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Interactive comment on "Syn-kinematic hydration reactions, dissolution-precipitation creep and grain boundary sliding in experimentally deformed plagioclase-pyroxene mixtures" *by* Sina Marti et al.

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Author's response to comments from Reviewer 2 (A.C.)

General comments

Rev.2: *This paper describes a series of deformation experiments performed on hydrous mixtures of plagioclase and pyroxene, designed to investigate the influence of syn- kinematic reaction on the strength and deformation mechanisms of lower crustal*

rocks. Through detailed microanalysis, the authors conclude that reaction-driven grain size re- duction enhanced dissolution-precipitation creep, leading to strain localization. Overall, this is an important and well-executed piece of work. However, I would like the authors to more thoroughly discuss the evolution of porosity through the experiments. The starting materials (powders) were hot-pressed in-situ during the PT ramp and run-in. No details are given regarding the porosity of the starting material, and it is possible that significant reaction took place before deformation began, while the samples were not fully densified. Observations of porosity/dilation in the deformed samples imply differential stresses in excess of the confining pressure (1-1.5 GPa), which are not supported by the mechanical data. Nevertheless, with some clarification, this has the potential to be a valuable contribution. The writing and figures are generally of excellent quality, although a few minor clarifications are needed, as detailed below.

Authors: We would like to thank you for your thorough revisions and greatly appreciate your comments and suggestions. Please find our replies below:

Specific comments / corrections

Rev.2: *Line 16 – need to be careful when talking about diffusion creep and grain boundary sliding as separate mechanisms. Grain boundary sliding always occurs during diffusion creep, as an accommodation mechanism for changing grain shapes (see Raj & Ashby, 1971; Gifkins, 1976).*

Authors: That is correct, we agree with this statement. The same has been noted

by Reviewer 1 to whom we answered: Thank you for pointing this out. We are not unaware of the relationship between diffusion creep and GBS. In the original manuscript, we listed both of them separately, as either diffusion creep or GBS could be the dominant strain accommodating mechanism, while the other is merely accommodating (diffusion creep accommodated by GBS vs. GBS accommodated by diffusion creep, e.g. correlating to Lifshitz and Rachinger sliding after Langdon, 2006, respectively).
The manuscript text lines have been modified, see revised manuscript lines 16-22. The title has been altered in response to this comment as well.

Rev.2: *Lines 20-21 – references needed for "It is often suggested that viscous deformation in monomineralic aggregates at mid- to lower crustal conditions is dominated by dislocation creep"*

Authors: The text lines have been modified, see revised manuscript lines 26 – 29.

Rev.2: *Line 47 – worth pointing out here that, in the absence of fluids/reaction, phase mixing is extremely inefficient (e.g., Linckens et al., 2014; Cross & Skemer, 2017). Thus, strain may preferentially localize into wet/reactive portions of the lithosphere (this is also supported by the experiments performed here, showing extensive phase mixing at low strains).*

Authors: This is a very important point, thank you for pointing us towards this. It has been incorporated in the revised manuscript lines 61-66.

Rev.2: *Line 70 – full-stop/period needs to be removed after "enstatite"*
Authors: Redundant period has been removed.

Rev.2: *Lines 85-87 – important to mention here that the samples were hot-pressed in-situ at experiment conditions during the run-in to the hit-point. What was the porosity of the starting material at the hit-point in the 1.0 GPa and 1.5 GPa experiments? How much reaction took place during the ramp to PT conditions, and during the run-in to the sample hit- point?*

Authors: Notion of the initial hydrostatic stage (lead run-in) has been added in revised manuscript lines 134–137. Amounts of reaction product present in different experiments at different stages can be found in lines 170-175, and notion of initial sample porosity prior to deformation was made in lines 169-170.

Rev.2: *Lines 70-72 – best to add all the abbreviations used here, to match with those given in Table 2*

Authors: The abbreviations are not included in these lines as they are not further being used in the text and only appear in Table 2 where they are declared in the caption.

Rev.2: *Line 89 – need to mention that thickness is measured parallel to the shear plane normal*

Authors: Thank you for pointing this out, the text has been modified accordingly. (see revised manuscript line 102)

Rev.2: *Lines 95-96 – this needs a bit of re-wording. γ_a will underestimate shear strain in localized zones, and overestimate shear strain in undeformed/low-strain zones.*

Authors: The text has been modified accordingly, see revised manuscript lines 108-114.

Rev.2: *Line 99 – "strain ratio" instead of "strain ration"*

Authors: Thank you this has been corrected.

Rev.2: *Line 129 – use of the word "near" here is a bit subjective. None of the samples exceed 50-60% of the Goetze criterion. It's probably sufficient to say that none of the samples exceeded the Goetze criterion, so brittle/dilational behavior is not anticipated (presence of open pores contradicts this, however – see below).*

Authors: We use the differential stress ($\Delta\sigma$) between the Pc and the load piston to compare with the Goetze criterion not the shear stress τ. τ supported by the sample inclined at 45° are obtained by Mohr circle construction from $\Delta\sigma$ and are half as much as the $\Delta\sigma$ (see also Appendix A3, lines 531f).

Rev.2: *Line 204 – I think this should be "intragranular" instead of "intergranular"*

Authors: We agree, thank you for pointing this out. The text has been modified accordingly.

Rev.2: *Line 207 – the presence of pores contradicts an earlier statement about the Goetze criterion not being exceeded, unless large local stresses along grain boundaries were sustained through the experiments. Alternatively, the opening sites shown in Figure 9 (particularly 9e, for example) could have formed during decompression.*

Authors: We disagree that the presence of pores is contradicting with the experimental conditions. Surely the high confining pressures and the activation of viscous deformation in the material will suppress large amounts of pore space opening, however this should not mean that no porosity at all is able to exist.
In fact, the observation of (small amounts of) porosity in experiments performed at high Pc & T conditions (with flow stresses below the Goetze criterion) has previously been observed in a number of studies, e.g. Tullis & Yund (1991); Dimanov et al. (2007); Rybacki & Dresen (2010); Precigout & Stünitz (2016). And is as well proposed for natural shear zones, e.g. Fusseis et al. (2009); Menegon et al. (2015).
A reason why porosity in experiments is not that uncommon to observe might be the high strain rates – in natural rocks, dilatant sites during grain boundary sliding can be filled by precipitating phases (e.g. Kruse & Stünitz, 1999; Kilian et al., 2011) or closed by plastic deformation of adjacent grains. However, as the displacement rate in experiments is high, pores might be more frequent to form as reaction rate and plastic deformation are not able to keep up with pore space formation.

The pores in our experiments are not very frequent and are also small, with sizes on the 10x nm scale. We don't know how long they are open but it is likely that their occurrence time is short.
Decompression porosity commonly is easily recognized by its location and orientation in cracks normal to the shortening direction – such features are different from what is described here.
The samples are almost fully compacted after the lead run-in (hydrostatic part of the experiment, see Appendix Figure 1c, prior to sample deformation)

Rev.2: *Section 3.4.3 – given the low symmetry of plagioclase (and large number of documented slip planes/directions), it may be more informative to determine slip systems using inverse pole figures – e.g., parallel to the shear direction, perpendicular to shear plane. See Fig. 11 in Miranda et al., 2016, JSG, for example, which shows (011)[-100] as the dominant slip system for intermediate- composition plagioclase (deformed at similar conditions to this study).*

Authors: We have modified Figure 12 to incorporate inverse pole figures for the three different sites. The normal pole figures are reduced to one set of pole figures that combine the data of all three sites together to show the texture pattern. See revised manuscript new Figure 12 and new text passages in sections 3.4.3 (lines 250f) and 4.5 (lines 402f)

Rev.2: *Lines 314-315 – I think it's more a case of host-controlled growth. Grains may nucleate in any orientation, but those with low interfacial energies w.r.t. the host will be the ones to grow.*

Authors: The area covered by the three EBSD maps would include a number of host grains (i.e. now replaced by fine grained albite). If the measured weak CPO is a result of host controlled growth then this would imply a CPO of the initial host grains. We consider this unlikely as e.g. we do not observe any significant amount of dislocation climb or creep in the remaining porphyroclasts.

Rev.2: *Lines 320-323 – are you able to say anything about the feasibility of the other CPO- forming mechanisms described here? Do grains have a crystallographically-controlled shape; are there systematic interphase misorientation relationships indicative of host- controlled nucleation/ growth? This would be interesting to add, but may be beyond the scope of the paper. . .*

Authors: Sadly we do not. The acquired EBSD data does not allow for these analyses, as e.g. (i) the albite grain size is so small that the EBSD points within a single grain are not enough to perform proper shape analyses and (ii) indexing was very low towards grain boundaries or in areas of very fine grains.

Rev.2: *Line 373 – G and t need to be defined*
Authors: $\triangle$Gt has been removed as it is not further used in the text.

Rev.2: *Line 364 – misspelling of "earlier"*
Rev.2: *Line 395 – "DPC" instead of "DCP"*
Rev.2: *Figure 1 caption – use "counterclockwise" instead of CCL*
Authors: Thank you for pointing this out, the text has been corrected accordingly

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Rev.2: *Figure 5 – it would be useful to point out where the “shear band close-up” images come from in the “overview” images*

Authors: The close-ups are not within the area of the overview images. We agree that it would be useful to have close-ups within the overview area. However the images were selected such that they show the representative microstructure with the best SEM acquisition quality. Unfortunately when selecting the images according to these criteria, the close-ups and overview images do not overlap.

Rev.2: *Figure 5k – the phase map colours are very faint, and are difficult to tell apart References*

Authors: Colours in Figure 5k have been enhanced.

Rybacki, E., Wirth, R. and Dresen, G., 2010. Superplasticity and ductile fracture of synthetic feldspar deformed to large strain. Journal of Geophysical Research, 115. B08209. doi:10.1029/2009JB007203

Dimanov, A., Rybacki, E., Wirth, R. and Dresen, G., 2007. Creep and strain-dependent microstructures of synthetic anorthite-diopside aggregates. Journal of Structural Geology, 29. 1049-1069.

Tullis, J. and Yund, R. A., 1991. Diffusion creep in feldspar aggregates: experimental

evidence. Journal of Structural Geology, 13(9). 987-1000.

Precigout, J. and Stünitz, H., 2016. Evidence of phase nucleation during olivine diffusion creep: A new perspective for mantle strain localization. EPSL, 455. 94-105.

Fusseis, F., Regenauer-Lieb, K., Liu, J., Hough, R.M., and De Carlo, F., 2009, Creep cavitation can establish a dynamic granular fluid pump in ductile shear zones: Nature, v. 459, p. 974–977, doi:10.1038/nature08051.

Menegon, L, Fusseis, F., Stünitz, H., and Xiao X., 2015. Creep cavitation bands control porosity and fluid flow in lower crustal shear zones. Geology. doi: 10.1130/G36307.1

Kruse, R. and Stünitz, H.: Deformation mechanisms and phase distribution in mafic high-temperature mylonites from the Jotun Nappe, southern Norway, Tectonophysics, 303, 223–249, 1999.

Kilian, R., Heilbronner, R., and Stünitz, H.: Quartz grain size reduction in a granitoid rock and the transition from dislocation to diffusion creep, Journal of Structural Geology, 33, 1265 – 1284, 2011.

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