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Perspective

Recent advances in Alpine studies: tracking the Caledonian–Variscan belt in the internal western Alps

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Recent advances in western Alps knowledge have concerned several key geodynamic issues. The deep structure of the belt, and then the implication of the lower crust and lithospheric mantle in the collisional deformation were recognized through seismic–reflection and tomographic studies. The origin of the Piedmont–Ligurian Ocean and adjacent palaeomargins was thoroughly elaborated through comparison with central Atlantic and the Galicia margin (it is worth to point here another striking similarity, i.e. with the oceanic margin of southwestern Australia [4]). A wealth of field and laboratory studies have been devoted to the Alpine synkinematic metamorphism, and particularly to the early, high-pressure–low-temperature (HP–LT) metamorphism, which increases from the Fe–Mg carpholite-bearing, low-grade blueschist-facies units of internal Briançonnais, to the eclogite and ultra-high pressure (UHP) units of the internal massifs (IM) and overthrusting ophiolites [9,22 (and references therein)]. The peak pressure mineral assemblages from the ophiolites and IM are now clearly dated from the Early to Late Eocene. Kinematic and thermal models have been coined taking into account the chemical composition of the crust [14]. The HP–UHP metamorphism of western Alps yield a magnificent record of the Penninic subduction history, at last established in the educational documents on the western Alps collisional belt [1,19]. The present-day frontiers in western Alps studies rather concern (*i*) the mechanisms of exhumation of the buried rocks and their quantitative modelling (e.g., [17,20,26] and references therein), (*ii*) the active tectonics of the belt, i.e. the subtle balance between compression and collapse, uplift and decay (field, seismic and GPS studies; see references in [8]).

The paper by Ganne et al. [11] just appeared in *Comptes rendus Geoscience* usefully address the problem of the exhumation mechanisms in the Ambin Massif (Fig. 1). The latter Briançonnais inlier and its northern and southern equivalents (South Vanoise, Ruitor, internal Grand-Saint-Bernard, and Acceglio–Longet, respectively) have been equilibrated in the epidote–garnet blueschist facies, close to 14 kbar, 450 °C, when subducted at ca 45-km depth during the Alpine convergence (e.g., [7,20,25]). However, Ganne et al. [11] also offer a new interpretation of the Alpine versus pre-Alpine structure and metamorphism in the Ambin basement. Indeed, at the crustal scale, western Alps mostly consist of continental crust rocks originating from the European palaeomargin (External Massifs) and its southeastern dependencies (Briançonnais and IM: Dora–Maira, Gran Paradiso, Monte Rosa). Therefore, deciphering the nature, origin and evolu-

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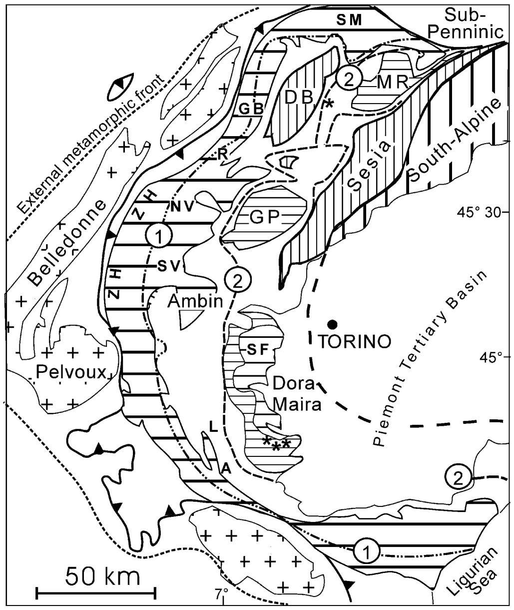

Fig. 1. Sketch map of the Western Alps, with location of the cited areas. Crosses: external massifs. Large horizontal ruling: Briançonnais. Tight horizontal ruling: internal massifs (including SF). Tight vertical ruling: Austro-Alpine. Circled numbers: external-ward boundaries of Eocene HP–LT facies; 1: blueschist-facies; 2: eclogite-facies. Asterisks: UHP occurrences. Bold line with teeth: Penninic front. **A**: Acceglio; **DB**: Dent-Blanche; **GB**: Grand-Saint-Bernard; **GP**: Gran Paradiso; **L**: Longet; **MR**: Monte Rosa; **NV**: North Vanoise; **R**: Ruitor; **SF**: Sanfront–Pinerolo; **SM**: Siviez–Mischabel; **SV**: South Vanoise; **ZH**: Zone houillère.

tion of the basement rocks exposed in the Alps beneath the thin veneer of sediments and oceanic slivers is certainly a reasonable prospect.

Borghi et al. [5] regarded the lowermost complex of Ambin (Clarea Group) as a giant relic of pre-Alpine structures, including a pristine, shallow-dipping foliation underlined by HT micas (Si-poor muscovite, brown biotite) and synkinematic garnets. By contrast, Ganne et al. [10,11] argue that the pre-Alpine, HT foliation is only preserved in microlithons of the shallow-dipping foliation. The latter foliation must be considered as Alpine, as it is associated with synkinematic garnets that contain glaucophane and phengite inclusion trails in their rims. If correct (as it seems), this deprives us of the hope of never restoring the fabric of the pre-Namurian orogen in the internal western Alps. Some Palaeozoic granitoids still display their magmatic structure preserved within metric to decametric undeformed lenses, under eclogitic (Monte Mucrone in the Sesia Zone) or UHP conditions (Brossasco meta-granite of southern Dora–Maira), but the foliation planes, lineations and minor fold axes from the pre-Namurian schist lithologies have been systematically transposed and/or reactivated during the Alpine orogeny – except in the poorly metamorphic External Massifs.

By contrast, mineralogical records of high-grade, HT pre-Alpine metamorphism are widespread in the Briançonnais and IM. Barrovian-type minerals like muscovite, biotite, staurolite, andalusite, sillimanite/kyanite, Mn–Ca rich garnets, hornblende, are frequently preserved, surrounded by Alpine HP–LT overgrowths such as phengite, chlorite, chloritoid, glaucophane. Variscan/Eo-Variscan dates (330–360 Ma) were obtained by Monié [21] on large muscovite and biotite plates from Ambin and Col du Longet schists, and by Giorgis et al. [13] from the Grand-Saint-Bernard (Pontis) basement metapelites. In the Valsavaranche backfold, the Cogne metadiorite yielded ca 360-Ma U–Pb zircon ages [3]. The Variscan record ends with Late Carboniferous–Permian fluviatile deposits in elongated grabens and hemigrabens (e.g., 'Zone houillère', Pontis, Mont Fort), which seem to prefigure the Triassic–Liassic Neo-Tethyan rifting [27]. Late Carboniferous granitoids have been dated in orthogneisses from the Zone houillère [3] and from the lower unit (Sanfront–Pinerolo) of Dora–Maira [6]. They likely occur in the Money unit beneath Gran Paradiso [18]. Gabbros and subalkaline granitoids of Permian ages (270–280) are associated with the early rifting of Pangea on both sides (Penninic and Austro-Alpine/South-Alpine) of the future ocean [3,24].

However, increasing evidence of a complex, long-lasting evolution of the pre-Namurian orogen resulted in the last decade from U–Pb zircon dating (conventional and/or single grain methods) of orthogneisses from the Briançonnais and IM. A complex magmatic activity of Late Cambrian-Ordovician age [3,6,16] is now clearly documented there, including: (*i*) a 520–480-Ma-old alkaline magmatism resulting in banded mafic and felsic horizons ('leptyno-amphibolites' association), mostly observed in the Siviez–Mischabel and Vanoise–Ambin basement nappes; (*ii*) slightly younger, 480–450-Ma-old aluminous intrusives of likely anatectic origin, recognized in the Ruitor–Sapey and Pontis (Grand-Saint-Bernard) nappes. This mafic-felsic magmatism was correlated with the Chamrousse (Belledonne) Cambro-Ordovician ophiolite, the Vieux Chaillol (Pelvoux) leptyno-amphibolites, and similar associations from south Massif Central, Armorica, Iberia, Poland, and first referred [15] to a major, peri-Gondwanan extensional event. However, eclogite lenses surrounded by retro-eclogite associations are preserved in the pre-Alpine amphibolites of the Siviez–Mischabel nappe [27] and Ruitor [16], suggesting a previous, HP–LT event. In the Sub-Penninic units of the central Alps, eclogite formation and subsequent granulite and migmatite stages have been dated at ∼470–445 Ma (see references in [24]). Numerous similar data from the Austro-Alpine and South-Alpine domains eventually suggest that a complete 'south-Caledonian' cycle (instead of a simple extensional event) could have occurred in the whole Alpine realm, as well as in the southern domain of stable Europe [24,28].

To conclude, the stimulating papers of Ganne et al. [10–12] fall within the frame of an active interest for the Caledonian-Variscan legacy to the Alpine basement. It is certainly worth to note also their potential, economic importance: the South Vanoise and Ambin massifs are on the route of the future base tunnel of the Lyons–Turin TGV line (see [2,23,29]).

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