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Interactive comment on "Deformation mechanisms in mafic amphibolites and granulites: record from the Semail metamorphic sole during subduction infancy" *by* Mathieu Soret et al.

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Reviewer: Marco Herwegh (Referee)

Dear authors, dear editor This article deals with the microstructural evolution of the metamorphic sole of exhumed mantle in Oman using samples form three different sites. Based on vertical sample transects, the authors investigate microfabric changes as a function of increasing distance to the hanging wall peridotite and attribute these changes to changing deformation processes as a function of progressive exhumation. They excellently document changes in mineral assemblages, phase distributions, mineral chemistry and geometric microstructural (grain sizes, grain aspect ratios) aspects

as well as CPOs. Based on these data they come up with a generalized conceptual model where on the prograde metamorphic path dehydration reactions lead to the formation of amphibole, plag, cpx, grt aggregates where the latter two being rigid inclusions in a weak amphibol-plag matrix. Fluid assisted grain fracturing lead to grain size reduction, where then fine-grained mixed polymineralic aggregates deformed by diffusion creep processes (including grain boundary sliding and mass transfer processes). Cpx and grt clasts reduce their grain size further by fracturing and dynamic recrystallization, respectively. With reducing temperature cpx and grt are strongly altered and a matrix consisting of amphibole and plagioclase dominates. Seeing evidences for subgrain rotation formation in amphiboles, the authors claim a transition to dislocation creep, although still being in a polymineralic system. The formation of shear bands with precipitation of epidote as well as nucleation of new amphiboles indicate an important role of fluids down to these retrogressed conditions. Linking the microfabric evolution to qualitative rheo- logical considerations, inferences about the stability and mechanical coupling across the plate interface are finally made. The article is of great scientific interest for the subduction zone community particularly when interested in the mechanical coupling and the role of potential grain scale processes. The authors excellently document a nice suite of microfabric transitions giving important insights into the role of grain-scale processes in this environment. Using quantitative microstructural analysis, EBSD as well as microchemistry, they applied state of the art analytical techniques to achieve their aimed goals. The article is very well written and structured as well as excellently illustrated. Despite all these positive aspects, I have some major scientific points which are either not sufficiently presented or, in my opinion even wrongly interpreted, needing a careful re-examination during the revision of this manuscript.

Authors: First of all, we would like to thank Marco Herwegh for his detailed review and comments. Please, find our answers here after.

Reviewer: These points are: 1) One of the major goals of this manuscript seems the link between microfabric and crustal-scale interplate mechanics. For me the already at the microscale important gaps exist. Despite spreading bits and pieces of rheological terminology in a not very organized manner in results and discussion sections, a proper sequential description of arguments/hints on rheology at the different stages of microfabric evolution and a subsequent thorough discussion is currently missing. For example, already in the re- sults terminology like 'load-bearing framework' etc. is used. Here the authors need first to describe which parts of the polymineralic aggregates show brittle and which ductile processes (what they in parts do well) not going further at that stage. In the discussion, these findings have then to be revisited and thoroughly treated in a rheological point of view. Which are the mechanically weak phases, which ones are strong? Please use for this argumentation the microstructural criteria presented before. See next point.

Authors: The result and discussions sections have been thoroughly reworked to better describe, distinguish and discuss the different deformation mechanisms in the amphibolite. The term "load-bearing framework" has been removed.

Reviewer: 2) Currently the discussion dives right away into the deformation behavior of amphibole. This is a big step for a reader. Why not first revisiting the major aspects and goals, discussing then the general rheological aspects of the different aggregates and defining the rheological key players in the system? In this way, the authors could ideally set the scene for the subsequent treatment of the individual mineral phases.

Authors: An introduction of the discussion has been added summarizing the microstructures observed each individual phases and their potential explanations in terms of deformation mechanisms. This will allow the reader to better understand the influence of each phase on the overall mechanical behavior of the rock.

Reviewer: 3) My next concern is the way how the terms 'recrystallization' and 'dynamic recrystallization' are used or that the terms 'chemically-induced recrystallization' and 'nucleation of grains' (in the sense of precipitation out of a fluid) are missing. For readers experienced with these processes, which in my opinion all occur in the pre-

sented samples, the current use/not use of this terminology is somewhat confusing. Here a clear definition in the introduction on all these terms is mandatory. DYNAMIC RECYSTALLIZATION is always associated to deformation and MUST be related to reorganization of dislocation structures.

Authors: The terms "recrystallization" and "dynamic recrystallization" were both used to define recrystallization during intracrystalline deformation through reorganization of the dislocations in the crystal lattice. By opposite, the terms "precipitation" and "nucleation" was used to define chemically-driven crystallization (reaction product), either as new grains or as overgrowth rims on existing grains.

Reviewer: In case of cpx, the authors use undulose extinction apply this term to subgrain rotation and the formation of new recrystallized cpx gains in the mantle of cpx cores. These new CPX grains are surrounded by new amphibole grains clearly documenting a chemical reaction/mass transfer and not an individual dynamic recrystallization process. I am also wondering whether really subgrain rotation recrystallization is active or the grains either chemically nucleate completely new or present host cpx fragments disintegrated along cleavage planes and being then subject of rotational reorientations.

Authors: The core of clinopyroxene porphyroclasts shows undulose extinction but no subgrain formation. The small clinopyroxene grains in the wings present a quite variable grain size, which is unlikely to occur in a formation by dynamic recrystallization. New compositional maps have been therefore conducted to better constrain the origin of the small grains around clinopyroxene porphyroclasts. The results are in agreement with the reviewer's comment. They clearly evidence a formation through microfracturing of the host mineral (the porphyroclast rich in NaAl) associated with small grain rotations together with localized dissolution-precipitation of secondary clinopyroxene (poor in NaAl) and amphibole.

Reviewer: This new statement has been thoroughly described and discussed in the new version of the manuscript. Since EBSD data were made it should be easy to detect the grain refinement/nucleation process and to document this also in the manuscript. Also the changes in the Ti content in the amphiboles make me suspicious. Dynamic recrystallization per se cannot produce chemical changes. Here you need chemical driving forces such as chemically-driven recrystallization or chemically-driven grain boundary migration etc. I listed in the attached document a bunch of literature to this subject one can look at and cite. Last but not least the nucleation of new phases is a very important process. I have the impression that the current version of the manuscript does not highlight this point strong enough, since this process provides the fabric with new, unstrained, chemically equilibrated grains. See next point.

Authors: We do not suggest that amphibole dominantly accommodated the deformation in the dislocation creep regime. Rare amphibole show evidence for plastic deformation (undulose extinction mostly) but no spatial correlation have been observed with the chemical zonation. The Ti zonation in amphibole rather documents dissolution precipitation process localized along grain boundaries and microfractures.

Reviewer: 4) The authors claim that pinning in the polymineralic fabric keeps the grain size small. I attached some references hoping to help the readers to find relevant references with this respect. Please note that pinning alone cannot keep a grain size small in nature since coupled grain coarsening would led the grains grow. In a dynamic system, such as present in the metamorphic sole of Oman, the presence of grain boundary sliding requests the formation of cavities at grain triple junctions to maintain strain compatibility. Such dilatational domains either are filled by growing neighbor grain (dissolution- precipitation) or new phases nucleate (note both processes are chemically driven, this is why the discriminations/definitions made above are so important). With the nucleation of new grains a steady supply of small grains helps to keep the average grain size small and supports the pinning behavior efficiently.

Authors: The pinning effect has been removed from the new version of the manuscript.

Reviewer: 5) Transition from diffusion creep to dislocation creep towards lower temperature: dislocation creep is a deformation mechanism in monomineralic materials undergoing crystal plastic deformation. Hence a fabric needs subgrain (low angle) or grain boundaries (high angle) to be able to accommodate for such creep processes and recover them. If I interpret the microstructures and given statements correctly, there exist nothing in the present samples such as monomineralic layers but they are all polymineralic. Hence you would need interface boundaries between grains to be able to recover dislocations, which in my opinion makes no sense. Hence, dislocation creep cannot be the dominant deformation mechanism in such a polymineralic aggregate. The only statement that can be made is that within a mineral phase, dislocation creep may become more important. This does not mean that the bulk aggregate is deforming by dislocation creep as a whole.

Authors: The activation of the dislocation creep regime towards lower temperature was essentially related to the high degree of retrogression leading to the crystallization of monomineralic aggregates of plagioclase (sample SE13-76). However, the intense plagioclase serecitization did not allow us to correctly quantify the microstructures and crystal orientations in plagioclase. We have therefore decided to moderate our interpretation on the transition from diffusion creep to dislocation creep in the new version of the manuscript.

Reviewer: 6) Last but not least, the attached PDF contains a list of further suggestions/corrections as well as few suggestions for adaptations in figures.

Authors: Suggestions and corrections have been taken into account.

Reviewer: I hope these comments help during the revision. With kind regards Marco Herwegh Please also note the supplement to this comment: https://www.solid-earth-discuss.net/se-2019-28/se-2019-28-RC2-supplement.pdf Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2019-28, 2019.

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