Geological background of the western Alps

Introduction

The onset of the Alpine cycle proper could be placed when the Alpine Tethys ocean opened, i.e. in Early to Middle Jurassic time (Favre and Stampfli, 1992; Manatschal, 1995; Froitzheim and Manatschal 1996; Bill et al., 1997), following the opening of the Central Atlantic ocean (Steiner et al., 1998). This is a fundamental difference between Alpine geology s.str. and Tethyan geology s.l., or between the Alpine orogen (Alps and Carpathes) and the Tethysides (Dinarides-Hellenides, the Middle-East mountain belts and the Himalayas s.l.). The NeoTethys ocean, whose closure was responsible for the formation of the Tethysides orogen, actually does not directly interfere with Alpine geology s.str., and the Alpine Tethys should be regarded more as an extension of the central Atlantic ocean in the Tethyan realm rather than a branch of the large and older NeoTethys ocean (Stampfli, 2000). In that sense, the onset of the Alpine cycle could be placed in the Carnian, a period corresponding to the final closure of PaleoTethys in the Mediterranean and Middle-East regions (Stampfli et al., 2001a; 2002a) and to the onset of rifting in the central Atlantic-Alpine domain (Favre and Stampfli, 1992).

The overall tectonic evolution

We can regard the western Alps as issued from an accretionary prism related to the closure of the Alpine Tethys where different geological objects, corresponding to different stages of accretion, can be recognised:

- oceanic accretionary prism of the Piemont ocean (the western Alps portion of the Alpine Tethys), including crustal elements from the former toe of the southern passive margin (lower Austroalpine elements),

- accreted material of the Briançonnais terrain derived from the Iberic plate,

- accreted material of the Valais domain, representing the toe of the European (Helvetic s.l.) passive margin

- accreted material of the former European continental margin and rim basin,(Helvetic s.str. domain).

In time, one passes from the oceanic accretionary prism to the formation of the orogenic wedge proper that we place after the detachment or delamination of the subducting slab in the Early Oligocene (e.g. Stampfli and Marchant, 1995). The resulting heat flux allowed some more units to be detached from the European continental slabs and resulted in large scale subduction of continental material (Marchant and Stampfli, 1997b) and obduction of the more external units:

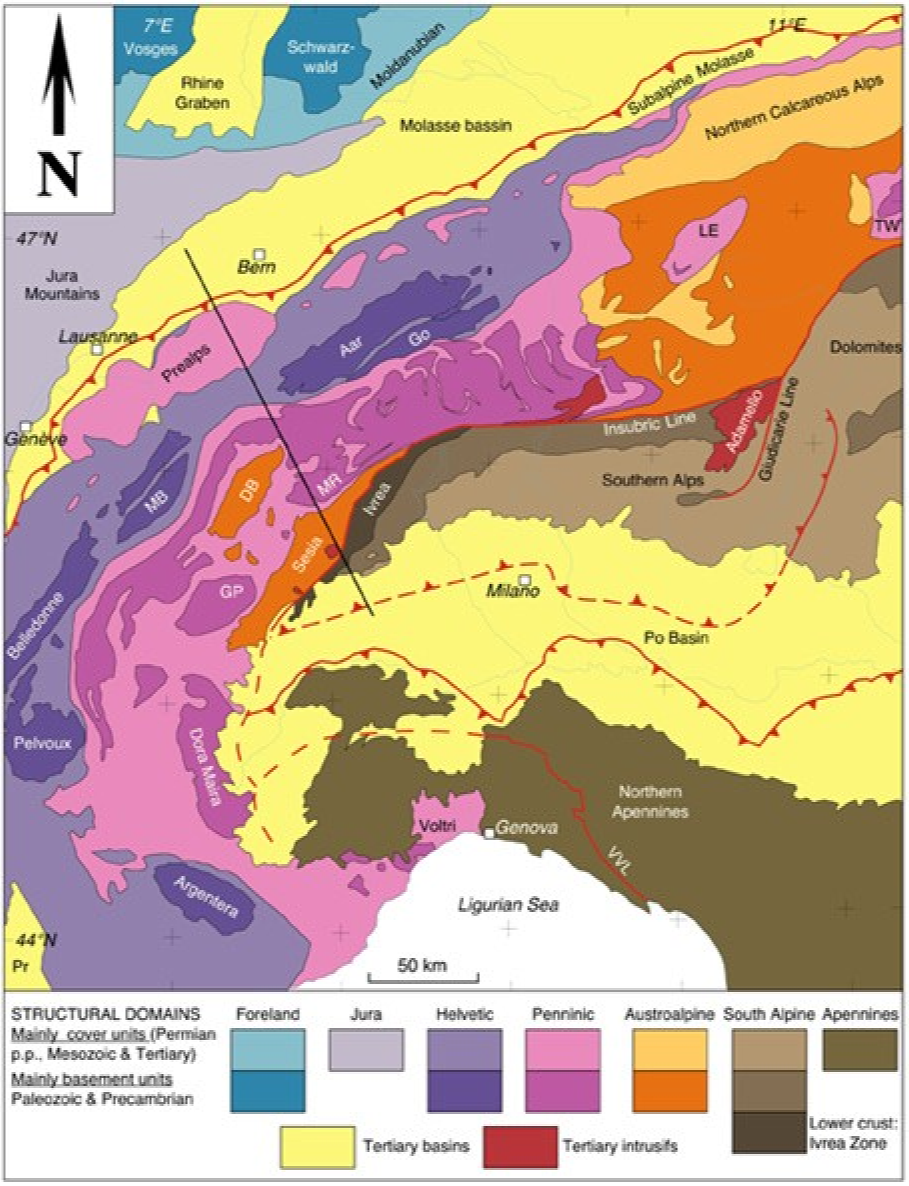
-external Variscan massifs and their cover,

- molassic basin,

- Jura mountains.

To these accretionary events one has to add other tectonic processes such as the "Pyrenean" inversion phase (Late Cretaceous-Middle Eocene) that affected the Helvetic margin accompanied and followed by the Paleogene flexure event of the lower European plate (Paleocene to Miocene) in front of the tectonic wedge.

Figure 1. Tectonic map of the Western Alps (modified from Berthelsen, 1992b).



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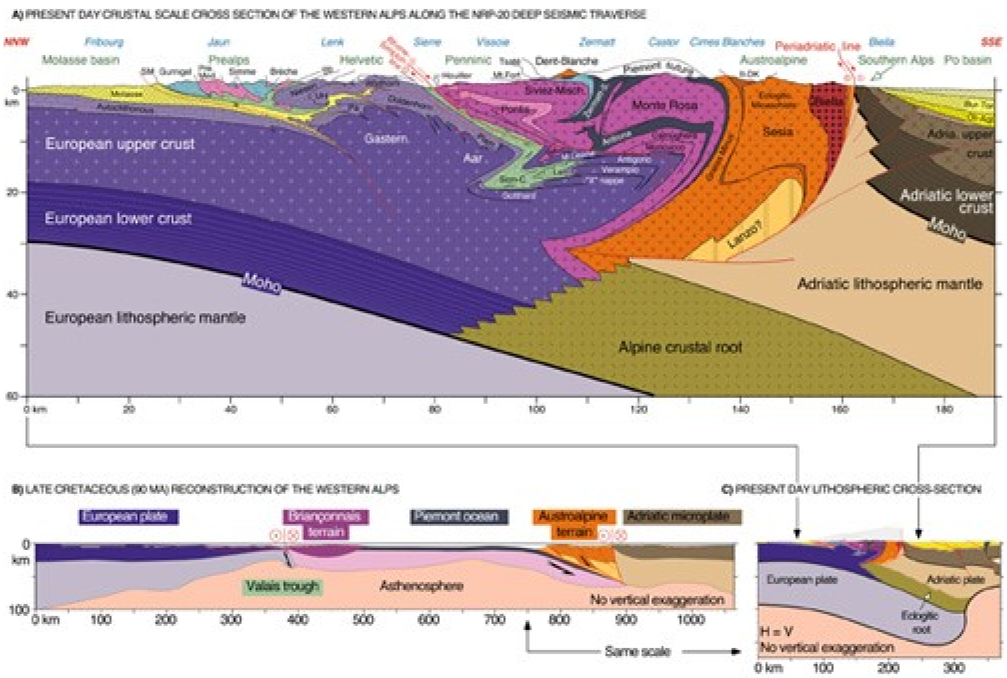
Ao = Adamello intrusions; DB = Dent Blanche nappe; Go = Gotthard massif; GP = Grand Paradis massif; LE = Lower Engadine window; MB = Mont Blanc massif; MR = Monte Rosa nappe; Pr = Provence basin; TW = Tauern window; VVL = Villalvernia-Varzi-Levanto line.

Structural units seen on a present day Alpine cross-section, as in figures 1 and 2, represent remnants of palaeogeographic units whose main bodies were subducted (more than 90%). Each tectonic package is formed of obducted or underplated material with a geodynamic signature, which allows to replace them in their former palaeogeographic domain (i.e. rim basin, rift shoulder, passive margin, oceanic sequences, inversion basin, flexural bulge). In doing so, geodynamic markers (rift shoulders erosion, synrift deposits, denuded mantle) can be used to reconstruct the diverging phases, whereas palaeo-structures, ages of flysch deposits, of exotic terrain deposits and of metamorphism, as well as structural indicators, are used to reconstruct converging processes.

Figure 2. Cross-section of the western Alps



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Cross-section of the western Alps on a western Switzerland transect, and simplified palinspastic model, (modified from Marchant, 1993; Marchant and Stampfli, 1997a). Location shown on figure 2 (thin black line).

The structural framework of the western Alps

The present structural framework of the western Alps is shown in figures 1 and 2 (modified from Marchant, 1993; Marchant and Stampfli, 1997a; Marchant and Stampfli, 1997b), and are based on a structural model developed mainly by the Lausanne school (e.g Escher et al., 1997; Escher et al., 1988; Steck et al., 1997; Steck et al., 1989).

This structural model separates the Alpine belt into different structural domains shown in different patterns on the figures. They are from north to south:

The Jura Mountains

This is the most external domain, incorporated in the Alpine chain last (from 11 to 3 Ma). It is characterised by typical thin skin tectonic with a décollement located in Triassic evaporitic deposits. This décollement horizon runs under the Molasse basin and is rooted in the external massifs overthrust (recent developments on this domain are found in Sommaruga, 1999).

The Molasse basin

Formerly representing a flexural foreland basin, it became a piggyback basin during the Jura overthrusting. It comprises a sedimentary sequence starting with a Mesozoic cover similar to the Jura, followed by a major hiatus from Late Cretaceous to Eocene or Oligocene due to the fore bulge uplift. The Molasse deposits started in Late Oligocene and lasted until Late Miocene and are made of shallow water marine or continental deposits. It is separated in a southern deformed unit (Subalpine molasse) and a less deformed northern domain, which covered a large part of the Jura before its folding. (Burkhard and Sommaruga, 1998).

The Préalpes

This is a composite terrain consisting of elements from the European margin at the base (Ultrahelvetic, Niesen nappes), an important sedimentary sequences derived from the Briançonnais domain s.l. forming the bulk of the Préalpes (Médianes Plastiques and Rigides, Brèche nappes) and the Nappes Supérieures (Gurnigel, Simme, Gets) formerly pertaining to the oceanic accretionary prism of the Alpine Tethys. The Préalpes are therefore quite exotic and represent the exported suture of the orogen thrusted over the external crystalline massifs. For an extended bibliographic data base on the Prealps see: http://www-sst.unil.ch/research/prealps/index.htm

The external massifs

The Aiguilles Rouges crystalline massif and its parautochthonous cover represent the substratum of the Subalpine molasse. The Mesozoic sequence is more distal than the Jura sequence, but the lower part is missing (Triassic evaporites, Liassic platform). This area was a high during the Alpine Tethys rifting as a consequence of unloading to the south in the Helvetic rim basin.

The Mont Blanc crystalline massif and its cover the Morcles nappe, represent the northern part of the Helvetic domain. Those crystalline massifs represent the Variscan basement of the northern fringe of the orogen. They are made of metamorphic rocks in amphibolitic facies, Permo-Carboniferous clastics and Permo-Carboniferous granitoids.

The Helvetic nappes

This classical domain of the Swiss Alps (Masson et al., 1980) consists of the Morcles (Doldenhorn), Ardon, Diablerets and Wildhorn nappes. The first two where deposited on the Mont Blanc massif, the décollement level being generally the Toarcio-Aalenian shales. The Mesozoic sequence of these nappes is different from the Jura-parautochthonous sequence. The Lias-Dogger sequence is influenced by crustal extension which resulted in the formation of the Helvetic rim-basin to the north of the Piemont rift shoulder. The Late Jurassic and Cretaceous sequence is marked by the progradation of a carbonate platform which never succeeded filling-up the Wildhorn basin and never reached the distal rifted Helvetic margin. Major uplift took place in Late Cretaceous and Paleocene time, related to the flexure of the European margin and the Pyrenean movements. A general transgression of the fore-bulge took place during the Eocene forming a new carbonate platform which gave way progressively to the flysch deposits (see figure 16). In France the Helvetic domain is called Dauphinois.

The Ultrahelvetic nappes

These nappes are found in several locations: first as a sole of the Préalpes massif; as klippen on the Helvetic nappes and in the Helvetic root zone. They represent distal portion of the southern part of the Helvetic rim basin, the rift shoulder area and the attenuated northern rifted margin of the Alpine Tethys. The Mesozoic sequence contains Triassic evaporites, a Liassic-Dogger platform sequence and a condensed, starved Late Jurassic-Cretaceous pelagic sequence.

The lower Penninic nappes

These highly metamorphic, mainly crustal nappes represent the former rift shoulder and syn-rift domains of the European margin. They consist of the Verampio, Antigorio and Monte Leone crystalline nappes with incomplete Mesozoic cover and the Lebendun nappe composed of thick clastic deposits attributed now to former syn-rift deposits (Spring et al., 1992). Some Ultrahelvetic nappes and the Niesen nappe were certainly partially deposited on this lower Penninic nappes domain. The Niesen nappe contains Jurassic syn-rift deposits at its base and then inversion related Late Cretaceous clastics.

The Valais suture zone

Coming from this relatively thin structural domain we find mélanges like the Submédianes zone of mixed elements of the Valais trough and distal Helvetic margin origin, found now as separate elements in the Préalpes. The distal clastics and pelagic Cretaceous deposits of the Sion-Courmayeur zone would have been deposited on the Helvetic distal margin and the ocean-continent transition zone (the Valais trough). Denuded continental mantle units like the Geisspfad massifs represent this transition found within the lower Penninic nappes named Valaisan domain in the paleogeographic nomenclature. The infra-Moncucco ophiolitic zone represents Piémont oceanic crust trapped between the Helvetic margin and the Briançonnais exotic terrain. This suture is better expressed in central Switzerland where the Bündnerschiefer accretionary prism (between the European Adula nappe and the Briançonnais Tambo nappe; Schmid et al., 1990) contains a fair amount of Piemont MORB relicts. A Late Eocene mélange is found between the Valais zone and the Briançonnais domain (Pierre Avoi unit, Bagnoud et al. 1998). Generally speaking this domain is poorly dated.

The middle Penninic nappes

This domain belonged formerly to the Briançonnais terrain and is exotic in regard to the more external units, an observation already made by Schardt at the end of the 19th century (Masson, 1976). It is made of the Zone Houillère (Permo-Carboniferous graben), the Pontis basement nappe on which the Préalpes Médianes Plastiques were deposited, the Siviez-Mischabel basement nappes on which the Préalpes Médianes Rigides were deposited. These basement nappes are made of Variscan polymetamorphic rocks with a sedimentary cover including Permo-Carboniferous clastic deposits transgressed by a Mesozoic sequence, most of it detached from its substratum and transported to the north in the Préalpes region. The Préalpes Médianes domain was a rim basin of the European margin, located north of the rift shoulder. It can be regarded as a lateral southwestern equivalent of the Helvetic rim basin and was formerly located south of France. The duplication of these rim basin/rift shoulder elements on a western Alpine cross-section is a fundamental feature of the western Alps.

In the more internal part of the middle Penninic units are found the Mont-Fort nappe (located in the Valais) and Brèche nappe (located in the Préalpes), representing the former syn-rift part of the European margin on the Briançonnais transect. This type of unit are sometime called pre-Piemontais units as they represent the transition to the Piemont ocean (the western Alps part of the Alpine Tethys ocean, its Italian part being referred to as Ligurian, its Austrian equivalent being often referred to as Penninic ocean).

The upper Penninic nappes

This domain represents the suture zone of the Alpine Tethys (Piemont suture). It is made of a large scale accretionary mélange comprising the former oceanic accretionary wedge of the Alpine Tethys (the Tsaté nappe, with relicts of blue schist metamorphism), from which the non-metamorphic Nappes Supérieures are derived (the Gurnigel, Simme and Gets nappes of the Préalpes domain) and a zone of (eo-Alpine?) Alpine HP-LT metamorphism made of mixed oceanic and continental crustal units (Zermatt-Saas Fee and Antrona ophiolitic nappes and the Internal Massifs).

The eclogitic internal massif (Mont Rose, Gran Paradiso, Dora Maira) are continental exotic blocks of disputed origin (lower Austroalpine, Briançonnais or even Helvetic e.g. Froitzheim, 2001), underplated in the accretionary complex, sometimes at great depth (over 100 km for UHP Dora-Maira eclogites) and subsequently mixed with oceanic elements in a westward tectonic escape movement during their extrusion.

The Austroalpine nappes

These mainly crustal nappes in western Switzerland represent the former southern passive margin of the Alpine Tethys. The thinned part of the margin was probably subducted and partially underplated to form the exotic elements now found in the Piemont suture zone (? parts of the Internal Massifs). The rest of this domain (the Dent Blanche klippe and Sesia zone) formed the former back-stop of the Tsaté accretionary prism and was partly overthrusted by the Adriatic micro-continent (South Alpine units). Subsequently this overthrust was largely deformed by the back-folding of the orogenic wedge and the indentation of the Adriatic plate. Major lateral movement of these units took place during the Late Cretaceous and they can be regarded as displaced terrains in regard to Adria. The Sesia zone records Late Cretaceous HP-LT metamorphism.

The South Alpine domain

This domain represents the northern margin of the Adriatic microplate, its northeastern part (Canavese) collided with the displaced Austroalpine elements during their westward escape in Late Cretaceous. So here too, we have a potential duplication of the southern marginal domain and a possibility of trapped oceanic rocks between the Canavese and Sesia units. The Adriatic lower crust is outcropping in the Ivrea zone which forms the present day back-stop of the Western Alps orogen. This back stop was strongly affected by two events: the back folding of the internal units since Oligocene and the emplacement of the peri-Adriatic plutonic rocks derived from the detachment-delamination of the Tethyan slab more or less at the same time.

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