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Solid Earth
Discussions

Interactive comment on "Short wavelength undulatory extinction in quartz recording coseismic deformation in the middle crust – an experimental study" *by* C. A. Trepmann and B. Stöckhert

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We thank Luca Menegon very much for his careful and constructive review, and for thoroughly checking the figures. In the following we respond to the comments one by one. The reviewer's comments are given in quotation marks.

1. Water

"...This is an excellent and innovative idea, and the sound experimental and microstructural data produced by the Authors (as well as observations from naturally deformed rocks) are certainly interpretable in these terms. However, high stress deformation under HIGH T conditions is not necessarily the result of seismic activity, and this is particularly true for quartz. An alternative interpretation, which is not in conflict with the Authors' believe, is based upon the effect of water on the creep strength of quartz, and I invite the Authors to consider mentioning it in the discussion. It has been known for decades that water has the potential to reduce creep strength dramatically, by enhancing crystal plasticity in nominally anhydrous minerals even if only present as a few parts per million (ppm) (Kronenberg Tullis 1984; Mackwell et al. 1998). On the contrary, extremely dry conditions result in very high creep strength of minerals. "Dry" quartz is well known for being extremely strong and for showing very high plastic yield strength in the lab, on the order of 2.0–3.0 GPa even at temperatures of 1000_C (e.g., Griggs and Blacic, 1965; Blacic and Christie, 1984; Kronenberg et al., 1986). Under these conditions, quartz shows high stress (or low T) deformation microstructures, as shown in Menegon et al. (2011). High stress can lead to local fracturing, fluid infiltration (if available), dynamic recrystallization/grain size reduction, and substantial weakening. In other words, there is the alternative possibility that the sequence of microstructures documented in the present manuscript as the result of "kick-creep" experiments could be indicative also of dehydration/hydration cycles experienced by quartz at lower crustal conditions, without necessarily invoking seismic activity. But as stated before, these two interpretations are not mutually exclusive (e.g. pseudotachylytes in dry lower crustal rocks: Austrheim and Boundy, 1994)."

In our study we are NOT dealing with high-stress deformation at HIGH temperatures. Our study is concerned with high-stress deformation at temperatures of 400°C in "kick" experiments, designed to simulate coseismic loading in the uppermost plastosphere. Temperatures of 900 - 1000°C in the subsequent "creep" experiment are only required to speed up low-stress deformation accompanied by recovery and recrystallization, which otherwise would not be accessible on laboratory time scales. The trade temperature for rate is commonplace in experimental rock deformation, being the only way to achieve measurable deformation at stress levels corresponding to those prevailing in nature (e.g. Paterson, 1987, 1990; McLaren, 1991; Evans and Kohlstedt, 1995). The influence of dehydration/hydration effects on rock strength to explain high-stress deformation at high temperatures is an interesting problem, but necessarily remains beyond the scope of our study. As such, we would prefer not to address this complex topic here, as we feel that it would distract from our central point.

2. Deformation bands – recrystallization bands.

“The microstructure of deformation bands parallel to prism planes and to rhombohedral planes looks very similar in Figs. 6a, b, thus suggesting a similar origin.”

Deformation bands are characterized by approximately planar boundaries parallel to prism planes, and by a higher misorientation angle of about 10-15° (Fig. 6a, b, d). Deformation bands parallel to rhombohedral planes have not been observed. Locally deformation band boundaries can be decorated by new grains.

“In particular, there is no evidence for progressive and systematic rotation of the crystal lattice when approaching the prism-parallel deformation band (Fig. 6d), so that the recrystallization mechanism in the deformation bands was probably not subgrain rotation recrystallization. This is also suggested by the microstructure in Fig. 5b, showing large recrystallized grains with a rectangular shape locally “protruding” into the more highly strained quartz host grain. This could indicate grain boundary migration and growth from strain-free nuclei along fractures, driven by the reduction in strain- and surface energy, or alternatively precipitation/growth from aqueous fluids (e.g. Vernooij et al. 2006).”

New grains are interpreted to have formed by “nucleation and growth” in highly-damaged zones, i.e. zones of localized high strain, for example along fractures. The phenomenon has been described in detail by Trepmann et al. 2007. Whether old grains deformed in the “kick” experiment are replaced by new grains, or their internal structure resulting from inhomogeneous deformation evolves into deformation bands or SWUE by dynamic recovery, depends on type and degree of local damage during initial high-stress deformation. In zones of brittle grain size comminution or extremely high dislocation densities, new grains developed. In contrast, in areas of less intense inhomogeneous crystal plastic deformation, dynamic recovery results in SWUE. The effect of fluids on recrystallization is beyond the scope of the present study. Grain boundary migration is known to be facilitated by the presence of fluids (e.g., Drury and Urai, 1990; Mancktelow and Pennacchioni, 2004), while Vernooij et al. (2006) discuss precipitation of quartz from a solution in voids and microfractures produced in quartz deformation experiments with 1 vol.% of added water. This is quite different from our conditions. Here the shape of the new grains in relation to the deformed host requires grain-boundary migration. The incipient stage ("nucleation") is discussed in Trepmann et al. (2007) and details of this process cannot be readily inferred from the present microstructure.

“Is there the possibility that also these deformation bands have exploited (micro)fractures formed during the kick experiments? Or perhaps healed microfractures (decorated by fluid inclusions trails?) originally present in the starting material? “

The local occurrence of deformation bands and zones of recrystallization is controlled by microstructural heterogeneity (strain localization) introduced during the kick experiment; these can in turn be controlled by microstructural heterogeneity of starting material. Direct correlation between preexisting heterogeneities and occurrence of deformation bands is hardly possible, however, given (1) stereological problems inherent in a 2D section through a 3D object and (2) modification of preexisting microstructure during the experiment.

3. Minor comments

“Page 282, line 5: A corresponding: : : Page 283, line 15: van Daalen et al., 1999 Page 289, line 10: A second set Page 289, line 23: refer only to Fig. 7a, as Fig. 7b shows pole figures and not microstructures Page 289, line 28: refer to Fig.7c rather than 7b-d Page 290, line 15: Fig. 8f does not exist; the rose diagram is an insert in Fig. 8c Page

295, line 10: Preserved large original portions”

The careful check for misspellings and mistakes in the reference list is greatly appreciated.

“Page 306, Fig. 3: Please indicate also r and z in addition to the Miller indices in (a), as r and z are frequently used in the text and in the figure caption. The arrays of microcracks and lamellae parallel to z are not clearly evident in (a), I would recommend enlarging this picture. The misorientation profile in (d) is dominated by the noise; I would rather omit the profile and enlarge fig. 3a instead. The oscillating change in crystallographic orientation is nicely shown in the map in (b) and the profile does not add anything to that. Caption: There is no yellow rectangle in (a). Please indicate what the yellow rectangle in (c) is.”

We agree that the misorientation profile does not provide additional information. The figure is modified according to the suggestions (see uploaded Figure 3).

“Page 307, Figure 4: It is really hard to see on these photos the details pointed out by the arrows. It would be nice if the Authors could specify here (or even better in the text) the meaning of cellular structure.”

Cellular structure denotes a microstructure with dislocation poor domains separated by poorly-ordered dislocation walls, well known from cold worked materials (e.g. Humphreys and Hatherly, 2004).

“Page 308, Fig. 5: What is the yellow rectangle in (c)? I would show the traces of misorientation profiles in (c) rather than in (d), because the oscillating change in misorientation is evident in (b).”

The figure has been modified according to the suggestions (see uploaded Figure 5). The yellow rectangle in (c) was indicating the location of polarized light micrograph in (a). As it was indeed distracting we removed it. The white rectangle in (d) indicates location of polarized light micrograph in (b).

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“Page 309, Fig. 6: in the caption of (b) replace red line with yellow line. Specify what the great circles in (c) indicate.”

In Fig. 9 (c), crystallographic planes, which are traced in (b) are indicated by great circles.

“Page 310, Fig. 7: What are the grey clusters of data points on the pole figures in (b) (particularly in the pole figure of r)?”

The grey clusters are Dauphiné twin domains. We agree that the Dauphiné twin orientations in the pole figure are distracting. Accordingly, in the pole figures Fig. 7b we now show only the parts colour coded in Fig.7a (see uploaded Fig. 7)

“Is (c) colour-coded according to the Euler angles?”

This is correct, the colour coding in Figure 7c is according to Euler angles.

“Page 314, Fig. 11: in the caption of (b) the Authors probably intend to refer to Fig. 10 rather than to Fig. 8.”

This is correct.

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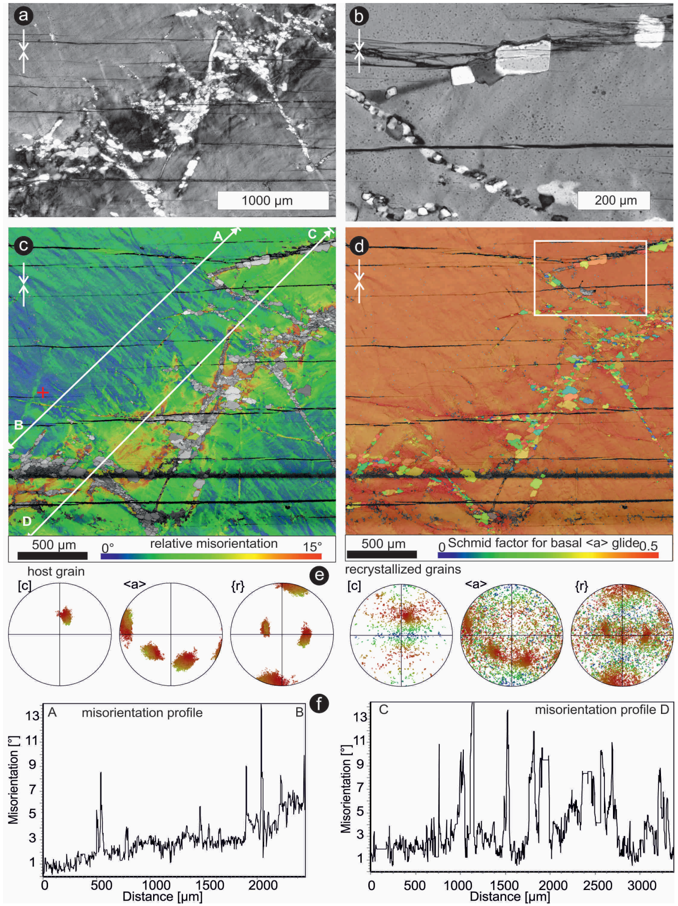

Fig. 1. New Figure 5

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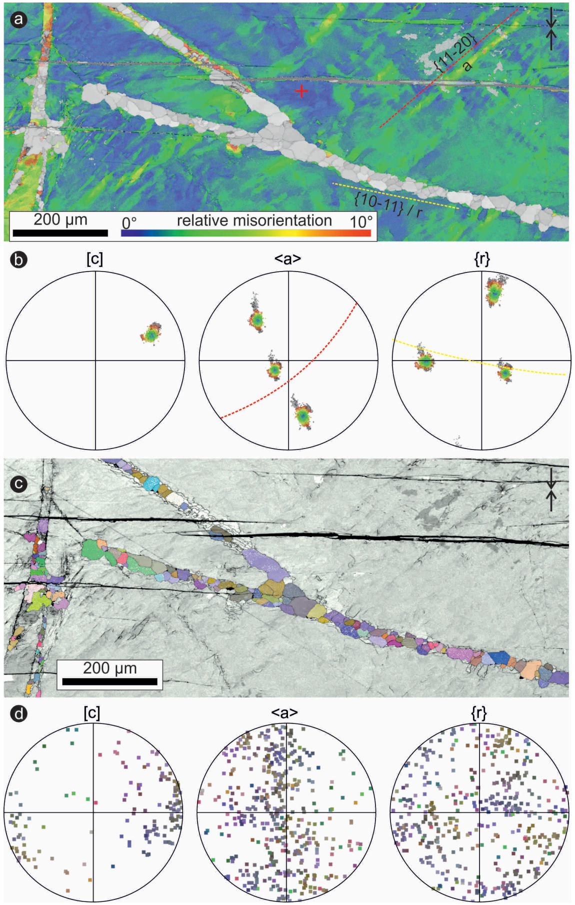

Fig. 2. New Figure 7

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