Solid Earth Discuss., 5, C282–C291, 2013
www.solid-earth-discuss.net/5/C282/2013/

Interactive comment on "The microstructural record of porphyroclasts and matrix of serpentinite mylonites – from brittle and crystal-plastic deformation to dissolution-precipitation creep" *by* J. Bial and C. A. Trepmann

J. Bial and C. A. Trepmann

jb@min.uni-kiel.de

Received and published: 12 July 2013

Reply to the comments by anonymous referee #1

We thank the anonymous referee for the critical and constructive review. We appreciate all suggestions and comments and will carefully consider them when preparing a revised manuscript. In the following we respond to all raised points one by one, answer questions and discuss the suggestions. The comments of referee #1 are given in

quotation marks.

A) General comments

"Reading the title and the abstract ("The aim is to differentiate between the potential record of independent successive deformation events."), I was expecting that this paper is mostly dealing with the description of the differences in microstructural features linked to different steps of the geodynamic evolution of the sampled serpentinite mylonites of the Voltri Massif, and the potential use of microstructure to unravel deformation history in complex terrains. On the other hand this is not clearly described through the paper and the aim is not achieved."

One of our main points is the documentation of an example, where the deformation record of porphyroclasts in mylonites is not associated with the deformation record of the matrix, but where the microstructures of the porphyroclasts are inherited from a completely independent earlier deformation than the microstructure of the matrix. This is opposed to the general approach, where the microstructures of porphyroclasts are correlated with the microstructure of the mylonitic matrix - which is certainly valid for many mylonites, but not necessarily for all. This study shows one example, where such a correlation is not valid, as such it is a new and original contribution to understanding microstructures and their use to unravel the geological history. The main conclusions are focusing on the rheology of the rocks and the recorded stress conditions during the different stages of deformation. We will strengthen our main points throughout the revised manuscript.

"1. most of the conclusions are based on petrological assumptions (not always convincing ones) mostly inferred from (dated) literature rather than from petrological observation of the studied samples."

The main conclusions are focusing on the rheology of the rocks and the recorded level of stress during the different stages of deformation; they are mainly based on microstructural and not on petrological observations. We will strengthen our rheological aspects in the conclusions and throughout the manuscript. We are happy to cite the most recent literature and greatly appreciate the additional references.

“2. the transition cited in the title among different deformation mechanisms are not described in the same mineralogy. Moreover the type of analysis performed in olivine and pyroxene is different from the one in antigorite.“

In this study, the microfabric development of partly serpentinized mylonitic peridotites is analyzed in detail in order to elucidate the grain-scale deformation processes in rocks that dramatically changed their mineral content and thus their rheological behaviour during the complex history and to get information on the stress conditions during the different stages. In our analyses of the antigorite, olivine and pyroxene microstructures we use polarization microscopy. In addition, EBSD analyses are performed in the coarse olivine and pyroxene porphyroclasts, with pronounced intracrystalline microstructures. As antigorite is very fine-grained and does show an associated SPO and CPO as indicated by the cleavage plane, i.e. the (001) basal plane, no EBSD measurements are required to describe the main characteristics of the antigorite microstructure for the purpose of this study.

“3. the geologic setting of the sampled area and mostly of the referenced literature are obsolete. they need to be updated, also because the Authors use the data from literature to infer most of the geological features of their samples and and to discuss the implications of their work. “

We greatly appreciate the additional references and are happy to cite also the most recent literature in the revised manuscript. The chapter “geologic setting” is carefully revised considering the additional references.

“4. the microstructural features of the serpentinite mylonites are poorly described . No references to the main structures in the field of the described foliation or to the relation with the previous foliations are reported. The conclusions (n.2) on antigorite and antigorite foliation are not sufficiently supported by the data and discussions.”

We will strengthen the discussion on microstructural features, as also requested by the second referee. More discussion is especially requested on the indications of dissolution-precipitation creep in the matrix and of the antigorite microstructures. We will add two more polarized light micrographs of antigorite microstructures (see uploaded Figure 8). The microstructure of the crenulation cleavages of antigorite and strain shadows surrounding the old porphyroclasts are indicators of dissolution-precipitation creep (see below). We will extend the sample description and description of the microstructural data, which will be divided into two separate Chapters (4. Sample description, 5. Microfabrics).

B) Specific comments

“Abstract page 366 Line 20 - "Accordingly, any intragranular deformation features of the newly precipitated olivine in strain shadows are absent" As they are strain shadows I expect that the strain is lower respect to the rest of the rocks and this cannot be related only to the general state of stress as suggested by the Authors.“

Strain shadows act as "sinks" during dissolution-precipitation creep. In areas parallel to the stretching lineations in the foliation plane, new material is precipitated from a fluid, which was originally dissolved from areas at high angle to the shortening direction, i.e. the "source" areas. As such the material in the shadow represents second-generation material precipitated from the fluid in comparison to the porphyroclasts. The porphyroclasts do show evidence of high-stress deformation (i.e. crystal-plastic deformation) but the new grains in the strain shadow do not. The conclusion therefore is quite robust that the stresses were not sufficiently high to allow for significant accumulation of strain by crystal-plastic deformation since precipitation of olivine in the strain shadow. Dissolution-precipitation creep suggests a Newtonian rheology and low stresses (e.g., Wassmann et al., 2011), whereas dislocation creep as indicated by partly recrystallized olivine porphyroclasts indicates a power law rheology, requiring high stresses (Fig. 9).

“line 25 -"of the oceanic lithosphere probably related to rifting processes" Why "oceanic litho-sphere? In the literature the Erro-Tobbio peridotite have been always interpreted as subcontinental lithospheric mantle (Rampone et al., 2005; Vissers et al., 1991, Piccardo, 2003,2008,2010)"

We agree and delete the misleading term here.

1 Introduction "The title and the abstract of the paper suggest a use of the microstructural/textural analysis as potential tool to unravel the superposition of different deformation events. So I was expecting an intoduction on this topic (the potential use of microstructures and deformation mechanisms in the analysis of polyphase metamorphic rocks). Despite the huge literature on the argument (i.e. the potential use of microstructure and textural as stress or temperature gauges in the olivine, pyroxene and antigorite) no references to the topic occur."

We completely revised the introduction considering literature on the use of microfabrics of metamorphic mafic to ultramafic rocks related to deformation processes and stress, strain-rate conditions during burial and exhumation, as also requested by the second referee:

In this study, we focus on the so far not widely used microstructural record of grain-scale deformation processes provided by partly serpentinized peridotite mylonites from the Erro-Tobbio unit (Drury et al., 1990; Hoogerduijn Starting, 1991; Scambelluri, 1991; Hoogerduijn Starting and Vissers, 1991; Hoogerduijn Starting et al., 1993; Vissers et al., 1991; 1995; Hermann et al. 2000) to obtain information on the rheology and the stress condition during the different deformation stages. These rocks dramatically changed their mineral content and thus their rheological behaviour during the complex geodynamic history. In comparison with experimental studies on the rheology of rock-forming minerals in metamorphic mafic to ultramafic rocks (omphacite: e.g., Avé Lallemant, 1978; Ingrin et al., 1992; Orzol et al., 2006; Zhang et al., 2006; Zhang and Green, 2007; Moghadam et al., 2010; olivine: e.g., Chopra and Paterson, 1981; Hirth and Kohlstedt, 2001; Zhang et al., 2000; Jung and Karato, 2001; Jung et al., 2006;

Druiventak et al., 2011; 2012; antigorite: e.g., Hilariet et al., 2007; Chernak and Hirth, 2010) microfabrics can yield information on the deformation mechanisms, as well as the stress and strain-rate conditions during burial and exhumation (e.g., Skrotzki et al., 1991; van der Wall, 1993; Altenberger, 1995; Jin et al. 1998; Zhang et al, 2000; Jung & Karato, 2001; Piepenbreier and Stöckhert, 2001; Stöckhert, 2002; Andreani et al., 2005; Auzende et al., 2006; Jung et al., 2006; Wassmann et al., 2012; Matysiak and Trepmann, 2012). The aim of this study is to use the successively overprinted and modified microfabrics of the partly serpentinized peridotite mylonites to differentiate between the potential record of independent grain-scale deformation processes and implications on the stress conditions. On the basis of the findings we discuss the implications for the inferred superposition of features associated with initial brittle and crystal-plastic deformation of the original mantle peridotites with features indicating dissolution-precipitation creep of the serpentinized peridotites.

2 Geologic Setting "The geologic setting, the references to the regional geology and to the petrology of the studied area are out-of-date. They are mostly based on the paper by Hoogerduijn Strating et al. (1990), but in the meantime a lot of papers and discussions on the ultramafics of the Voltri Massif and on the VM tectonic/geodynamic evolution have been published. New geochronological data of the high pressure metamorphism and new microstructural and petrologic data have been published. Even the interpretation of the geology (the serpentinite mylonite are really derived from the Erro Tobbio Unit?) of the area sampled by the Authors has been recently revised and questioned on published papers (see Capponi and Crispini, 2008-Geological Map Genova quadrangle, Piccardo, 2013 and Scambelluri, 2013 on the International Geology Review). An update of the literature and a correct description of the geologic setting is necessary. Most of the recent literature on the geology and petrology of the sampled area can be found reported in Scambelluri, 2013, in Capponi an Crispini, 2008 (http://www.isprambiente.gov.it/Media/carg/liguria.html), in Vignaroli et al., 2010, Malatesta et al., 2012."

We greatly appreciate this comment and we carefully revised the chapter “geological setting” considering also the most recent literature.

4. Sample description and microfabrics

“page 369-Lines 16 to 19: Is really a mineral paragenesis the one reported by the Authors or instead is it a mineral association? I suggest to avoid this confusion as the mineralogic association described by the Authors is also typical of the Peridotite Mylonites of the Erro Tobbio Unit (see for istance: Hoogerduijn Strating et al., 1991, 1993; Rampone et al. 2005). The mineral paragenesis is firstly described as consisting also of + Ti-clinohumite and enstatite, nevertheless Ti-clinohumite is not considered in the modal composition. It’s occurrence is important in these rocks, as described in literature, a more correct description of the sample mineralogic composition is required. I expect a more detailed petrographic and petrologic description if then they are used to infer the deformational steps and the paper conclusion.”

The partly serpentinized peridotite mylonites studied here, were collected in NW Italy about 10 km NW of Genova, SW of Mt. Poggio (N44°32.008, E8°46.666) and SW of Mt. Tobbio (N44°31.817, E8°46.649) of the Erro-Tobbio unit (Fig. 1). The modal composition is strongly varying but typically in the range of 46–51 % antigorite, 10-20 % olivine, 5-10% diopside, 5-7% chlorite, 2-3% spinel, 0-2% enstatite. Associated with these serpentinite mylonites vein-like structures containing Ti–clinohumite are widespread within the sampled area. The occurrence of Ti-clinohumite in the investigated partly serpentinized peridotite mylonites is in accord with the association of the samples to the Erro-Tobbio unit (Hoogerduijn Strating et al., 1991; Piccardo, 2013). Hoogerduijn Strating et al. (1993) distinguished five types of shear zone developed from original granular spinel lherzolithes from the Erro-Tobbio unit by mineral association, namely, spinel-bearing porphyroclastic tectonites, plagioclase-, hornblende-, and chlorite-bearing peridotite mylonites, and serpentinite mylonites. The samples investigated here, correspond to serpentinite mylonites, i.e., chlorite-bearing partly serpentinized peridotite mylonites.

6. Implications

“1-It’s not clear which are the evidences used by the Authors to consider the enstatite and the olivine in the pressure shadows as the results of the (1) and (2) reactions. As described in literature, these minerals developed also during the formation of peridotite mylonites during the pre-alpine"mantle evolution". 2 - How the Authors deduce that Olivine and Enstatite in their samples derived from the dehydratation process of antigorite and they don not derive from previous metamorphic stage¿‘

The presence of secondary olivine (fine-grained, internally not deformed) and pyroxene (fine-grained, no exsolution lamellae) in strain shadows indicates precipitation of new material from the pore fluid during dissolution-precipitation creep. The observation that olivine and pyroxene in the strain shadows are not crystal-plastically deformed – as opposed to the porphyroclasts - indicates insufficiently high stresses to accumulate significant strain by dislocation creep since precipitation. As such porphyroclasts and matrix minerals represent two successive deformation stages. Dissolution-precipitation creep requires the presence of a free fluid phase. Dehydration reactions of antigorite according to the reactions (1, 2) have been proposed to be recorded by the HP-LT metamorphic mineral assemblage of the Erro-Tobbio serpentinites (e.g., Hoogerduijn Strating and Vissers, 1991; Scambelluri et al., 1991; 2004; Ulmer and Trommsdorff, 1995; Hermann et al., 2000; Healey et al., 2009). These antigorite breakdown reactions can provide a considerable amount of fluid to depth of up to 200 km (Ulmer and Trommsdorff, 1995, Bromiley and Pawley, 2003, Scambelluri et al., 2004). It is suggested that fluid provided by these reactions also contributed to the recorded dissolution-precipitation processes. Furthermore, in this case the precipitation of olivine and enstatite on the expense of antigorite might even further promote dissolution-precipitation processes due to the enhancement of preferred sites of dissolution, i.e. phase boundaries. We will enhance this discussion accordingly in the revised manuscript to avoid confusion and to strengthen our argumentation.

“3 – The microstructures/texture in the peridotite and serpentinite of the Erro Tobbio

Unit have been also described in Hoogerduijn-Strating, 1991 (published PhD thesis) and 1993. I expect a reference or at least a comparison with the previous literature."

We will also add a reference to the published PhD thesis of Hoogerduijn Strating (1991) in addition to the already cited references (Hoogerduijn Strating 1994; Hoogerduijn Strating and Vissers 1991; Hoogerduijn Strating et al., 1990, 1993) and will more specifically give reference to their data.

"page 372 - line 21-24 - "It is remarkable that the deformed and recrystallised microstructure of the peridotites is partly preserved and not more effectively modified by serpentinization" This is not a new observation in these rocks and in general in metamorphic mylonites."

The microstructures of the porphyroclasts, as observed here, are inherited from a completely independent earlier deformation than the microstructure of the matrix. This is opposed to the general approach, where the microstructures of porphyroclasts are correlated with the microstructure of the mylonitic matrix – i.e., where porphyroclasts and matrix are deformed in the same event. In this case here, however, highly-strained peridotites (crystal-plastically deformed olivine and pyroxene porphyroclasts) are in a subsequent stage serpentinized and deformed by dissolution-precipitation creep - we feel that in this case it is indeed remarkable that the deformed and recrystallised microstructure of the peridotites is partly preserved and not more effectively modified by serpentinization. In the revised manuscript we will strengthen this difference to "general metamorphic mylonites", where by definition all mylonites are "metamorphic".

Interactive comment on Solid Earth Discuss., 5, 365, 2013.

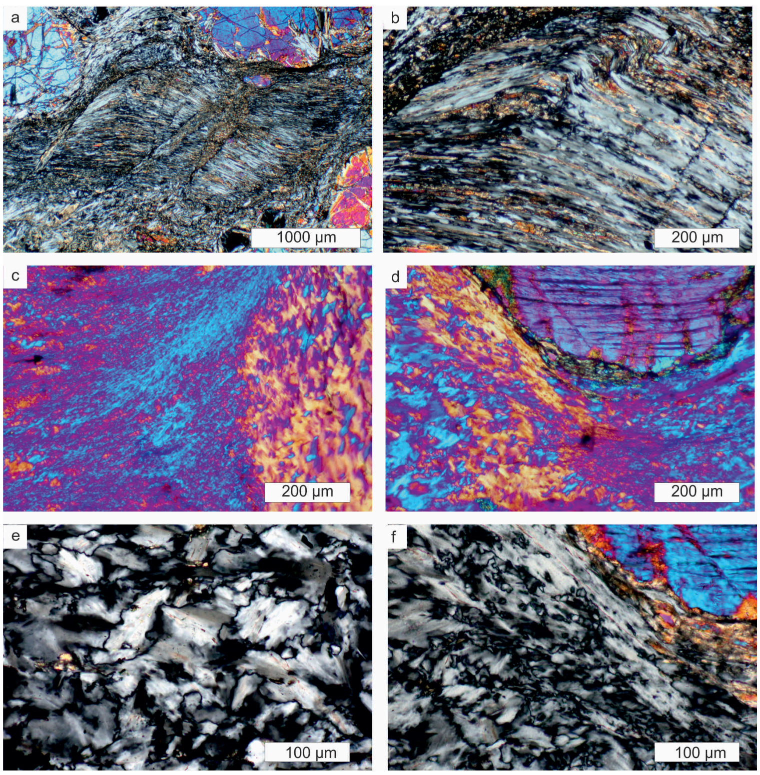

Fig. 1. Fig-08