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Interactive comment on "Experimental deformation and recrystallization of olivine – processes and time scales of damage healing during postseismic relaxation at mantle depths" *by* C. A. Trepmann et al.

Anonymous Referee #1

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First, the paper submitted to Solid Earth is a two fold paper: one on expermental deformation and annealing of peridotites (kick-and-cook experiments) and one on the implementation or extension of the Avrami-kinetic equation on recrystallization kinetics. Reading the abstract only, I was expecting that this paper is mostly dealing with experimentally produced microstructures that I am able to discuss. Reading the whole paper, I realized that I am not able to check the consistency and validity of the proposed extension of Avrami-analysis for time dependent growth rate. I apologize for that and I hope that another referee will be able to do it. I suggest to share the paper in two

companion papers. The remarks below will only concern pages 463 to 480 and 493 to 496 that I will treat as one paper.

The experiments presented by the authors are complementary to previous experiments (Druiventak et al., Terra Nova, 2011: Druiventak et al. EPSL, 2011). The major objectiveof the paper is aim to document the diagnostic recrystallization microstructures allowing to recognize non-steady state deformation and particularly coseismic deformation and post-seismic relaxation in mantle rocks in the seismogenic zone. This is an important question since some very large earthquakes are interpreted to have nucleated in the oceanic lithosphere. In a more general way, this paper questions the common view of deforming rocks in a continuous process assessing that rocks are deforming and recrystalizing concomittently. This is a very original idea proposed by the Stöckert's team for more than ten years now and that is slowly tracing its way in the international community. The scientific results and conclusions are presented in a clear, concise, and well-structured way. The figures are clear and all necessary. One figure could be added to better explain the grain size distribution and the implication of its measurement by EBSD. These experimental results and their interpretation and discussion represent a self-sufficient paper that I think should absolutely be published.

Major points:

Before describing two or three stages experiments in section 4, the authors quickly summarize the microstructures of the "kick" experiments (page 471-472). They describe intra- and inter-granular fractures, highly damaged zones and fragments, but never use the term of "cataclasis". However, all ingredients for cataclasis seem to be present and, in the highly damaged shear zones, we may expect some rigid rotation and high misorientation between small fragments which should survive after annealing. Papers by Druiventak et al. describe the CPO of new olivine grains after "kick-and-cook" experiments but not after "kick only" experiments. I think that this step is necessary to check if scattering of CPO in new grains is mainly due to "kick" (damage) or to "cook" (annealing-recrystallization). Moreover, as "comminution" is inferred as one of the two mechanisms of formation of the new recrystaallized grains, it would be useful to characterize this comminution before the "cook" experiment by some observations with an SEM-FEG for example (shape and size of the comminuted grains and of the pores between them).

Terminology: the term "recrystallized host fragments" is confusing. As far as I know, recrystallization is defined as the creation of new grains from highly deformed parent grains either during deformation or during a post-deformation anneal (Nicolas and Poirier, 1976, p. 137). Recovery (re-organization of dislocation) occurred in these host fragments which are not new grains. In my point of view, the growth of the host fragments during annealing ("cook") has not been demonstrated and migration of their grain boundaries neither. Why not "annealed host fragments" or solely "host fragments"? As a consequence, the term "recrystallized grains" used to designate the assemblage of "new grains" and "recrystallized host fragments" is also confusing. I strongly suggest to use "porphyroclasts" (as is in the paper) and "mosaic" where new strain-free grains and small porphyroclast fragments coexist. This is not only a problem of terminology, but concerns different mechanisms and makes the discussion unclear (page 479 lines 20-27 and page 481 lines 6-14, for example).

CPO of recrystallized grains. The Fig. 10b shows new grains in an intragranular fracture. In this case (001) are less scattered than (100) and (010) which are sinistrally dispersed (no point on the right-hand side of the blue dot). It may tell us that the microfracture has moved sinistrally -which is consistent with a vertical shortening direction- and that the small grains issued from cataclasis have suffered a solid rotation around (001) which is within the shear plane and perpendicular to the shear direction (blue dots in Fig. 10b). In the larger agregates, the host fragments are larger and, therefore, do not rotate easily and are able to keep the memory of the crystallographic orientation of the host crystal as the authors point out (page 479, lines 26-27).

As mentionned in the introduction, I did not check the maths. However, I was very perturbed by the absence of definition of the parameters used in the equations (page

481 and following).

References to related works: - Experiments of "kick-and-cook" have been performed with analogs (camphor, octachloropropane) that document the static recrystallization (see as one example the paper by Urai and Humphreys, 2000, http://virtualexplorer.com.au/special/meansvolume/contribs/urai/index.html; Piazzolo et al., Tectonophysics, 2006). I think that this litterature has to be refered in the present paper as some similar experiments in ceramics.

- In the discussion, a comparison of the results of these experiments with natural examples of "kick-and-cook" deformation in peridotites would be welcome I believe that the authors will have some examples in mind. Peridotite xenoliths in basalts or kimberlites are good examples because they have been deformed in the mantle and cooked in the lavas during their ascent. In some ultramafic massifs, pseudotachylytes or very high-strain shear zones have been described in peridotites. Is there some analogy in the host peridotites with the experiments presented here?

Detail remarks: page 467 -the initial material is a coarse-grained natural peridotite (Almklovdalen, Norway). Is it a chlorite-bearing peridotite or a Aheim dunite? In the first case, what happens with chlorite at high temperature (700-1100°C)? -line 19: 2 GPa?

Page 469 -lines 16 and following: As the grain size measurement is important in this paper, it could be useful to show an example. Why the expectation (expected?) value? Why not the mean value? -Plots of EBSD data: precise if all the measurements are used in the plots or if only One Point Per Grain (OPPG) is used. Precise also if the orientation of the plots is always the same (shortening direction orientated NS).

Page 471: - line 6: could you show the stress-strain curves for the "kick-and-creep" and the "kick-cook-kick" experiments?

Page 474: -line 5: The grain size in mosaic will increase with increasing "cook" temperature, but in detail, I guess that only the size of the new grains increases when the size of host fragments should decrease. -line 7-9: The variability slightly increases with increasing annealing temperature and annealing time (Fig. 5c and 5d) not only in absolute values but also relative to the expectation values (Table 1).

Page 474: -line 19: LAGBs are visible in fragments of hist grains when HAGBs are mostly visisble in new grains. Could it be an artefact due to misindexation or to pseudosymetry in olivine? -line 26: "Even after isostatic annealing at 1100° C for 69 h, the recrystallized host fragments (labelled “h” in Fig. 8a) show mostly concave and sutured boundaries whereas new grains exhibit isometric shape with curved convex boundaries."

Page 475: - line 26-28 (Fig. 11): in the B9028 sample, the new grains are completely different from the host grains but the host fragments have similar orientation than the host grains. Is there any difference in this case between all points plots and the OPPG plots?

Page 476: -line 7: "average" or "expected"? -line 9: "the observed CPO patterns are variable with strong scatter in orientations and unsystematic correlation with the host orientation (Fig. 11)": control by the host orientation is stronger in B9037 and B9038 than in B9038 and B9036 which were described as a "marked imprint of the crystallographic orientation of the host crystal" (page 475, line 24-25).

Page 479: -line 1: "some thermal effects" -line 18: "has also been observed"

Page 480: -line 16-20: This section is not very clear. Give reference for the positive correlation between d and T and precise that of the negative one between d and strain. "A positive correlation between the final grain size attained during static recrystallisation and annealing temperature as observed here (Fig. 5b, c, Table 1) has also previously been reported (references), as has a negative correlation between resulting grain size and accumulated bulk strain during the preceding deformation in metals (e.g. Fig. 4.16 in Nicolas and Poirier, 1976; Humphreys and Hatherly, 2004)."

Page 481: This paragraph is not entirely clear because of the used terminology "recrystallized host fragments" (spelling is recrystallised in some places and recrystallized in others). Lines 6-7 are a good example: "In contrast, at some distance of the highly damaged zones fewer and larger recrystallised grains (up to 40 μm) occur (Fig. 10a), likely due to a lower nucleus density for new grains and/or predominant occurrence of recrystallized host fragments over new grains." Why not: "In contrast, at some distance of the highly damaged zones fewer and larger recrystallised new grains (up to 40 μm) occur (Fig. 10a), likely due to a lower nucleus density for new grains and/or predominant occurrence of host fragments or porphyroclasts over new grains"? -line 9-12: "Furthermore, for the new grains that are almost free of defects on the one hand and the recrystallized host fragments that inherit the deformed microstructure on the other, variations in the driving force for growth during isostatic annealing have to be considered". In my point of view, the growth of the host fragments has not been demonstrated and migration of their grain boundaries neither. There is apparently no difference on the dislocation densities or microstructures between the core and borders of host fragments. -line 19-21: here there is only two types of grains: the new grains (interfacial energy) and the deformed grains (strain energy). It is much clearer and much simpler, even if the distinction is not easy and if both types may be mixed together in the mantle zone of the core-and-mantle structures.

Page 482 - line 26 and following, plateau in the grain size: we may expect that migration of grain boundaries may be limited by the number of the grains during the first stages of annealing and that, after a sufficient duration, Ostwald ripening may occur. Then, the smallest grains will disapear and the average grain size will increase (analog see-through experiments, http://virtualexplorer.com.au/special/meansvolume/). Is the duration of experiments long enough to allow Ostwald ripening?

Page 483: "Two alternative explanations deserve consideration. Firstly, ... Secondly, ...". The second consideration(continuation nucleation) is unlikely. A sentence of conclusion is waited there. If the resolution limitof the EBSD analysis is responsible for the initial stagnationof the grain size, it is important to well describe the method and to give an example (see remark above, page 469).

Page 493: -line 24: "control recrystallization, the effective activation energy"

Page 494: -line 2-5: the sentence is too long and not understandable.

Page 494-495: - Diagnostic microstructures: this is a very important point and a major contribution of this paper. As the grain size distribution in recrystallized areas may be one recognition criteria, it should be better explained and described by at least one example in this paper. -Reloading: "kick-cook-kick" experiments and localization of the second strain in porphyroclasts. Intuitively, I would expect that a fine grained aggregate would be more difficult to deform than a coarse grained aggregate at low temperature by dislocation gliding because dislocations glide willvery quickly pile-up at the grain boundaries. Therefore, strain will be shortly limited in the fine grained aggregate by work hardening.

Figure 5: Labels a, b, c and d are missing.

Figure 7b: LAGBs are visible in fragments of hist grains when HAGBs are mostly visible in new grains. Could it be an artefact due to misindexation or to pseudosymetry in olivine?

Figure 10a: FIB Locations of Fig. 7b-d and Fig. 7e, f are shown in yellow on this EBSD map. But there is no corresponding figure in the paper. I guess that these should be Fig. 9b-d and Fig. 9e, f.

Figure 13: the distinction between the different paterns is not as clear on the on-line version as on the printed version.

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