



Review

Review of metamorphic and kinematic data from Internal Crystalline Massifs (Western Alps): PTt paths and exhumation history

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ABSTRACT

Detailed geological mapping combined with micro-structural and petrological investigation allowed to clarify the tectono-metamorphic relationships between continental and oceanic units transition in the Penninic domain of the Western Alps. The three study areas (Gressoney, Orco and Susa sections) take into consideration the same structural level across the axial metamorphic belt of the Western Italian Alps, i.e., a geological section across the Internal Crystalline Massifs vs Piedmont Zone boundary.

The units outcropping in these areas can be grouped into two Tectonic Elements according to their tectono-metamorphic evolution. The Lower Tectonic Element (LTE) consists of the Internal Crystalline Massifs and the Lower Piedmont Zone (Zermatt–Saas like units), both showing well preserved eclogite facies relics. Instead, the Upper Tectonic Element (UTE) consists of the Upper Piedmont Zone (Combin like units) lacking evidence of eclogite facies relics.

In the Lower Tectonic Element two main Alpine tectono-metamorphic stages were identified: M_1/D_1 developed under eclogite facies conditions and M_2/D_2 is related to the development of the regional foliation under greenschist to epidote-albite amphibolite facies conditions. In the Upper Tectonic Element the metamorphic stage M_1/D_1 developed under blueschist to greenschist facies conditions and M_2/D_2 stage under greenschist facies conditions.

These two Tectonic Elements are separated by a tectonic contact of regional importance generally developed along the boundary between the Lower and the Upper Piedmont zone under greenschist facies conditions.

PT data compared to geochronology indicate that the first exhumation of ICM can be explained by buoyancy forces acting along the subduction channel that occurred during the tectonic coupling between the continental and oceanic eclogite units. These buoyancy forces vanished at the base of the crust where the density difference between the subducted crustal units and the surroundings rocks is too low. A stage where compression prevails on the previous exhumation followed, which leads to the development of the regional foliation under greenschist to amphibolite facies metamorphic conditions. Further exhumation occurred after the M_2/D_2 stage at shallower crustal levels along conjugated shear zones leading to the development of a composite axial dome consisting of eclogite-bearing continental-oceanic units (ICM and Zermatt–Saas Zones) beneath greenschist ones (Combin Zone).

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1. Introduction

The Western Alps (Fig. 1) are a subduction related, continent–continent, collisional orogen and its axial portion represents a fossil subduction complex (Austroalpine–Penninic wedge) that was developed before and during continental collision. Large fragments of low-density continental crust were deeply subducted and then exhumed together with ophiolitic remnants of the consumed oceanic lithosphere (Ernst, 1971; Dal Piaz et al., 1972). Petrologic estimates show that these units were variously buried to depths >30–40 km (in some cases >100 km), as clearly documented by blueschist- and eclogite-facies assemblages (Frey et al., 1974, 1976; Compagnoni et al., 1977; Spalla et al., 1996; Oberhänsli et al., 2004) that are locally coesite bearing (Dora Maira nappe; Chopin, 1984; Zermatt–Saas ophiolite at Lago di Cignana; Reinecke, 1991).

A multidisciplinary approach to the study of the Alpine mountain belt allowed a better knowledge of the geodynamic evolution of this orogen and has led many workers to suggest different exhumation mechanisms for high-pressure (HP) rocks (Platt, 1993; Ballevre and Merle, 1993; Reddy et al., 1999).

However, some disputes about the timing of tectonic coupling between oceanic and continental units still remain controversial. Lapein et al. (2007), on the basis of geochronological data and PTt path analysis, had proposed that the Monte Rosa–Gran Paradiso Massifs and the Zermatt–Saas Zone were coupled during eclogite-facies tectono-metamorphic stage and have been exhumed together by a buoyancy-driven process. Instead Kassem and Ring (2004) proposed that the Gran Paradiso has been coupled to the Zermatt–Saas Zone during initial stages of subduction under brittle conditions. Finally Pleuger et al. (2005) suggested tectonic coupling of the Monte Rosa Massif and the Zermatt–Saas Zone after the eclogitic stage, but before the greenschist facies metamorphic re-equilibration.

Even the role of extensional tectonic during orogenesis is still a matter of debate, particularly in regard to its scale, duration and significance in the evolution of convergent plate margins (e.g., Beltrando et al., 2010b). Although evidence for extensional deformation has been found in many orogenic belts, it is still unclear whether extension represents a local exception to the dominant shortening regime, related to lithospheric thickening (e.g., Burg and Chen, 1984; Burchfield and Royden, 1985; Froitzheim et al., 1994; Schmid et al., 1996; Wheeler et al., 2001), or whether it can represent a transient dominant deformation mode at the scale of the whole orogen (e.g., Collins, 2002; Forster and Lister, 2005; Wells and Hoisch, 2008). Detailed studies in the internal zones have illustrated that many of the preserved structural features may not be related to NW-directed thrusting but developed during SE-directed extension (Wheeler and Butler, 1993; Reddy et al., 2003) that is linked to the exhumation of eclogite facies units formed by subduction.

This work has the aim to reconstruct the tectono-metamorphic evolution of the Internal Crystalline Massifs and their relationships with the overlying Piedmont Zone according to detailed geological mapping of three different key-areas reported in Gasco (2010), Gasco et al. (2009), Gasco and Gattiglio (2010) for GP, Gasco and Gattiglio (2011) for MR, and Gasco et al. (2011a) for DM.

In this paper the tectono-metamorphic relationships in three key-areas at the contact between Internal Crystalline Massifs (ICM) and the Piedmont Zone are discussed. Indeed, detailed structural mapping, analysis of the geometrical relationship between the different generations of foliations and petrological investigation give new insights on the relative timing of the tectonic contacts between the Internal Crystalline Massifs and the Lower Piedmont Zone and between the Lower and the Upper Piedmont Zone.

The main results consisted in the identification of a tectono-metamorphic gap (i.e., an extensional shear zone) within the Piedmont Zone that separate a footwall comprising eclogite-bearing units (Gran Paradiso, Dora Maira, Monte Rosa Nappes and the Lower Piedmont Zone) from an hangingwall of eclogite-free rocks (Upper Piedmont Zone). Moreover, the structural evolution of the studied units and of the tectonic contacts separating them was indicative of different relative time for nappe stacking. According to these results some interesting questions arose, whether these shear zones can be traced at the orogen scale and how the structural evolution and the nappe stacking are correlated to the exhumation mechanisms of the Internal Crystalline Massifs.

2. Geological setting

2.1. The Internal Crystalline Massifs

The Internal Crystalline Massifs mainly consist of a composite pre-alpine basement and of a Permo-Mesozoic cover, which is locally preserved at the borders of the nappes. The pre-alpine basement consists of a polymetamorphic complex formed of pre-Carboniferous metasediments and metabasites, and of a monometamorphic complex composed of metasediments, probably of (Permo)-Carboniferous age, known as Furgg Zone in MR (Bearth, 1952; Dal Piaz, 1966; Wetzel, 1972), Money Complex in GP (Compagnoni et al., 1974) and Pinerolo Complex in DM (Vialon, 1966; Borghi et al., 1984). In the ICM are also present monometamorphic meta-intrusives of granite to diorite composition. The intrusives are mainly regarded as late-Variscan (review and discussion in Hunziker et al., 1992). The sedimentary protoliths of the polymetamorphic basement are mainly pelitic with subordinate basic lenses and dolomitic marble levels, whereas coarser clastic facies and graphite-rich pelites predominate in the monometamorphic basement, with widespread metabasite and marble in the Furgg Zone. The polymetamorphic nature of the first complex is illustrated by occasional relicts of pre-Alpine parageneses of HT amphibolite facies (Ms–Bt–Grt–Sil) (abbreviations of minerals are given according to Kretz, 1983 with the update of Bucher and Frey, 2002), together with relicts of the original intrusive contacts with the late-Variscan orthoderivates (MR: Dal Piaz, 1971; GP: Compagnoni and Prato, 1969; Callegari et al., 1969; Battiston et al., 1987; DM: Sandrone et al., 1988, 1993).

The Internal Crystalline Massifs recorded an Alpine metamorphic evolution characterized by two main stages: an eclogite facies one, usually regarded as Eocene in age and a low-*P* greenschist to amphibolite facies re-equilibration of Upper Eocene to Lower Oligocene age (see Beltrando et al., 2010a for a review).

In the Monte Rosa the eclogite facies metamorphic conditions have been estimated with classical thermobarometry giving ca. 16 kbar and 500 °C (Chopin and Monié, 1984), 10 ± 2 kbar and

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