METAMORPHIC EVOLUTION OF THE CENTRAL ALPS: SIGNIFICANCE OF THE SUBDUCTION CHANNEL

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Recent results on the tectonic and metamorphic structure of the Central Alpine belt yield tight constraints on its kinematic and thermal evolution during the Tertiary (summaries in Pfiffner *et al.* 1997; Frey *et al.*, 1999). Our efforts to construct quantitative models of the thermal consequences of plate collision and our ongoing field studies lead us to suggest that the **Southern Steep Belt** (SSB) played a crucial role in the tectono-metamorphic evolution of the Alpine orogen. The SSB is an enigmatic tectonic unit, extending over ~80 km E-W just north of the Insubric lineament, with an average thickness of only ~5km (Fig. 1). Formerly called the "root zone" of the Penninic crystalline nappes, the SSB is known to have been affected during the late Oligocene-Miocene by transpressional back-thrusting and -folding. Subsequently it was intruded by minor calcalkaline magmas and affected by largely amphibolite-facies metamorphism and rapid uplift. Indeed some of the highest grade parts of the Lepontine metamorphic core complex are part of the SSB. Major questions are: Why did Barrovian conditions result? What was the source of the heat?

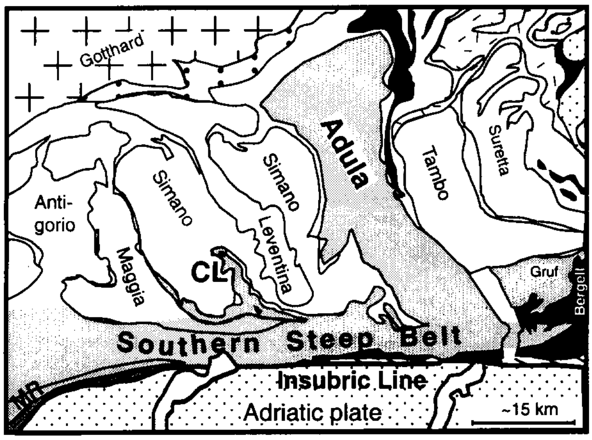

Fig. 1: Tectonic sketch map of the Central Alps with main nappes and units discussed. (CL: Cima Lunga series; MR: Monte Rosa nappe)

We propose that the **SSB** represents a **lithospheric-scale mélange belt**. Its internal structural organisation, highly variable rock contents, and its metamorphic record appear consistent with **tectonic accretion** of fragments at or near the Adriatic continental hangingwall during subduction of oceanic and continental elements (Fig. 2.a). This early part of the evolution, associated with the well established nappe-forming stage of the Central Alps, is responsible for two of the main characteristics of the SSB: (1) the close juxtaposition of many rock types (a variety of ortho- and paragneisses, metaclastics, carbonates and calcsilicates, mafics and ultramafics); (2) the ubiquity of a multitude of discontinuous bands, layers, lenses.

Following this first stage of accretion in the subduction channel, a fundamental **reversal in mass flow** was thus induced by slab break-off (von Blanckenburg and Davies, 1995, 1996). Though the tectonic mechanisms responsible remain controversial, there is ample evidence in the Central Alps that this event (at ~41 Ma) triggered rapid extrusion of several tectonic fragments (Adula nappe, Cima Lunga series, Monte Rosa nappe). Exhumation was guided along the prestructured subduction shear zones (Fig. 2.a), with some elements starting at depths of ~100 km. Rapid ascent within the subduction channel may have involved additional stacking, thrusting and fragmentation, as well as the addition of mantle material (Fig. 2.b).

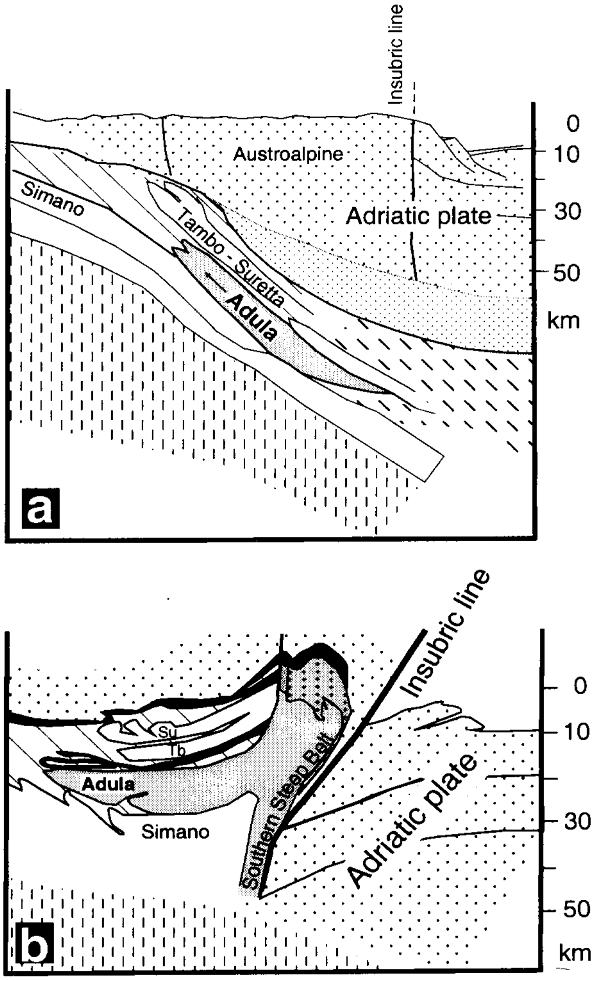

Fig. 2: Tectonic cartoon cross sections through the southern Central Alps, showing the geometry of the major units at different stages. **a**: ca. 40 Ma ago (after Pfiffner *et al.*, 1997); **b**: ca. 19 Ma ago (after Schmid *et al.*, 1996).

It is not clear at present whether the many subunits identified classically as separate "zones" within the SSB (*e.g.* Zones of Mergoscia-Arbedo, Dascio-Bellinzona) were juxtaposed only during this phase of tectonic obduction or were already in mutual contact as a result of earlier accretion to the Adriatic hangingwall. In any case, emplacement to upper crustal levels (~15 km) was complete ~30 Ma ago. At this stage of the evolution the SSB acted as conduit for magmas, and several **calcalkaline intrusives** of the

Bergell-Iorio series crosscut steep backfolds in the SSB (Berger *et al.*, 1996).

In addition, **migmatites** are widespread in the SSB. Leucosomes developed during and following the Insubric backthrusting, vary from highly strained to undeformed. Microstructural evidence of partial melting is observed in quartz-feldspar gneiss, pelites, and hornblende-bearing protoliths. In the latter, the presence of a free, aqueous fluid during partial melting is indicated; some pelitic migmatites show evidence of muscovite dehydration melting. Migmatic gneisses, containing 5-30% leucosome in some zones, host stringers of high pressure boudins and bands, including, **eclogite, garnet peridotite**. For example, at Alpe Arami (which, according to regional mapping (*e.g.* Fischer, 1974), is part of the SSB) peak pressure conditions reached 33±3kbar at 775±25°C (Trommsdorff *et al.*, 1999) shortly following slab breakoff, about 40 Ma ago (Gebauer *et al.* 1996); similar conditions have been documented for garnet peridotite of Monte Duria (Nemis et al, 2000). Garnet amphibolite boudins of the SSB (near Gorduno) indicate rapid decompression from P=23 ±3kbar at 750±50°C to P=8±1kbar at 675±25°C, followed by (±isobaric) heating to 750±40°C (M.Tóth *et al.*, 2000) prior to 30 Ma ago. PT-conditions (Fig. 4) and textures due to decompression reactions in these high-pressure relics in the SSB are strikingly similar to those documented for relics in the southern parts of the Adula nappe (Heinrich, 1982, 1986) and in the Cima Lunga series (Nimis *et al.*, 1999). In view of the strongly imbricated structure in each of the latter two tectonic units and the similarity of high-pressure relics contained in them, we infer that their exhumation may have been closely linked to that of the SSB. Indeed, it seems more than likely that their exhumation occurred jointly, inside the same tectonic channel. To what extent the more western Monte Rosa nappe and the Zermatt-Saas Fee ophiolites (Rubatto *et al.*, 1998), in their ascent from eclogite facies conditions, may have been involved in the same mass flow system, is currently being investigated.

Subsequent to emplacement of these in the Alpine nappe system, beneath the Austroalpine "orogenic lid", the entire Lepontine nappe stack was affected by **Barrovian regional metamorphism**. Essentially postkinematic heating produced well constrained PT-conditions (Todd and Engi 1997); these overprinted also the tectonically exhumed high pressure fragments and the SSB. The age of this metamorphic overprint diminished from ~28Ma in the SSB to ~20Ma in the central parts of the Lepontine (Engi *et al.*, 1995).

The **source of the heat** responsible for this Barrovian event has been identified as a major problem. Jamieson *et al.* (1998) invoked the presence of tectonically accreted radioactive material (TARM) to account for the heat flow required. Though the amounts and distribution of TARM considered by these authors appear unrealistic (at least for the Central Alps), we have pursued their idea, recognizing a predominance of upper crustal material (*i.e.* enrichment in radiogenics) in the SSB. We have constructed models aimed to quantify to what extent mass movement, TARM, and partial melting influenced the thermal evolution of the Alpine subduction/ collision system. Our 2D finite element models (Roselle *et al.*, 2000) incorporate the tectonic scenario sketched above. Model properties for TARM were chosen with reference to the rock types and abundances in the SSB.

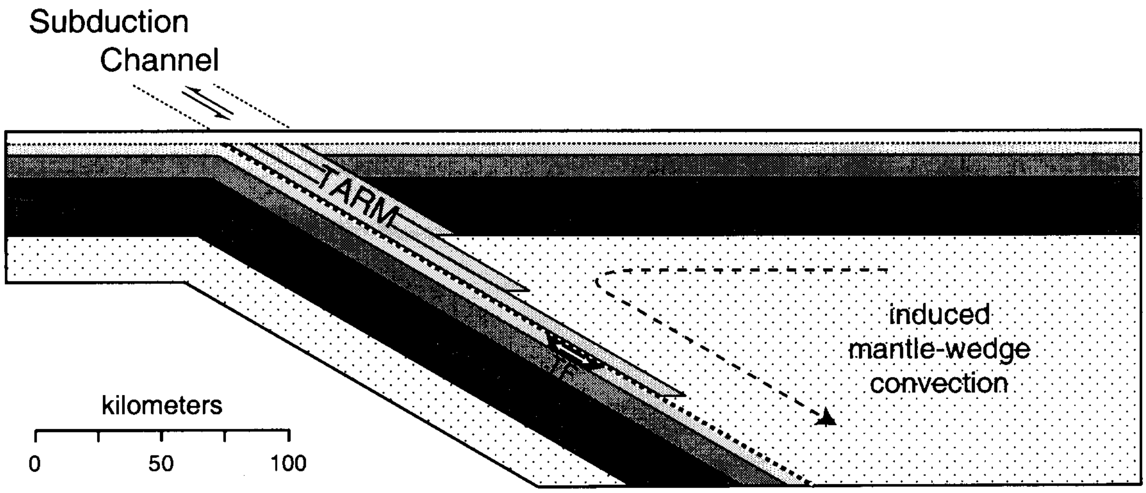

Fig. 3: Topology of finite element models (Roselle *et al.*, 2000) designed to simulate the thermal evolution of the lithosphere during an orogenic cycle. A tectonic fragment (TF) is first a subducted then tectonically extruded along the subduction channel. Upper crustal sheets (TARM) accreting to hangingwall provide additional source of radioactive heat.

During simulated plate convergence, fragments representing *e.g.* the Adula nappe are allowed to be subducted to depths of ~100km prior to rapid ascent (modelled at 3-8 cm/a). Note that subduction of the underlying plate is continuing. Upper crustal sheets (mimicing TARM in the SSB) are allowed to develop along the hangingwall. The combined effects of heat advection, shear heating and conduction are followed in dynamic calculations of the transient thermal field. Model calculations include the effects of partial melting in the crust. Results are depicted as movies in 2D-sections, and predicted PTt-evolutions are compared to those of actual samples in corresponding positions of the Central Alpine belt (*e.g.* from the Adula nappe).

PTt-paths in the Lepontine turn out to be strongly affected by the dynamics in the subduction channel. There is no direct evidence pertinent to the amount (thickness) of TARM nor on the depth it reached in the subduction channel.

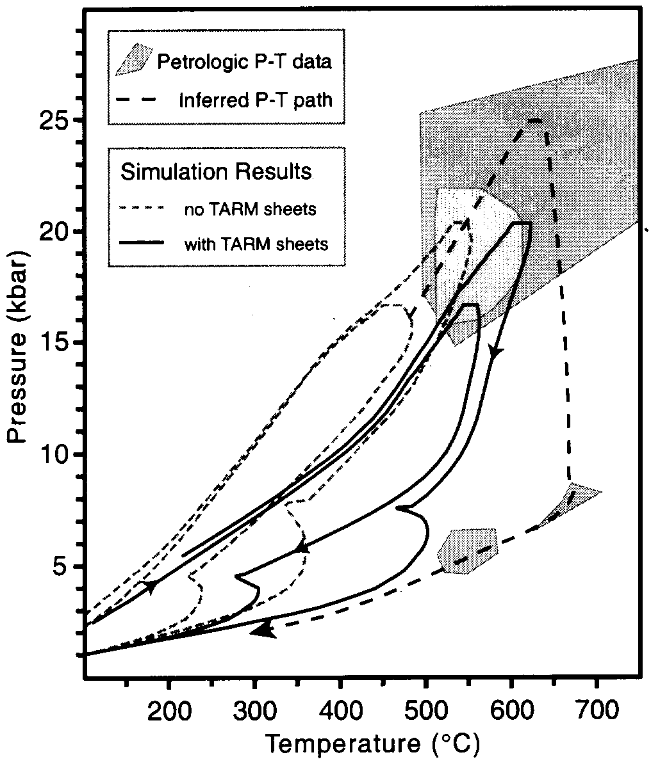

Fig. 4: Thermobarometric results and inferred PT-path from the southern Adula nappe (as reviewed by Frey and Ferreiro Mählmann, 1999) compared to model PTt-paths (Roselle *et al.*, 2000) computed for a tectonic fragment that developped in the subduction/exhumation channel. Note thermal effect of three upper crustal TARM sheets (each of 5 km thickness).

For model temperatures of the high-pressure fragments to be as high as those documented for the Eocene eclogite event (*e.g.* in the Adula nappe), it is sufficient to introduce a few km of TARM, but they must reach depths of 80-100km at least. At least for the (simplistic) exhumation kinematics studied so far, TARM appears to have a minor influence on the temperatures reached upon ascent. Partial melting sustained advective heat input to southern parts of the Lepontine belt and contributed towards amphibolite facies (Barrovian) metamorphic overprint during the Miocene, but the temperatures resulting in our models for the latest stage are still somewhat lower than observed. Additonal heat sources may be required in the form of further intrusives that have not reached the erosional surface visible today. Alternatively, accumulation of larger TARM masses in the frontal (wedge) part of the subduction system may have acted as an additional heat source at mid-crustal levels. Either one of these processes or a combination thereof seems required to generate the final heating phase during emplacement of the SSB and the associated tectonic fragments (Adula, Cima Lunga, Tambo, Suretta, Antigorio, Monte Leone, Monte Rosa?) beneath the Adriatic lid. It is during this final emplacement stage (dated at 35-32 Ma) that the major backfolds in frontal parts of several of these nappes are likely to have developped.

The model presented here for the dynamics of the SSB evidently constitutes but a first attempt to account for its role in the transition from subduction to collision tectonics. Important aspects include the incorporation in the SSB of high-pressure fragments and their rapid exhumation, the formation of late-Alpine migmatite, and the consequent advection of heat to southern parts of the Alpine orogen. At this preliminary stage, our comprehensive model is, by necessity, simplistic, incomplete and only partially successful in accounting for many known geological features of the Central Alps. We stress, however, that despite a century of detailed field studies documenting the heterogeneity of the SSB and stressing its unusual features, no alternative model has been proposed so far for this remarkable tectono-metamorphic unit.

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