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Three-dimensional geometry and tectonostratigraphy of the Pennine zone, Central Alps, Switzerland and Northern Italy

Michael Maxelon, Neil S. Mancktelow*

Geological Institute, ETH Zentrum, CH-8092 Zurich, Switzerland

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Abstract

Continental collision during Alpine orogenesis entailed a polyphase deformation history (D_1–D_5) in the Pennine zone of the Central Alps. The regional tectonostratigraphy was basically developed during D_1 and D_2, characterised by isoclinal, typically north-closing recumbent anticlines, separated by pinched-in synclines, on the scale of tens of kilometres. Later deformation phases (D_3 and D_4) warped the stack into wavy to open folds. Exhumation of this zone resulted locally in later vertical shortening and folding of already steep fabrics (D_5).

Three-dimensional models of the nappe pile were constructed, based on geostatistical assessment of the regional foliation field and considering the abundant structural field data. These models indicate the existence of five principal tectonostratigraphic levels developed during D_1 and thus equivalent to nappe units s. str.: the Gotthard, the Leventina–Antigorio, the Maggia–Simano (and probably the Monte Leone as well as the Composite Lepontine Series), Lebendun–Soja and Adula–Cima Lunga levels. All these tectonic units formed part of the passive continental margin of Europe prior to the onset of the Alpine orogenesis.

Individual isoclinal post-nappe folds reflect relative displacements on the order of 40 km or more. The most prominent D_2 post-nappe structure is the Wandfluhhorn Fold, structurally equivalent to the northern closure of the Leventina–Lucomagno Antiform. The Lebendun and Monte Leone folds are of similar magnitudes and also affect the whole nappe pile, whereas the smaller Mogno and Molare synforms only refold the Maggia–Simano nappe internally. Principal D_3 and D_4 structures are the tight Mergoscia Synform directly north of the Insubric Fault between Bellinzona and Locarno (Southern Steep Belt), the Maggia Steep Zone, forming the steep western limb of the Campo Tencia Synform and subdividing the Lepontine dome into the Simplon and Ticino subdomes, the Chiéra Synform steepening the dominant foliation in the north (Northern Steep Belt) and the Vanzone and Claro Antiforms steepening the dominant foliation in the south (Southern Steep Belt). The current geometry of the Northern and Southern Steep Belts reflects an interplay between D_4 and D_3, involving both fold interference and reactivation/tightening.

Keywords: Pennine Alps; nappe tectonics; 3D models; recumbent folds; superposed folds; mid-crustal deformation; polyphase deformation

* Corresponding author.
E-mail address: neil.mancktelow@erdw.ethz.ch (N.S. Mancktelow).

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1. Introduction

The Central Alps are probably the best studied example of mid-crustal deformation during continental collision, with observations spanning one and a half centuries. However, as often stated before, the kinematics during the Cenozoic Alpine orogenesis were so *thoroughly three-dimensional* (Merle et al., 1989) that our understanding of the geometry of the deformed units is still limited. This work attempts to summarise the large amount of existing data, together with our own observations, and to integrate them into an internally consistent three-dimensional model. The development of such an internally consistent model is critical to understanding the geometry and kinematics of this 'classic' area in particular and of mid-crustal fold nappe development in general. Modern computer-based technology greatly aids this approach. We use semi-interactive geometrical modelling based on modern GIS (Geographic Information System) and CAEM (Computer Aided Earth Modelling) tools, allowing the integration of an amount of data that would be well beyond the scope of manual methods.

1.1. General alpine framework

The Alps are the result of collision between the European continent and the Adriatic microplate and represent a critical component within the overall Tethyan orogenic framework (e.g. Stampfli et al., 1998). The classical Alpine region stretches from Nice to Vienna, ranging across southeastern France, northern Italy, Switzerland, Austria, northern Slovenia and parts of southern Germany. The molasse basins of southern Germany and the Po Plain limit the mountain belt to the north and south respectively. Whereas the main Alpine trend in the central and eastern regions is WSW–ENE, in the west the Alps form a major arc, before merging into the NNW–SSE-striking Apennines of the Italian peninsula (see Fig. 1). This marked directional change has been attributed to complex and diachronous differential movements related to indentation of the European continent by the Adriatic microplate (e.g. Panza and Müller, 1978; Müller et al., 1980; Schmid et al., 1987, 1989; Pfiffner and Heitzmann, 1997).

The often confusing nomenclature of the rock units exposed in the Alps reflects both the long time period of geological study and the diverse groups (and languages) involved. Regional tectonic units were generally defined on the basis of Mesozoic paleogeography (in the most part for the upper Jurassic to Cretaceous, i.e. during opening of the Alpine Tethys). Four broad tectonostratigraphic divisions are of principal importance:

- The *Helvetic units* represent the shelf and proximal continental margin of the European continent. Reflecting this paleogeographic position, the Mesozoic Helvetic sediments are generally dominated by platform carbonates and marls, with marl dominating in more distal regions. The more southerly marly units are often referred to as *Ultrahelvetic units*.
- The *Penninic units* form the region between the distal European margin and the corresponding distal margin of Adria. From the Engadine Window (Fig. 1) to the west there is a threefold division of the Penninic units into two oceanic domains separated by a continental high. This threefold division is referred to either as North, Middle, and South Penninic or more traditionally (and geographically) as the Valais, Briançonnais and Piemont-Ligurian zones.
- The *Austroalpine units* originate from the stretched and thinned eastern Adriatic continental margin. They now occur as far-travelled allochthonous thrust sheets overriding the Penninic units.
- The *Southern Alps* originate from the stretched and thinned Adriatic margin in the west. In contrast to the west or north vergent Austroalpine structures, south vergent folds and thrusts dominate this zone. Thrust sheets on the scale of the Austroalpine units are not developed.

Milnes (1974b) suggested a subdivision of the Penninic units into *Lower* and *Upper Penninic* units. Paleogeographically the Lower Penninic units were positioned directly north of the Valais zone and are effectively equivalent to the Ultrahelvetic units. The Upper Penninic units in turn represent those immediately south of the Valais zone, i.e. derived from the Briançonnais continental fragment. In addition to this division, Milnes (1974b) introduced the term *Subpenninic Complex* for the structurally lowest part of the Penninic units forming the link between the