)

Here are some other comments:

3) Lines 68-72

The description of EGS sounds like per definition these systems are only found at depth of at least 5 to 6 km, assuming a standard geothermal gradient like in Switzerland. But there are areas elsewhere in the world where the geothermal gradient is not standard, and where high temperatures are found shallower, and where EGS is needed because the necessary permeability is not there. In my opinion, EGS should be defined as a promising technology when there is sufficiently high geothermal temperature but not enough permeability to allow for heat harvesting. That can be a depth of 5-6 km or deeper, but can also be shallower.

4) Line 81-82

Since this is a review paper for the broad community, I would add a sentence or two explaining induced seismicity.

5) Line 105

Suggest adding “small (micro-seismic)” before induced seismic events are important monitoring.....”

6) Line 124

“...experiment is currently being....”. The term “currently” may be correct at the time of writing the manuscript, but this paper will be read in 10 years or longer into the future. Change to “has been conducted in 2017...”

7) Line 147

Change “envisaged” to “envisioned”.

8) Line 147-148

Timeline may be off. The text discussed the early Hot Dry Rock work in the 70s and then notes that the design was adopted from oil and gas hydrofracture technology. Is this true? The current shale oil and gas hydro-fracturing with long horizontal wells was developed later, in the 90s and 2000s. But maybe I misunderstood?

9) Line 154

Add “new” before tensile fractures.

10)Line 208-209

Sentence structure. I suggest changing to: "The paucity ofis largely a result of the considerable depth of typical geothermal resources (e.g., several kilometers), which..."

11)Line 207ff

Going through the discussion of "Reservoir-scale experiments", I see various deep drilling and stimulation projects described, but no differentiation in terms of the rock types that were tested. Hydromechanical behavior is fundamentally different in crystalline vs argillite rocks, and this needs to be brought out here. Perhaps the same applies to other section of the manuscript; please check.

12)Line 231ff

I suggest adding that when slip is mostly aseismic then the obvious yet important result is that micro-seismic measurements will not allow monitoring of slip.

13)Line 247

Add "deep" between 3.5 km and reservoir.

14)Section 2.1.2

What about the many relevant lab studies out of Penn State on hydroshearing (Marone, Elsworth).

15)Section 2.2

There is a dedicated section of "Hydraulic Fracturing". Should there also be a dedicated section on "Hydroshearing Experiments"? Or is that included in 2.1? If so, perhaps be more upfront about it because the title of Section 2.1 is "Stimulation Process".

16)Line 354.

Instead of "remote" say: "at a distance of xxx from..."

17)Line 404-408.

Please give specific reference for this sentence.

18)Line 465.

Is it "van Ass" or "van As"?

19)Line 534-545.

I suggest adding references to the work conducted for EGS sites in the U.S. at the Geysers.

20)Line 591.

Change "question" to "questions"

21)Line 629

Same issue as before with the term “The ongoing...”. The term “ongoing” may be correct at the time of writing the manuscript, but this paper will be read in 10 years or longer into the future.

22)Line 630

Consider changing “experiment tries to contribute to the filling....” with “experiment addresses this research gap”. Same in Line 651: Change “is to contribute in finding” To “is to find answers”.

23)Section 3.2.1.1

As mentioned before, there is some going back and forth with present and past tense in the description of the experimental design, which is confusing. Consider present tense in Lines 708 and 709 for example (are drilled, are dedicated) vs. Lines 720 and 728 (was characterized, were used). Or look at lines 899-900 (the post stimulation phase) which is now back to past tense (were determined..., were isolated).

24)Section 3.2.1.2 ff

Nice to see text here going back to research questions. Just numbering the research questions is a bit cumbersome for reader but I am not sure how to improve and verbalize the numbers.

25)Line 825 and 826

Very awkward use of present tense. Sentence “More detailed processing of the complete data is performed” Is obviously wrong since a reference to the processing is given in the same sentence.

26)Lines 846ff

How was the maximum injection volume determined? Simulations?

27)Line 852

Add “initial” before transmissivities.

28)Line 877-878

How did the team know that 5L/min would be sufficient to induce initial damage?

