# Deformation of Dry High-pressure Eclogites During Tectonic Slicing of Subducted Oceanic Lithosphere: a Case Study From the Monviso Ophiolite, Italy

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## 1. INTRODUCTION

Exhumed high-pressure (HP) ophiolite bodies are key to understanding important geodynamics processes occurring along the plate-interface within subduction zones, yet the nature of their detachment and recovery is not well-understood. For example, HP ophiolites from some localities typically exhibit a mélange (or mixed block-in-matrix) structure, while other Alpine ophiolites represent complete oceanic lithospheric sections that remained coherent during subduction and exhumation. Thus, Alpine ophiolites present a different model for heterogeneous deformation in subduction zone settings: strain must be highly localized along discrete shear zones (slicing) rather than widely distributed within the plate-interface (mélange).

### Research Questions:

- How is strain localized in subducting oceanic lithosphere (discrete or distributed)?
- Why is there evidence for brittle vs. viscous deformation in different rock types?
- Does the juxtaposition of low-strain and high-strain rocks give us any clues into the nature of detachment of HP ophiolites in subduction zones (i.e., how do these observations relate to strain localization)?

### Hypotheses:

- Strain is localized within certain weak lithologies and progressively widens into distributed shear zones over a few Ma (Locatelli et al., 2018; Broadwell et al., 2019).
- Low-strain rocks can escape deformation by remaining embedded within relatively strong (dry) rocks until major fluid ingress progressively weakens permeable rocks within shear zones (Locatelli et al., 2018; Broadwell et al., 2019).

## 2. GEOLOGIC SETTING

The Monviso ophiolite is part of a 350 km belt of metamorphosed (ultra)mafic and sedimentary rocks that extend across the western Alps from Italy to Switzerland (dark green and light blue units shown in Figure 1; Locatelli et al., 2019). These rocks are interpreted as the exhumed remnants of oceanic lithosphere and seafloor sediments that were subducted beneath the African continental margin beginning in the Cretaceous (Angiboust et al., 2012). Previous studies suggested that the Monviso ophiolite formed as a deep subduction mélange, where large blocks and slivers of oceanic lithosphere were exhumed in a serpentine-rich channel along the plate interface (Lombardo 1978). However, more recent studies interpret the Monviso ophiolite as a structurally-coherent section of oceanic lithosphere that was sliced off the subducting plate at eclogite-facies conditions (~80 km depth) and exhumed with only minor modification—evident by consistent PT estimates across all subunits within the Monviso ophiolite (Angiboust et al., 2011, 2012; Locatelli et al, 2019). Thus, the Monviso ophiolite presents a unique opportunity to understand important aspects of plate-interface mechanics in subduction zones, including the extent of strain localization (discrete vs. broad) and deep seismic cycles.

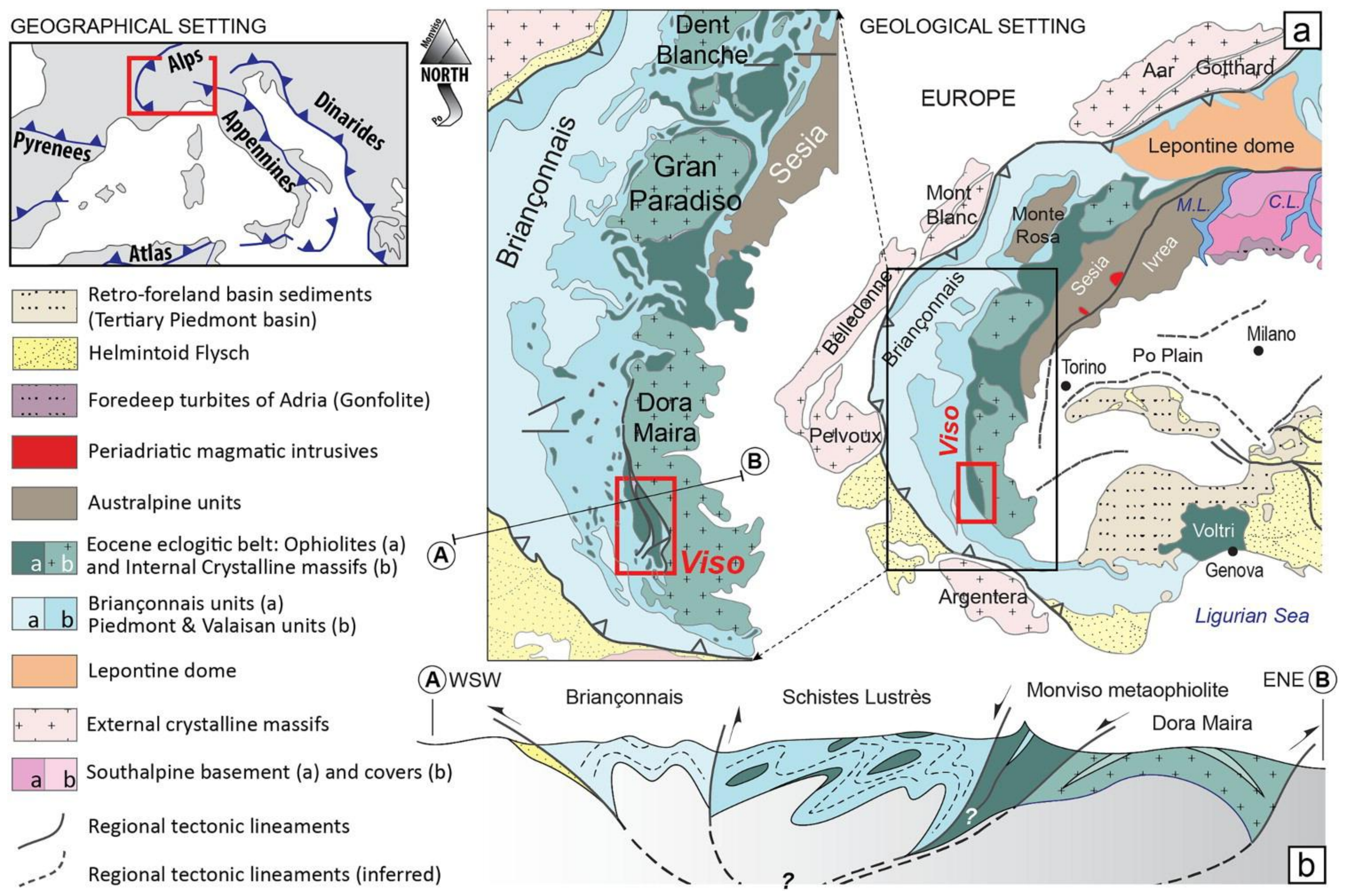


*Figure 1.* *(a) Generalized map showing the spatial distribution of sedimentary (light blues) and mafic/ultramafic (dark greens) units in the western Alps. (b) Simplified cross-section showing the major structures and tectono-metamorphic units across the Alps. From Locatelli et al. (2019).*

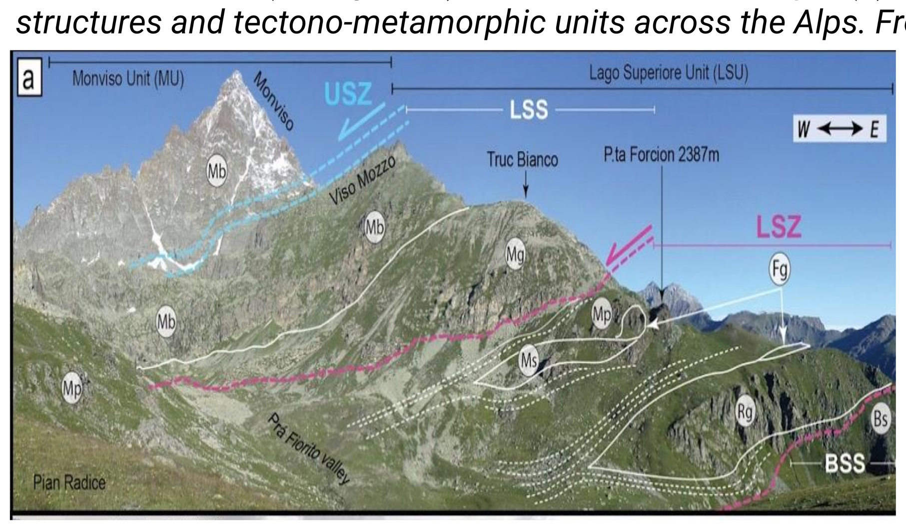


*Figure 2.* *Panoramic view of the Monviso ophiolite showing the major structures and lithologic units. From top to bottom, the ophiolite consists of the Monviso Unit (MU), Lago Superiore Unit (LSU), and Basal Serpentinite Subunit (BSS) separated by the Upper Shear Zone (USZ) and Lower Shear Zone (LSZ), respectively. The LSU contains large blocks and slices of various lithologies in a serpentine-rich matrix. From Locatelli et al. (2019).*

## 3. FIELD OBSERVATIONS

Macro textures observed in the field show the variation in not only rock type but metamorphic processes that have occurred in the area. Brecciation in Figure 4. shows evidence of brittle deformation at HP conditions. The boudin in Figure 5. represents ductile deformation, in stark contrast to Figure 4.

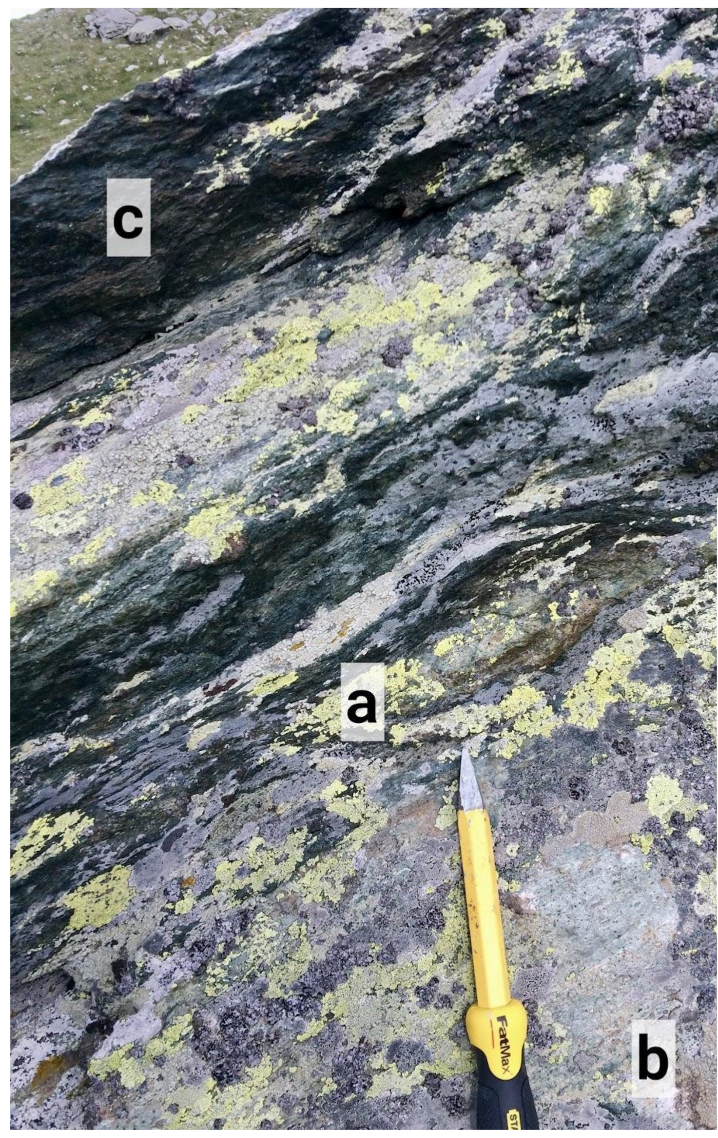


*Figure 3.* *Metagabbro block within the LSU of the Monviso ophiolite, Italy, showing heterogeneous lithology and viscous deformation. (a) Relatively undeformed Fe-Ti metagabbro boudin (center near tip of tool; low strain) between (b) foliated Mg-Al metagabbro (bottom, light pale green; moderate strain) and (c) a metasomatized rim (top, dark green; high strain). Other metagabbro blocks show brittle deformation features (see Figure 6).*

*Figure 4.* *Fe-Ti metagabbro block within the upper LSU of the Monviso ophiolite, Italy, showing brittle deformation fabrics. Brecciated garnet-omphacite-rutile metagabbro pieces are cemented within an omphacite-rich matrix, indicating that brittle deformation occurred at eclogite-facies conditions (~80 km depth). These features are interpreted as evidence for seismic cycles and/or (de)hydration-related embrittlement facilitating deep slicing of oceanic lithosphere along the plate interface in subduction zones (e.g., Locatelli et al., 2018).*

## 4. METHODS

M17-K808D01 was prepared into a doubly-polished thick section (100 µm; Figure 3). Metamorphic mineral assemblages and textures were analyzed using optical microscopy. Micro-textures and chemical compositions were analyzed by collecting high-resolution backscatter electron maps (3072×2304) and semi-quantitative chemical maps (1024x786) with a Zeiss Supra 35 VP FEG SEM equipped with a Bruker Quantax 100 Energy Dispersive x-ray microanalysis system (EDS) at the Center for Advanced Microscopy and Imaging (CAMI), Miami University.

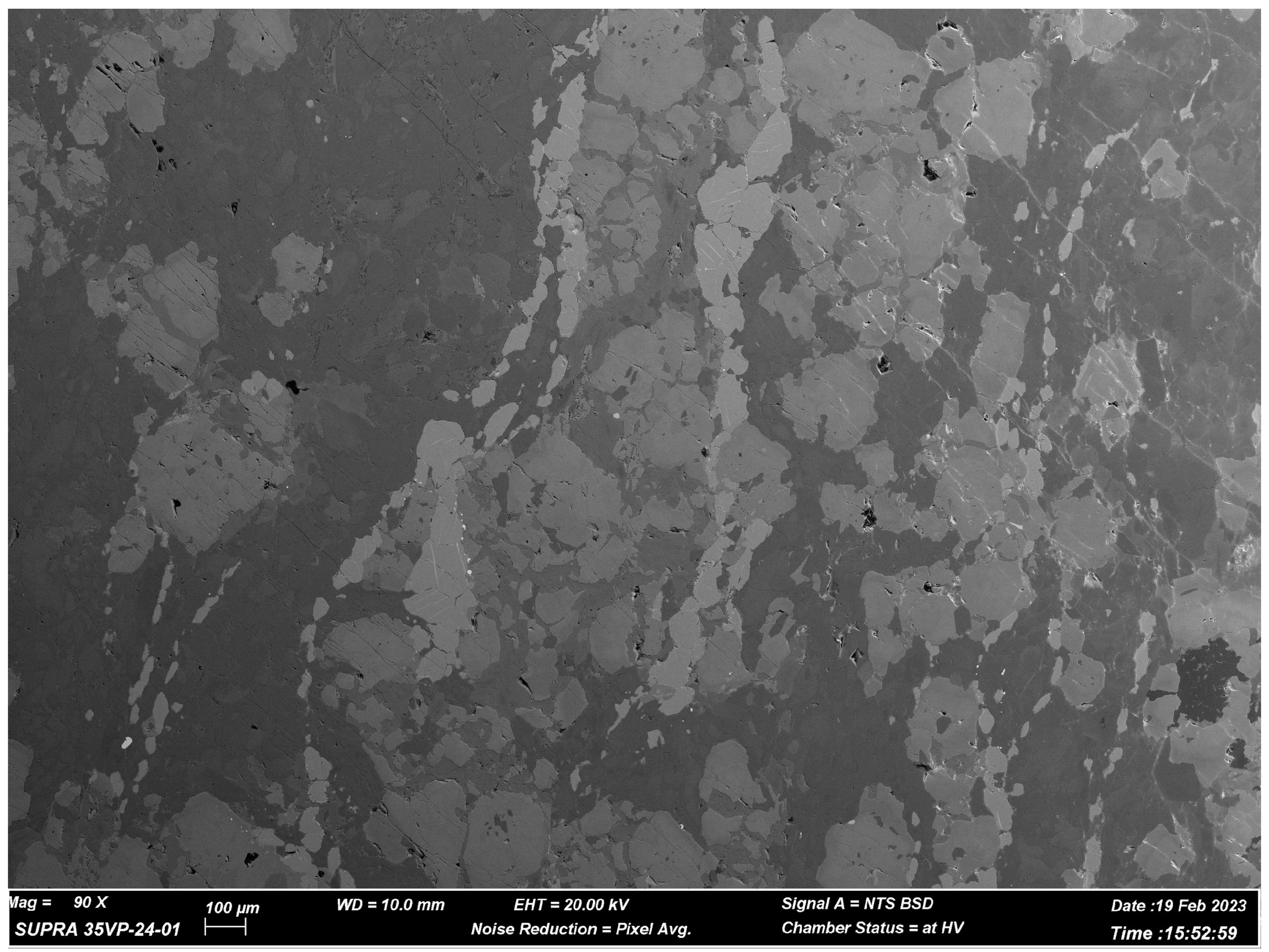


*Figure 5.* *SEM analysis of sample M17-K808D01 showing microtextures of rutile, garnet and omphacite. Rutile grains are the lightest grey, garnet is intermediate grey, and omphacite is the darkest grey.*

## 5. OPTICAL PETROGRAPHY

Figure 4 is a sample of a thin section taken from a serpentinite schist found within the LSZ. It is made up of hydrous phases and shows clear signs of deformation. This is in stark contrast to Figure 5, which was sampled from an eclogite block meters away from within the same unit. It is composed of garnet + omphacite + rutile, all of which are anhydrous phases formed at high pressure.

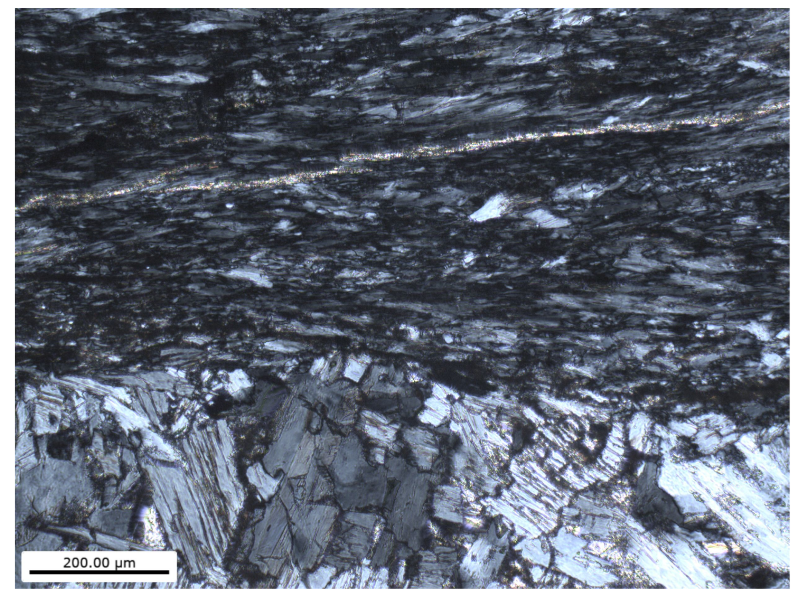


*Figure 6.* *A section of a thin section of a LSZ serpentinite schist under crossed polarized light (XPL). The small grain sizes, strong foliated fabric and irregular grain boundaries are evidence for dynamic recrystallization in a wet, high-strain shear zone. Sample M17-K809F01 Monviso ophiolite.*

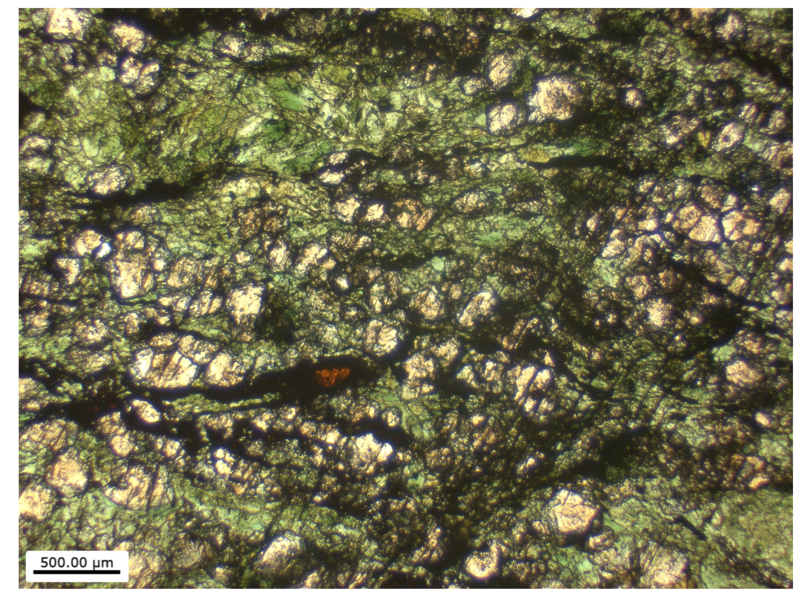


*Figure 7.* *A section of a thin section of an LSZ eclogite under plane-polarized light (PPL). The relatively defined and observable grain boundaries along with the primary magmatic textures shown are evidence of an undeformed and non-strained rock. Sample M17-K808D01 Monviso ophiolite.*

## 6. DISCUSSION AND CONCLUSIONS

### Textural Analysis:

While the rutile textures found in sample D01 appear to indicate a weak foliation fabric formed within the rock during deformation at HP conditions, the omphacite grains show little to no signs of dynamic recrystallization (elongated grains and/or irregular grain boundaries) or foliation (preferred orientations of minerals). This suggests that the rutile grew interstitially under relatively dry and static conditions—reflecting the rocks primary magmatic texture. In contrast to the static textures observed in sample D01, sample F01, a serpentinite taken from the same unit of the LSZ, has an ultramylonitic texture with a well-defined foliation fabric of hydrous minerals. Thus, sample F01 indicates dynamic recrystallization in the presence of free fluids during shearing.

### Brittle vs. Viscous Deformation:

Optical and SEM images of sample D01, an eclogite with a durable and strong (dry) lithology, show no noticeable features of viscous deformation (e.g., foliation fabrics, irregular grain boundaries, and/or shear sense indicators). On a macro level, we see varying textures throughout the LSZ including the brecciated garnet-omphacite-rutile metagabbro shown in Figure 4. While breccias including HP mineral assemblages can be interpreted as forming at shallow conditions (e.g., sedimentary breccias formed at the seafloor) that are later recrystallized at HP conditions, Figure 4 shows breccia clasts embedded in an omphacite-rich matrix, which suggests that this breccia formed at HP conditions. Brittle deformation commonly occurs at much shallower depths (20-40 km), whereas the mineralogy of Figure 4 indicates that brittle deformation must have occurred at 80 km or more. Failure analysis of similar eclogitic rock types demonstrates that it is possible to brittlely fracture rocks at 80 km depths if the pore fluid pressure is close to lithostatic (0.8–1; Broadwell et al., 2019). It is therefore plausible that sudden dehydration of hydrous phases (chlorite, lawsonite, brucite, and/or serpentinite) during eclogitization could indeed result in brittle deformation, even under high confining pressures at 80 km depth

## 7. REFERENCES

- Agard, P., Plunder, A., Angiboust, S., Bonnet, G., & Ruh, J. (2018). The subduction plate interface: Rock record and mechanical coupling (from long to short timescales). Lithos, 320, 537-566.
- Locatelli, M., Verlaguet, A., Agard, P., Pettke, T., & Federico, L. (2019). Fluid pulses during stepwise brecciation at intermediate subduction depths (Monviso eclogites, W. Alps): First internally then externally sourced. Geochemistry, geophysics, geosystems, 20(11), 5285-5318.
- Locatelli, M., Verlaguet, A., Agard, P., Federico, L., & Angiboust, S. (2018). Intermediate-depth brecciation along the subduction plate interface (Monviso eclogite, W. Alps). Lithos, 320, 378-402.
- Lombardo, B. (1978). Osservazioni preliminari sulle ofioliti metamorfiche del Monviso (Alpi Occidentali).
- Angiboust, S., Agard, P., Raimbourg, H., Yamato, P., & Huet, B. (2011). Subduction interface processes recorded by eclogite-facies shear zones (Monviso, W. Alps). Lithos, 127(1-2), 222-238.
- Angiboust, S., Langdon, R., Agard, P., Waters, D., & Chopin, C. (2012). Eclogitization of the Monviso ophiolite (W. Alps) and implications on subduction dynamics. Journal of Metamorphic Geology, 30(1), 37-61.
- Kirkland S. Broadwell, M. L. (2019). Transient and periodic brittle deformation of eclogites during intermediate-depth subduction. *Earth and Planetary Science Letters*, 91-102

## 8. ACKNOWLEDGEMENTS

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