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Structural and sedimentary records of the Oligocene revolution in the Western Alpine arc

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ABSTRACT

The northwestwards-directed Eocene propagation of the Western Alpine orogen is linked with (1) compressional structures in the basement and the Mesozoic sedimentary cover of the European foreland, well preserved in the External Zone (or Dauphiné Zone) of the Western Alps and (2) tectono-sedimentary features associated with the displacement of the early Tertiary foreland basin. Three major shortening episodes are identified: a pre-Priabonian deformation D1 (N-S shortening), supposedly linked with the Pyrenean-Provence orogeny, and two Alpine shortening events D2 (N- to NW-directed) and D3 (W-directed). The change from D2 to D3, which occurred during early Oligocene time in the Dauphiné zone, is demonstrated by a high obliquity between the trends of the D3 folds and thrusts, which follow the arcuate orogen, and of the D2 structures which are crosscut by them. This change is also recorded in the evolution of the Alpine foreland basins: the flexural basin propagating NW-wards from Eocene to earliest Oligocene shows thin-skinned compressional deformation, with syn-depositional basin-floor tilting and submarine removal of the basin infill above active structures. Locally, a steep submarine slope scar is overlain by kilometric-scale blocks slided NW-wards from the orogenic wedge. The deformations of the basin floor and the associated sedimentary and erosional features are kinematically consistent with D2 in the Dauphiné foreland. Since ∼32 Ma, the previously subsiding areas were uplifted and the syntectonic sedimentation shifted westwards. Simultaneously, the paleo-accretionary prism, which developed during the previous, continental subduction stage, was rapidly exhumed during the Oligocene collision stage due to westward indentation by the Adriatic lithosphere, which likely enhanced the relief and erosion rate. The proposed palinspastic restoration takes into account this two-stage evolution, with important northward transport of the distal passive margin fragments (Briançonnais) involved in the accretionnary prism before the formation of the western arc, which now crosscuts the westward termination of the ancient orogen. By early Oligocene, the Ivrea body indentation, which was kinematically linked with the Insubric line activation, initiated the westward escape and the curvature of the arc was progressively acquired, as recorded by southward increasing counter-clockwise rotations in the internal nappes. We propose that the present N-S trend of the Ivrea lithospheric mantle indenter which appears roughly rectilinear at ∼15 km depth could be a relict of the western transform boundary of Adria during its northward Eocene drift. The renewed Oligocene Alpine kinematics and the related change in the mode of accomodation of Africa–Europe convergence can be correlated with deep lithospheric causes, i.e. partial detachment of the Tethyan slab and/or a change in motion of the Adria plate, and was enhanced by the E-directed rollback of the eastern Ligurian oceanic domain and the incipient Ligurian rifting.

1. Introduction

The Alpine orogen resulted from the collision of the Adriatic microplate, supposedly linked with Africa, with the European continental margin of the Western Tethys ocean during Early Tertiary times. The Africa–Europe convergence was oriented N-S (Dewey et al., 1989; Rosenbaum et al., 2002) but the Adriatic microplate may have moved independently during the Tertiary (Channel, 1996; Handy et al., 2010). The Western Alpine orogen is well documented but the paleogeographic restoration is still debated (Schmid et al., 2004; Handy et al., 2010). The arcuate shape has been interpreted in different ways, involving (i) pre-Alpine (Tethyan) paleogeographic inheritance on the European margin side (Lemoine et al., 1989), or due to the shape of the Adriatic indenter (Tapponnier, 1977); (ii) purely collisional origin due to indenter-induced body forces causing variable transport/spreading directions, referred to as the radial outward model (Platt et al., 1989b); (iii) plate motion with rotation of the Adriatic microplate

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and/or part of the Penninic foreland (Vialon et al., 1989; Collombet et al., 2002 and references therein), or with change in relative motion of the Adriatic microplate (Schmid and Kissling, 2000; Ford et al., 2006 and references therein). As proposed by Handy et al. (2010), a sharp change occurred at about 35 Ma, in the motion and configuration of the Adriatic microplate, and the subsequent Oligocene dynamics could be partly driven by the initiation of the Ligurian rollback subduction and associated eastward retreat (Vignaroli et al., 2009).

Nevertheless, the finite radial shape of the Western Alpine arc cannot be simply restored without facing overlap problems in its central part. This geometry results from progressive deformation events from Eocene to Miocene, and involves rotations of ancient kinematic indicators during younger deformation stages, especially in the Internal Zones (Fig. 1; Choukroune et al., 1986; Collombet et al., 2002; Rosenbaum and Lister, 2005). There is evidence of anticlockwise rotation of transport directions through time, both in the External and in the Internal Zones (e.g. Lemoine, 1972; Merle and Brun, 1981; Steck, 1998; Schmid and Kissling, 2000; Ceriani et al., 2001), so that the initial geometry can only be restored through consideration of incremental displacements (Capitanio and Goes, 2006).

The present arc is outlined by a lithospheric thrust ramp commonly called "Crustal Pennine Thrust" (CPT, Fig. 1), exposed at present at the front of the Internal Zones, which are metamorphic, and corresponding to at least an 80 km offset of the Moho along the ECORS-CROP profile (Guellec et al., 1990; Kissling et al., 2006; Lardeaux et al., 2006). This feature occurred quite late in Alpine history and does not fit the earlier Alpine kinematics and geometry, particularly in the Internal Zones (Schmid and Kissling, 2000; Dèzes et al., 2004; Thomas et al., 1999). However, in the footwall of the "Crustal Pennine Thrust", that is, in the External Zone, the displacements and rotations are moderate (Gratier et al., 1989; Aubourg et al., 1999). It is thus possible to observe the interference between differently oriented shortening stages during the development of continental collision more easily than in the Internal Nappes stack the building of which was polyphase and involved in continental subduction.

The aim of this paper is to depict how the Alpine Oligocene plate revolution is recorded within the external part of the Alps, both in terms of deformation and of sedimentary evolution through times. The arguments considered are (i) the interference structures and variably-directed nappe displacements that are found in the External Zone within the Dauphiné and southern Subalpine domains of the western and southwestern parts of the arc (Fig. 2) and (ii) synsedimentary deformation and displacements of the Tertiary foreland basins over the External Zone. A review of structural, metamorphic and chronological data available from the whole western and central Alps provides an integrated framework for the investigated kinematic changes.

Cross-folding in the External Zone has been previously interpreted as an interplay between Pyrenean and Alpine shortening events, that is between the Iberian and Apulian plates kinematic effects (i.e. Lemoine, 1972; Ford, 1996). It is shown here that a significant part of N-S shortening is actually younger than the "Pyrenean-Provence" event and just preceeded the westward Oligocene propagation of the Internal Nappes. It is proposed that these structures, which formed around the Eocene-Oligocene boundary, are linked to the NW propagating Adria–Europe collision during the early stage of the Alpine orogenesis.

2. Structural and stratigraphic setting

The External Zone of the Western Alps (Fig. 1) is composed of elevated crystalline basement massifs having recorded the Hercynian orogeny (Corsini et al., 2004; Guillot et al., 2009), surrounded by a Tethyan sedimentary cover of Mesozoic age and scattered remnants of Cenozoic Alpine foreland basins (e.g. De Graciansky et al., 2010, and references therein). The basement massifs trend NE-SW from Mont-Blanc to Belledonne, and NW-SE in the southernmost part of the Alpine arc (Argentera). The NE-SW trend corresponds to the Hercynian fabric reactivated in large-scale tilted fault blocks during the Tethyan rifting (e.g. Lemoine et al., 1986 and references therein). This part of the European palaeomargin of the Tethys suffered approximately E-W shortening in the footwall of the CPT during Alpine orogenesis (e.g. Dumont et al., 2008 and refrences therein), The Pelvoux massif, which is located at the transition between the NE-SW and NW-SE trends, has a sub-circular shape (Fig. 2) because it suffered several non-coaxial Pyrenean and Alpine shortening events (Ford, 1996; Dumont et al., 2008).

This compressional interference structure was first affected by N-S shortening events commonly assigned to the "Pyrenean-Provence" stage, during late Cretaceous to Eocene times (Meckel et al., 1996; Ford, 1996; Michard et al., 2010). Subsequently, that is during late Eocene to earliest Oligocene, a first set of non-metamorphic nappes ("Embrunais Nappes", Figs. 1 and 2), composed of late Cretaceous deep-water sediments likely of oceanic origin and of Mesozoic cover detached from the distal and middle parts of the European palaeomargin, were gravitationally transported towards more proximal portions of the European foreland (Kerckhove et al., 1978; Merle and Brun, 1981; Ford et al., 2006). It is observed that the later stages of thrust system propagation (from middle Oligocene onwards) were more radially directed (Choukroune et al., 1986; Platt et al., 1989a). The main associated crustal-scale structure corresponds to the "Crustal Pennine Thrust" CPT (Figs. 1 and 2), which represents the limit between the foreland (including the early Embrunais Nappes; E, Fig. 1) and the metamorphic, Internal Nappes stack (Sue and Tricart, 2003). The Pelvoux massif was lying in the footwall of both the NW-ward directed Embrunais Nappes and the W-ward directed Internal Nappes, which crosscut the latter (Dumont et al., 2008). This explains its antiformal dome geometry.

The Mesozoic series overlies a sharp, late Hercynian unconformity, developed as a peneplanation surface which became flat and horizontal over the whole study area between late Carboniferous and early Triassic times. The so-called Dauphiné type (central part of the External Western Alps) and Subalpine Mesozoic sequence (Subalpine massifs and southern part of the arc; Fig. 2) are characterised by the following formations:

- Late middle to Late Triassic: thin peritidal dolomites showing only minor thickness variation, which implies that the whole area remained flat and horizontal until near end-Triassic times. The Triassic sequence, which is only made of carbonates in Dauphiné, remains attached to the basement, but it thickens further S and SE in the SE-France basin (Courel et al., 1984), and also in the Internal Nappes, including evaporites which provide widespread detachment layers. The Triassic sequence is capped by thin alkaline to transitional basaltic flows in Dauphiné, which may indicate the startpoint of Tethyan rifting.
- Lowermost Liassic (early to middle Hettangian) transgressive platform carbonates grade upwards into thick early Liassic to Middle Jurassic hemipelagic marls and limestones. These latter formations are coeval with repeated stages of extensional faulting (Chevalier et al., 2003; Dommergues et al., 2011), and show important thickness and facies changes due to differential subsidence (Lemoine et al., 1986; Dumont, 1998).
- Late Jurassic to early Cretaceous pelagic, post-rift carbonates are rarely preserved in the Dauphiné massifs, but the post-rift unconformity is locally observed thanks to Tithonian limestones directly overlying the Hercynian basement (Barféty and Gidon,