THE THERMAL STATE OF BIELLA PLUTON COUNTRY ROCKS AS A TOOL TO UNRAVEL THE LATE OROGENIC TECTONICS OF THE WESTERN ALPS

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Introduction. Crustal level and timing of late-orogenic plutons represent powerful tools for constraining the late exhumation history of tectonic units, within collisional belts. This work aims to contribute to this topic by quantitatively determining the thermal state of Biella Periadriatic pluton country rocks during its emplacement within the continental HP metamorphic rocks of the Sesia-Lanzo Zone (SLZ), in the western Austroalpine domain (Zanoni *et al.*, 2008, 2010; Zanoni, 2016 and refs. therein). During the Alpine subduction and exhumation, the Sesia-Lanzo Zone records a polyphasic tectono-metamorphic evolution. Pluton cooling involved contact metamorphism overprinting eclogitic to greenschist facies assemblages in the country rocks. On the basis of the amount and type of contact metamorphic assemblages the aureole extent was mapped and the variation of recorded thermal peak validated by comparison with numerical modelling of the heat transfer during magma crystallisation. Thus, this work aims constraining the late exhumation history of the internal western Alps by determining the crustal level of pluton emplacement and the thermal gradient of its country rocks at the time of intrusion.

Geological setting. The Alps developed during subduction and closure of the Mesozoic Tethys and subsequent continental collision over Cretaceous–Oligocene times (e.g. Dal Piaz, 2010; Handy *et al.*, 2010; Spalla *et al.*, 2010). The Alpine convergent system involved the subduction of the European lithosphere underneath the Adria plate. The Periadriatic line is a main crustal break of the Alpine bounding the Southalpine continental crust acting as backstop wall of the orogenic wedge during the convergence (Polino *et al.*, 1990). This lineament (Fig. 1) separates tectonic units that during the Alpine convergence experimented intense deformation and

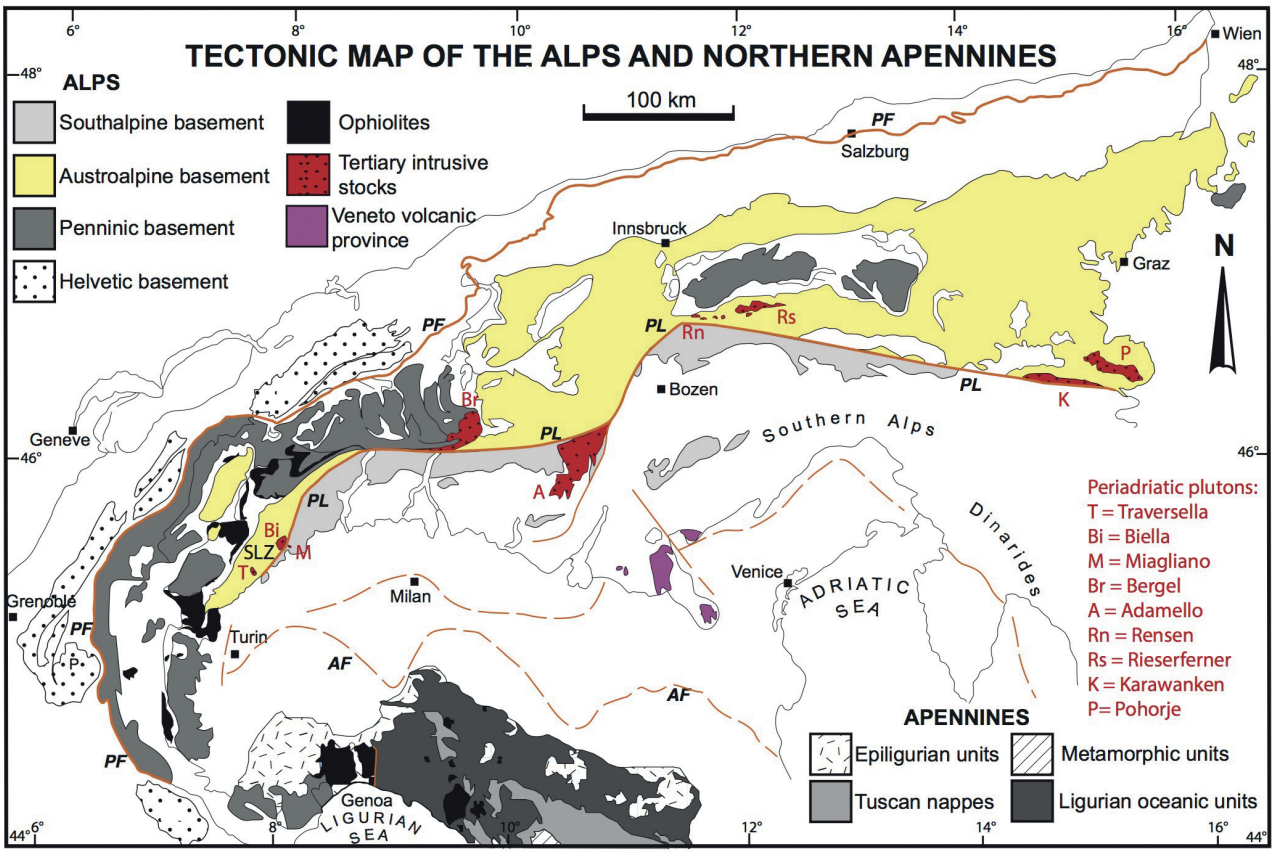

Fig. 1 – Tectonic map of the Alps and northern Apennines. PF = Penninc front; PL = Periadriatic line; AF = Apennine front; SLZ = Sesia Lanzo Zone.

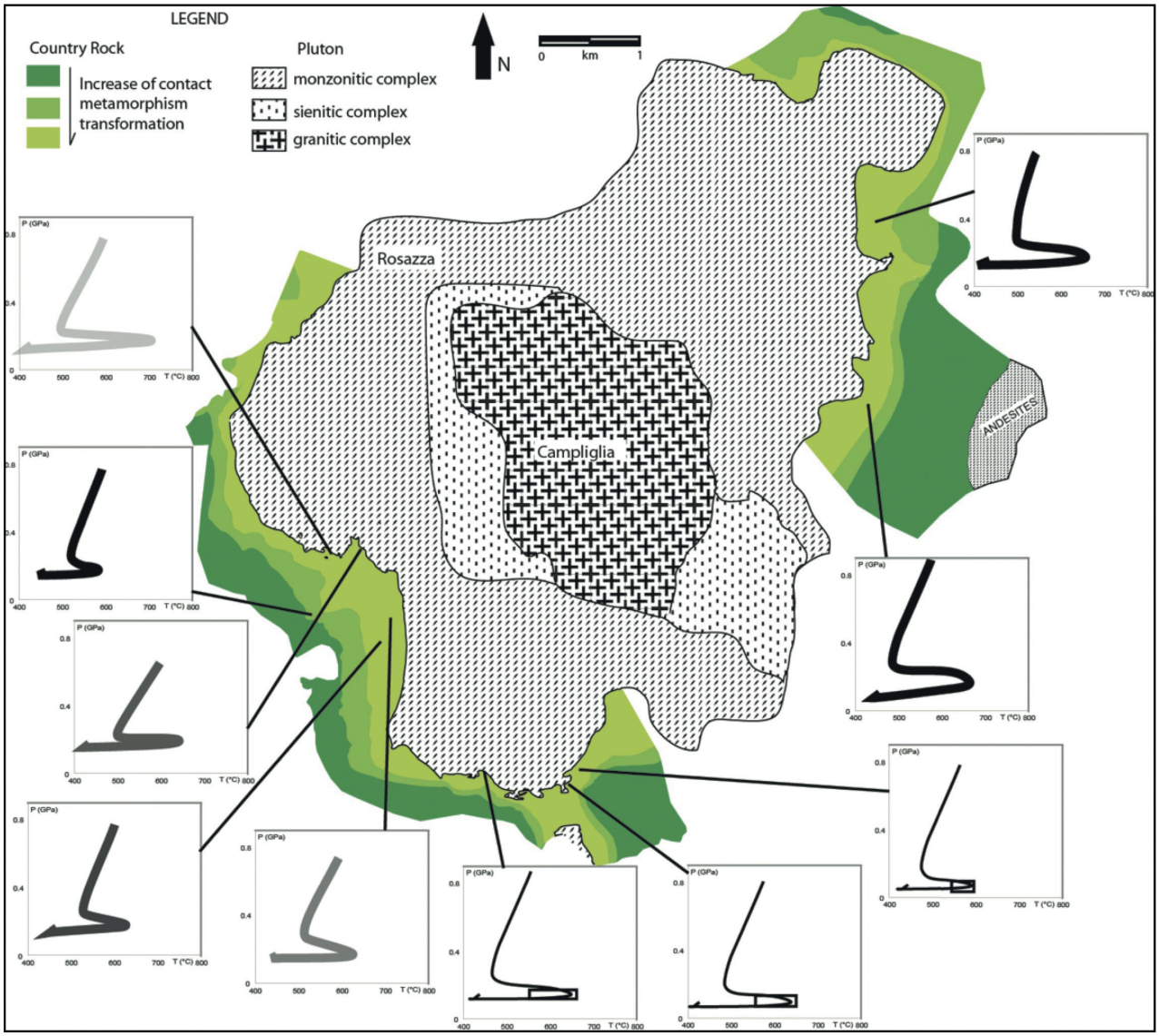

Fig. 2 – Summary of P-T evolution in Biella aureole at different distances from the pluton margin. Thick line: P-T from calculated petrogenetic grids; thin line: P-T from independent thermobarometry only.

metamorphism (i.e. Austroalpine and Penninic domains) from rocks that recorded only shallow structural level deformation (i.e. Southalpine domain). The Periadriatic line is interpreted as the ascent path for the late collisional Oligocene magmas, which emplaced to form the Periadriatic plutons (Rosenberg, 2004). The Periadriatic plutons are traditionally considered as derived from the Alpine slab breakoff (Von Blanckenburg and Davies, 1995). However recently the Tertiary magmatic rocks south of the Periadriatic line, such as the southern Adamello pluton, Veneto Volcanic province, and dykes in the central Southalpine, are supposed to be generated during Alpine subduction (Tiepolo *et al.*, 2011; Bartoli *et al.*, 2013; Bergomi *et al.*, 2015). The Austroalpine domain of the western Alps consists of continental rocks tectonically sampled by the margin of Adria plate during subduction (e.g. Roda *et al.*, 2012) and is actually divided into two main tectonic units, namely the Sesia-Lanzo Zone (SLZ) and Dent Blanche nappe. Both tectonic units were subducted and exhumed during the Alpine cycle when the oceanic subduction was still active (Spalla *et al.*, 1996; Babist *et al.*, 2006; Roda *et al.*, 2012). Between 60 and 80 Ma the SLZ reached the P-peak during subduction (Bussy *et al.*, 1998; Cenki-Tok *et al.*, 2011), corresponding to eclogite conditions at about 550°C and ≥ 2 GPa (Zucali *et al.*, 2002; Zucali and Spalla, 2011). Eclogite metamorphism is followed by decompression blueschist and greenschist re-equilibrations (Pognante *et al.*, 1980; Zucali *et al.*, 2002), related to later

exhumation stages (e.g. Spalla *et al.*, 1991). The shallower levels of the exhumation path took place between 45 and 30 Ma (Inger *et al.*, 1996; Cortiana *et al.*, 1998; Babist *et al.*, 2006; Zanoni *et al.*, 2010). To the east the SLZ is delimited by the Periadriatic line and in its inner part hosts the Biella and Traversella plutons (Zanoni *et al.*, 2008; Zanoni 2010, 2016). The Biella pluton shows concentric zoning with the outer part constituted by monzonite and the inner part by syenite and granite and a calc-alkaline composition (Bigioggero *et al.*, 1994). The pluton has been dated at about 30 Ma (Romer *et al.*, 1996; Berger *et al.*, 2012) and its country rocks belong to the Eclogitic Micaschists Complex (Fig. 2).

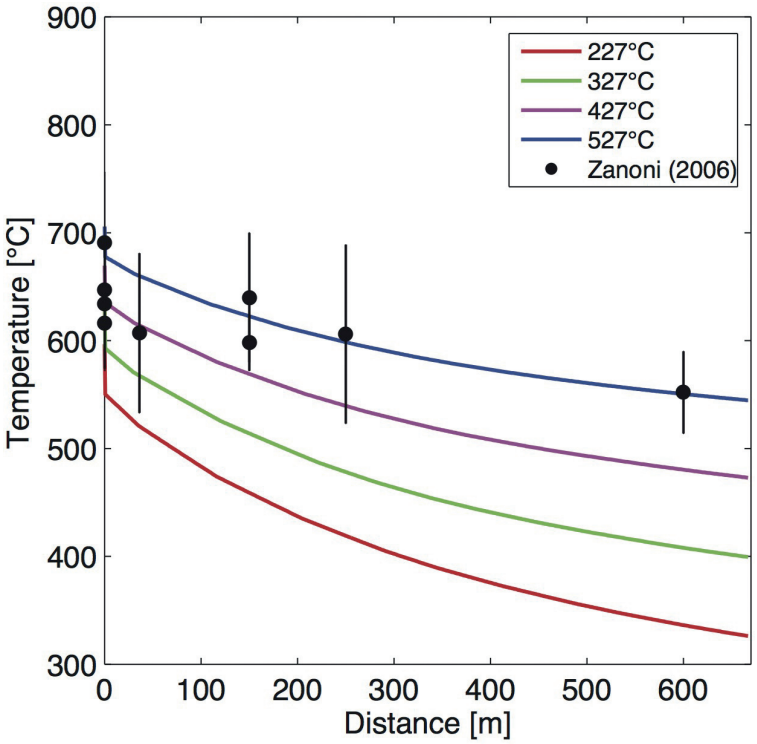

Fig. 3 – Spatial distribution of Tmax due to heat conduction from the pluton to host rock for different base temperatures (lines) and comparison with natural data (dots).

Results. Along the northeaster and southwester margins of the Biella pluton country rocks consist of metapelites, meta-aplites and metagranitods with minor metabasites. During the Alpine convergence country rocks recorded up to six ductile deformation stages that predated the intrusion of the pluton. Only locally syn-intrusive folding and faulting are recorded in the country rocks. Generally brittle structures post-date pluton emplacement. The igneous rocks record a magmatic foliation that in place is parallel to the pluton margin. During the emplacement the country rocks recorded different type of contact metamorphism assemblages that vary with the country rock type and the distance from the pluton margin. The contact metamorphism parageneses form fine-grained coronitic structures that overprinted eclogite parageneses and local greenschist parageneses. With the distance from the pluton the amount of contact metamorphism parageneses decrease. Close to the pluton margin the contact metamorphic mineral assemblages are characterised by plagioclase, K-feldspar, cordierite, biotite, spinel, Al-silicate (sillimanite closer and andalusite farer from the pluton), and locally corundum, orthopyroxene and garnet. Locally, up to about 10 m far from the pluton margin, partial melting is recorded. With the distance from the pluton corundum, orthopyroxene, garnet, spinel, and sillimanite disappear. The contact metamorphic minerals are detected up to about 900 m far from the pluton in plain view (Fig. 2). In igneous rocks interstitial amphibole has an Al content compatible with intrusion depth variable between 4 and 7 km. Ti content in amphibole and equilibrium between amphibole and plagioclase are consistent with intrusion temperature between 670 and 720°C (Zanoni *et al.*, 2010). In the country rocks temperature peak, reached during pluton crystallisation, vary between about 700°C at the pluton margin, and 550°C at about 600 m far from the pluton (Zanoni *et al.*, 2010). The comparison of thermal estimates in the country rocks with a 2D conductive thermal model for pluton cooling shows that the best fit is for initial temperature in the country rocks between 430 and 530°C at 8 km depth (Fig. 3). That involves a thermal gradient of the country rock at time of intrusion ranging between 55 and 65°C/km.

Conclusions. The crustal level of Biella pluton emplacement is as shallow as a few kilometres and this is consistent with magmatic rocks intersecting all ductile structures in the country rocks

and with contact metamorphism assemblages replacing greenschist facies assemblages. The computed extent of the aureole for the simulations is wider than the mapped one because the computed thermal boundary of the aureole is between 300 and 400°C. Finally, the thermal gradient of the country rocks at the time of pluton intrusion is sufficiently high to justify the emplacement of Biella pluton during the accomplishment of the break-off of the Alpine slab.

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