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Interactive comment on "Structure of Suasselkä Postglacial Fault in northern Finland obtained by analysis of local events and ambient seismic noise" *by* Nikita Afonin et al.

Nikita Afonin et al.

elena.kozlovskaya@oulu.fi

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Dear Editor,

Please consider my comments to the manuscript entitled Structure of Suasselka Postglacial Fault in northern Finland obtained by analysis of local events and ambient seismic noise by Afonin et al. (doi 10.5194/se-2016-90). The authors analyse data from a temporary network consisting of 12 stations deployed in the vicinity of the Suasselka post-glacial fault to study the fault inner structure. Many analysis tools are used, which support a complementary approach to fault zone characterization. However, I feel that parts of the analysis and parts of the presentation and discussion can be improved. The manuscript should be suitable for publication in Solid Earth Discussions

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Discussion paper

after some moderate to major revision.

I waive my anonymity,

Gregor Hillers

General comments:

The authors discuss aspects of low-velocity damage zones and some resulting implications for faulting. However, in the introduction, they refer only to damage zones in strike-slip faulting environments. These damage zones are persistent features of mature strike-slip fault zones. They evolve over geologic times; their width and the velocity reduction depends roughly on the cumulative fault offset. In addition to this persistent structure, the degree of the velocity reduction, being a proxy for the material's degree of granularity, varies on time scales associated with the seismic cycle. How does this concept relate to the context of post-glacial faults discussed here?

Reply: Fault damage zones have been reported not only for strike-slip faults, but other fault types as well. For example, Kim et al., (2004) in their detailed review demonstrated that damage zones show very similar geometries across a wide range of scales and fault types, including strike-slip, normal and thrust faults. Kim et al. (2004) also demonstrated the general complexity of fault damage zones (in particular, those activated by mutual slip events). Such zones generally are characterized by multiple fracture patterns. That is why we think that the concept of fault damage zone can be used in context of post-glacial faults as well. The correspondent reference to the paper by Kim e al. (2004) is added to the Introduction part.

Comment: What is the cumulative offset of such faults in general and of the Suasselka fault in particular? What is the sense of motion? Under these circumstances, is the signature of a distinct low-velocity zone expected to be resolved?

Reply: Recent studies suggest that the seismic activity in the area of the SPGF continued from 9730 to 5055 call BP (Sutinen et al., 2014). Thus one would expect that this long-term activity resulted in formation of complex structure of the fault zone. However, the present state of knowledge about the SPGF do not give answer to the question concerning sense of motion and cumulative offset of this particular fault system. Our study revealed some general characteristics of this zone, but further studies would be necessary in order to answer all this questions.

Comment: Considering the earthquake analysis, the database of (downdip) earthquakes observed with the network could be further considered for reconstruction of observables that can be used to infer fault structure. (The authors claim that 2-15 km deep seismicity indicates that the fault is stillactive (line 14 page 5). Does the fault reach 15 km deep?)

Reply: In our study we discovered a number of seismic events recorder by the DAFNE array and originating from the depth of 2-15 km. The depths distribution for events originating from the particular area of the fault zone is shown in the new Fig. 3 (inset). It is seen that the deepest event originate from the depth of 8.5 km. The correspondent explanation of the figure is added to Page 7, lines 13-15.

Comment: Fault zone head or trapped waves can provide important, high-resolution information on material contrasts along and within fault zones. Distinguishing events that do or do not excite head or trapped waves indicate dis-continuous structural elements.

Reply: Unfortunately, in our study it was not possible to analyze trapped waves. The main reason for this was that the events considered in our studies were weak compared to those used for investigation of trapped waves in modern active fault areas (one needs to remember that we are dealing with the area of intraplate seismicity and post-glacial fault). That is why the signal from them was seen clearly at the nearest stations only. At remote stations the signal-to-noise ratio was poor and correlation of phases correspondent to trapped waves was not possible.

Comment: Considering the noise analysis, the authors group cross-fault correlation pairs (termed Group 1) and pairs of stations located on either side of the fault (Group

2). (How are pairs including the 6 stations (50% of the stations) located on top of the mapped fault (Fig. 1) classified?). This approach may certainly be motivated by the relatively sparse station spacing. However, it also reflects the first-order concept of a low-velocity zone sandwiched between two competent blocks. I think the authors must discuss the application of this model better.

Reply: Separation of station pairs into two groups was based on analysis of distribution of all dispersion curves that is bi-modal (see the new Fig. 12). More detailed information about two groups of stations is added to text (P 11, L 3-10).

Comment: Then, the width of the inferred low-velocity region from group-1 results is simply estimated to correspond to the smaller wavelength in the considered frequency band, 1.5 km. This is quite a large value for a fault characterized by a small cumulative offset (the authors may compare this to values obtained from the normal fault hosting the L'Aquila earthquake or any other well-studied fault exhibiting similar characteristics, but not strike slip faults in California).

Reply: We added comparison to the L'Aquila fault zone properties estimated from special distribution of seismicity in the paper by Valoroso et al., 2013 (Page 13, Lines 13-18). They showed that the width of the L'Aquila fault zone varies along strike from 0.3 km where the fault exhibits the simplest geometry and experienced peaks in the slip distribution, up to 1.5 km at the fault tips with an increase in the geometrical complexity. This is in good agreement with the rough estimate of the SPGF zone width in our study.

Comment: What prevents the authors from regionalizing the results as in doi:10.1007/s00024-014-0872-1? First, dispersion curves can be obtained from each pair. This yields, second, 2-D lateral group velocity maps on a grid, which can, third, be inverted for local shear wave profiles.

Reply: Unfortunately, we were not able to find the paper using doi provided by the reviewer (probably there is a typo in doi number). But at the early stage of our research we tried to calculate 2D velocity sections. Our major conclusion from this exercise was that it would be better to provide reliable first-order approximation of the fault zone area than not very reliable 2D model of the area. For station pairs installed on the same sides of the fault there were too few dispersion curves for reliable 2D results, but scatter and bimodal distribution of dispersion curves is a very well documented feature (see Fig. 12 of the revised manuscript). Therefore, we calculated 2 averaged dispersion curves and solved inversion problems for each of them. These models can be considered as the first-order approximation of the general structure of the fault zone. We hope that our paper would motivate further studies of this particular fault zone with denser network and better spatial resolution.

I think the figures can very much be improved. Is the data from the “areomagnetic” map used as a background synonymous with topography? If not, why is (areo)magnetic data used in the background? Figures 1-3 can be merged into two figures, perhaps even into just one. Please provide a large-scale inset that shows the target region, say, in relation to Scandinavia or Finland. The red “lines” under the DAFNE network in Figure 1 appear as rectangle, boxes. Show the seismicity in Figure 3 in relation to the mapped Suasselka fault. Consider an inset that shows the depth distribution of the seismicity (with error bars).

Reply: We made a new Figure 1 with topography as a background and merged Figures 3 and 4 into one. A subplot with depth distribution of seismicity is also shown in Fig. 3. The error bars differ insignificantly for depth determination, that is why they are not shown. The correspondent explanation is given in the text (Page 6 Lines 9-11). It is known that aeromagnetic maps provide important input for geological mapping. In our study the aeromagnetic map is selected as a background because it shows position of tectonic boundaries and ancient sutures in the region.

Comment: Figure 4: Why not use white for zero amplitude. The figures all look the same; that is what the authors point out in the text, but I wonder whether elimination of redundant data wouldn’t be a better strategy for visualization here. I find the color range not exhausted in Figure 5.

Reply: Figures with spectrograms were corrected (now zero amplitudes are denoted by white colour).

Specific comments: page 1, lines 11, 17: I doubt whether the network with station spacings on the order of 10 km allows probing of the “inner structure” of the fault, except, as said, if high-resolution approaches based on fault zone trapped and head waves are considered.

Reply: Depth distribution of seismicity also provides information about the inner structure of fault zones (c.f. Valoroso et al., 2013). In our study we managed to find events originating from the SPGF fault zone and estimated their depths. As we explained in reply to previous comment, usage of trapped waves was not possible.

p 1, l 28: More than one rupture is needed to create a low-velocity zone (see above).

Reply: In the case of the SPGF it was more than one rupture as the seismic activity in the area of the SPGF continued from 9730 to 5055 call BP (Sutinen et al., 2014).

P 2, l 15: Consider references to earthquake and noise tomographies in fault zone environments

Reply: the proposed references are added.

Allam, A.A., Ben-Zion, Y. & Peng, Z. Seismic Imaging of a Bimaterial Interface Along the Hayward Fault, CA, with Fault Zone Head Waves and Direct P Arrivals Pure Appl. Geophys. (2014) 171: 2993. doi:10.1007/s00024-014-0784-0

Zigone, D., Ben-Zion, Y., Campillo, M., Roux, P., Seismic Tomography of the Southern California Plate Boundary Region from Noise-Based Rayleigh and Love Waves et al. Pure and Applied Geophysics 172,5:1007-1032, 2015 DOI: 10.1007/s00024-014-0872-1.

p 3, l 32: If the sensors were repeatedly visited, why did problems with cables persist?

Consider a homogeneous, standard date format.

Reply: Our stations were installed during September-October, 2011, and all the cables were secured by plastic tubes and buried. In Lapland, the temperatures in winter reach -40 C, and the ground is frozen, so it is absolutely not possible to extract the cables from the ground until June, even if the wrong polarity is seen in the data. Moreover, changing the cables as such remote stations during the experiment is equal to stopping the registration for 1-2 weeks, because the cables could not be repaired directly at sites. As our priority was continuous registration, we solved the problem by making correspondent changes in the final miniSeed data.

P 5, l 26: "distortion" of EGF: In the present context, "decrease in signal-to-noise" ratio would perhaps be better.

Reply: The text was corrected

p. 7, l 5-8: Is there an inversion performed to conclude the 5 m top-layer-thickness? Could theauthors briefly comment on the main ingredients?

Reply: There are no inversion results for top-layer thickness. We estimated this thickness from H/V analysis and used the relationship between thickness of the soft layer, resonance frequency and the existing petrophysical data about seismic velocities in our region (http://www.geopsy.org/documentation/geopsy/hv.html).

p. 7, l 10 ff: Is the symmetry larger 15 km/ asymmetry smaller 15 km a persistent feature of all correlations? Or is it somehow related to just station DF01?

Reply: We observed the asymmetry for all pairs of stations with interstation distances smaller than 15 km (not only for DF01). Figure with EGF calculated between DF01 and each other stations, is presented as an example.

P 7, l 15 ff: Overlapping of pulses at short wavelength is not indicative or related to asymmetry. In general, I find the discussion as to why EGFs are asymmetric at distances smaller than 15 km confusing. How are the envelopes constructed and group velocities estimated? On each lag-side individually? Or are negative and positive lag EGFs stacked?

Reply: Overlapping of pulses for waves with length more than interstation's distances, of course, is not related with asymmetry, we just observe two parts of EGF together as one part because time shift for casual and acasual parts of EGF's is less or equal to about one period. EGF with overlapping of pulses appears as the asymmetry, therefore in the text we used the term "asymmetry". We changed it to "apparent asymmetry" in the revised version of the manuscript. We estimated group velocity by lag with the largest coefficient of correlation. But if coefficients of correlations are identical for positive and negative lags, we calculated the averaged velocity.

P 8, l 3: Can error bars be added to Fig 10? They are also given in Fig. 11.

Reply: Figure 10 (Fig. 12 of the revised version) is modified and all set of EGF is shown. This gives the information about scatter of two averaged dispersion curves.

p 9, l 16: I find it too vague and not supported by robust observations to talk about "inside the fault area", if this refers to the low-velocity region that is imaged by the adhoc 2-group approach (see above).

Reply: we think that two models obtained in out study can be considered as the first-order approximation of the SPGF area. This first order approximation clearly show the existence of low velocity area associated with the SPGF. But further studies with largest resolution would be necessary to get more detailed information.

Interactive comment on Solid Earth Discuss., doi:10.5194/se-2016-90, 2016.