Deformation mechanisms at intermediate depths in subduction zones: the rock record of earthquakes and slow-earthquakes

(Proposer: Prof. Giorgio Pennacchioni)

Subduction zones host, at depth, different deformation processes that result in earthquakes s.s. and slow earthquakes. The location of these processes in the subduction system is well imaged by modern seismological and geodetic datasets, but the deformation processes responsible for either earthquakes or slow earthquakes is still enigmatic and debated. The recognition of these processes is crucial for understanding how plate motion is accommodated at these major plate boundaries.

Intermediate-depth earthquakes are distributed in a double-seismic zone (upper and lower planes of seismicity at the plate interface and within the plate, respectively). This seismicity has been suggested to occur as result of either dehydration embrittlement due to fluid release associated with breakdown of hydrous minerals or, especially in the case of the lower subduction plane, to brittle failure of dry peridotite (but still affected by local hydration). Subduction of oceanic sediments and altered crust, and especially of serpentinized mantle peridotites (from fluid-rock interaction in at low spreading ridges and during plate bending at the trench), play a major role in triggering dehydration embrittlement during fluid release.

Deep slow earthquakes are located downdip of the locked portion of the seismogenic subduction interface, capable of hosting regular earthquakes of up to M > 9, over a depth range of 25-60 km. Reconstruction of the p-T paths of present-day subducting plates indicates that slow earthquakes occur in a range of temperatures around 350-550 °C. As for earthquakes s.s., a critical role of fluids for triggering slow earthquakes is suggested from geophysical data that indicate low seismic velocities and Vp/Vs ratios for subduction domains hosting slow earthquakes. The presence of a compositional/rheological heterogeneity, inducing strong strain partitioning during bulk flow, have also been inferred as a potential context for slow slip deformations. This structural architecture may (i) allow coexistence of vein-sealed fracturing in low strain domains and shear flow in surrounding high strain domain, and (i) geometrically buffer the rate and amount of slip along the weaker matrix.

The stack of metamorphic units of the European collisional Alpine belt provides an ideal playground to study the deformation and fluid-rock processes occurring along the a subducting interface and responsible for the range of above-mentioned deformation behaviours: (i) the internal part of the stack includes exhumed tectonic units that experienced blueschist to eclogite facies metamorphism corresponding to the range of p-T conditions where either slow earthquakes or intermediate-depth earthquakes s.s. occur (Fig. 1 a); (ii) the Alpine high-pressure stack is formed by tectonic slices that mainly moved along the subduction interface; (iii) the oceanic plate was formed in a slow-spreading ridge context and therefore consists of thick, serpentinitized mantle peridotites at the top, that is now recorded by the extensively serpentinized bodies of the Alpine ophiolites; (iv) many of these tectonic units record the occurrence of conspicuous fluid migration during subduction metamorphism as evidenced by common networks of veins filled with high-pressure minerals (Fig. 1b); (v) most units include compositionally and rheologically heterogeneous domains at scales ranging from metre to kilometre scale that resulted in strong strain partitioning within the structural package.

The Ph.D candidate will study selected examples of exhumed deformation systems, that include extensive network of veins formed under blueschist to eclogite facies conditions, as potential record of earthquakes or deep slow slip events and slow earthquakes. Quantitative field mapping (photogrammetric 3D outcrop reconstruction from on-ground or UAV-assisted photographic survey) will aim at reconstructing the relationships and time sequence of the different structural elements with particular emphasis on (i) relationships between veins and shear layers with associated fault rocks; (ii) recognition of cyclicity in deformation and incremental slip/veining stages (e.g. crack-seal growth of vein fibres), and (iii) estimate of displacement associated with individual slip episodes and veining. Reconstructed structural maps will guide sampling of the different deformation elements for the lab analysis. This latter will include: (i) high-resolution microstructural/microchemical analysis with the Tescan Essence SEM-FIB system at the Dept. of Geosciences of the University of Padova equipped with multiple detectors (CL, SE, BSE, EBSD, EDS, WDS, STEM); (ii) petrological analysis to constrain the ambient conditions of deformation; (iii) *in-situ* trace element and isotopic analysis to discriminate the possible source of and paths fluids in the subduction zone.

The project will aim at:

(i) Finding proxies to discriminate between vein systems derived either from seismic faulting or deep slow earthquakes.

(ii) Understanding the scales, pathways and rates of fluid-assisted deformation within rheologically heterogeneous rock systems during loading at high-pressure subduction conditions and stress release stages.

The project will initiate with the study of the 2 ultramafic ophiolitic massifs of Voltri (Erro-Tobbio Unit) and Lanzo in the western Alps. The Erro-Tobbio Unit consists of large bodies of serpentinized meta-peridotites recording extensive dehydration during the prograde subduction path with extensive production of metamorphic olivine-Ti-clinohumite-antigorite reaction bands and veins (formed at ca. 500 °C and 1.5 GPa, i.e. within the field of slow earthquakes/slow slip and tremors: SST in Fig. 1a) that interact with coeval antigotite-bearing discrete shear zones. The Moncuni body of the Lanzo Massif consists of a kilometre-sized lens of pristine dry ophiolitic peridotite wrapped around by serpentine (antigorite) mylonite bearing metamorphic olivine and Ti-clinohumite formed by de-hydration during plate subduction. The metaperidotite exceptionally preserves abundant eclogite-facies pseudotachylytes (frictional melts produced during seismic fault slip) that record seismicity at intermediate subduction depth. Therefore, Moncuni represents an almost unique case to study the relationships between seismic fracturing and fluid-induced veining in the low strain, dry domains and surrounding ductile serpentinite, respectively.

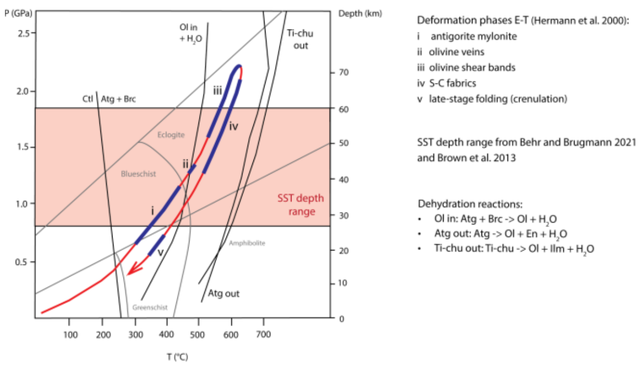

Fig. 1a: P-T path for the ophiolitic Erro-Tobbio Unit of the Voltri Massif (western Alps). The pink area represents the depth range estimated for the occurrence of slow earthquakes in present-day subduction zones.

Fig. 1b: Veins filled with omphacite within a boudin of eclogite wrapped by mylonitic schists

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