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Polyphase ductile/brittle deformation along a major tectonic boundary in an ophiolitic nappe, Alpine Corsica: Insights on subduction zone intermediate-depth asperities

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ABSTRACT

In an ophiolitic nappe of Alpine Corsica, a major fault zone superimposes metagabbro over serpentinite and peridotite. Ductile and brittle deformation structures are observed in the fault damage zones. In the metagabbro damage zone, early deformation culminates in blueschist or eclogite facies conditions and consists of west-verging mylonitization alternating with pseudotachylyte-forming faulting with undetermined vergence. This early deformation is likely coeval with west-verging seismic (pseudotachylyte-forming) reverse faulting in the footwall peridotite or with aseismic distributed cataclastic deformation of footwall serpentinite. These early events (aseismic mylonitization or distributed cataclasis and seismic faulting) are interpreted as reverse faulting/shear in an east-dipping subducting oceanic lithosphere in Cretaceous to Eocene times. Late deformation events consist of ductile shear and seismic faulting having occurred under retrograde greenschist conditions. Kinematics of the ductile shear is top-to-the-east. These events are interpreted as the result of syn-to post-collision extension of Alpine Corsica in Eocene to Miocene times. The heterogeneous distribution of pseudotachylyte veins along the fault zone (abundant at peridotite-metagabbro interfaces, rare or absent at serpentinite-metagabbro interfaces) is interpreted as the consequence of contrasted frictional properties of the rocks in contact. High-friction peridotite-metagabbro contacts could correspond to asperities whereas low-friction serpentinite-metagabbro contacts could correspond to creeping zones.

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1. Introduction

Subduction zone seismicity is a major concern in terms of seismic hazard assessment and mitigation. Indeed, on average, it accounts for more than 85% of the seismic energy released in the world (Scholz, 2002). Particularly worrisome are seismic ruptures at the plate interface, at depths shallower than 60 km (so-called shallow depth seismicity, Frohlich, 2006). Such ruptures are able to trigger giant tsunamis that can add to devastation resulting from ground shaking (Satake and Tanioka, 1999). Though less concerning than the shallow one, intermediate-depth seismicity, with hypocenters between 60 and 300 km, still constitutes a major threat in coastal areas, either through direct shaking (Frohlich, 2006) or through indirect loading of shallower close-to-failure faults (e.g., Astiz et al., 1988).

Earthquake studies indicate that seismic rupture surfaces are not homogeneous but are constituted of patches or domains with contrasted physical characteristics. Such heterogeneities, basically taken into account in the concepts of asperities or barriers, are observed in intra-plate as well as in inter-plate seismic fault surfaces (Das and Aki, 1977; Kanamori and Stewart, 1978; Aki, 1979; Lay and Kanamori, 1981; Lay et al., 1982; Bakun and McEvilly, 1984; Nadeau et al., 1995; Igarashi et al., 2003; Seno, 2003; Yamanaka and Kikuchi, 2004; Bürgmann et al., 2005; Semmane et al., 2005). Heterogeneities are tentatively characterized by differences in earthquake physical parameters such as coseismic slip, seismic moment release, stress drop, seismic coupling ratio, frictional properties (friction coefficient or rate-and-state dependent friction law $a - b$ parameter, Gutenberg-Richter law b parameter) or pore pressure. Some asperities seem to be spatially persistent, at least at the scale of several years or several tens of years (Bakun and McEvilly, 1984; Nadeau et al., 1995; Igarashi et al., 2003; Okada

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et al., 2003; Hasegawa et al., 2007). Such a spatial persistency suggests that the location of asperities is, at least partly, controlled by specific rocks that in turn likely influence the values of the above-mentioned physical parameters. In subduction zones, asperities are mostly described along the plate interface seismogenic zone (megathrust) of the upper 50–60 km. At depths larger than 60 km, asperities are less commonly reported and are poorly localized (Igarashi et al., 2003; Hasegawa et al., 2007; Legrand et al., 2012).

Pseudotachylytes containing blueschist to eclogite facies mineral assemblages are considered to result from earthquake faulting at intermediate to large depths in subduction zones (Austrheim and Boundy, 1994; Lund and Austrheim, 2003). Their study can thus provide insights on the physical or chemical processes that trigger, accompany or follow intermediate-depth seismic ruptures (John and Schenk, 2006; Andersen et al., 2008, 2014; John et al., 2009). An example of such blueschist to eclogite facies pseudotachylytes likely formed in a subduction zone framework is provided by the Corsican occurrences initially reported by Austrheim and Andersen (2004) and subsequently analyzed from the petrographic, mineralogical or structural points of view by Andersen and Austreim (2006), Andersen et al. (2008, 2014), Deseta et al. (2014a and b), Magott et al. (2016) and Ferré et al. (2016). The paleo-seismic veins are distributed in the vicinity of a major fault surface separating oceanic crust rocks from oceanic mantle rocks.

The aim of this paper is two-fold. First, the relative chronology and the kinematics of the deformation episodes recorded in oceanic crust rocks are analyzed and then compared with the results of Magott et al. (2016) obtained in the mantle rocks. These investigations allow to distinguish aseismic ductile shear events and seismic faulting events which, for the earliest of them, took place in a subducting slab at depths around 60 km. Second, the presence or absence of seismic slip evidence is tentatively related to contrasts in friction of rocks that are in contact along faults. This tentative correlation provides information about the lithological nature of areas with strong coupling (asperities) *vs.* areas with weak coupling, thus suggesting a possible geological explanation for fault surface heterogeneities detected by seismological observations.

2. Geological setting

2.1. Geological setting of Alpine Corsica

Three main types of tectonic units are recognized in the Corsican segment of the Alpine-Apennine orogenic system (Mattauer and Proust, 1976; Faure and Malavieille, 1981; Mattauer et al., 1981; Jolivet et al., 1990, 1991; Fournier et al., 1991; Molli and Malavieille, 2011; Vitale-Brovarone et al., 2013, 2014): (i) the *Schistes Lustrés* units (Tethysian ophiolitic rocks and their sedimentary cover), (ii) the Corsica continental margin units (Variscan plutonic and volcanic rocks), and (iii) the *Nappes Superficielles* or Upper Nappes (ophiolitic units and various sedimentary rocks).

The stacking or imbrication of ophiolites and continental margin-derived units is classically interpreted as the result of an Eocene collision between the Apulian and European continental blocks following an east-dipping subduction of the Piemonte-Liguria Ocean and its ocean-continent transition zone in Cretaceous to Early Tertiary times (Mattauer and Proust, 1976; Mattauer et al., 1977, 1981; Fournier et al., 1991; Jolivet et al., 1991; Meresse et al., 2012; Vitale-Brovarone et al., 2013; Lagabrielle et al., 2015). More complex models call for a shift from the east-dipping ‘Alpine’ subduction of the Piemonte-Liguria Ocean to a west-dipping subduction, either intra-oceanic or beneath a continental or island-arc microblock (Guerrera et al., 1993; Malavieille et al., 1998; Durand-Delga and Rossi, 2002; Molli and Malavieille, 2011; Turco et al., 2012).

Most of the Corsica Alpine units underwent a HP/LT (blueschist to lawsonite-eclogite facies) metamorphism, associated to a top-to-the-west kinematics (Lahondère, 1996; Vitale-Brovarone et al., 2013). This HP/LT metamorphism is considered to result from the Alpine subduction during Eocene (55-34 Ma, Brunet et al., 2000; Martin et al., 2011; Maggi et al., 2012). Vitale-Brovarone and Herwartz (2013) suggested that the metamorphic peak could be between 34 and 37 Ma. A late retrograde greenschist facies metamorphic event occurred during the exhumation of Alpine Corsica in the Oligocene-Miocene. This event is associated with non-coaxial top-to-the-east ductile shear (Jolivet et al., 1990, 1991; Fournier et al., 1991; Brunet et al., 2000; Rossetti et al., 2015).

2.2. Study area

The study area is located around the Cima di Gratera peak and consists of an ophiolitic nappe thrust over continental units (so-called Mordeda-Farinole and Pigno-Olivaccio units, Lahondère, 1996; Meresse et al., 2012) through a fault zone labelled φ_1 (Fig. 1). The nappe, referred to as the Cima di Gratera nappe, is a part of the *Schistes Lustrés* complex and is composed of two units: a lower ultramafic unit consisting of serpentinite including decameter to hectometer-scale elliptical masses of variably serpentinized peridotite, and an upper mafic unit composed of metagabbro. The contact between the two units is a fault surface referred to as φ_2.

2.3. The ultramafic unit

The ultramafic unit consists predominantly of massive serpentinite (former peridotite with a volume proportion of serpentinization > 80%). However, decameter to hectometer-scale masses of fresh to moderately serpentinized peridotite are locally preserved in the serpentinite. The fresh peridotite is composed of olivine (Fo_{84}), clinopyroxene, enstatite and minor plagioclase, Cr-spinel and magnetite, with the modal proportions of a plagioclase lherzolite (Deseta et al., 2014a). In moderately serpentinized peridotite, olivine is replaced by serpentine, talc and magnetite. Serpentinite is composed of serpentine, talc, magnetite and pyroxene, the latter being almost entirely recrystallized into bastite. Raman spectroscopy indicates that serpentine mostly consists of antigorite (Magott, 2016).

Most peridotite masses are located in the center or to the west of the study area and immediately beneath φ_2 (Fig. 1). Rare pyroxenite and gabbro dykes were observed in the peridotite near φ_2. Foliated serpentinite is found locally at the top of the unit, immediately beneath φ_2 (see below, C type deformation zone) or scattered within the median part of the unit, away from φ_2.

According to Deseta et al. (2014a), the peridotite underwent two greenschist facies metamorphic events leading to partial recrystallization of diopside and enstatite to tremolite and actinolite, and of olivine to talc and serpentine. The first metamorphic event is related to the hydrothermal alteration associated with the ocean-continent-transition extension. The second metamorphic event is interpreted as retrograde metamorphism during syn-to post-collision extension (Deseta et al., 2014a). Because the peridotite composition does not allow the formation of medium-to high-pressure diagnostic mineral assemblages, it is impossible to ascertain whether the ultramafic unit underwent a HP/LT metamorphism or not.

Peridotite is crossed by numerous pseudotachylyte fault veins (Andersen and Austreim, 2006; Andersen et al., 2008, 2014; Deseta et al., 2014a; Magott et al., 2016). Most of them are flat-lying and are

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