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# $^{40}Ar–^{39}Ar$ laser dating of ductile shear zones from central Corsica (France): Evidence of Alpine (middle to late Eocene) syn-burial shearing in Variscan granitoids

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ABSTRACT

The island of Corsica (France) plays a central role in any reconstruction of Western Mediterranean geodynamics and paleogeography but several key aspects of its geological evolution are still uncertain. The most debated topics include the interpretation of the Corsican orogen as the result of an east- or west-directed subduction, and the actual involvement of the Variscan basement of Corsica in the Alpine orogenic cycle. This study integrates $^{40}Ar–^{39}Ar$ laserprobe, mesostructural, microtextural, and microchemical analyses and places relevant constraints on the style, *P–T* conditions, and timing of Alpine-age, pervasive ductile shear zones which affected the Variscan basement complex of central Corsica, a few kilometers to the west of the present-day front of the Alpine nappes. Shear zones strike ~NNE–SSW, dip at a high angle, and are characterized by a dominant sinistral strike-slip component. Two of the three investigated shear zones contain two texturally and chemically resolvable generations of white mica, recording a prograde (burial) evolution: (1) deformed celadonite-poor relicts are finely overgrown by (2) a celadonite-rich white mica aligned along the main foliation. White mica from a third sample of another shear zone, characterized by a significantly lower porphyroclast/matrix ratio, exhibits a nearly uniform high-celadonite content, compositionally matching the texturally younger phengite from the nearby shear zones. Mineral-textural analysis, electron microprobe data, and pseudosection modeling constrain *P–T* conditions attained during shearing at ~300 °C and minimum pressures of ~0.6 GPa. In-situ $^{40}Ar–^{39}Ar$ analyses of coexisting low- and high-celadonite white micas from both shear zones yielded a relatively wide range of ages, ~45–36 Ma. Laser step-heating experiments gave sigmoidal-shaped age profiles, with step ages in line with in-situ spot dates. By contrast, the apparently chemically homogenous high-celadonite white mica yielded concordant in-situ ages at ~34 Ma, but a hump-shaped age spectrum, with maximum ages of ~35 Ma and intermediate- to high-temperature steps as young as ~33–32 Ma. Results indicate that the studied samples consist of an earlier celadonite-poor white mica with a minimum age of ~46 Ma, overgrown by a synshear high-celadonite white mica, developed at greater depth between ~37 and 35 Ma; faint late increments in shearing occurred at ≤33–32 Ma, when white mica incipiently re-equilibrated during exhumation. Results suggest that ductile shearing with a dominant strike-slip component pervasively deformed the Corsican basement complex during the emplacement and progressive thickening of the Alpine orogenic wedge and broaden the extent of the domain affected by the Alpine tectonometamorphic events. Integration of petrological modeling and geochronological data shows that the Variscan basement of central Corsica, close to the Alpine nappes, was buried during the late Eocene by ≥18 km of Alpine orogenic wedge and foreland deposits. Our results, combined with previously published apatite fission-track data, imply an overburden removal ≥15 km from the late Eocene (Priabonian) to the early Miocene (Aquitanian), pointing to a minimum average exhumation rate of 1.3–1.5 mm/a.



## 1. Introduction

Shear zones are sites of localized deformation that may develop under brittle to ductile conditions and may act as preferential pathways for fluid migration in the crust (e.g., Alsop and Holdsworth, 2004).

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Deformation and fluid circulation are strongly interconnected: they enhance each other, and both facilitate reaction kinetics, and in turn mineral nucleation and/or mineral re-equilibration under changing *P–T* conditions. This is consistent with the fact that ductile shear zones commonly display a plethora of microstructures and reaction textures that provide valuable insights about deformation kinematics and physical conditions during shearing, thereby representing an ideal target for investigating orogenic processes. Furthermore, constraining timing and duration of deformation within these fault systems is a fundamental prerequisite in order to estimate length and rate of geological processes. However, direct dating of shearing by radioisotopic techniques is proven to be difficult as the submillimeter spatial heterogeneity of most ductile shear zones requires thorough interpretation of geochronological analyses in the light of microscale structural, textural and chemical data (e.g., Di Vincenzo et al., 2007; Mulch and Cosca, 2004; Mulch et al., 2005). Shear zones are commonly well-developed in granitoids, frequently exploiting brittle precursors (joints) and dykes (Pennacchioni, 2005). Typical examples are reported from the Variscan granitoids of the Mt. Blanc massif in the Western Alps (e.g., Guermani and Pennacchioni, 1998), the Zentralgneise Unit of the Eastern Alps (e.g., Pennacchioni and Mancktelow, 2007) and the South Armorican Massif (e.g., Tartèse et al., 2012).

The island of Corsica, located in the Central Mediterranean Sea (Fig. 1), is traditionally viewed as consisting of two discrete geological domains dominantly deformed either during the Variscan or the Alpine orogenies (e.g., Jolivet and Faccenna, 2000; Molli, 2008). Despite its central role in any reconstruction of the Western Mediterranean geodynamics and paleogeography, several key aspects of its geological evolution need to be clarified. One of the most debated aspects is the interpretation of the Corsican orogen as the result of an east- or west-directed subduction, possibly involving a polarity change (e.g., Argnani, 2012; Brunet et al., 2000; Lacombe and Jolivet, 2005; Malavieille et al., 1998; Molli, 2008; Molli and Malavieille, 2011; Vitale Brovarone and Herwartz, 2013). Equally uncertain is the extent of involvement of the Variscan continental crust of Corsica in the Alpine orogenic cycle (e.g., Lacombe and Jolivet, 2005).

It has long been known that a set of pervasive NNE–SSW-striking ductile shear zones affect the Variscan basement of Corsica (Laurent, 1976; Maluski, 1977a; Rossi and Rouire, 1980; Rossi et al., 1994). Similarly oriented structures affect north-central Sardinia, but they mainly developed under brittle conditions (Carmignani, 1996). The presence of ductile shear zones in Corsica suggests that deformation took place at depth, under temperature conditions suitable for ductile deformation, which require a minimum overburden of ~12 km, assuming a paleogeothermal gradient of 20–25 °C/km. In Corsica individual shear zones can be as much as a few hundreds of meters wide, and can be traced over distances of several kilometers. In most cases, shear zones developed entirely within Variscan granitoids. In a few instances (e.g. the large shear zone immediately to the north of the village of Vivario, central Corsica), shear zones experienced such intense deformation that they were mistaken for elongated outcrops of Eocene foreland siliciclastic rocks (Amaudric du Chaffaut et al., 1983).

Several basic aspects of the shear zones occurring within the Variscan basement of Corsica still need to be defined, including *P–T* conditions attained during shearing and timing. Geochronological data are limited to unpublished K–Ar and $^{40}Ar–^{39}Ar$ data quoted in Laurent (1976) for deformed granitoids from central Corsica (Golo valley), yielding middle–late Eocene ages, and to $^{40}Ar–^{39}Ar$ discordant age profiles reported in Maluski (1977a, 1977b, 1978) for plagioclase, K-feldspar, amphibole and biotite of deformed granitoids from several localities of Variscan Corsica. Maluski (1977a, 1977b) proposed the possible existence of an Alpine phase of deformation based on low-temperature steps from K-feldspar age spectra.

This paper presents the results of a detailed investigation using $^{40}Ar–^{39}Ar$ experiments (both laser step-heating and laser in-situ techniques) on three 10 to 100 meter-thick shear zones from the Variscan basement in central Corsica, close to the Alpine nappes. Geochronological data were supplemented by detailed microstructural, microchemical and microtextural data, and petrological constraints on the physical conditions attained during shearing. Results provide *P–T* and temporal constraints on the burial history of the Variscan basement during emplacement and thickening of the Alpine orogenic wedge, and have implications for the overall Alpine structural evolution of Corsica.

## 2. Geological background

The island of Corsica comprises two different geological domains that prevalently recorded either Alpine or Variscan tectonics (e.g. Durand-Delga, 1978; Malavieille et al., 1998; Molli, 2008). The Alpine domain is located in northeastern Corsica (Fig. 1B) and consists of a nappe-pile edifice comprising Mesozoic ophiolitic rocks, associated sedimentary sequences and slices of continental basement, all of which were tectonically emplaced on the "autochthonous" Variscan domain and underwent blueschist to eclogite-facies metamorphism during the Alpine orogenic cycle (Molli, 2008; Vitale Brovarone et al., 2013). The oceanic units are considered remnants of the Ligurian–Piedmontese basin, which developed between the European and the Adriatic continental margins during Triassic rifting and the Jurassic oceanic spreading phases (Garfagnoli et al., 2009). In the course of the Alpine orogenic cycle, the Ligurian–Piedmontese oceanic basin underwent contractional tectonics and HP/LT metamorphism due to oceanic subduction followed by continental collision. Emplacement of the Alpine units took place during nearly W-directed shearing, synchronous with HP/LT metamorphism (Jolivet et al., 1998). Contractional tectonics was replaced by large-scale extension during the Oligocene, with subsequent collapse of the previously overthickened orogenic wedge (Garfagnoli et al., 2009; Malasoma and Marroni, 2007). Three main Alpine tectonic elements can be distinguished, from the top to the bottom (Molli and Malavieille, 2011): 1) the upper-Nappe system, also known as Nappe Supérieure; 2) the Schistes Lustrés composite nappe; and 3) units derived from the Corsica continental crust.

The Nappe Supérieure includes the Balagne, Nebbio and Macinaggio units. On the whole, they consist of both deformed ophiolitic and continental units, mainly associated with Late Cretaceous siliciclastic and calcareous-marly flysch deposits (Molli and Malavieille, 2011 and references therein). The occurrence of prehnite–pumpellyite bearing mineral assemblages in mafic rocks indicates that these units were metamorphosed under subgreenschist-facies conditions (Marroni and Pandolfi, 2003). The tectonically underlying Schistes Lustrés complex comprises Ligurian Tethys metaophiolites and associated Jurassic to Cretaceous metasedimentary cover. Relicts of the Mesozoic ocean-continent transition domain, represented by exhumed mantle rocks, ophiolitic metagabbros and metabasalts interlayered with slices of continental upper crust, are commonly found within the Schistes Lustrés complex (Martin et al., 2011; Molli and Malavieille, 2011; Vitale Brovarone et al., 2011). Both ophiolitic and continental units recorded subduction-related deformation and underwent subgreenschist to lawsonite-eclogite metamorphism (Brunet et al., 2000; Malasoma and Marroni, 2007; Vitale Brovarone et al., 2011). The lowermost Alpine structural domain consists of the Corsican-derived continental units, and included variably reworked crystalline rocks of the Variscan basement and locally its Mesozoic to Middle Eocene sedimentary cover, deposited on the distal part of the Corsica continental margin (Molli and Malavieille, 2011 and references therein). The Internal Continental units include the Tenda Massif and other tectonic slices (Centuri and Serra di Pigno–Farinole units – Fig. 1B), which are interlayered within the Schistes Lustrés complex (Molli et al., 2006). The Tenda Massif represents a portion of the western Corsica basement involved in the Alpine orogeny and mainly consists of Variscan (late Carboniferous) granites overlain by dacitic volcano-sedimentary formations, both intruded by Early Permian leucogranites or by an Early–Middle Permian gabbroic complex (Vitale Brovarone et al., 2013 and references therein). These rocks underwent epidote-blueschist to lawsonite-eclogite