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Crystalline nappes in the Cental Alps: case study Suretta nappe and Bernhard nappe complex

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The Suretta nappe in the Grisons (eastern Switzerland) and the Bernard nappe complex in the Valais (western Switzerland) are both part of a major basement-bearing nappe stack attributed to the Middle Penninic nappe system of the Swiss Alps which is derived from the Briançon swell. They formed in the course of Alpine southward subduction of the Briançon swell beneath the Piemont-Ligurian ocean and the Adriatic continental margin and subsequent collision with the European continental margin. Their present-day shape intrigued Emile Argand who reconized much of their structure and kinematics.

The *Suretta nappe* is exposed on the eastern flank of the Lepontine dome in eastern Switzerland. The general axial plunge of about 30° towards the ENE of all units in this area together with the Alpine topography provides an oblique section through the entire Suretta nappe. The Suretta nappe was detached by a basal thrust within the crystalline basement. Its internal structure is governed by a major thrust fault and several folds in the upper part of the nappe. A Permian shallow intrusion (Rofna Porphyry complex) occupies the frontal part of the nappe.

The *Bernard nappe complex* is exposed on the western flank of the Lepontine dome in western Switzerland. It consists of an imbricate stack of basement slices and Permian-Triassic clastics. A large-scale fold is associated with an inverted Permian basin.

The structure of both nappes is controlled by pre-existing structures, leading to regional complexities and differences between and within the study areas, which are difficult to predict in any general model. In the case of the Suretta nappe, Jurassic normal faults probably served as a trigger for the localization of early folds and thrusts, and the occurrence and shape of the Rofna Porphyry complex influenced the level of basal detachment of the Suretta nappe. In the case of the Bernard nappe complex, a Permian graben structure largely controlled the deformation style, i.e. fold versus thrust relationships.

The structural architecture of both the Suretta nappe and the Bernard nappe complex can be interpreted as being basically the result of three main deformation phases:

(1) The Avers phase and the Evolène phase respectively are responsible for the northward detachment of Briançon cover units (e.g. Schams nappes, Klippen nappe) and for the contemporaneous emplacement of Piemont-Liguria rocks (e.g. Avers nappe, Tsaté nappe) onto Briançon basement and its adhered cover. This is a typical example for cover substitution. Relics of brittle deformation features at thrust contacts point to an early brittle thrusting stage, marking the onset of a continuous thrusting history during the Paleocene and Eocene.

(2) The Ferrera phase of the Penninic system of the eastern Swiss Alps equals the Anniviers phase of the Penninic system of the western Swiss Alps. These phases represent the main stage of ductile deformation during nappe formation. Mainly nappe imbrication, associated with isoclinal folding affected the Briançon continental crust. The transport direction is inferred to be NNW and deformation probably took place during the Eocene.
(3) Eocene-Oligocene backfolding and backshearing severely modified the geometry of the Middle Penninic nappes: the Niemet-Beverin phase (in the Grisons) and the Mischabel phase (in the Valais). While thrusting continued at the base of the nappes, large-scale folding affected parts of the nappes. The upper levels of the nappes were strongly affected by top-to-the-S(E) shearing in this process, resulting in the formation of mélange zones. Fold axes associated with this phase constantly trend ENE-WSW in both study areas.

The Tauern Window (Eastern Alps. Austria): a new tectonic map, with cross-sections and a tectonometamorphic synthesis

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We present a tectonic map of the Tauern Window and surrounding units (Eastern Alps, Austria), combined with a series of crustal-scale cross-sections parallel and perpendicular to the Alpine orogen (Swiss Journal of Geosciences in press). This compilation, largely based on literature data and completed by own investigations, reveals that the present-day structure of the Tauern Window is primarily characterized by a crustal-scale duplex, the Venediger Duplex (Venediger Nappe System), formed during the Oligocene, and overprinted by doming and lateral extrusion during the Miocene. This severe Miocene overprint was most probably triggered by the indentation of the Southalpine Units east of the Giudicarie Belt, initiating at around 20 Ma and linked to a lithosphere-scale reorganization of the geometry of mantle slabs. A kinematic reconstruction shows that accretion of European lithosphere and oceanic domains to the Adriatic (Austroalpine) upper plate, accompanied by high-pressure overprint of some of the units of the Tauern Window, has a long history, starting in Turonian time (around 90 Ma) and culminating in Lutetian to Bartonian time (45-37 Ma).

The Tauern Window exposes a Cenozoic nappe pile consisting of crustal slices derived from the distal continental margin of Europe (Subpenninic Units) and the Valais Ocean (Glockner Nappe System). These were accreted to an upper plate already formed during the Cretaceous and consisting of the Austroalpine Nappe pile and previously accreted ophiolites derived from the Piemont-Liguria Ocean. The present-day structure of the Tauern Window is characterized primarily by a crustal scale Late Alpine duplex, the Venediger Duplex, which formed during the Oligocene. This duplex was severely overprinted by doming and lateral extrusion, most probably triggered by the indentation of the Southalpine Units east of the Giudicarie Belt, which offset the Periadriatic Line by some 80 km, beginning at around 20 Ma ago and linked to a lithosphere-scale reorganization of the geometry of the mantle slabs.

While this work hopefully contributes to a better understanding of the three-dimensional structure of the Tauern Window, two important problems remain. Firstly, what was the relative contribution of orogen-parallel extension by normal faulting, escape-type strike-slip faulting and orogen-normal compression, all of which acted contemporaneously during the Miocene? The answer to this question has a strong bearing on the relative importance of tectonic vs. erosional denudation. Secondly, there remains the unsolved problem of the quantification of kinematic and dynamic interactions between crustal (Adria-indentation, Carpathian roll-back and Pannonian extension) and mantle structures (reorganization of the