

RESPONSE TO COMMENTS OF REFEREE #2 (Luca Menegon)

Referee's first comment: *The microstructure of granulites suggests that the recrystallized grain size (in particular of plagioclase) could have been modified by annealing and grain boundary area reduction. Triple junctions at 120 degrees are common, and the subgrains in plagioclase appear to be considerably smaller than the recrystallized grains (Fig. 3b). This can obviously have an influence on the palaeopiezometric estimate, and should be discussed in the paper. Also, the interpretation of the bimodal grain size distribution of plagioclase and cpx in xenolith SQ-16 is unclear. My understanding is that the Authors have used the smaller grain size for their piezometric estimate, but the small grains occur as clusters along grain boundaries. Is the smaller grain size indicative of a late, higher stress deformation at decreasing P, T conditions?*

Author's response: The first part of the comment is similar to the first comment of Referee #1, and we therefore repeat the response. We acknowledge that grain boundary area reduction may have modified grain size, and potentially influenced paleopiezometry results. To address the question of how much has the microstructure been modified by grain boundary area reduction, we quantified the type of plagioclase triple junctions in the three granulite xenoliths, which we used to estimate stress. We found that stable (~120°) triple junctions between plagioclase grains range from 6% to 21%, resulting in a partial foam microstructure (cf. Kidder et al., 2016, J. Struct. Geol.) We interpret this observation to suggest that plagioclase grains have only partly been affected by grain-boundary energy driven grain-growth. The two granulites with the highest number of stable triple junctions of plagioclase grains (15% and 21%) record lower differential stresses (12 and 14 MPa, respectively), compared to the xenolith with the lower number of stable triple junctions. It seems that the microstructure of these two xenoliths has been affected in some extent by grain growth, which could be associated with deformation during decreasing stress conditions.

We cannot exclude the possibility that the smaller plagioclase recrystallized grains have formed due to high stress deformation during decreasing pressure and temperature conditions. However, we consider an explanation including high stress deformation at constant conditions as more plausible. Clinopyroxene grains in xenolith SQ-16 also show a bimodal grain size distribution, but we do not observe any relationship between the size of recrystallized grains and the estimated equilibration temperatures.

Change in manuscript: We added in the manuscript the quantitative description of the type of plagioclase triple junctions and discussed the influence of grain boundary area reduction on piezometric estimates. For xenolith SQ-16, we rephrased the text to make it clearer that we used the arithmetic mean of the smaller recrystallized grains of the bimodal distribution in order to estimate the differential stress. We also added a discussion on the possibility of smaller grain sizes being associated with deformation at decreasing temperature and pressure conditions.

Referee's second comment: *The microstructural evidence of grain boundary sliding is convincing (e.g. quadruple junctions, misorientation angle distributions), however the grain size is rather coarse for grain boundary sliding in crustal rocks. The Authors seem to rule out a possible effect of melt on deformation, because melt pockets are undeformed. But is it possible that an earlier generation of melt had assisted deformation and promoted melt-enhanced diffusion creep in the coarse-grained phases? See for example Rosenberg & Berger (Physics and Chemistry of the Earth (A), 2001).*

Author's response: At relatively low stresses, such as those estimated for the San Quintin mafic granulite xenoliths, grain boundary sliding may become active at larger grain sizes. The high homologous temperatures estimated in the mafic granulites also facilitate the transition to diffusion creep at larger, than the expected, grain sizes. Thus, we think that it is possible to explain grain boundary sliding in the coarse-grained granulites without invoking a possible effect of melt. However, we acknowledge that the presence of earlier melt may have assisted diffusion creep, and therefore, grain boundary sliding. If true, the recrystallized plagioclase and clinopyroxene grains occurring as clusters either along the boundaries or within the junction areas of porphyroclasts, could have initially crystallized from an intergranular melt, followed by plastic deformation. Our microstructural observations do not favor this interpretation. The presence of core-and-mantle structures and the occurrence of recrystallized grains with twins oriented at low angle to the twins of adjacent porphyroclasts, suggest that the recrystallized grains have formed by subgrain rotation recrystallization of neighboring porphyroclasts. Nonetheless, we acknowledge that with our analytical approach we cannot exclude the presence of nanoscale intergrain melt films, which would support melt-enhanced grain boundary sliding, as noted by the referee.

Change in manuscript: We discussed the potential existence and role of grain boundary melt films.

Referee's comment on old lines 33-35: *This sentence is a bit vague - please expand. Time-dependent behaviour as a function of what? Strain? Microstructural evolution? Fracturing coupled to fluid infiltration?*

Author's response and change in manuscript: This sentence has been removed from the revised manuscript.

Referee's comment on old line 39: *Please define this transitional mechanism better. Are you referring to DisGBS? Or to semi-brittle flow also at lower crustal conditions?*

Author's response and change in manuscript: We refer to DisGBS and we added this information in the revised version.

Referee's comment on old line 141: *How was P constrained?*

Author's response and change in manuscript: We assumed pressure equal to the maximum pressure constrained from phase equilibria modeling. As we mention in the text, the effect of pressure on calculated two-pyroxene temperatures is minor (only 0.02 °C/MPa).

Referee's comment on old lines 185-186: *Check if the piezometric calibrations that you used have also applied scaling factors to their 2d grain size measurements. If not, I would remove it - it's probably better to measure the grain size exactly in the same way as in the piezometric calibrations.*

Author's response and change in manuscript: The dry olivine paleopiezometer of van der Wal et al. (1993) is calibrated by multiplying the mean diameter by a factor of 1.2 (Drury, 2005; Geol. Soc. London, Sp. Pub.). The Twiss (1977) paleopiezometer that we use for plagioclase is theoretical. To allow direct comparison with the results from the van der Wal et al (1993) piezometer, we multiplied the mean plagioclase grain size with the same scaling factor (1.2) that we used for olivine.

Referee's comment on old lines 195-196: *Same comment as above. Accounting for 3d is good practice, but has it been done in the piezometric calibrations used here?*

Author's response and change in manuscript: If not corrected, the mean intercept length will underestimate the mean subgrain size used in the paleopiezometer. For this reason, we decided to apply a scaling factor in order to convert mean linear intercepts to mean grain diameters.

Referee's comment on old line 215: *Indicate the mantle of new grains in Fig. 2b.*

Author's response and change in manuscript: We traced the mantle of recrystallized grains.

Referee's comment on old line 216: *Subgrains are not clearly visible in Fig. 2b.*

Author's response and change in manuscript: We removed this part.

Referee's comment on old line 284: *Were primary- and recrystallized px analysed separately? Are these two T indicating crystallization (900 degrees) and recrystallisation (750 degrees) conditions?*

Author's response and change in manuscript: We have analyzed pyroxene grains of various sizes and we did not observe any relationship between the estimated equilibration temperatures and the size of the analyzed grains.

Referee's comment on old lines 292-293: *Fig. 7c is SQW-115 according to the caption. (a) and (b) are SQW-76 ad -78 according to the caption.*

Author's response and change in manuscript: We have modified the text and figure to ensure consistency.

Referee's comment on old line 306: *I would include the figure with the grain size distributions (Fig. S5) in the main paper.*

Author's response and change in manuscript: Following referee's suggestion we included the figure into the main paper.

Referee's comment on old line 359: *[001] parallel to lineation is not evident in the pole figure of SQW-115.*

Author's response and change in manuscript: We rephrased the text.

Referee's comment on old line 361: *Ji et al (2014) not in the reference list.*

Author's response and change in manuscript: We added the reference.

Referee's comment on old line 371: *I cannot see maxima of [001] subparallel to the lineation in Fig. 8b. A max of the poles of (100) subparallel to the lineation is evident only in SQL-48.*

Author's response and change in manuscript: We rephrased the text.

Referee's comment on old lines 523-524: *Subgrains look smaller than rexx grains in Fig. 3 (especially in plagioclase).*

Author's response and change in manuscript: We removed this argument.

Referee's comment on old line 687: *I am a bit confused here. Your estimates of lower crust viscosity suggest that your granulite xenoliths may be a snapshot of postseismic creep, not of interseismic deformation.*

Author's response and change in manuscript: We rewrote this part of the text refining our explanations.

Referee's comment on old Figure 12: *What are the red lines in (b)?*

Author's response and change in manuscript: We explained the red and blue lines in the revised figure caption.