Scanning the Alps in the Pelvoux–Viso geotraverse: a multidisciplinary geological and geophysical approach

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In the framework of the French GeoFrance 3D rechearch program, a new crustal-scale image of the South Western Alps along the Pelvoux-Viso transect has been performed from a combination of :

1. A new geological map coupled with petrological and thermochronological investigations showing the major crustal discontinuities.
2. Spot satellite image analysis and Digitation Elevation Models in order to obtain the main brittle finite strain pattern.
3. Local earthquake tomography based on the regional seismicity.
4. New gravity data to precise the moho depth.
5. Isostatic modelling using a reference surface at 100 km depth.

We precise the geometry at depth of the Monviso eclogitized ophiolites as well as the position of a deformed rigid mantle indenter of Apulian origin. The location of the earthquake hypocenters with respect to the main velocity contrasts and focal solutions combined with geologic and tectonic constraints allow us to propose a tectonic interpretation at crustal-scale of the recent to present-day tectonics.

The proeminent features are :

- The existence of a slice of cold and rigid mantle of Apulian origin beneath the Dora Maira massif. This rigid mantle body is truncated by a system of deeply-rooted vertical faults related to the Insubric line.
- The Apulian mantle acted as an indenter driving the decoupling of the European crust and at least a part of the exhumation of the high-pressure metamorphic units.
- The deep architecture is characterized by the stacking of crustal slices detached from the European lithosphere. Some of these slices, like the Acceglio unit, represent tectonic extrusion within the overlying Schistes lustrés.
- The Monviso eclogitized ophiolites are plunging up to 20 km depth below the Queyras Schistes lustrés.
- The contrasted tectonic significance of regional seismicity : The Briançonnais seismic arc is related to a network of normal faults and associated strike-slip faults developed during a transtensive regime. The Piemontese seismic arc corresponds to the mantle indenter. The Padane arc is related to inverse fault and associated strike-slip faults which account for the shortening of the Apulian crust.

Finally this new crustal-scale geometry of South Western Alps was used to discuss :

1. The present-day tectonic pattern,
2. The respective roles of tectonic and gravity forces as well as the significance of the present-day topography,
3. The significance of the recent alpine geodynamics with respect to a 3D crustal geometry.

Tectonic features of foredeep basins and foreland plates, and their influence on the geometry of collision mountain belts: the example of the Italian Apennines

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The geometry of collision mountain belts changes through time due to the development of progressively younger tectonic slices that are detached from the foreland, and are piled within the orogenic thrust array. Most detached slices bear the structural signatures of early tectonic events, usually consisting of extensional and contractional deformations; the former are generally restricted to pre-orogenic foreland sequences, and may reveal early passive-margin histories, whereas the latter, abundant within syn-orogenic deposits, record the development of foredeep basins. A clear documentation of pre- and syn-orogenic structures from recent and active convergent margins provides, therefore, useful constraints for the study of continental collision processes.

The Central Apennines of Italy, a Neogene belt that originated from the closure of the Mesozoic Tethys Ocean, is an excellent field laboratory for investigating the time-space relationships among pre- and syn-orogenic deformations. The shape of Messinian and Pliocene foredeeps, whose depocentres are systematically located above Triassic and Jurassic fault-bounded depressions, reflects the architecture of the Mesozoic basins and seamounts. This pattern allows for an interpretation of the high differences in subsidence rates during the Neogene in terms of reactivation of Mesozoic passive-margin extensional structures. Integrated surface and sub-surface data show that synsedimentary normal faults within pre- and syn-orogenic sequences inhibited thrust ramp development, thus outlining the dominant controls of pre-existing structures on the geometry of the thrust stack pile. The present arcuate shape of the Central Apennines results from a superimposed structural heritage phenomenon, where the architecture of the Tethyan Mesozoic paleomargin, and the consequent distribution of Miocene–Pliocene syn-orogenic foredeep basins, strongly influenced the construction of the belt. These combined lines of evidence represent, therefore, a critical step towards an improved interpretation and modelling of the Apennines, as well as of other evolving belt – foredeep – foreland systems.

3D finite element models of continental collision zones

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2D finite element models provide valuable insights in the strain history and stress distribution of continental collision zones and orogens, respectively. In addition, fully coupled thermal and mechanical analyses allow to reconstruct the temperature field and the metamorphic evolution of the rocks in the crustal welt. However, 2D models are limited by their plane strain assumption so that important processes like lateral extrusion and orogen-parallel extension cannot be taken into account.

The present study attempts to overcome these limitations by a 3D thermomechanical model. Extending the mantle subduction model of Beaumont & Quinlan (1993) to 3D, it consists of two crustal blocks symmetric about a vertical plane in the center of the evolving model orogen. Continental convergence is described by applying horizontal displacement boundary conditions at the base of one block, while the base of the other is fixed in the direction of convergence.

The vertical model sides are constrained by lithostatic and, optionally, plate boundary forces. A dynamic, i.e. a coupled thermomechanical modeling approach based on the commercial software package ANSYS is used. The model crust is divided into an upper and a lower part, each characterized by specific thermal and mechanical material properties. An elastic-perfectly plastic material law with pressure-dependent yield strength is used to approximate the irreversible deformation in the brittle domain, while ductile deformation is approximated by temperature-dependent creep laws. In order to describe large amounts of plate convergence as well as surface processes a remeshing routine was developed as add-on to ANSYS. This algorithm allows to replace a deformed finite element grid by a new, undeformed one while maintaining the overall model geometry. Marker points of an independent tracking grid, advected by the current finite-element grid, are used to store the material point histories in terms of displacement, deformation and temperature evolution.

3D parameter studies illustrate how rheological properties and temperature field control the amount of lateral extrusion as well as of crustal exhumation. Lateral extrusion is obviously an efficient process to transport rocks away from the center of an orogen both in vertical as well as in horizontal direction. Vertical distribution of lateral transport decides whether this process promotes or obstructs syncollisional exhumation. Lateral extrusion focused on upper crustal levels may drive tectonic unroofing. In contrast, diffuse extrusion distributed over the entire crustal profile results in reduced crustal thickening and decrease in orogenic topography and erosion rate, respectively. Thus, the modeling results show large variations in stress and strain not only between the orogen and its foreland but also within a vertical crustal section.