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Cretaceous-Eocene compression in the central Southern Alps (N Italy) inferred from $^{40}Ar/^{39}Ar$ dating of pseudotachylytes along regional thrust faults

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ABSTRACT

The integration of structural analyses with $^{40}Ar/^{39}Ar$ dating of fault-related pseudotachylytes provides time constraints for the reconstruction of the Alpine evolution of the central portion of the South Alpine orogenic wedge. In the northern sector of the belt a Variscan basement is stacked southward on the Permian to Mesozoic cover along regional faults (Orobic and Porcile thrusts). Fault zones, slightly postdating a first folding event of Alpine age, experienced a complex evolution through the ductile and brittle deformation regime, showing greenschist facies mylonites overprinted by a penetrative cataclastic deformation. Generation of fault-related pseudotachylyte veins marks the onset of brittle conditions, lasting up to the youngest episodes of fault activity. $^{40}Ar/^{39}Ar$ dating of the pseudotachylyte matrix of 9 samples give two separated age clusters: Late Cretaceous (80–68 Ma) and latest Palaeocene to Middle Eocene (55–43 Ma). These new data provide evidence that the pre-Adamello evolution of the central Southern Alps was characterised by the superposition of different tectonic events accompanying the exhumation of the deepest part of the belt through the brittle–ductile transition. The oldest pseudotachylyte ages demonstrate that south-verging regional thrusting in the central Southern Alps was already active during the Late Cretaceous, concurrently with the development of a synorogenic foredeep basin where the Upper Cretaceous Lombardian Flysch was deposited.

Our reconstruction provides direct evidence for an important Cretaceous "EoAlpine" orogenic event which was nearly coeval to the HP metamorphism affecting the Austroalpine units of the eastern Alps. In our view, the Upper Cretaceous Southern Alps can be interpreted as the south-verging retrobelt, which formed during subduction phenomena active to the north in the Austroalpine realm.

1. Introduction

In most orogenic belts, radiometric dating of syntectonic minerals allows to numerically date the regional structural evolution. On the other hand, if deformation occurs at low temperature metamorphic conditions, such method cannot be applied. Thus, in the past, absolute time-markers were generally derived by indirect evidence of active deformation in the sedimentary record of the foreland basins or by dating pre-, syn- and post-tectonic magmatic bodies. Recent techniques developed for the accurate dating of fault-related pseudotachylytes (Kelley and Spray, 1997; Müller et al., 2002) and clay minerals in fault gouge (van der Pluijm et al., 2001) provide a novel and unique opportunity to constrain fault motions and, consequently, active deformation in orogenic belts.

The Orobic Alps (central Southern Alps, N Italy) represent a non-metamorphic fold-and-thrust belt formed during the Alpine orogenic events. The age and extent of Alpine deformation in the central Southern Alps is a matter of debate since the work of De Sitter and De Sitter-Koomans (1949) and the first tectonic interpretations by Gaetani and Jadoul (1989) and Laubscher (1985). The absence of an Alpine metamorphism and syn-tectonic sediments within the mountain belt significantly hampers the reconstruction of the timing of the deformation events. The first reliable radiometric age constraints for the Alpine deformation were given in the past by Rb/Sr and K/Ar isotopic data (Del Moro et al., 1983) on the Adamello pluton (43–31 Ma) which crosscuts part of the fold and thrust structures occurring in the central Southern Alps (Del Moro et al., 1983; Brack, 1984; Schönborn, 1992). Recent U-Pb zircon data on magmatic bodies postdating regional thrust faults (D'Adda et al., 2010) constrain to pre-Middle Eocene times thrust activity west of the Adamello, suggesting that the whole orogenic wedge of the central Southern Alps was already formed before Middle Eocene. On the other hand, the onset of the Alpine deformation still remains to be constrained. The occurrence of a Late Cretaceous orogeny was envisaged by several authors (Laubscher, 1985; Doglioni and Bosellini, 1987; Bernoulli and Winkler, 1990; Bersezio

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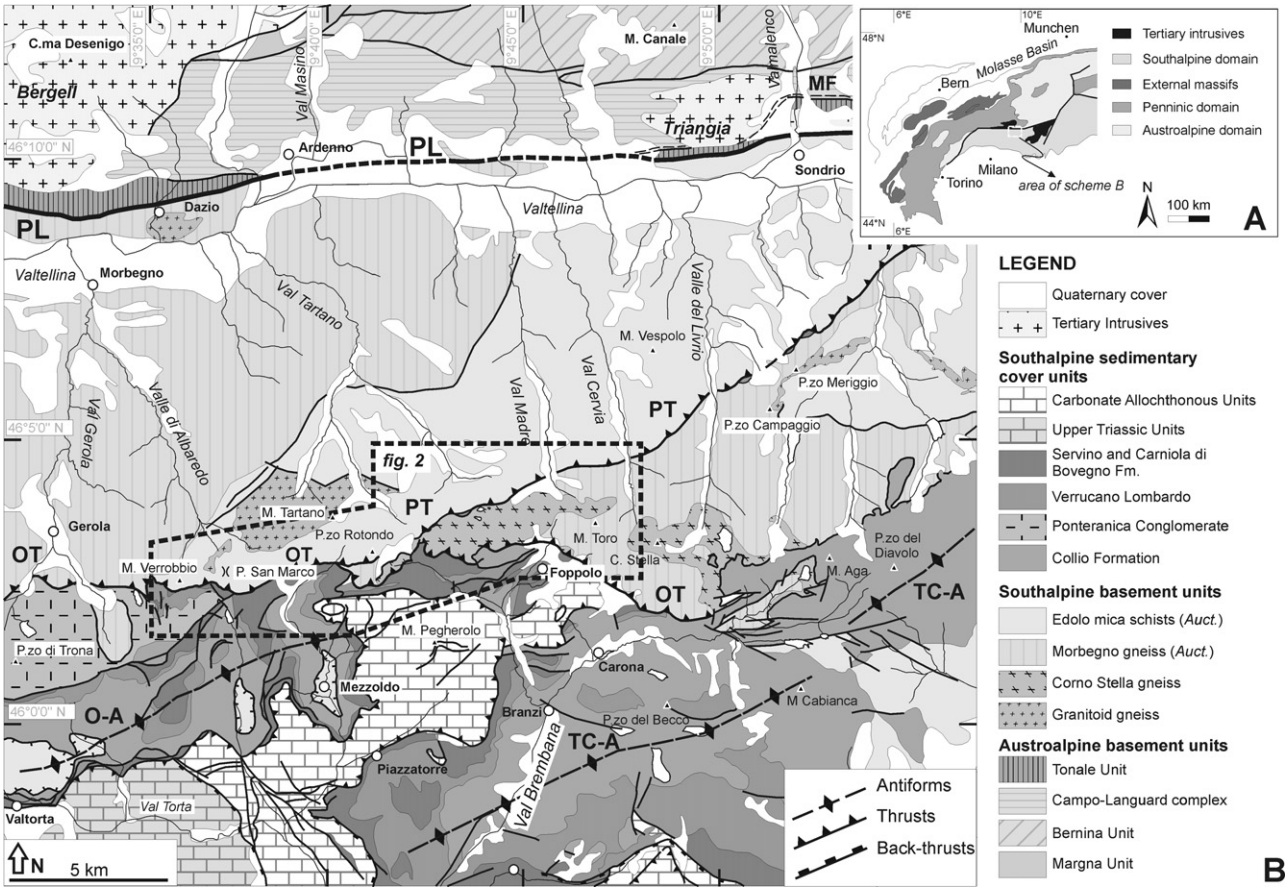

Fig. 1. Tectonic outline of the study area. (a) Tectonic outline of the Western and Central Alps. (b) Geological sketch of the central Orobic Alps (Southalpine tectonic domain). The Orobic and Porcile thrusts are evident east of Passo San Marco where the South Alpine basement overrides the Permian-Mesozoic sedimentary cover along the Orobic and the Porcile thrusts represent an intra-basement brittle/ductile shear zone. The extent of the detailed geological map of Fig. 2 is highlighted. The geological sketch was drawn on the basis of existing maps (Casati and Gnaccolini, 1967; Forcella and Jadoul, 2000) and original field work by the authors. OT, Orobic Thrust; PT, Porcile Thrust; PL, Periadriatic Lineament; MF, Mortirolo Fault; O-A, Orobic Anticline; TC-A, Trabuchello-Cà Bianca Anticline.

et al., 1993) based on the occurrence of a thick Cenomanian to Campanian turbiditic succession deposited in the Lombardian basin and now exposed in the southern sector of the belt.

The occurrence of fault rocks formed along regional thrust faults affecting the Variscan crystalline basement of the belt (the Orobic and Porcile thrust) offer the opportunity to date the oldest deformational events. Pseudotachylyte veins occur, in fact, within these fault zones, discontinuously decorating thrust surfaces (Siletto, 1990; Meier, 2003; Carminati and Siletto, 2005).

In this paper, we show how new $^{40}Ar/^{39}Ar$ data on pseudotachylytes can be integrated with fold, cleavage and fault zone analyses to reconstruct the onset and subsequent stages of the Alpine deformation in the central Southern Alps which are up to now poorly constrained. Considering that some of the obtained pseudotachylyte ages give a direct evidence for Cretaceous compressive deformation in the Southern Alps, we also discuss the possible relationships with the Cretaceous orogenic events recognised in the Austroalpine domain (Schmid et al., 2004) and its bearings for the geodynamic evolution of the Alps.

2. Geological outline of the central Southern Alps

The central Southern Alps are located between Como Lake and the Giudicarie Line (Fig. 1). They belong to the S-verging retro-belt of the Alps (Laubscher, 1985), from which they are separated by the E–W trending Tonale Line, a segment of the Periadriatic fault system (Schmid et al., 1989). The structure of the Southern Alps west of the Giudicarie Line is typical of a *thick-skinned* fold-and-thrust belt (Carminati et al., 1997), which involves both the basement and a Permian to Cenozoic cover succession. Alpine metamorphism was weaker than that suffered by the Austroalpine units to the north of the Tonale Line (Carminati et al., 1997; Crespi et al., 1982; Spalla et al., 1999; Colombo and Tunesi, 1999), attaining lower greenschist facies conditions (Carminati et al., 1997; Crespi et al., 1982; Albini et al., 1994).

The pre-Alpine basement of the Southern Alps is thrust southward on the Permian to Mesozoic sedimentary successions along the Orobic thrust and related faults, which form a continuous fault system extending more than 80 km in length (Fig. 1). South of the Orobic thrust, an array of three anticlines, with a dextral *en-échelon* arrangement, the *Orobic Anticlines* (Schönborn, 1992), occurs. These regional folds show WSW-ENE trending axes and affect both the metamorphic basement and the sedimentary cover ranging from the Upper Carboniferous-lowermost Permian Basal Conglomerate to the Triassic Servino and Carniola di Bovegno. The *Orobic Anticlines* are bounded to the south by the Valsassina-Valtorta-Valcanale fault system that acted as a wedging fault during south-verging thrust propagation (Laubscher, 1985; Schönborn, 1992).

South of the Valsassina-Valtorta-Valcanale fault, E-W trending antiformal thrust stacks occur. They consist of Lower Triassic to Carnian formations, forming large S-verging thrust sheets (*Carbonate Allochthonous Units* of Gaetani and Jadoul (1989). These units are back-thrusted to the south by an Upper Triassic succession along the south-dipping Clusone – Oltre Antea fault system (Zanchi et al., 1990). The external part of the belt includes also the Jurassic and Cretaceous successions, unconformably covered by the Oligo-