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Interactive comment on "Lithosphere tearing along STEP faults and synkinematic formation of lherzolite and wehrlite in the shallow subcontinental mantle" *by* Károly Hidas et al.

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Dear Authors, dear Editor,

This manuscript highlights the microstructural character of shallow subcontinental mantle xenoliths that are interpreted to sample the mantle section of a major Subduction-Transform Edge Propagator (STEP) fault. Microstructural and mineral chemistry data are used to infer synkinematic melt-rock interactions that led to enrichment of refractory harzburgite in coarse-grained clinopyroxene and fine-grained orthopyroxene, at deeper and shallower levels of the system, respectively. The described processes are interpreted to provide insights into melt-present deformation in mantle shear zones,

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associated with the operation of STEP faults. The presented data are good and the discussion, interpretations, and conclusions are all consistent with the data presented. The manuscript is well written, and the figures are of high quality. Figure 10 is excellent. Despite my lengthy comments, I find the manuscript very interesting and intriguing, and my recommendation is to be accepted following minor revision. Below, I list some comments and suggestions that the Authors could consider addressing.

1) What are the implications of the described melt-rock interactions on the mechanical behaviour of STEP faults? The sampled suite of xenoliths offers unique insights into processes that take place in the mantle section of a STEP fault, so the Authors could go one step further and explore how the described microtectonic evolution may have affected mantle strength and rheology. For example, the Authors could use the olivine subgrain size, which is mentioned in the Methods section but not included in the manuscript, to determine the stress levels at different depths of the lithosphere. In samples where the microstructures are controlled by dynamic recrystallization, the olivine recrystallized grain size could be used, as well.

2) A long-standing problem in mantle xenolith studies is the lack of a clear foliation and lineation, which leads to the production of thin sections in random orientations relative to the rock shape fabric. As a result, the EBSD-derived crystallographic orientations are rotated so as to match one of the common crystallographic texture types described in the literature. Similar workflow is followed in this study. The main problem here becomes the discrimination between the different orthorhombic CPO patterns. The axial-[100], axial-[010], and orthorhombic symmetries can still be identified (e.g., with the use of the BA-index as done here) without the need to plot the crystallographic texture data relative to the rock shape fabric. As a solution to this problem, the use of X-ray Computed Tomography (XRCT) was recently proposed, where rock fabric can be determined quantitatively by the 3D shape of spinel grains (Chatzaras et al., 2016, already cited in the manuscript). In fact, to the best of my knowledge, the first paper in which XRCT was used for visual determination of the rock fabric in mantle xenoliths,

was of this manuscript's first Author (Hidas et al., 2007). The Authors could use the rock billets from which the thin sections were produced to determine quantitatively the rock fabric using XRCT, and replot the EBSD data relative to the fabric reference framework. That said, here the Authors do not attempt any discrimination between the different orthorhombic CPO patterns, so their workflow is totally appropriate for the level of interpretation. It is just that the use of XRCT would provide information currently inaccessible for the analyzed xenolith suite.

3) Olivine CPO in the coarse-grained xenoliths has a dominant axial-[100] symmetry, while it transitions toward an axial-[010] symmetry in the fine-grained xenoliths, where shearing combined with extensive synkinematic melt-rock interaction is interpreted to take place along a ductile shear zone associated with the Rif-Tell STEP fault. Based on these observations / interpretations, I am thinking of the following CPO and tectonic evolution, which the Authors may want to consider. Olivine axial-[100] CPO symmetry could be the result of constrictional strain associated with mantle upwelling in the slab window beneath the North African margin. An axial-[100] CPO pattern in both olivine and plagioclase was observed in xenoliths from the San Quintin volcanic field in Baja California (van der Werf et al., 2017), which is also interpreted to lie above a slab window (e.g., Zhang et al., 2012), similar to the Oran volcanic field. In the Oran xenoliths, mantle rocks were then captured from the inferred shear zone at the mantle section of the STEP fault. Focused melt migration along the shear zone and potential transpressional deformation (based on Figure 10) may have caused a transition of olivine CPO toward axial-[010] symmetry. The observed variations in microstructures and olivine CPOs could reflect either vertical or lateral heterogeneities in the North African SCLM.

Detailed treatment of either of these comments might require lengthy additions to what is already a reasonable-sized manuscript. These comments should be considered only as suggestions.

Minor comments

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Page 1, lines 28-29: The Authors mention that grain size is “uncorrelated with modal variations”, while in lines 31-32 (same page), it is mentioned that “Olivine grain size in the fine-grained peridotites depends on the size and volume fraction of the pyroxene grains”. How do these statements fit together?

Page 5, lines 11-13: Please state the exact number of samples (and identify their names) in which the thin sections were produced relative to the common structural framework (normal to foliation and parallel to lineation). Also, a suggestion for Figure S1, would be to use the horizontal line and the star (as in Figure 5) to show the foliation and lineation in the samples cut relative to the rock shape fabric.

Page 6, Lines 5-7: I don’t think that the Authors present in the manuscript the calculations of the subgrain boundaries length and subgrain density mentioned here. Either remove this description or include the results in the manuscript. Having said that, I think that the manuscript would benefit from the inclusion of these data, if subgrain size is used for estimating differential stress. See comment 1.

Page 6, Lines 8-17: Following on the previous comment, the KAM2, Mis2Mean, and GOS data described here are not presented in the manuscript. Exception is Figure 3, where two Mis2Mean maps are included. The Authors may want to revise the Methods section removing the description of these parameters. Alternatively, they could use the data to describe the microstructural characteristics of different mineral phases and grain sizes.

Page 8, Line 19: Please mention some sample names in which the reader can observe the feature you describe here (elongated patches of clinopyroxene aggregates). It would also be useful to highlight these features in the relevant EBSD phase maps.

Page 8, Line 21: “Strain-free” is an interpretation. Please describe the observations that lead to this interpretation.

Page 8, Line 23: Please highlight on the photomicrograph or EBSD map of Figure 3 these cusp-like terminations at triple junctions.

Page 8, Line 27: “locally showing reaction microstructure” is an interpretation. What are the relevant microscale observations?

Page 9, Lines 16-18: Please be more specific to which samples in Figure 5b you refer. HAM-005b does not show an axial-[010] symmetry.

Page 9, Lines 26-27: Looking the CPO plots, and particularly those of DZ-003, which is the oriented thin section, I am not convinced that this is the case. The maximum of the orthopyroxene [100] axes lies within the foliation plane at high angle to the lineation, although two smaller concentrations near the pole to the foliation are also present. Moreover, please mention which are the oriented thin sections so that the reader can track the information mentioned in the text.

Page 9, Lines 29-30: If orthopyroxene [010] and [001] axes are distributed subparallel to olivine [010] and [001] axes, we would expect the same relationship to hold for the [100] axes, as well. This is not the case in HAM-007, where olivine [100] axes are oriented at high angle to orthopyroxene [100] axes.

Page 10, Lines 4-5: In methods, the Authors describe a 2-12o range for subgrain boundaries, so I am wondering why they chose a different range of angles to analyse low-angle misorientations. Moreover, could the Authors explain the criteria for choosing the 400 μm grain size threshold for the misorientation analysis? Earlier on (page 8, lines 2-3), they defined the coarse and fine grained porphyroclasts based on a 800 μm grain size threshold.

Page 11, Lines 16-17: I agree with this statement only for the coarse-grained xenoliths (green color). When it comes to the rest three microstructural types, I do not see a clear trend. I am wondering whether a plot of grain size versus estimated temperature would help the Authors to make their argument more clear. This is quite important point, because if there is no clear positive correlation between grain size and temperature,

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the Authors might want to consider the possibility that the xenoliths sample a horizontal strain gradient across the STEP fault. I am also wondering whether any fine-grained xenoliths have been reported from Souahlia. The lack of fine-grained xenoliths might be indicative of an horizontal strain gradient between Souahlia and Ain Temouchent.

Page 11, Lines 25-27: Some more information regarding the calculation of the Zener parameter might be useful to be included in the manuscript. Specifically, were all orthopyroxene and clinopyroxene grains in each sample included in the analysis, or porphyroclasts were excluded? In the latter case, what was the maximum size of grains included? Moreover, I am not sure that we can separate the contribution of orthopyroxene and clinopyroxene grains to the pining of olivine grains. In the current analysis, the underlying assumption is that the only second phase is either orthopyroxene or clinopyroxene, and the rest area/volume is occupied mainly by olivine. Such assumption could work for samples with only a small fraction of the other pyroxene. Otherwise, the two pyroxenes should be considered together.

Page 12, Lines 3-4: In agreement with Figure 8, the Authors state here that olivine grain growth is impeded by the small, interstitial pyroxene grains. However, in page 8, lines 25-26, it is mentioned that in the xenoliths with an equigranular microstructure, the small pyroxene grains “occur in monophase patches rather than showing phase mixing”, which is actually not what we see in the cited Figure 3e.

Page 12, Lines 23-25: Development of axial-[100] CPO symmetry in olivine has also been attributed to constrictional strain (Chatzaras et al., 2016).

Page 13, Lines 15-30: I do not think that the one hypothesis necessarily precludes the other. Olivine shearing in the presence of melt could take place in transpressional deformation, where the (001)[100] and (010)[100] (as suggested by the concentration of rotation axes around [001] in Figure 6 for the fine-grained xenoliths) olivine slip systems could both be active due to strain compatibility requirements.

Page 14, Lines 14-15 and 22: Please name the deformation mechanisms.

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Papers cited

Van der Werf, T.F., Chatzaras, V., Kriegsman, L., Kronenberg, A., Tikoff, B., Drury, M.R., 2017. Constraints on the rheology of lower crust in a strike-slip plate boundary: Evidence from the San Quintin xenoliths, Baja California, Mexico. Solid Earth, 8, 1211–1239, doi:10.5194/se-2017-45

Zhang, X., Paulssen, H., Lebedev, S., and Meier, T.: 3D shear velocity structure beneath the Gulf of California from Rayleigh wave dispersion, Earth Planet. Sc. Lett., 279, 255–262, 2009.

Sincerely, Vasileios Chatzaras

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