

J. Alcalde (Referee #2)

General Overview:

This manuscript presents the outcomes of a seismic reflection study carried out in the Pärvie fault system. The manuscript is well written and uses precise terminology, although a few sentences in the text are too reiterative or require slight rewriting. Some figures are not clear and the captions require rewording.

Dear Dr. Juan Alcalde, we would like to thank you for spending time and providing us with your constructive comments. We have tried to address the comments and here we post our response to each.

This work complements the one carried out by Juhlin et al. (2010) and produces deeper images of the target faults. However, I am missing more discussion about the differences in the results amongst these two experiments, especially giving that the new experiment has successfully increased the imaged depth of the faults in almost 5 km.

One of the objectives of this experiment is to provide subsurface information to the DAFNE project. The authors should describe in more detail how the results of this work would affect the planning of this drilling project, both in the introduction and in the discussion/conclusion.

The integration of the seismic image with the earthquake data is also a very attractive outcome that should be expanded by the authors if possible. I would suggest adding a cross-section figure of the study area, based in the seismic image and showing the characteristics of the proposed fault models. This could provide a clear summary of the conclusions of your work and will help the reader to understand your interpretation.

Followed. An additional figure (Fig. 10) is added to show the general interpretation and location of possible boreholes.

Specific comments:

P: page number; L: line number

Abstract

P538, L1-12: One third of the abstract describes the geological setting of the study area, and this is far too long. You should focus on the specific problems/hypotheses that you will be resolving in the paper; if the reader wants more information about the area or the seismic regime it will search it inside the paper.

Followed.

L9-11: The word “fault” is repeated 4 times in this sentence. Please rewrite.

This sentence is slightly modified.

L16: “which followed the 2007 line” could be omitted.

Removed.

L20: Please use pronounced or strongly, but not both (it is redundant).

“pronounce” is removed.

L25: Explain the purpose of these wells better.

Information from these boreholes will be used to better understand fault structures and stress fields along the faults at depth. This explanation is added to the text now.

1 Introduction

The current order of the paragraphs in the Introduction is slightly confusing. Consider starting from the description of the area in large scale to a focus on the specific problematic addressed in your work. Also, briefly mention the approach used to address these problems (e.g., standard seismic processing).

The introduction is now restructured according to your suggestions.

P539, L17: Fig 1 does not show the geophysical studies that you refer in the text, please revise.

Revised.

L21: Add “...the faults at depth and their extent.” or similar.

Done.

P540, L2-3: “...sub-horizontal reflections from the area...” Which area? The Burträsk? The Pärvie? Please clarify this sentence. It is confusing to know which area you are describing.

The Pärvie area. We added the area name in the text.

L20-23: You are making a comparison with the Juhlin et al 2010 experiment, but you have not described that experiment yet (i.e., you cannot use “more powerful” or “sparser” if you have not described “than what”). Giving that one of the major features of this work is the comparison with the Juhlin experiment, the authors could give more details about this previous experiments, especially in those factors that have changed. This includes marking the Juhlin et al 2010 profile in the maps (at least in Fig 1) or if it is located in the same place, mention it in the text.

Followed.

L23-25: “Several kilograms... operated hammer”. This sentence is too vague, please rewrite.

The sentence changed to: “Using several kilograms of explosives in deep shot holes will generally generate seismic signals that penetrate the earth deeper than a surface based hammer”.

P540 L28 to P541 L5: These are the conclusions of your work. The introduction is not the place

to describe the results of your experiment, but to state the purpose and objectives of your research and the possible outcomes.

Removed and modified.

2 Tectonics and seismicity of the area

P541, L15: This sentence is too long, divide it. For example: "...end glacial fault; **this is** consistent with...".

Followed.

L16-23: Summarize this part, it contains too many details (e.g., the sentence "After dismantling of the..." can be removed).

We removed the sentence. We did keep the rest as these details have bearing on the interpretation section of the paper.

P541 L25 to P542 L2: Please rewrite this sentence.

The text was slightly revised, this comment is a little unclear to us.

P542, L2: "Cross-sections show that...". Which cross-sections? Do you have any figure or references for this statement?

Added reference.

L4-6: Figure 1 does not show the dip of the zone of earthquakes, nor their depth. Please consider adding this information to Figure 1.

Figure 1 shows that the earthquakes are closer to the fault scarp in the central parts of the fault than in the south and north. We rephrased this. We do not add earthquake cross-section or depth sections as that would increase the length of the paper, and since the relevant earthquake data is shown in the cross-section in Figure 9.

L23: You use UTM coordinates in your maps and now lat/long. Please be consistent.

As we discuss the WSM data for all of Fennoscandia we think that it is more suitable to use the latitude instead of the Swedish XY coordinates, also since we do not refer to any of the events in the map.

L17-29: This paragraph refers to the Fennoscandian stress field (hence large scale). Please reorganize this section so it begins with the description of the big picture and then reduce the scale towards the local scale (study area).

Chapter 2 is organized as large scale seismicity, seismicity on the Pärvie fault, stress measurements on the Pärvie fault and then back to the large scale stresses. As the large scale stress indicators are purely focal mechanisms and we briefly mention the results of focal mechanism determination on the Pärvie fault, it is good to have discussed the earthquake observations and locations first. We therefore would like to keep the current organization of the Chapter. We have however deleted the last paragraph in the Chapter, which is more

Introductory.

3 Seismic acquisition

P543, L15: Please add the percentage of wells with full charge and minimum (instead of "In some shots", "in x% of the shots").

Followed.

L16-18: "Table 1..." to "... (See Fig. 1)" Put this two sentences at the beginning of the section. Its current place lies in the middle of the source description and interrupts the reading. Also notice that Figure 1 does not show the Juhlin et al. (2010) experiment. Please add it if possible.

We moved the two sentences to the beginning of the section. In the second sentence, it is mentioned that the profile was laid out almost in the same location as the old survey. So they are seen as one line in Figure 1.

L19-21: Any comments on the reuse of the boreholes and its effect in the data?

Generally re-using shot holes, may decrease the effective energy into the ground. But in our data set this effect is not very significant.

L27: Figure 2 does not show the shots and receivers. Please rewrite.

Figure 2 shows sparsity and the midpoint distribution of the data. The text is modified to hit the point.

4 Seismic data processing

P544, L4: Why did you apply an inner trace mute? Please explain. Also, please add a comment about noise sources found in the study area, if any (if not make it clear as well).

We applied the inner trace mute to remove bad traces.

The main sources of noise in the data were traffic on the road close to the profile, and natural features like drainages. The text is re-written now.

L11: Please add a comment on the maximum time shift obtained with the residual static calculation (i.e., add "(less than X ms)" after "significant improvement.").

Done.

L17: Figure 5 only shows 5 seconds of record, and figs 6 and 9, 15 seconds. Did you process the data down to the 27 seconds recorded? Did you crop the data? If so, mention it in your work flow. Also, did you find any interesting feature in the deepest part?

Recording length was 25 s and we looked at the data down to 25 s first. Since there was no clear reflection after 5 s then we decided to work with the upper 5 s of the data. In this paper, we just show 5 s and Figures 6 and 9 show a depth-converted and migrated section (vertical axis is Depth in Km).

L21-24: Do the authors anticipate any potential problems derived from the use of such variety of velocity models used? If so, please comment.

Please note that the new survey was designed in a way to enhance the dipping faults/structures. Therefore, imaging required a high velocity model. For migration and depth-converting the seismic section we used the gradient velocity model from the 3D local earthquake tomography provided by Lindblom et al. (2015). The text is modified to clarify this.

L24: I have no access to Lindblom et al., (2014), because at the date of this revision the paper is under revisions. Giving that you are using a velocity model extracted from their work, it would be nice to show this velocity model in your manuscript, or at least expand the description in the text. This becomes especially important when you discuss the differences in reflectivity between the faults.

This paper is now accepted and will be published soon. So information and the velocity model we refer to, will be available.

L25: The sentence "Table 2 shows..." should be the first sentence in the Seismic Data Processing part. You have been describing the work flow since the beginning and thus it should be referred at the beginning of the paragraph.

Done.

P545, L2: Which velocity model are you talking about in this sentence? Please rephrase.

Rephrased. We used the gradient velocity model from the 3D local earthquake tomography provided by Lindblom et al. (2015).

5 Interpretation

I suggest the addition of a subtitle here: "5.1. General Interpretation" (or similar) and change "Reflectivity of the faults" to 5.2.

Generally it is not recommended to have a subtitle immediately after a section title. So we prefer to keep this format.

P545, L6: Are you using the same nomenclature when describing the faults (i.e. R1, R2 etc.) than Juhlin et al. 2010? If so, please clarify. If not, be careful because it is very confusing for the readers.

Yes, we use the same arrangement that Juhlin et al. (2010) had used to name the faults. An explanation is added in the text.

L22: I have not access to Mikko et al., 2014.

The paper is now accepted and will soon be out in GFF.

Mikko, H., C.A. Smith, B. Lund, M.V.S. Ask, R. Munier, LiDAR-derived inventory of post-glacial fault scarps in Sweden, GFF, doi: 10.1080/11035897.2015.1036360.

P546, L1-6: Juhlin et al., 2010 describes in detail the potential origin of these sub horizontal reflections. Please expand this interpretation using your own images (which are now deeper).
In the text we have mentioned that these sub-horizontal reflections are deeper than the ones observed in images by Juhlin et al. (2010). We think these reflections may also originate from ultramafic intrusions at depth.

L5-6: "A similar interpretation..." this sentence is too vague. Please rewrite.

Done.

5.1 (5.2.?) Reflectivity of the faults

We prefer to keep this format.

P546, L12: Add references for these statements.

The following reference are added: (Haney et al., 2007; Haugen and Schoenberg, 2000; Jones and Nur, 1982).

Haney, M., Snieder, R., Ampuero, J.-P. and Hofmann, R.: Spectral element modelling of fault-plane reflections arising from fluid pressure distributions, *Geophys. J. Int.*, 170(2), 933–951, doi:10.1111/j.1365-246X.2007.03437.x, 2007.

Haugen, G. U. and Schoenberg, M. A.: The echo of a fault or fracture, *Geophysics*, 65(1), 176–189, doi:10.1190/1.1444708, 2000.

Jones, T. and Nur, A.: Seismic velocity and anisotropy in mylonites and the reflectivity of deep crustal fault zones, *Geology*, 10(5), 260–263, doi:10.1130/0091-7613(1982)10<260:SVAAIM>2.0.CO;2, 1982.

P547, L1-7: This is the theory, but what about in the Pärvie fault system? Is there any data that could clarify this? Perhaps well/core data? Is this one of the objectives of the DAFNE project? Please, clarify.

There is no deep borehole in the area and it is the aim of the DAFNE project to drill the faults and investigate their characteristics. This is discussed in the discussion part.

L10: "If a fault is still active..." Please rewrite.

Done.

L8-17: I cannot see the reduction in thickness of the R3 fault. In general, this paragraph needs rewriting.

In this part we refer to "R1" and we think the thickness of the reflection appears to decrease with depth. Therefore, this suggests that most likely the fracture zone is larger, close to the surface.

6 Discussion

P547, L20-21: "...while Juhlin... to about 2-3 km" This portion of the sentence should go in the introduction.

Here in the discussion part, we have tried to compare the new study with the previous one by Juhlin et al. (2010). It would be too early to discuss this in the Introduction without any evidence and showing the new results.

L22: "In Fig. 9..." This sentence should go in the figure caption of Figure 9, here it is not necessary.

Rephrased.

L23: Please expand the explanation on why you cannot see fault R2 in your image.

Slightly modified.

L25: Add "(red dots in Fig. 9)" after "...the location of earthquakes".

Done.

P548, L4: This is a good outcome of your work. Are there any similar examples in literature?

Sausse et al. (2010) have tried to model complex 3D structure of some fault systems which cause seismicity in their area. They showed the seismicity is associated mainly with the intersection of the faults. This reference is added to the text.

Sausse, J., Dezayes, C., Dorbath, L., Genter, A. and Place, J.: 3D model of fracture zones at Soultz-sous-Forêts based on geological data, image logs, induced microseismicity and vertical seismic profiles, Comptes Rendus Geoscience, 342(7–8), 531–545, doi:10.1016/j.crte.2010.01.011, 2010.

L7: Why do the earthquake activities indicate this? Because they are more spread? Please expand this.

Yes, The earthquake activities north and south of the study area are more spread to the east and indicate that this may be the case. The text is modified.

L11: Add "seismic" in between "deeper events".

Done.

L16-24: What was the original idea of the DAFNE project and why it has now changed? Target depths? Will your work have an impact in the planning of the sampling activities (i.e., could any of your models be checked with the drilling? Please explain.

Text has been to give more information on the goals of the DAFNE project and how the project may impact our seismic interpretation.

7 Conclusions

P548, L26: Remove the first sentence. "A deep seismic survey was carried out to better understand the Pärvie fault system...".

The conclusion is slightly modified.

P549, L3: "The N/S ratio was good" Add "thanks to the use of explosive source".

Done.

L4: "processing method" Add "down to 15 seconds".

We added "down to 5 s", since being the case here.

L5: Remove "in the subsurface".

Done.

L6: "using Stolt migration..." Add "and a velocity model extracted from...".

Changed to "The reflections were migrated to their true locations using the finite difference migration method with a velocity model extracted from the 3D local seismic network tomography and were traced down to a depth of about 7.5 km."

L10: Be careful: the difference in thickness alone does not explain the difference in reflectivity. Please rewrite.

We have reworded this conclusion to indicate that a larger impedance contrast may also explain the stronger reflectivity.

L14-17: Please rewrite this subparagraph.

Slightly modified.

Table 1

Add: number of shots, traces recorded, trace length, % of shots with full charge

Done.

Table 2

Add step numbers to the processing steps, so you can refer to them in the figures.

Done.

Figure 1

The background map does not add significant information to the figure. A topographic map would provide clues about the characteristics of the terrain, the elevation etc. Mark the Pärvie fault and the subsidiaries and/or use the nomenclature used later in the text (i.e., R1, R2 etc.). Mark the location of the previous seismic survey (Juhlin et al., 2010).

We followed this comment. Figure 1 was modified in a way to provide a closer look at the area. We provided an additional elevation map in the figure as Fig1b.

Figure 2

Remove the crosses in the background map. Mark the Pärvie fault and the subsidiaries and/or use the nomenclature used later in the text (i.e., R1, R2 etc.). Mark the location of the previous seismic survey (Juhlin et al., 2010).

Done.

Caption: add that this mentioned weak reflection marked on the map correspond to receiver 105 if this is the case; if not mark the zone of the weak reflections. Add the topographic background if possible.

Done. We added the topographical map in Figure 1.

Figure 3

Caption: Add the meaning of the black arrows. Are these shots raw or processed? Until what step? Please write it in the caption.

Done.

Figure 5

Caption: Add the meaning of the black arrows

Done.

Figure 6

Caption: Add the meaning of the black arrows and the two ellipses. Why do you say “6000 m/s approximately”? Are these shots raw or processed? Until what step? Please write it in the caption.

This is changed to “Fig. 6. The migrated section. The reflections (shown by the arrows) were migrated to their true locations using the velocity model provided by Lindblom et al. (2015).”

Figure 7

Mark R1 and R3 in the figure, with an arrow instead of a red line if possible.

Done. The faults are shown by red arrows.

Figure 8

Correct “ultramafic” in the caption.

Corrected.

Figure 9

Change the color of the earthquakes or of the fault sticks. The question marks are not visible.

Done.