CC BY

Phase mixing induced by granular fluid pump during mantle strain localization

Jacques Précigout[1], Cécile Prigent[2], Laurie Palasse[3] and Anthony Pochon[1]

[1]Institut des Sciences de la Terre d'Orléans (ISTO), Université d'Orléans, UMR-CNRS 7327, Orléans, France [2]Institut des Sciences de la Terre de Grenoble (ISTerre), Université Joseph Fourier, UMR-CNRS 5275, Grenoble, France [3]Bruker Nano GmbH, Am Studio 2D, Berlin, Germany

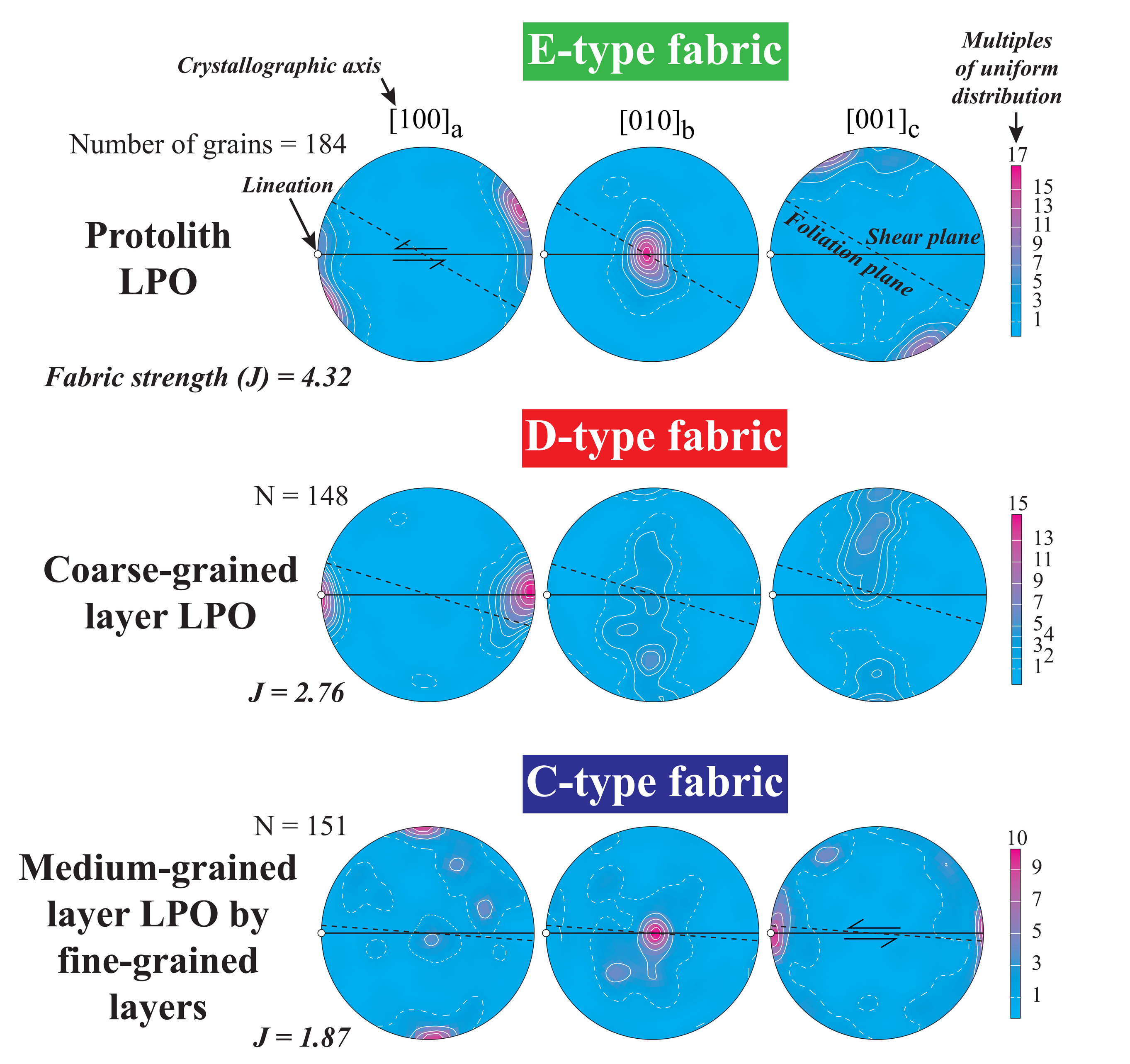
Corresponding email: jacques.precigout@univ-orleans.fr

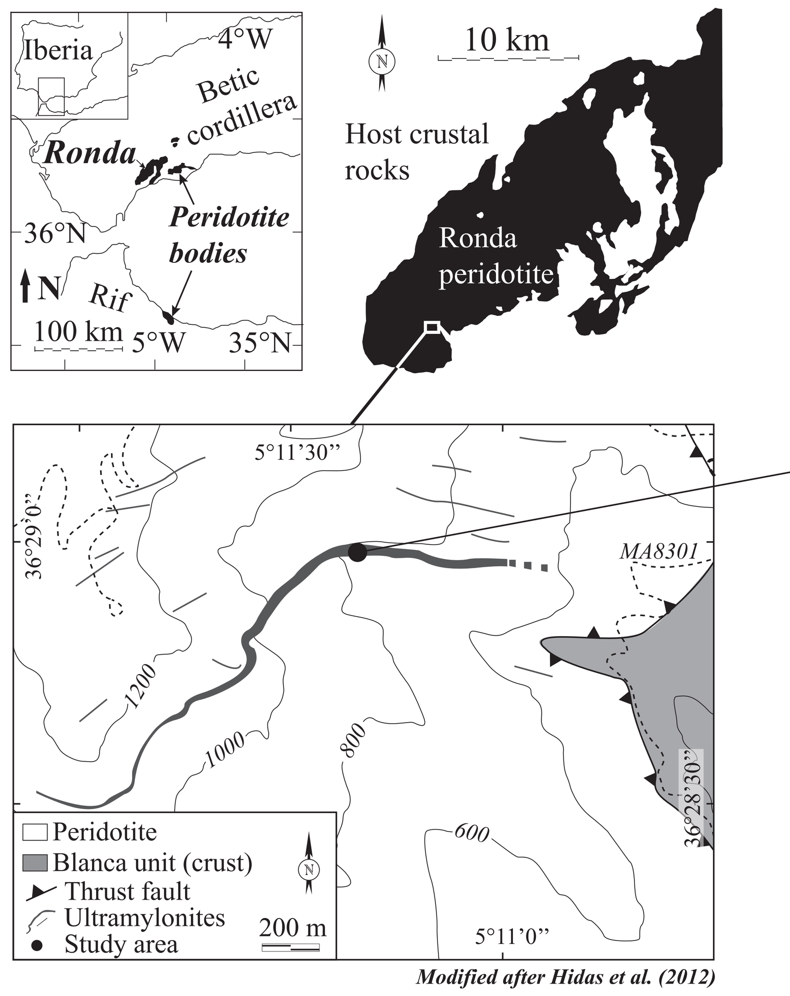
Introduction

As mantle rocks flow, strain may localize in response to rheological processes that give rise to mantle shear zone where high-strain deformation and substantial grain size reduction commonly occur (Boullier and Gueguen, 1975; Drury et al., 1991; Warren and Hirth, 2006). Mantle viscous strain localization is often attributed to phase mixing that would enhance grain-size-sensitive granular flow - mostly controlled by Grain Boundary Sliding (GBS) - through grain boundary pinning (Warren and Hirth, 2006). However, recent data show that GBS alone cannot end-up with randomly mixed phases (Hiraga et al., 2013), questioning the nature of mantle ductile strain localization. Here we show microprobe analyses, coupled EDX/EBSD mapping and olivine Lattice Preferred Orientation (LPO) accross a shear zone of peridotite in the Ronda massif (Spain). We highlight syn-tectonic water draining towards fine-grained layers where both GBS and phase mixing occur. Our results suggest that water converges as a result of GBS-induced creep cavitation during strain localization, promoting phase mixing through dissolution/precipitation of secondary phases in newly formed cavities. This process provides a key for the relationships between GBS and phase mixing, and hence, for the origin of viscous strain localization in the mantle.

3 Olivine fabric geometry across the shear zone

EBSD-based Lattice Preferred Orientation (LPO)





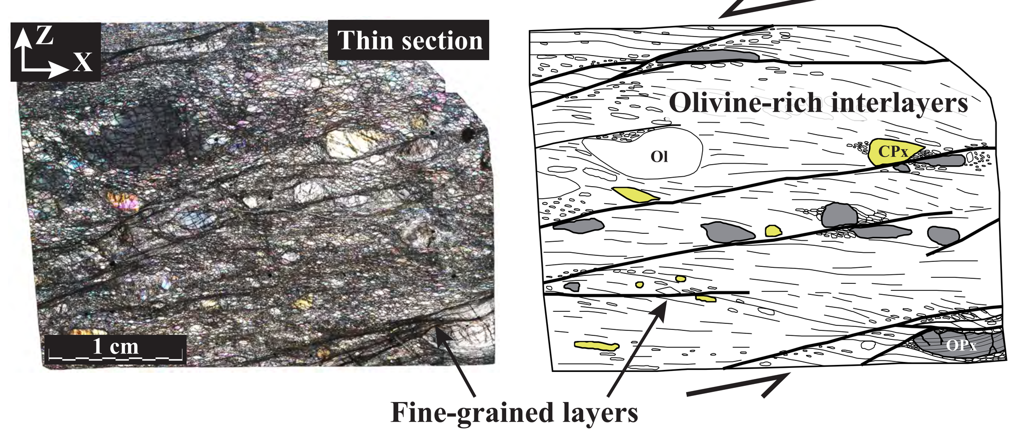
Modified after Hidas et al. (2012)

1 Peridotite shear zone in the Ronda massif (Spain)

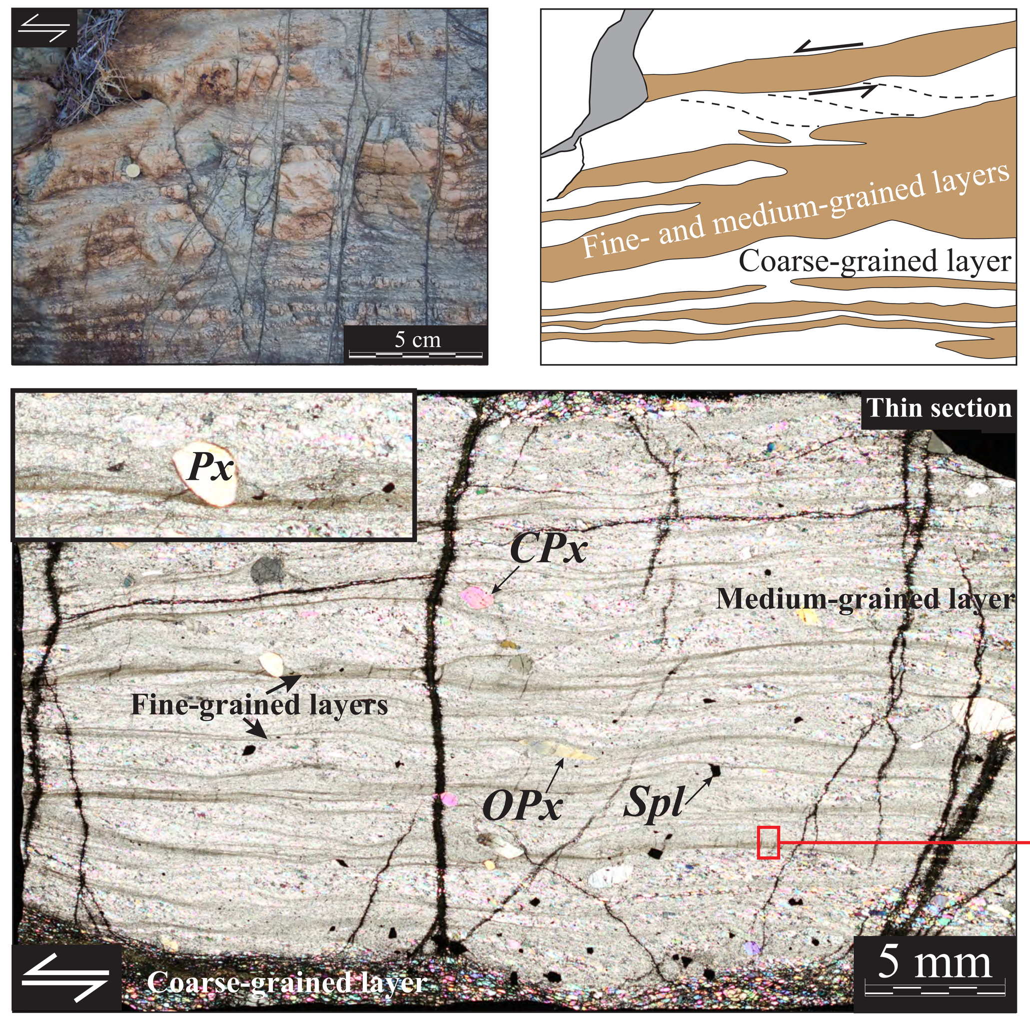
Pressure = from 10 to 5 kbar

Temperature = from 1000 to 700°C

2 Transitional protolith



4 Layering of the peridotite ultramylonite

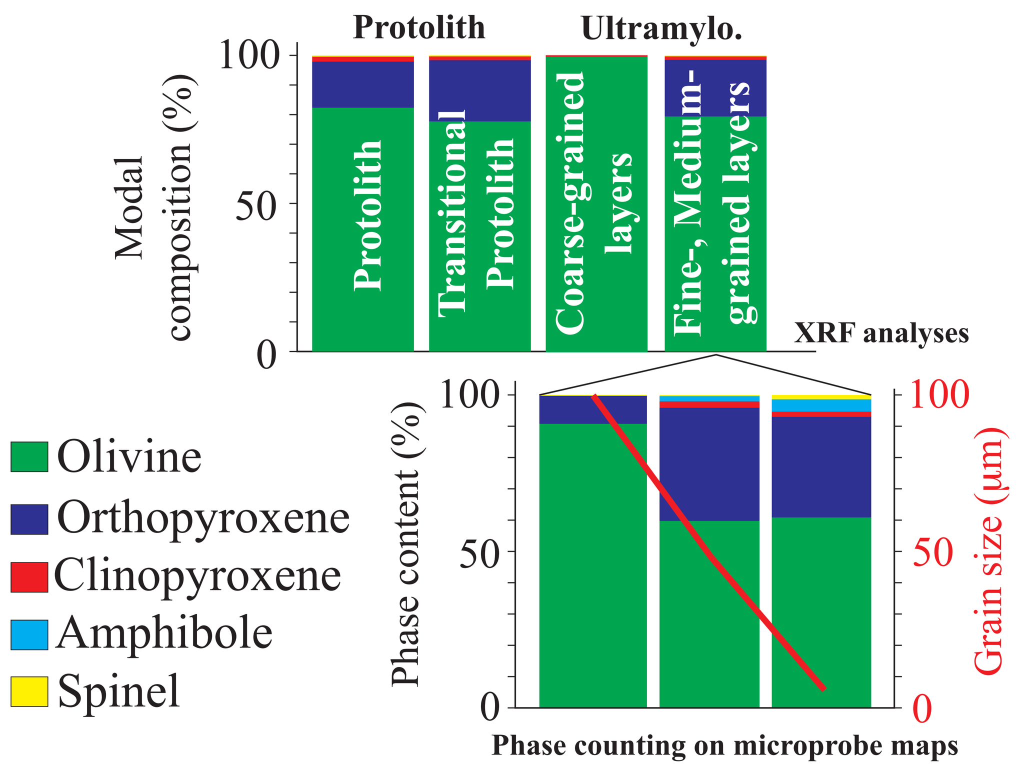


Results summary

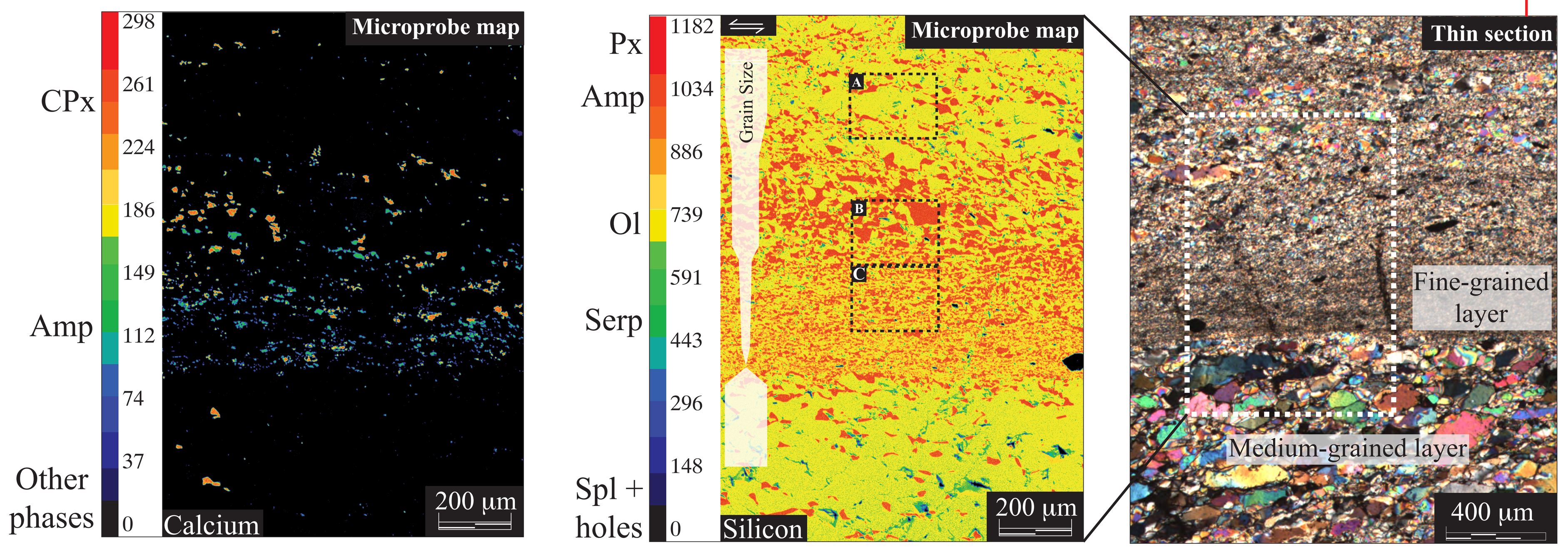
Strain localization affects a spinel-bearing olivine-rich harzburgite in the southwestern Ronda peridotite 1. It occurred during decompression and cooling from 10 to 5 kbar and from at least 1000°C to 700°C, respectively (Hidas et al., 2012). Both the protolith and ultramylonite have similar compositions; no metamorphic reactions are observed, although appearing of plagioclase after spinel have been described in near pyroxenite layers (Hidas et al., 2013). The shear zone shows a progressive transition from the protolith to ultramylonite, giving rise to a transitional protolith where fine-grained layers develop along pyroxenes porphyroclasts 2. Excepted for these fine-grained layers that show near random LPO, both the protolith and transitional protolith develop E-type olivine fabric 3, typical of plastic deformation in conditions of moderate water content (Katayama et al., 2004).

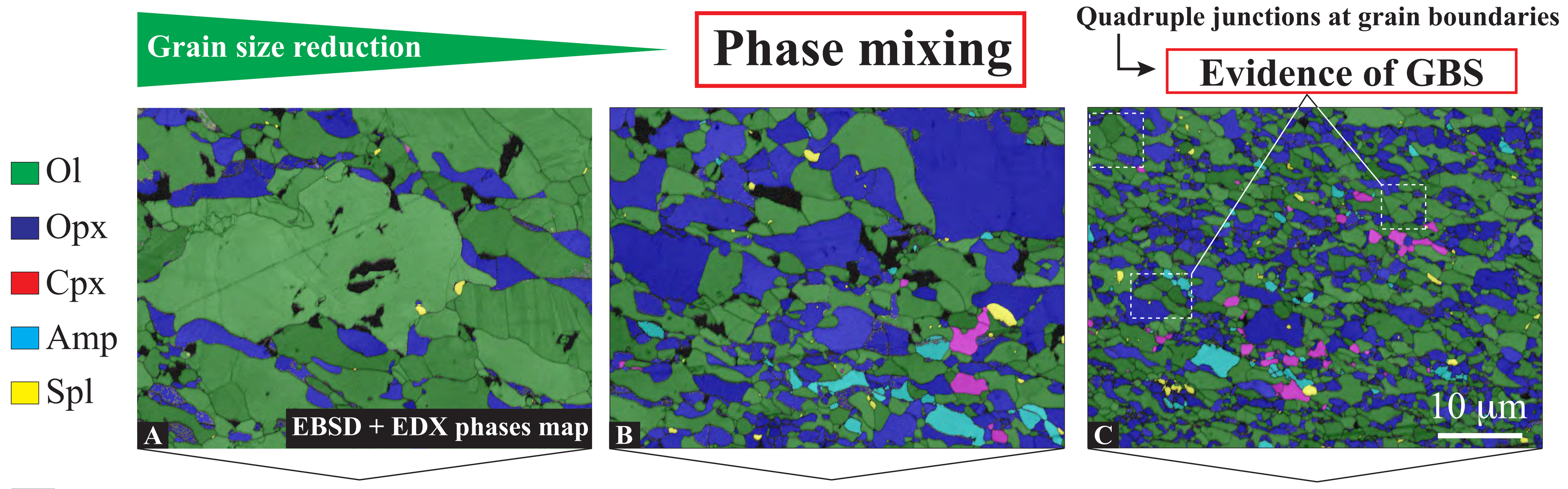
In contrast to the protolith, the ultramylonite shows a strain-related layering of coarse-grained and medium-grained layers, where bands of very fine grains occur 4. While olivine of the coarse-grained layers have a dunitic composition 5 and develop D-type fabric 3, which is typical of anhydrous olivine (Bystricky et al., 2000), the medium-grained layers show overall E-type fabric, but also C-type fabric 3 in some areas nearby fine-grained layers. This latter is typical of water-rich conditions (Katayama et al., 2004). Futhermore, microprobe analyses and coupled EBSD/EDX mapping in fine-grained layers reveal 1/ a substantial increase in pyroxenes content (enrichment in Silicon and Calcium), and 2/ the presence of amphiboles where grain size is the smallest 6. A perfect phase mixing occurs in these layers. Finally, observations of quadruple junctions at grain boundaries and a randomization of the olivine fabric with grain size reduction both indicate an enhancing of GBS-controlled granular flow at the expense of plastic flow in fine-grained layers 7 (Warren and Hirth, 2006; Précigout and Hirth, 2014).

5 Modal compositions

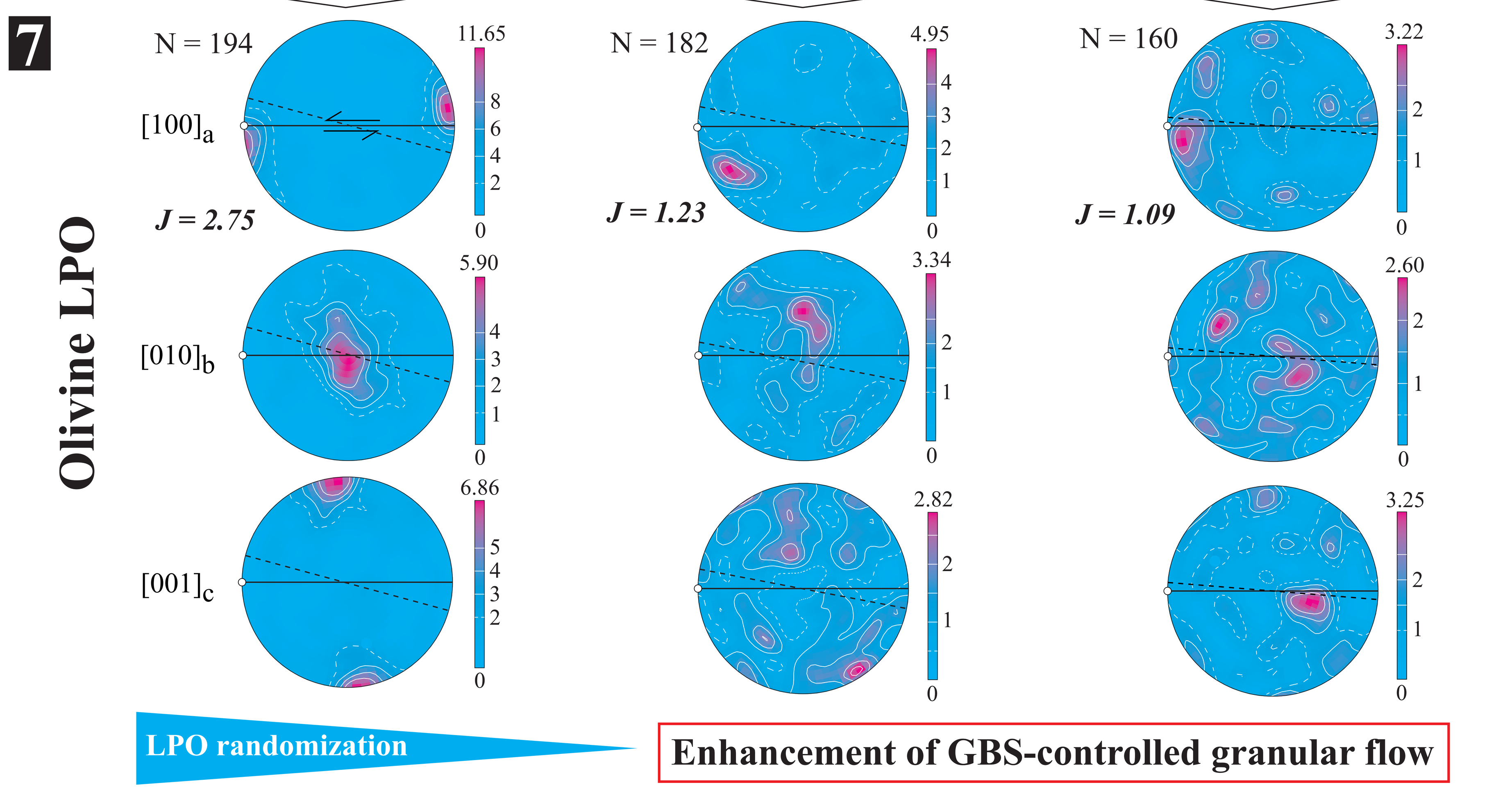


6 Elements/Phases distribution in fine-grained layers



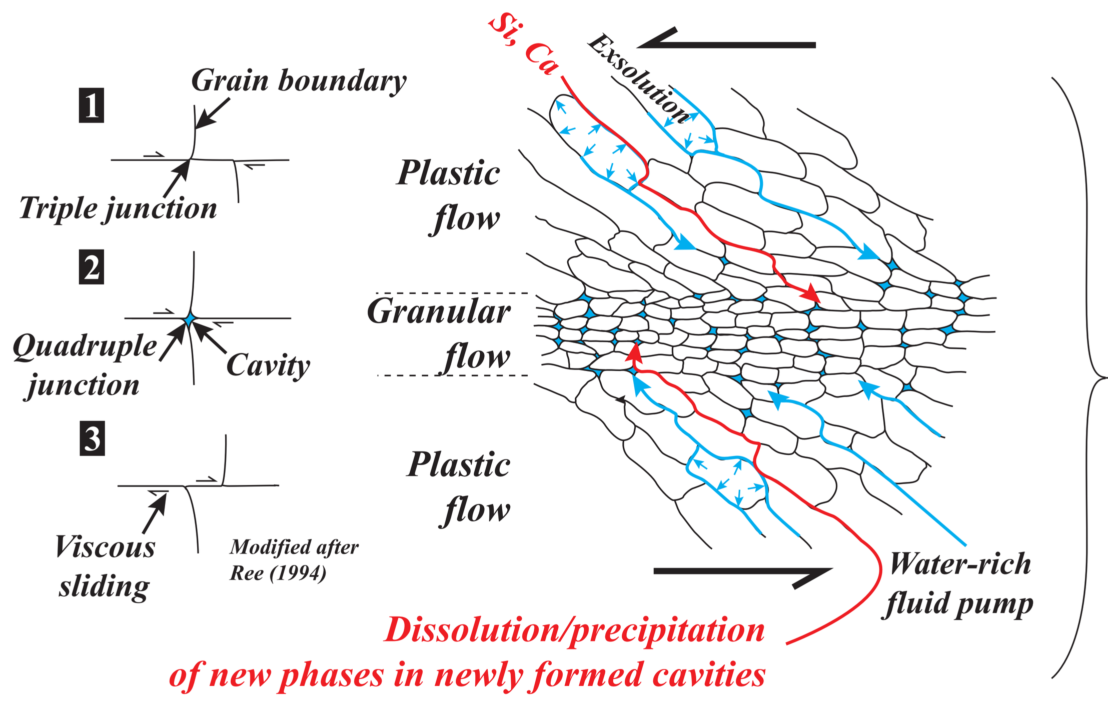


7

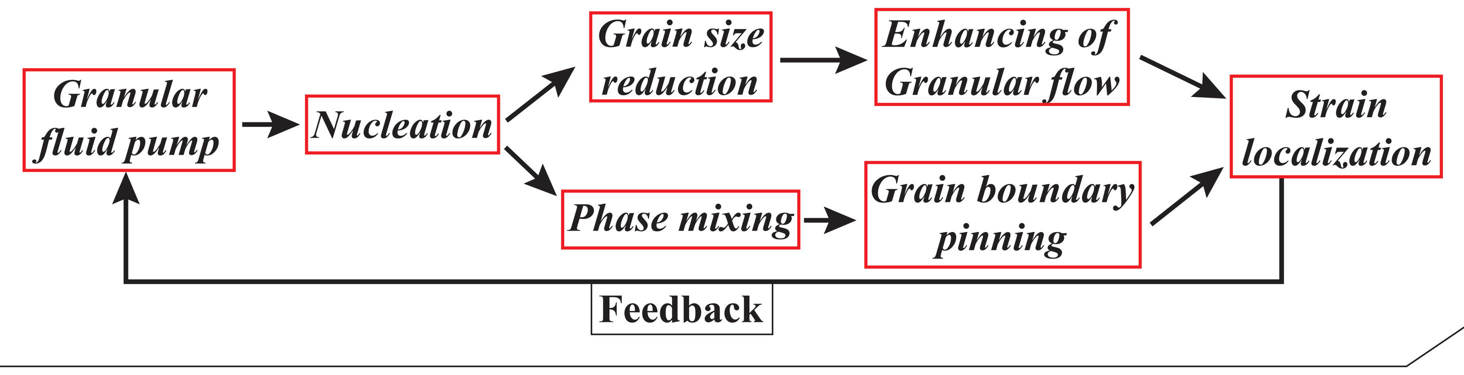


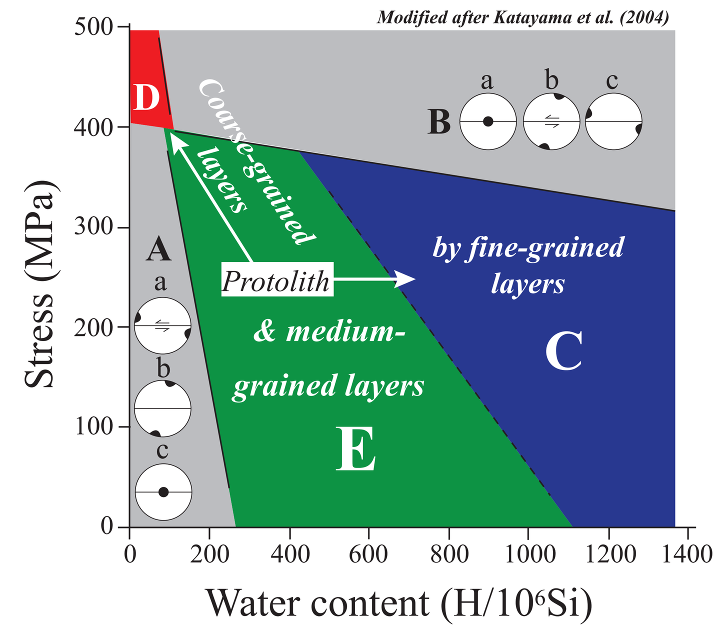
Discussion: evidences of granular fluid pump in a mantle shear zone

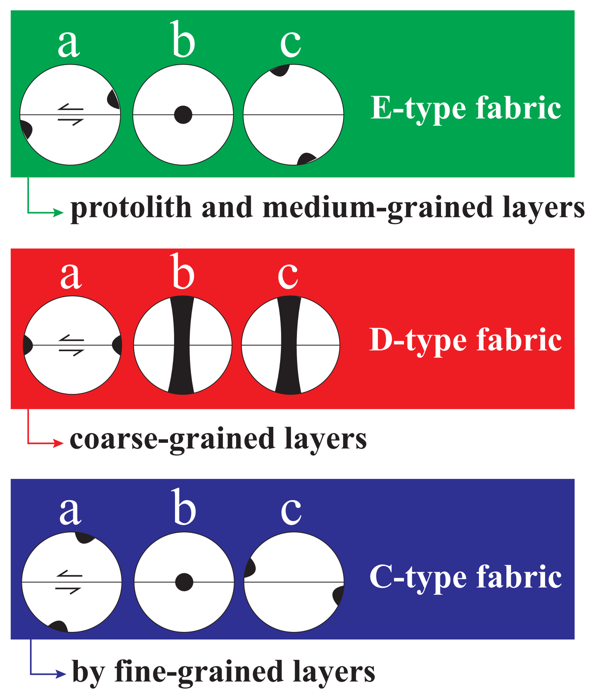
Creep cavitation induced by granular flow: a key for...



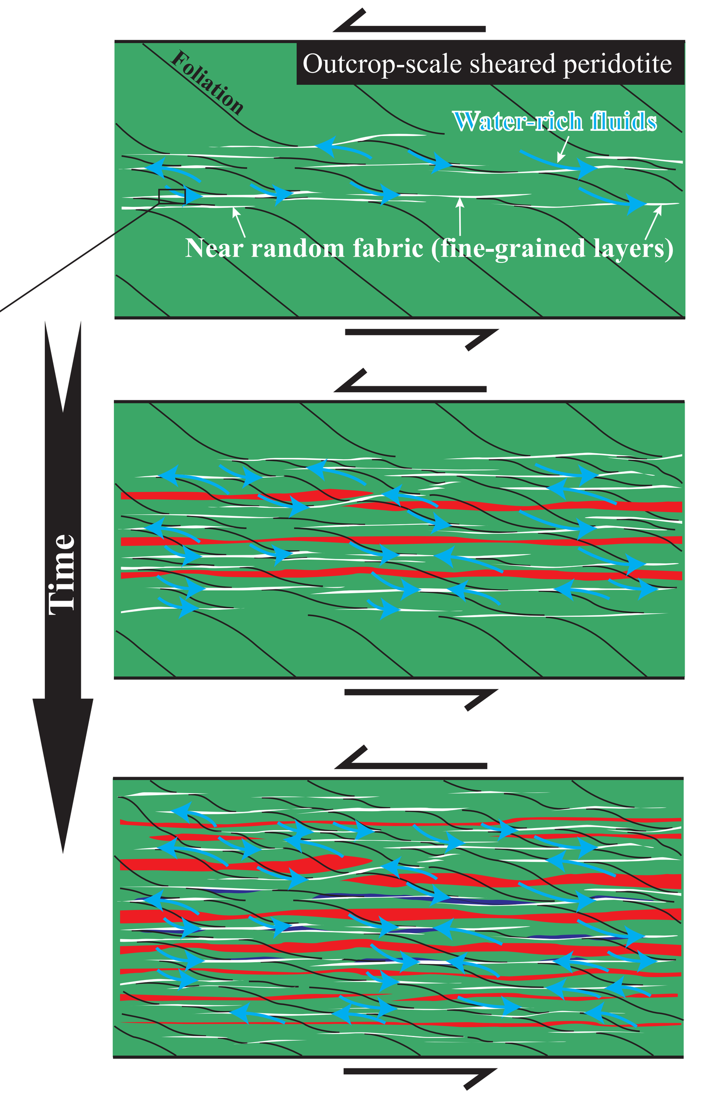
... 1/ GBS-related phase mixing and strain localization,...







...and 2/ strain-induced layering at outcrop scale



Conclusion

Our findings highlight - for the first time in a mantle shear zone - the occurrence of granular fluid pump that results from creep cavitation in fine-grained layer. Through nucleation of new phases in creeping cavities, this strain-induced process provides a key for strain localization promoted by phase mixing and grain boundary pinning, both required to enhance granular flow and subsequent strain weakening. This process also accounts for 1/ the intimate relationship between phase mixing and grain boundary sliding, and 2/ the strain-induced layering in the ultramylonite. We stress however that natural documentations of granular fluid pump only concerned so far shear zones developed at a maximum pressure/depth of 10 kbar/30 km (Geraud et al., 1995; Fusseis et al., 2009; this study), whereas water circulation occurs at depth a way higher than 30 km. At these great depths, we have no clue whether strain capacities are still enough to overcome pressure and generate GBS-induced micro-cavities. We therefore conclude with the following issue, potential object of future investigations: what is the depth/pressure threshold of mantle granular fluid pump?

References:

Boullier, A.M., and Gueguen, Y. (1975) SP-Mylonites: Origin of Some Mylonites by Superplastic Flow. Contribution to Mineralogy and Petrology 50: 93-104.
Bystricky, M., Kunze, K., Burlini, L., et al. (2000) High Shear Strain of Olivine Aggregates: Rheological and Seismic Consequences. Science 290: 1564-1567.
Drury, M.R., Vissers, R.L.M., Van der Wal, D., et al. (1991) Shear Localisation in Upper Mantle Peridotites. PAGEOPH 137, 439-460.
Fusseis, F., Regenauer, K., Liu, J., et al. (2009) Creep cavitation can establish a dynamic granular fluid pump in ductile shear zones. Nature 459: 974-977.
Géraud, Y., Caron, J.-M., and Faure, P. (1995) Porosity network of a ductile shear zone. Journal of Structural Geology 17: 1757-1769.
Hidas, K., Booth-Rea, G., Garrido, C.J., et al. (2012) Backarc basin inversion and subcontinental mantle emplacement in the crust: kilometre-scale folding and shearing at the base of the proto-Alboran lithospheric mantle (Betic Cordillera, Southern Spain). Journal of Geological Society, London 170, 47-55.
Hidas, K., Garrido, C.J., Tommasi, A., et al. (2013) Strain Localization in Pyroxenite by Reaction-Enhanced Softening in the Shallow Subcontinental Lithospheric Mantle. Journal of Petrology 54: 1997-2031.
Hiraga, T., Miyazaki, T., Yoshida, H., et al. (2013) Comparison of microstructures in superplatically deformed synthetic materials and natural mylonites: Mineral aggregation via grain boundary sliding. Geology 41: 959-962.
Katayama, I., Jung, H., and Karato, S.-I. (2004) New type of olivine fabric from deformation experiments at modest water content and low stress. Geology 32: 1045-1048.
Précigout, J., and Hirth, G. (2014) B-type olivine fabric induced by Grain Boundary Sliding. EPSL 395: 231-240.
Ree, J.-H. (1994) Grain boundary sliding and development of grain boundary openings in experimentally deformed octachloropropane. Journal of Structural Geology 16: 403-418.
Warren, J.M., and Hirth, G. (2006) Grain size sensitive deformation mechanisms in naturally deformed peridotites. EPSL 248: 438-450.