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Age and temperature constraints on metamorphism and exhumation of the syn-orogenic metamorphic complexes of Northern Apennines, Italy

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ABSTRACT

The Apennine Range is a young convergent orogen that formed over a retreating subduction zone. Syn-orogenic metamorphic rocks are exposed in the mid-Tuscan ridge, Tuscan coast and Tuscan Archipelago and provide information about processes of continental subduction and exhumation associated with accretion and retreat. Apatite and zircon fission-track analyses were applied to some of these syn-orogenic metamorphic rocks. The new low-temperature thermochronological data helped to constrain the timing of the metamorphic peak and the age and modality of exhumation of these rocks that were structurally buried at 20 to 40 km depth during the main tectonogenic phase of the Northern Appenine belt. In the Giglio and Elba islands and in the Monti dell'Uccellina, along the coast, minimum ages of partially reset zircon samples yielded a first time constraint on the Late-Oligocene age of the metamorphic peak. The ca. 27 Ma obtained at the Monti dell'Uccellina is coeval to that found in the Alpi Apuane (located at the northern termination of the mid-Tuscan ridge). The data from the Tuscan Archipelago point to a slightly older age. In the Monti Pisani, south of the Alpi Apuane, and in the Argentario Promontary along the coast, south of the Monti dell'Uccellina, completely reset zircon samples, but composed by different populations, were behaving as multiple thermochronometers and confirm the already proposed isothermal nature of the exhumation occurred after the metamorphic peak. Zircon P1 peak indicated that at 13–10 Ma rocks were already at shallow crustal levels (<9 km). Zircon minimum ages and apatite ages point to a sharp increase in the exhumation rate at ~6–4 Ma. Data indicate a common thermal history for the whole mid-Tuscan ridge and coastal outcrops. The 6–4 Ma increase in exhumation rate can be attributed either to unroofing due to the extensional tectonics or to a contractional "out-of-sequence" or "re-activation" event occurring in the internal sector of Tuscany already affected by a regional extensional regime.

1. Introduction

The evolution of orogenic chains consists of at least four phases: 1) the main syn-collisional event characterized by the burial and regional HP–LT peak metamorphism of the tectonic units; 2) late syn-collisional event during which the metamorphic units exhume to shallow structural levels; 3) post-orogenic extension linked to isostatic unroofing eventually coupled with the emplacement of magmatic bodies (Jolivet et al., 1998, 2003; Vai and Martini, 2001; and references therein); 4) topographic development and erosion. In particular, the exhumation mechanism of high-pressure metamorphic rocks is still a crucial and debated problem, despite the numerous studies published over the decades. The main proposed mechanisms are: 1) Core-complex, post-orogenic fully extensional model (Hamilton, 1987; Kligfield et al., 1984; Lister and Davis, 1989; Wernicke et al., 1987); 2) Syn-contractional exhumation coupled with extensional detachments (e.g. Jolivet et al., 2003; Ring et al., 1999); and 3) Syn-contractional wedge extrusion and/or buoyancy-triggered exhumation (e.g. Chemenda et al., 1997; Ernst et al., 1997; Vannay and Grasemann, 2001). The simultaneous activity of shortening-induced low-angle normal faults during the formation of an orogenic stack with the exhumation of HP metamorphic rocks, is particularly well documented for the European Alps and Aegen Sea (Chatzaras et al., 2006; Ring et al., 1999; Ring and Glodny, 2010). The emplacement of granitoids in extended continental crust can also contribute to the unroofing of the deep tectonic units (Bortolotti et al., 2001; Pertusati et al., 1993).

The use of two or more thermochronometers with different closure temperatures allows to set constraints to the material paths

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and deformational style within an orogenic wedge with time (Batt et al., 2001; Batt and Brandon, 2002; Fuller et al., 2006). In particular, they can trace the pathway of the rocks from their burial to subsequent exhumation till exposure.

In this frame, the Northern Apennines chain is one of the best known orogens and includes metamorphic and non-metamorphic units, superposed during the Oligocene–Middle Miocene syn-collisional events, and then affected by post-orogenic extension and magmatism (Bortolotti et al., 2001; Jolivet et al., 1998; Vai and Martini, 2001). Its complex evolution is characterized by the typical eastward migration of the compressional front coupled with concomitant extension in the hinterland due to the slab retreat and roll-back (Royden et al., 1987; Faccenna et al., 2004; and references therein).

In the Tuscan part of the Northern Apennines, several exposures of continental syn-orogenic HP–LT to Barrovian metamorphic rocks (i.e. Tuscan Metamorphic Units = TMU) occur (Fig. 1). Most of the Tuscan metamorphic inliers comprise Verrucano metasediments, an originally continental mostly siliciclastic sequence deposited during the Triassic syn-rifting stage of the Tuscan sector of the Gondwanaland (Aldinucci et al., 2008; Pandeli, 2002; Rau and Tongiorgi, 1974). These rocks were buried to depth of 20 to 40 km, reaching HP/LT metamorphic peak conditions, and successively experienced a rapid exhumation up to a depth of 10–15 km (Brunet et al., 2000; Giorgetti et al., 1998; Jolivet et al., 1998; Theye et al., 1997).

While the metamorphism of the Verrucano metasediments has been studied by many authors with different techniques (for a compilation of the existing data see Franceschelli et al., 2004 and references therein), few geo- and thermo-chronological data constraining the timing of the tectono-metamorphic events of the Northern Apennines chain and successive rock exhumation exist. In particular, the available data are mainly related to the Alpi Apuane (Balestrieri et al., 2003; Brunet et al., 2000; Fellin et al., 2007; Kligfield et al., 1986) where the presence of two main growth stages of white mica (phengite and muscovite) was related to two main tectono-metamorphic events in Tuscany: the thickening event (D1) in Late-Oligocene–Early Miocene and the decompression event (D2) in Middle Miocene during which the rocks started to be exhumed.

For the Alpi Apuane core, a wide data set for the low temperature thermal characterization is available (apatite and zircon FT analyses and apatite and zircon U–Th/He datings in Fellin et al., 2007 and reference therein), whereas low-temperature thermochronological data are totally lacking for the other TMU occurrences. In this study, zircon and apatite FT methods have been applied for the first time on Verrucano samples from Monti Pisani, Monti dell'Uccellina, Argentario Promontory, Giglio Island and eastern Elba Island. In addition we sampled the Pseudomacigno siliciclastics, the Oligocene foredeep turbiditic formation at the stratigraphic top of the TMU, in the Elba Island. The obtained data allow: (i) to constrain the maximum temperatures that the metamorphic rocks experienced during their

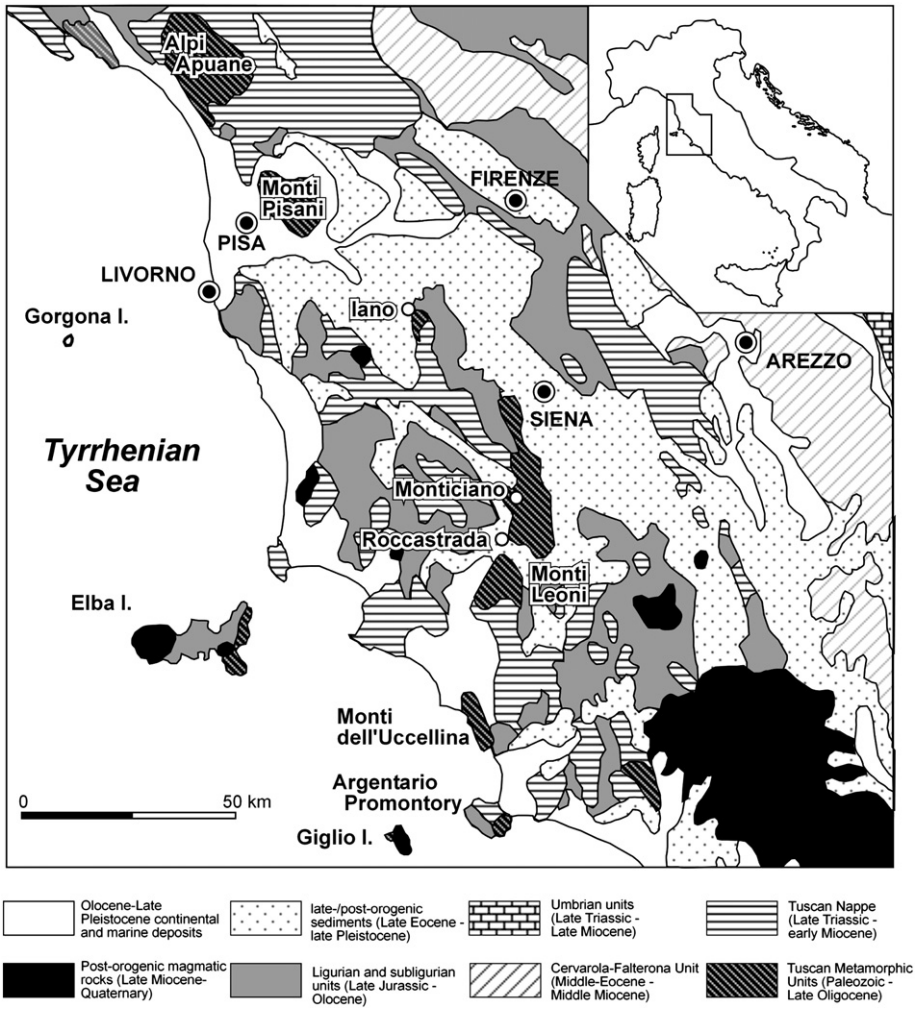

Fig.1. Geological sketch map of the Northern Apennine. See the locations of the outocrops of Tuscan Metamorphic Units.