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Fossil intermediate-depth earthquakes in subducting slab mantle linked to differential stress release

Marco Scambelluri (1), Giorgio Pennacchioni (2), Mattia Gilio (3), Michel Bestmann (4), Oliver Plümper (5), and Fabrizio Nestola (6)

(1) University of Genova, Dipartimento di Scienze della Terra, Ambiente e Vita, Italy (marco.scambelluri@dipteris.unige.it), (2) University of Padova, Dipartimento di Geoscienze, Padova, Italy (giorgio.pennacchioni@unipd.it), (3) University of Pavia, Dipartimento di Scienze della Terra e dell'Ambiente, Pavia, Italy (mattia.gilio@unipv.it), (4) Friedrich-Alexander University of Erlangen-Nürnberg, GeoZentrum Nordbayern, Erlangen, Germany (michel.bestmann@fau.de), (5) Utrecht University, Department of Earth Sciences, Utrecht, The Netherlands (O.Plumper@uu.nl), (6) University of Padova, Dipartimento di Geoscienze, Padova, Italy (fabrizio.nestola@unipd.it)

Subduction-zone seismicity is caused by accumulation and release of stress from shallow levels down to intermediate depths (50-300 km). Intermediate-depth earthquakes are inaccessible to direct investigation: knowledge relies on seismic data, rock-deformation experiments and modelling, showing that the seismic activity concentrates either inside the subducting lithosphere, or in kilometres-thick hydrated layers along the plate interface. In comparison, field-based studies of exhumed high-pressure rocks have so far been under-utilised to directly study fossilized earthquake phenomena. The cause of intermediate-depth seismicity in subduction settings is uncertain, but is typically attributed either to rock embrittlement associated with fluid pressurization, or to thermal runaway instabilities.

Here we document the exceptional preservation of glass in pseudotachylyte (the product of frictional melting during co-seismic faulting) in oceanic gabbro-peridotite from the Lanzo ultramafic Massif (Western Alps). This rock suite is a fossil analogue to oceanic lithospheric mantle undergoing present-day subduction, and the pseudotachylyte formed under eclogite-facies conditions (60-70 km depth) during subduction (Scambelluri et al., 2017). Most part of the studied gabbro-peridotite is poorly hydrated to dry: the rocks show a high-temperature mantle-to-oceanic mylonitic foliation, but escaped crystal-plastic deformation (and largely metamorphism) during Alpine subduction and exhumation. The dry gabbro-peridotite section contains minor volumes (5vol%) of hydrated metaperidotite and metagabbro recording static, eclogite-facies metamorphism.

In dry, unaltered gabbros, pseudotachylytes preserve pristine glass including microlites of olivine, plagioclase, clinopyroxene and locally pyrope-rich garnet. Raman analysis establish that the glass is dry. Within peridotite pseudotachylyte did not preserve glass, but consists of a microcrystalline annealed groundmass and microlites. Pseudotachylytes cut through the eclogitized metagabbro and metaperidotite: delopment of cataclastic clinopyroxene cemented by omphacite and overgrowth of damage microfaults by eclogitic garnet indicate that pseudotachylytes developed under high-pressure conditions (550 °C, 2.1 GPa). These pseudotachylytes are therefore hosted in near anhydrous lithosphere free of coeval ductile deformation, which excludes an origin by dehydration embrittlement or thermal runaway processes. Our observations indicate that seismicity can be explained by the release of differential stresses accumulated in strong, dry, metastable rocks.

The survival of glass and the absence of subduction-related ductile deformation demonstrate the dramatic control of aqueous fluids over the kinetics of metamorphic reactions and rheology. The development of mantle and oceanic high-temperature foliations (ca. 800 °C) indicate a temperature threshold for crystal-plastic deformation to occur in these dry rocks, consistently with the temperature cut-off for both the oceanic environment and intermediate depth seismicity in subducting plates. These rocks represent a proxy for the rheological behaviour of a subducting dry oceanic lithosphere, which is rarely exposed in exhumed orogenic accretionary wedges that mainly incorporate material from the fluid-rich subduction channel.