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Brittle deformation during Alpine basal accretion and the origin of seismicity nests above the subduction interface

Armel Menant[a], Samuel Angiboust[a,*], Patrick Monié[b], Onno Oncken[c], Jean-Michel Guigner[d]

[a] Institut de Physique du Globe de Paris, Sorbonne Paris Cité, Univ. Paris Diderot, CNRS, F-75005 Paris, France
[b] Géosciences Montpellier UMR-CNRS 5243, Place E. Bataillon, 34090 Montpellier, France
[c] GFZ German Research Center for Geosciences, D-14473 Potsdam, Germany
[d] Sorbonne Universités – Institut de Minéralogie, de Physique des Matériaux et de Cosmochimie, 75005 Paris, France

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ABSTRACT

Geophysical observations on active subduction zones have evidenced high seismicity clusters at 20–40 km depth in the fore-arc region whose origin remains controversial. We report here field observations of pervasive pseudotachylyte networks (interpreted as evidence for paleo-seismicity) in the now-exhumed Valpelline continental unit (Dent Blanche complex, NW. Alps, Italy), a tectonic sliver accreted to the upper plate at c. 30 km depth during the Paleocene Alpine subduction. Pre-alpine granulite-facies paragneiss from the core of the Valpelline unit are crosscut by widespread, mm to cm-thick pseudotachylyte veins. Co-seismic heating and subsequent cooling led to the formation of Ti-rich garnet rims, ilmenite needles, Ca-rich plagioclase, biotite microliths and hercynite micro-crystals. ^{39}Ar–^{40}Ar dating yields a 51–54 Ma age range for these veins, thus suggesting that frictional melting events occurred near peak burial conditions while the Valpelline unit was already inserted inside the duplex structure. In contrast, the base of the Valpelline unit underwent synchronous ductile and brittle, seismic deformation under water-bearing conditions followed by a re-equilibration at c. 40 Ma (^{39}Ar–^{40}Ar on retrograded pseudotachylyte veins) during exhumation-related deformation. Calculated rheological profiles suggest that pseudotachylyte veins from the dry core of the granulite unit record upper plate micro-seismicity (M_w 2–3) formed under very high differential stresses (>500 MPa) while the sheared base of the unit underwent repeated brittle–ductile deformation at much lower differential stresses (<40 MPa) in a fluid-saturated environment. These results demonstrate that some of the seismicity clusters nested along and above the plate interface may reflect the presence of stiff tectonic slivers rheologically analogous to the Valpelline unit acting as repeatedly breaking asperities in the basal accretion region of active subduction zones.

1. Introduction

The 30–40 km depth region of subduction interfaces is characterized by a great variety of deformation patterns including megathrust ruptures, after-slip creep and slow-slip events which may overlap in time and space (e.g. Obara and Kato, 2016 and references therein). Along-strike variability of the interface mechanical behavior is either explained by locally higher pore fluid pressures (Tobin and Saffer, 2009; Moreno et al., 2014) or generated by the presence of conditionally unstable segments due to the presence of asperities at the slab surface (e.g. Scholz and Small, 1997). These asperities not only correspond to seamounts and guyots but may also represent plateaus, extinct arcs or detached continental allochtonous terranes (e.g. Ben-Avraham et al., 1981). The collision of such terranes has unavoidably important mechanical and geodynamic implications on the subduction margin (e.g. Vogt and Gerya, 2014). Parts of these slivers escape sinking in the mantle and undergo underplating in the basal accretion site at c. 35 km depth together with slices of sedimentary affinity (Platt, 1986; Angiboust et al., 2014).

Basal accretion of sedimentary material is generally envisioned as an aseismic process (e.g. Moore et al., 1991) and high seismicity clusters commonly observed above the interface in the fore-arc region have been interpreted as the consequence of slab-derived fluids (e.g. Tsuji et al., 2008). However, such seismic events might

* Corresponding author.
E-mail addresses: menant@ipgp.fr (A. Menant), angiboust@ipgp.fr (S. Angiboust), patrick.monie@gm.univ-montp2.fr (P. Monié), oncken@gfz-potsdam.de (O. Oncken), jean-michel.guigner@impmc.jussieu.fr (J.-M. Guigner).

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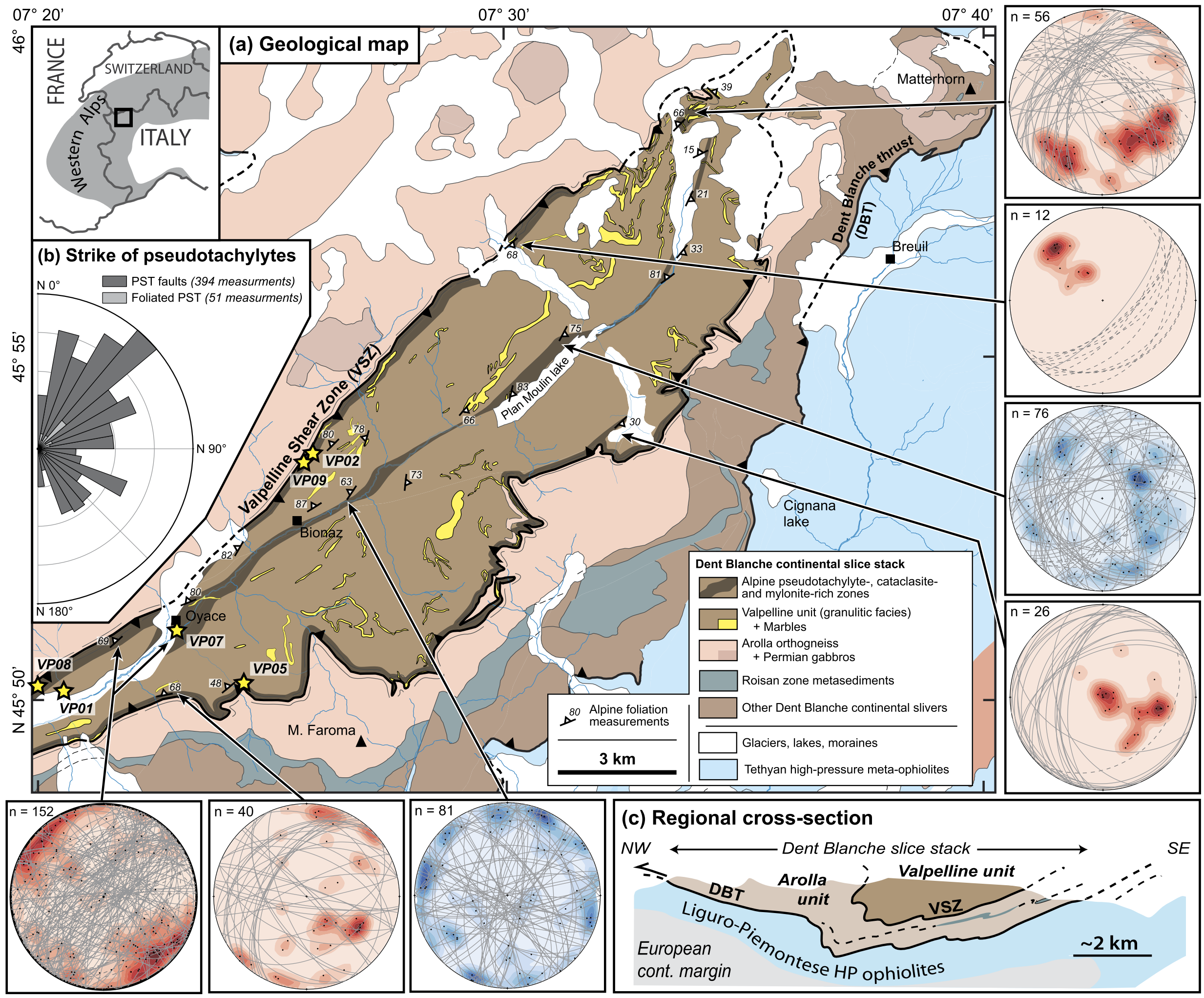

Fig. 1. Geology of the Dent Blanche Complex. *a*. Geological map of the center of the Dent Blanche syncline and its relationship with underlying meta-ophiolites (Combin and Zermatt-Saas units; modified after Dal Piaz et al., 2015). Blue and red stereographic projections summarize the structural data acquired on pseudotachylyte (PST) faults in the core and at the base of the Valpelline unit, respectively. Inset map localizes the working area. *b*. Orientation diagram summarizing the strike of pseudotachylytes in the studied area. *c*. Cross section showing the simplified tectonic structure of the Dent Blanche complex and the location of the Valpelline unit within this continental slice-stack. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

also reflect the presence of rheologically stronger lithologies in deep duplex structures. Exhumed metamorphic complexes constitute an ideal target to understand deformation patterns in the hanging wall of subduction zones (e.g. Bachmann et al., 2009). We herein focus on a continent-derived stack of slivers basally accreted between 30 and 40 km depth during Alpine subduction (Dent Blanche complex, Italy; Angiboust et al., 2014). While Alpine deformation generated numerous ductile networks across the entire Dent Blanche slice stack (e.g. Pennacchioni and Guermani, 1993), one of these accreted slivers exhibits an anomalously brittle behavior with a high concentration of pseudotachylytes veins. Despite recent debate on the question (Pec et al., 2012), the pervasive micro-fracturing and the generation of melt associated with frictional heating production during fault slip is generally viewed as a reliable petrophysical indicator of paleo-seismicity (e.g. Di Toro et al., 2006; Andersen et al., 2008). This case study represents a natural laboratory to understand the role of rheological asperities on seismicity distribution in the basal accretion region of active subduction zones.

2. Geological setting

The internal zones of the W. Alps are formed by a west-verging stack of continental and oceanic nappes emplaced during subduction between Cretaceous and Eocene times (Polino et al., 1990; Rosenbaum and Lister, 2005). The consumed oceanic realm (i.e. Liguro–Piemontese domain) has been interpreted as a slow-spreading seafloor punctuated with numerous extensional continental allochtons formed during the rifting phase and now intercalated with metamorphosed ocean-derived slivers in the Alpine edifice (e.g. Beltrando et al., 2010). Along the Italy–Switzerland border is exposed the Dent Blanche klippe, which represents a 50 km-long composite stack of continent-derived orthogneiss with local intercalation of metasedimentary material, subducted down to blueschist facies conditions between 60 and 45 Ma (i.e. 400–450 °C; 1.0–1.5 GPa; Ballèvre et al., 1986; Angiboust et al., 2014; Fig. 1). The continental slivers forming the Dent Blanche slice-stack are commonly related to the Apulian margin, on the African side of the ocean (Polino et al., 1990; Dal Piaz, 1993). The basal part of the Dent Blanche slice-stack is composed by km-thick slivers of mylonitized orthogneiss (i.e. Arolla and Mt Mary units) overlain by the Valpelline unit, a km-thick granulite-facies sliver now exposed in the core of the Dent Blanche syncline over c. 25 km along strike (Fig. 1c). The Valpelline unit, interpreted as a fragment of the lower crust buttress (Ivrea zone; Polino et al., 1990) is dominantly composed of garnet-rich paragneiss (i.e. “kinzigites”) and to a minor extent mafic amphibolites and marble lenses (Diehl et al., 1952; Pennacchioni and Guermani, 1993