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Interactive comment on "Experimental grain growth of quartz aggregates under wet conditions and its application to deformation in nature" *by* Junichi Fukuda et al.

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The reviewer gave three major comments regarding (1) the use of the term "grain growth" associated with the process, (2) characteristics of epitaxially growth quartz, and (3) combination of static grain growth driven by grain boundary energy and strain-induced grain boundary migration under plastic deformation occurring in nature. He/she also gave other comments for specific places in the manuscript, some of which are associated with the major comments. We thank for these helpful comments. We will show all of the reviewer's comments and revised points.

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Discussion paper

Reviewer: (1) It would be necessary that the authors early in the manuscript state, how they use the term “grain growth” with respect to grain boundary migration and driving forces. At some point a contrasting juxtaposition/discussion of the processes of grain boundary migration driven by the reduction in interfacial free energy and grain boundary migration driven by the reduction in stored elastic strain energy (i.e., reduction in dislocation density) would be helpful. In this context the wording “contribution of grain growth to deformation” used several times in the manuscript and the title “Experimental grain growth. . .and its application to deformation. . .” might get clearer.
Authors: This is a helpful comment. In this study, we used the term, “grain growth” as grain boundary migration driven by grain boundary energy under static pressure and temperature conditions. As the reviewer commented here, clarifying this process would be helpful. Also, as the reviewer commented in (2), we also observed epitaxial growth of quartz grains especially when 10 wt% of water is added. The shapes and growth features formed by epitaxial growth are obviously distinguished with those formed by grain growth. Thus, according to the reviewer’s comment here, we explained “grain growth” we focus in terms of the above process (page 1, line 26). In addition, as the reviewer commented in (3), we also described the contribution of strain-induced grain boundary migration under plastic deformation. To sum up, we distinguished the following wordings; grain growth, epitaxial growth, strain-induced grain boundary migration.

Reviewer: (2) The authors also discuss non-hydrostatic conditions in their experiments, especially in the context of dissolution-precipitation and epitaxial growth: is there any systematic relation of the shape of the growing crystals and/or crystallographic orientation with respect to sample shape and/or position in the experimental apparatus or to platinum jacket, or similar? As the authors also analysed the microfabric, a few words on this topic might be useful. In this context also formation of “growth

rims" in the sense of epitaxial crystallization by precipitation from the pore fluid should be compared and contrasted to grain growth.
Authors: We described the detailed textures of epitaxially grown grains in the revised manuscript (page 7, line 3): We observed an alignment of epitaxially grown quartz grains from the platinum jacket as a substrate, meaning that the quartz grains are elongated perpendicular to the jacket caused by a separation of the jacket wall from the inner sample part (namely, the powder and novaculite). As for the crystallographic orientations, we did not measure them, but according to previous studies for vein quartz grains (e.g., Cox and Etheridge, 1983 for natural samples; Okamoto et al., 2011 for experimental samples), they showed that the elongated axes are c-axes.

Reviewer: (3) When discussing the relevance for natural conditions and application of paleopiezometers some information on how to evaluate the contribution of grain growth in nature, for example as opposed to strain-induced grain boundary migration during recrystallization, would be valuable. I feel, this should be discussed by citing previous studies published on this topic.
Authors: We agree. In the revised manuscript, we cited references for strain-induced grain boundary migration (White, 1977; Poirier and Guillopé, 1979; Jessell, 1987). Then, we discussed textures formed by static grain growth and by dynamic recrystallization, i.e., strain-induced grain boundary migration. The former gives straight grain boundaries and the latter does irregular grain boundaries. We also added theoretical assumptions by previous studies for dynamic recrystallization (Austin and Evans, 2007; Shimizu, 2008), where grain boundary migration is balanced with static grain growth. When static grain growth overcomes strain-induced grain boundary migration, the texture by the former would be enhanced. We carefully discussed this possibility in the Discussion section (page 11, line 9).

Reviewer: A few specific comments/suggestions are listed as follows:
Abstract
Page 1, line 10: Delete the first word of the abstract “The”
Authors: Done.

Reviewer: Page 1, line 11: please specify “large porosity” or rephrase
Authors: We changed “large” to “substantial”. In our samples, porosities can not be evaluated quantitatively because of fracturing during unloading and plucking of grains during thin sectioning.

Reviewer: Page 1, line 12: please specify “dense” or rephrase
Authors: We deleted “dense”.

Reviewer: page 1, line 19: What is the contribution of grain growth to plastic deformation? See point (1)
Authors: According to the reviewer’s major comment (1), in the early Introduction section, we clarified the process of grain growth in terms of grain boundary migration and the driving force producing larger grains with straight grain boundaries (i). Then, in the Discussion section, as we replied to the major comment (3), we described strain-induced grain boundary migration due to plastic deformation producing irregular grain boundaries (ii). Then, we gave a discussion with the competition between the processes (i) and (ii) following our reply here.

Reviewer: Introduction

Here, I feel that some aspects on grain boundary migration driven by the reduction in strain- and surface energies, i.e. a contrasting juxtaposition of strain-induced grain boundary migration (or recrystallization) and grain growth, would be helpful, see point (1).
Authors: According to the comment, we explained the process of grain growth we focus, which is driven by grain boundary energy and movements of smaller grains with higher grain boundary mobility. As for strain-induced grain boundary migration (dynamic recrystallization), we discussed it in the Discussion section.

Reviewer: Page 2 line 16: Again: What is the contribution of grain growth to deformation? See point (1)
Authors: As we mentioned in the original manuscript, grain growth changes grain size, which can control deformation behavior (grain-size-insensitive creep and/or grain-size-sensitive creep). To recall this, we mentioned it again here in the revised manuscript.

Reviewer: Samples
Page 3, line 21: A few more information of the sample of novaculite would be helpful. Why is the term “quartzite” used, is it a metamorphically overprinted novaculite?
Authors: The novaculite sample is not metamorphically overprinted. We realized that calling the sample novaculite is suitable not to give confusion. We changed “quartzite” to “novaculite” throughout the manuscript.

Reviewer: Discussion
Page 8, lines 20/21: Please reorganize, the influence of porosity is discussed later in detail.
Authors: The reviewer is right. We deleted this paragraph and moved some of the sentences from here to the later paragraph that discusses pores and grain growth

(page 9, line 32).

Reviewer: Page 8 line 26-31: Please discuss, why/where dissolution and why/where precipitation should take place. Why is at specific sites epitaxial growth occurring? See points (1, 2)
Authors: Dissolution can occur anywhere since water can dissolve quartz in our experimental conditions (experimental study by Hunt and Manning, 2012). We confirmed epitaxial growth on the quartz grains next to the Pt jacket because the Pt jacket is removed from the quartz grains (probably due to excess pore pressure effects). We discussed this in page 9, line 20 in the revised manuscript.

Reviewer: Page 9, line 2: Please discuss why the dihedral angle effects grain growth. If the dihedral angle changes at the different conditions, what is the effect on the process of grain growth? For example any discussion on the interfacial free energy would be good here (see point 1).
Authors: We realized that we did not discuss the effect of wet grain boundaries on grain growth, which is summarized as follows. Wet grain boundaries assist diffusion of Si (Farver and Yund, 2000), resulting in faster grain growth than in dry grain boundaries. We added this sentence with the reference in the revised manuscript (page 9, line 27). Furthermore, wet grain boundaries may be formed or not under fluctuation in the experimental condition that we discuss here (900 °C and 1.5 GPa). This may explain the large data scatting. We also added sentences about this in the same place.

Reviewer: Page 9, line 8: That grain growth of quartz takes place by grain boundary migration assisted by H2O is not new, please state references. Here, the term grain boundary migration occurs for the first time in the manuscript – too late for a paper on grain growth. . . (see point 1)

Authors: We deleted this sentence because we added a new sentence according to the reviewer's comment on page 9, line 2 in the original manuscript. This new sentence includes a new reference (Farver and Yund, 2000), which showed faster Si diffusion in wet grain boundaries, resultantly causing faster grain growth than in dry grain boundaries. As for the term "grain boundary migration" of grain growth, we explained the process in the Introduction section according to the major comment (1).

Reviewer: Page 9, lines 11/12: When considering non-hydrostatic conditions: is there any control of principal stress directions on crystallographic orientation and/or shape of the growing crystals? See point (2)
Authors: We have omitted the sentence, because the discussion of the island and channel structures and its consequences would take too much room in this manuscript, and the point is not that important as to include this discussion here.

Reviewer: Page 9, line 13: Please provide some more information on the island-channel structure transport and its role on grain growth.
Authors: We have omitted the sentence, because the discussion of the island and channel structures and its consequences would take too much room in this manuscript, and the point is not that important as to include this discussion here.

Reviewer: Page 10: Any discussion on how to evaluate that grain growth took place in natural rocks would be helpful. This relates to the comparison on grain boundary migration driven by the reduction in stored elastic strain energy (i.e. reduction in dislocation density) versus grain boundary migration driven by the reduction in interfacial free energy, as well as formation of growth rims, see point (3)
Authors: We distinguished these two mechanisms of grain boundary migration (i.e., reduction in dislocation density here vs. reduction in interfacial free energy in

the Introduction section; see our reply to comment 1). We have expanded the discussion of how to distinguish grain growth from dynamic microstructures in this section.

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Discussion paper