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Tectono-metamorphic evolution of the Briançonnais zone (Modane-Aussois and Southern Vanoise units, Lyon Turin transect, Western Alps)

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ABSTRACT

In the central Western Alps, a combined structural, petrological and ^{40}Ar–^{39}Ar geochronological study of the Modane-Aussois and Southern Vanoise units yields important constraints on the timing of deformation and exhumation of the Briançonnais zone. These data help to decipher the respective roles of oceanic subduction, continental subduction and collision in the burial and exhumation of the main units through time. In the Modane-Aussois unit top to the NW thrusting (D1) was followed by top to the east shearing (D2) interpreted by some as normal faulting and by others as backthrusting. Pseudosection calculations imply that D1 deformation occurred at 1.0 ± 0.1 GPa and 350 ± 30 °C. Analysis of chlorite–phengite pairs yield P–T estimates between 0.15 and 0.65 GPa and between 220 and 350 °C for the D2 event. Phengites along the D1 schistosity (sample M80) yields an ^{40}Ar–^{39}Ar age of 37.12 ± 0.39 Ma, while D2 phengites yield ages of 35.42 ± 0.38 (sample M173) and 31.60 ± 0.33 Ma (sample M196). It was not possible to test whether these ages are altered by excess argon or not. Our interpretation is that the D1/D2 transition occurred at ~37 Ma at the beginning of decompression, and that D2 lasted until at least ~32 Ma. Pseudosection calculation suggests that the Southern Vanoise unit was buried at 1.6 ± 0.2 GPa and 500–540 °C. D1 deformation occurred during exhumation until 0.7–10.5 GPa and 370 ± 30 °C. Published ages suggest that D1 deformation possibly started at ~50 Ma and lasted until ~37 Ma. D2 deformations started at P–T conditions close to that recorded in Modane-Aussois unit and lasted until 0.2 ± 0.1 GPa and 280 ± 30 °C at ~28 Ma. The gap of 0.6 ± 0.3 GPa and 150 ± 130 °C between peak metamorphic conditions in the two units was concealed by thrusting of the South Vanoise unit on top of the Modane-Aussois unit during D1 Deformation. Top to the east deformation (D2) affects both units and is interpreted as backthrusting.

Based on these data, we propose a geodynamic reconstruction where the oceanic subduction of the Piedmont unit until ~50 Ma, is followed by its exhumation at the time of continental subduction of the continental Southern Vanoise unit until ~45 Ma. The Southern Vanoise is in turn underthrusted by the Modane-Aussois unit until ~37 Ma (D1). Between 37 and 31 Ma the Modane-Aussois and Southern Vanoise units exhume together during backthrusting to the east (D2). This corresponds to the collision stage and to the activation of the Penninic Thrust. In the ~50 Ma to ~31 Ma time period the main thrusts propagated westward as the tectonic context switched from oceanic to continental subduction and finally to collision. During each stage, external units are buried while internal ones are exhumed.

1. Introduction

Although the formation of high pressure (HP) and ultrahigh pressure (UHP) rocks is an integral process occurring in oceanic or continental subduction (Ernst, 2001), their exhumation is a transient processes occurring during oceanic subduction or during continental collision (Ernst, 2001; Agard et al., 2008). The transition

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from oceanic subduction to continental collision is marked by the subduction of the continental margin, still attached to the down-going oceanic slab, when HP To UHP rocks of continental origin are produced (Chopin, 1987) and exhumed (Guillot et al., 2009). Moreover, this period is crucial in the evolution of mountain belt as it records a decrease of the plate convergent rate, the progressive transition from marine to continental sedimentation due to continental uplift of the lower plate and the transition from low temperature to middle temperature geothermal gradient (Guillot et al., 2003). Understanding the exhumation of high and ultra-high pressure (HP to UHP) rocks is a major challenge in our knowledge of plate convergence and mountain building processes. Exhumation of HP to UHP rocks results from the interaction of boundary forces, buoyancy, rheology, geometry of the subduction channel and surface processes (Jolivet et al., 2003; de Sigoyer et al., 2004; Agard et al., 2008; Guillot et al., 2009). The timing of exhumation with respect to the onset of continental subduction has important bearings on the exhumation processes (Brun and Facenna, 2008; Guillot et al., 2009). Models proposed for the exhumation depend upon the orogenic context i.e. subduction or collision. Pro- and back-thrustings coupled with strong erosion and the formation of foreland basins take place during collision. A wide variety of exhumation model have been proposed during the subduction stage: channel flow (Cloos, 1982), corner flow (Platt, 1986), extensional collapse (Dewey et al., 1993), thrusting towards the foreland (Steck et al., 1998), buoyancy assisted by erosion and tectonics (Chemenda et al., 1995), compression of a soft zone between two rigid blocks (Thompson et al., 1997), serpentinite channel (Guillot et al., 2001), and coaxial extension associated with a decoupling fault (Jolivet et al., 2003).

The Western Alps are a good example for studying the exhumation processes of HP to UHP metamorphic rocks as early HP-LT metamorphic relics have been widely preserved. It is a curved orogenic belt consisting of a nappe stack of continental terranes, that are from the top to the bottom Austroalpine, Internal Crystalline Massifs, Briançonnais zone and External Alps (Fig. 1). Two oceanic domains separate these continental domains (Fig. 1): the Piedmont zone between the Austroalpine and the Internal Crystalline Massifs and the Valais oceanic unit squeezed between the Briançonnais zone and the external Alps along the Penninic Thrust (e.g. Schmid and Kissling, 2000; Rosenbaum et al., 2005).

In the internal part of the belt, HP to UHP metamorphic rocks formed and exhumed during distinct periods: 65 Ma for the Austroalpine massif (Duchene et al., 1997), between 65 and 45 Ma for the Piedmont zone (Agard et al., 2002; Lapen et al., 2003), between 45 Ma and 35 Ma for the Internal Crystalline Massifs (Duchene et al., 1997; Meffan-Main et al., 2004) and the Briançonnais zone (Markley et al., 1998; Freeman et al., 1997) and at 35 Ma for the Valais unit (Bousquet et al., 2002). The variation in metamorphic ages and a geothermal gradient lower than 10 °C km^{-1} in these rocks suggest that such nappes formed in a subduction wedge from 65 to 35 Ma (Rosenbaum et al., 2005; Ford et al., 2006; Lardeaux et al., 2006; Gabalda et al., 2008). The transition from subduction to collision is dated at ca. 35 Ma and is associated with the activation of the Pennine thrust (Schmid and Kissling, 2000; Pfiffner et al., 2002; Leloup et al., 2005; Rosenbaum et al., 2005; Beltrando et al., 2010; Dumont et al., 2011). Recently this age has been confirmed on the basis of P–T–t estimates of alpine metamorphism in the External zone (Rolland et al., 2008; Simon-Labric et al., 2009). Such event is associated with the formation of backthrusts from the internal part of the belt (Tricart, 1984; Platt et al., 1989; Schmid and Kissling, 2000; Tricart and Sue, 2006) to the boundary between the Pô plain and the Alpine belt (Carrapa and Garcia-Castellanos, 2005; Escher and Beaumont, 1997; Roure et al., 1990).

In the internal part of the Western Alps, tectonics associated with exhumation is polyphased (e.g., Lanari et al., 2012). Early, top to N or NW direction of nappe emplacement and shearing accommodated the earliest and rapid exhumation of the HP and UHP continental units. This tectonic phase (D1) is observed and interpreted everywhere as a thrusting phase (Agard et al., 2002; Markley et al., 1998; Bousquet et al., 2002; Reddy et al., 2003; Bucher et al., 2003; Ganne et al., 2007; Wheeler et al., 2001; Le Bayon and Ballèvre, 2006).

The D1 nappe stack is often affected by top to the east or SE shearings (D2). In the Piedmont zone, these D2 structures accommodate a significant part of the exhumation in a context of extension (Agard et al., 2002; Reddy et al., 1999; Rolland et al., 2000; Ganne et al., 2006, 2007). A late Eocene age (>35 Ma) is proposed for these structures (Agard et al., 2002; Reddy et al., 1999).

Others top to the east or southeast structures occurred after the major exhumation phase. Some of these structures are responsible for the fan shape of the Western Alps and are interpreted as back-thrusts (Tricart, 1984; Platt et al., 1989; Escher and Beaumont, 1997; Le Bayon and Ballèvre, 2006; Tricart and Sue, 2006). An Oligocene Age (~33–25 Ma) is attributed to these structures by analogy with other ones observed further SE at the rear of the Pô plain (Carrapa and Garcia-Castellanos, 2005; Roure et al., 1990) and that are coeval with the formation of foreland basins (Schmid

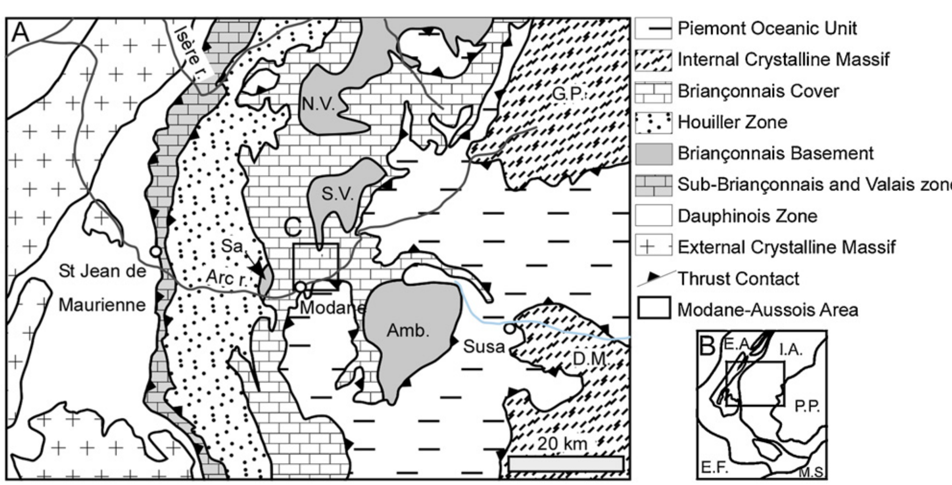

Fig. 1. Structural context of the studied area. Inset map: general context of the western Alpine belt. E.A., external Alps; E.F., European forland; I.A., internal Alps; M.S., Mediterranean sea. The frame locates the main map. Main map: main units of the central Western Alps. Am., Ambin; D.M., Dora-Maira; G.P., Gran Paradiso; N.V., Northern Vanoise; P.P., Po plain; Sa, Sapey; S.V., Southern Vanoise. The frame corresponds to the studied area (Figs. 2 and 5).