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Solid Earth
Discussions

Interactive comment on "Relationship between microstructures and resistance in mafic assemblages that deform and transform" *by* Nicolas Mansard et al.

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Author's response to comments from Reviewer 2 (L.M.)

General comments

Rev.2: This manuscript presents a detailed experimental study of the feedback between mineral reactions and deformation in "wet" mafic assemblages deformed under high P, T conditions with a Griggs-type solid medium apparatus. The experimental samples have been investigated in detail with electron microscopy (including EBSD) and image analysis techniques. The work aims to test the role of synkinematic mineral

reactions on the rheology of mafic assemblages of different compositions. Depending on different rates of reaction progress and of the associated microstructural development, the stress-strain behaviour and the extent of weakening varies in the different assemblages. The results highlight that differences in mechanical strength depend on the microstructural evolution of the assemblage, which in turn is determined by the rate and the type of synkinematic mineral reactions. The Authors assume that faster reaction rates depend on the higher intracrystalline water content in the starting material. The results are also discussed in terms of the strain localization potential of pyroxene vs amphibole-dominated mafic assemblages. The conclusions are largely supported by the results, and further highlight the fundamental feedback between mineral reactions, deformation, and strain localization. The paper is very well written and illustrated, the experimental work and the microstructural analysis are meticulous, and the overall dataset is of high quality. I definitely recommend this article for publication in Solid Earth. I have only a few suggestions for minor revisions, keyed to line numbers. Congratulations to the Authors on this very good piece of work.

Authors: We are very thankful for the thorough and constructive review. We greatly appreciate the comments and suggestions to the manuscript.

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Rev.2: Line 62: if I may, I suggest to add the work by degli Alessandrini et al (Lithos 2017), as it investigated in detail the effect of reactions on the rheology of pyroxene-bearing mafic assemblages deformed at lower crustal conditions.

Authors: Correct, this is a good suggestion. We have cited the paper and have added this work to the list of references (line 62-63).

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Rev.2: Line 136: please add information on the grain size of the starting material to justify the spot size of 40 x 40 mm2 used for the FTIR analysis. Many grains of the

starting material look considerably smaller than this sport size in the BSE images.

Authors: We thank the reviewer for pointing this out, it was not very clear in the text. Double-polished thick sections ($\sim$150–200 μm) of the starting materials were prepared for FTIR analysis. These thick sections were prepared from mineral powders for the Mg-rich opx + plag sample and from a natural section of mylonite for the Fe-rich opx + plag sample. In both cases, the grain size used for FTIR analysis is much larger (>100 μm) than the one we decided to use in our experiments (between 10 and 20 μm). Many grains would indeed be much too small for the spot size of 40 $\times$ 40 μm2. The text has been modified accordingly (lines 133-139).

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Rev.2: Line 221: it might be correct that mineral reactions preferentially occur in strongly deformed areas, but likewise it might be that layers of reaction products (that originally nucleated in a different position) are transposed and smeared off along the foliation. This is typically the case, for instance, in recrystallized myrmekite (see Ceccato et al., 2018). I would argue that mineral reactions in shear zones tend to form at sites of stress (and elastic strain) concentrations (which are typically those facing the instantaneous shortening axis), so that perhaps low-strain samples are more appropriate to identify the nucleation sites of mineral reactions.

Rev.2: Line 400: please see my comment to line 221. Perhaps the reaction products nucleated elsewhere and were transposed/smeared along the porphyroclast tails with increasing strain. From some BSE images, it seems that the entire porphyroclasts are locally rimmed by reaction products (e.g., Fig. 7c, Figs. 10), so I wonder what the original nucleation site was.

Authors: The two previous comments are related, so we decided to group them together to avoid repetition. We have recently published a paper that discusses in more detail these aspects of original nucleation in the early stages of deformation in the Mg-rich opx + plag assemblages (Mansard et al., 2020 – JSG). In hot-pressing exper-

iments, we document that the reaction products occur as thin coronas at the Opx1-Plag1 phase boundaries or in cracks. The rims grow concentrically around old grain relicts without any specific locations at Opx-Plag phase boundaries. At peak stress, little change compared to the hot-pressing experiments, although the amount of reaction products increases slightly and start to coalesce to form partially connected aggregates. At intermediate shear strain, we observed the development of subparallel fine-grained polyphase shear bands, originating from tails that extend from the edges of original Opx, and progressively coalesce to form an interconnected network. Thus, the phase mixing starts at the edges of the original Opx that is gradually consumed by the reaction as evidenced by irregular Opx boundaries, where new grains nucleate along low-stress sites. With increasing strain, these “thin” shear bands evolve into broader high-strain zones. As the reviewer′s comment is a discussion point and the microstructures shown in this manuscript do not provide any evidence for the reviewer′s point of view, we have not modified the text.

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Rev.2: Line 226-232: the cpx-forming reactions in the amph-plag assemblages are dehydration reactions, which typically result in the formation of melt even at 800-900°C (e.g., Wolff and Willie, 1994). Is there any microstructural evidence of melt pseudomorphs, and has the melt-in curve been calculated in the thermodynamic modelling in order to ensure that the experiments were performed fully into the solidus field?

Authors: This is a very important point, given that melt reactions may strongly influence the mechanical behaviour of rocks. Indeed, we had considered the possibility of the formation of melt given these experimental conditions of pressure and temperature, However, after extensive observation at the SEM, we did not find any microstructural evidence of melt pockets or pseudomorphs. We have added a sentence about that to the text (lines 242-243). In addition, according to thermodynamic modeling, the P-T conditions should be outside the melt-forming field.

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Rev.2: Line 276-282: please add sketches of the SC-SC' fabrics in Figs. 10a-c to better summarize these observations.

Rev.2: Line 303: whilst the SC' fabric is clear in Fig. 12c, Fig. 12a looks more an SC fabric. Please add sketches/annotations to highlight the fabric elements.

Authors: Here again, we decided to group the two previous comments together to avoid repetition. Following your advice, we have added annotations to several figures to highlight the fabric elements (Figs. 4a ; 6a-b ; 7a ; 12a-b-c). In the Mg-rich opx + plag samples, strain tends to produce mixed and connected fine-grained bands with C-type geometry in high-strain zones (e.g. Fig. 10a). In contrast, the Fe-rich opx + plag and amph + plag mixtures tend to form clusters and only locally connected amph-rich rich σ-tails at porphyroclasts, as S-C- (e.g. Fig 12a-b) or S-C'- (Fig. 12c) type geometries.

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Rev.2: Line 312: I understand that the pole figures are plotted as one point per grain; please provide the total number of the plotted grains, the step size and the average grain size of amphibole, so that the reader can make their judgement on the data acquisition and processing routines. How many data points did you consider representative to define an individual "grain"? Amphibole grain size in Fig. 13 looks < 1 micron, so I wonder whether many of you "grains" are actually individual data points that might encompass more than one single grain. Please clarify.

Authors: The reviewer has pointed out an important issue, we have added the data you mentioned (see caption of Figure 12 – line 1272). Then, we consider that 5 data points are required and are considered representative to define an individual grain. We have added a sentence about that to the methods section (line 151). With regard to the grain size in Figure 13, it is indeed extremely small. However, this figure is for the Mg-rich opx + plag assemblages. The pole figures in Figure 12 are associated only with the

Fe-rich opx + plag assemblages. Unfortunately, none of our EBSD analyses performed on Mg-rich opx + plag assemblages were convincing, due in part to the extremely small grain sizes in the mixture zones. To clarify, we have indicated in the caption that the data presented in Figure 12 are only associated to the Fe-rich opx + plag assemblages (line 1269).

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Rev.2: Line 360: is there any evidence of dislocation creep been potentially active in the strong phases? Do you have EBSD maps of porphyroclasts that could help understand this?

Authors: Unfortunately, none of our EBSD sessions on Mg-rich opx + plag assemblages were conclusive. This is most certainly due to the fact that we tried to study very fine grains within a narrow shear zone trapped between 2 very strong alumina pistons, thus making polishing very complex. The grain shapes of porphyropclasts do not suggest any deformation by crystal plasticity.

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Rev.2: Line 494-497: this is a very interesting and plausible interpretation. But the follow up question is how did the H2O stored in the interior of strong porphyroclasts become available for the reactions? Did microfracturing play a role here? Any evidence?

Authors: The reviewer has made an impotant point here. Indeed, cracking in opx is very common : original Opx clasts are locally cut by brittle fractures which refines the grain size of strong porphyroclasts. The cracking will make the H2O available for reactions. We have added a sentence to the text to say this (lines 509-511).

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Rev.2: Line 532: syn-kinematic mineral reactions are very important for the deformation of mafic systems also at higher metamorphic grades (see degli Alessandrini et al.,

2017). Here you also document dehydration reactions and their role on deformation.
Authors: The reviewer is right. We have added this work to the reference list (line 550).

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