Sissingh W (1998) Comparative stratigraphy of the Rhine Graben, Bresse graben and Molasse Basin: correlation of Alpine foreland events. *Tectonophysics* 300: 2249–284.

Stampfli G, Borel G, Cavazza W, Mosar J, and Ziegler PA (eds.) (2001) *The Paleotectonic Atlas of the PeriTethyan Domain*. CD-ROM, European Geophysical Society.

Ziegler PA (1988) Evolution of the Arctic-North Atlantic and the Western Tethys. *American Association Petroleum Geology, Mem.* 43; 198 p. and 30 plates.

Ziegler PA (1990) *Geological Atlas of Western and Central Europe*, 2nd Edn., Shell International Petroleum Minj. B.V., distrib. Geol. Soc., London, Publishing House, Bath, 238 p. and 56 encl.

Ziegler PA, Bertotti G, and Cloetingh S (2002) Dynamic processes controlling foreland development – the role of mechanical (de)coupling of orogenic wedges and forelands. *European Geophysical Society, Stephan Mueller Special Publication Series* 1: 29–91.

The Alps

O A Pfiffner, University of Bern, Bern, Switzerland

Introduction

The Alps as a Mountain Belt

The European Alps, a mountain chain with elevations reaching almost 5000 m, stretch from Nice to Vienna. The highest peak, Mont Blanc, reaches an elevation of 4807 m. Mont Blanc is part of a belt of granites that stretches from the Pelvoux massif in France to the High Tauern in Austria. The chain runs north–south from Nice, on northward, forming a 90° bend in Switzerland and then continuing eastward towards Vienna (Figure 1). It is narrowest in the transect of Switzerland. The mountain chain is dissected by numerous deeply incised valleys, some of which run parallel to the chain. To the north of the Alps, the Danube system drains into the Black Sea, the Rhine system drains into the North Sea, and the Rhone system drains into the Mediterranean. South of the Alps, the Po system drains into the Adriatic Sea.

The North-Alpine foreland basin, called the Molasse basin, stretches along the north side of the Alps. It was filled by sediments carried in by the rivers draining the Alps northward between 34 and 10 Ma. Similarly, the Po basin to the south of the Alps received the sediments from the Apennine chain and from the rivers draining the Alps southward. Both basins formed during the building of the mountain chain. The weight of the mountain chain flexed the tectonic plates on either side, creating depressions that readily filled and became shallow seas. Up to 35 km of rocks were eroded from the growing Alpine chain and accumulated in these depressions. Judging from the nature of the accumulated sediments, denudation of the growing chain kept pace with the vertical uplift. The rising mountain chain was probably never much higher than it is today.

Major Tectonic Units

The Alps formed as a result of the collision of the Eurasian and African plates, two continental tectonic plates that were initially separated by ocean basins. Starting around 100 Ma, these two plates moved closer to each other, closing the ocean basins between them and ultimately colliding. Consequently, on present-day tectonic maps of the Alps (Figure 2), it is possible to distinguish between rock suites pertaining to one or the other of these continents, or the ocean basins between them. The Helvetic zone, Jura Mountains, and the area north and west of the Alps pertain to the former European margin of the Eurasian Plate; the Austroalpine and Southalpine zones are parts of the former Adriatic margin of the African Plate. The Penninic zone is made up of sediments that accumulated in ocean basins that were located between the two continents, as well as the crustal rocks underlying these basins. During the closure of these basins and the ensuing collision of the two continental plates, the European margin was dragged down south-eastward beneath the Adriatic margin. The Eastern Alps are dominated by rocks of the upper plate, the Adriatic margin (Figure 2). Erosion has removed this upper plate almost completely in the Central and Western Alps. However, erosional remnants (termed 'klippen') of the upper plate in the Western and Central Alps, as well as pebbles carried out into the foreland by ancient rivers, prove that it once occupied much of the entire Alps.

The ocean basins between the Eurasian and Adriatic continental plates formed in response to the opening of the Atlantic Ocean. Figure 3 shows the palaeogeography at 170 and 130 Ma. Two basins, the Valais basin and the Piemont Ocean (sometimes called the Liguria–Piemont Ocean), formed between the European and Adriatic margins of the two continental plates. The two basins were separated by a microcontinent, the Briançonnais swell, which was connected to the Iberian Peninsula at the time. Plate

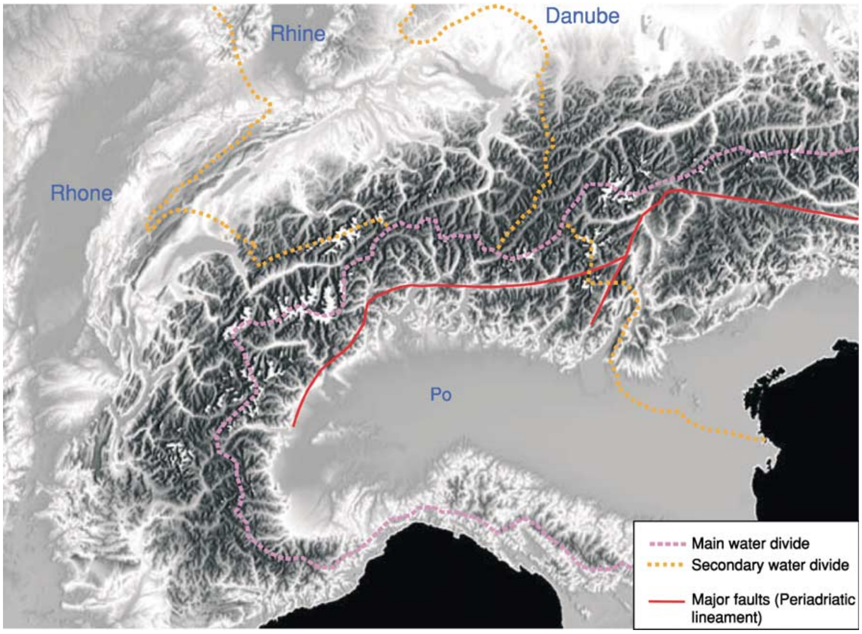

Figure 1 Digital elevation model, showing the large-scale geomorphic features of the Alps and surrounding areas.

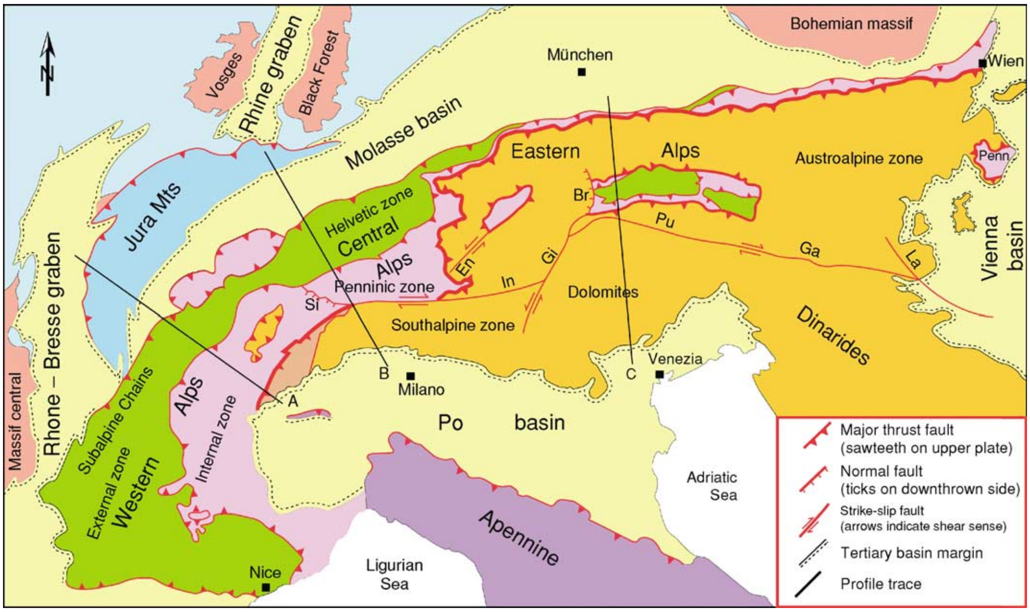

Figure 2 Tectonic map of the Alps, showing the major tectonic units. Sites A, B, and C correlate to orogen profiles A, B, and C in Figure 4. Faults: Br, Brenner; Si, Simplon; En, Engadine; In, Insubric; Gi, Giudicarie; Pu, Pustertal; Ga, Gailtal; La, Lavanttal.

movements during the opening of the Atlantic were such that the African plate moved eastward relative to the Eurasian plate, and both plates moved away from the North and South American plates. At an early stage (around 170 Ma), this sinistral plate movement occurred along a fracture zone that passed through Gibraltar. This opened the Piemont ocean in the area of the future Alps. At a later stage (around 130 Ma), when the opening of the Atlantic had proceeded further north, the sinistral movement occurred along a fault zone passing north of the Iberia–Briançonnais continental fragment along the Gulf of Biscay. This opened the Valais basin in the area of the future Alps.

The fate of the Piemont and Valais basins was controlled by convergence between the Eurasian and

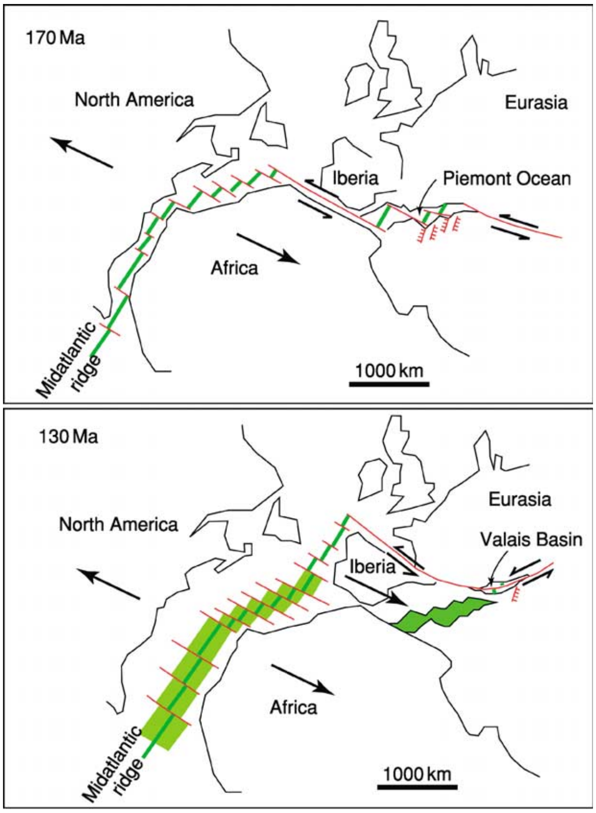

Figure 3 Palaeogeographical maps at 170 and 130 Ma, showing the future Alpine domain in the framework of the associated tectonic plates. Opening of the Piemont Ocean and the Valais Basin was closely linked to the opening of the Atlantic.

African plates. During this convergence, the basins were subducted beneath the Adriatic margin and were closed. Their lower part (the lithospheric mantle) was subducted and recycled into the mantle. Their upper parts (the crust and the sediments deposited in the two basins) were compressed and incorporated into the growing Alpine Orogen, where they now form the Penninic nappes. The European and Adriatic margins were also compressed during convergence and collision of the two plates. Consequently, the Helvetic nappes and the Jura Mountains, both of which consist essentially of Mesozoic shelf sediments, were formed on the European side. Similarly, the Austroalpine and Southalpine nappes represent the deformed Adriatic margin of the African plate.

Rock Types

When discussing the rock types that can be found in the Alps, it is useful to distinguish between rocks that formed prior to the opening of the Piemont and Valais basins and rocks that formed during and after the opening of the basins. In terms of Alpine geology, the older rocks are referred to as basement. This basement consists of two major units, crystalline rocks (granites and polymetamorphic gneisses and schists) and Palaeozoic sediments and volcanics, that pertain to mountain belts formed at 300 to 400 Ma. Granitic rocks are resistant to erosion, thus it is no surprise that they form many of the higher peaks in the Alps (including Mont Blanc).

The younger rocks are Mesozoic and Cenozoic sediments and volcanics ranging in age from 225 to 10 Ma. Large quantities of carbonates accumulated along the shelf seas of the continental margins, reaching thicknesses of more than 1 km. These carbonates now form the high cliffs that dominate the present-day morphology of the Alps. Sandstones and shales accumulated as basins on the continental slopes. In some instances, these basins were flanked by faults that formed in response to the breakup of the continents. Breccias accumulated at the foot of the steep fault scarps. The deepest part of the basins consisted of newly formed oceanic crust. Deep-sea sediments (radiolarian cherts) slowly covered the basaltic lava flows of the newly formed ocean floor.

Deep Structure of the Alps

A number of experiments have been designed to image the structure of the Alps to depths of over 50 km. Dynamite detonations and vibrator trucks located over a subsurface target generate seismic waves that travel downward and then are reflected back upward at various discontinuities in the Earth's crust. The upward-reflected waves (or echoes) are recorded by a surface array of geophones and processed into a coherent 2-dimensional image. The resulting seismic sections can then be interpreted in terms of subsurface geological structure. Figure 4 summarizes the findings for three transects through the Alps.

Western Alps

Within the framework of ECORS-CROP (CROP = CROsta Profonda = Deep Crust; ECORS = Etude de la Croûte Continentale et Océanique par Réflexion et Réfraction Sismiques = Study of the continental and oceanic crust by reflection and refraction sesimics), a joint project between France and Italy studying the deep continental crust by reflection and refraction sesimics, researchers have profiled a transect across the Western Alps (site A in Figure 2). The profile in Figure 4A summarizes the findings of the ECORS–CROP project. The Western Alps have an asymmetric structure. On the European margin, i.e., in the western part of the Alpine orogen, the crust–mantle

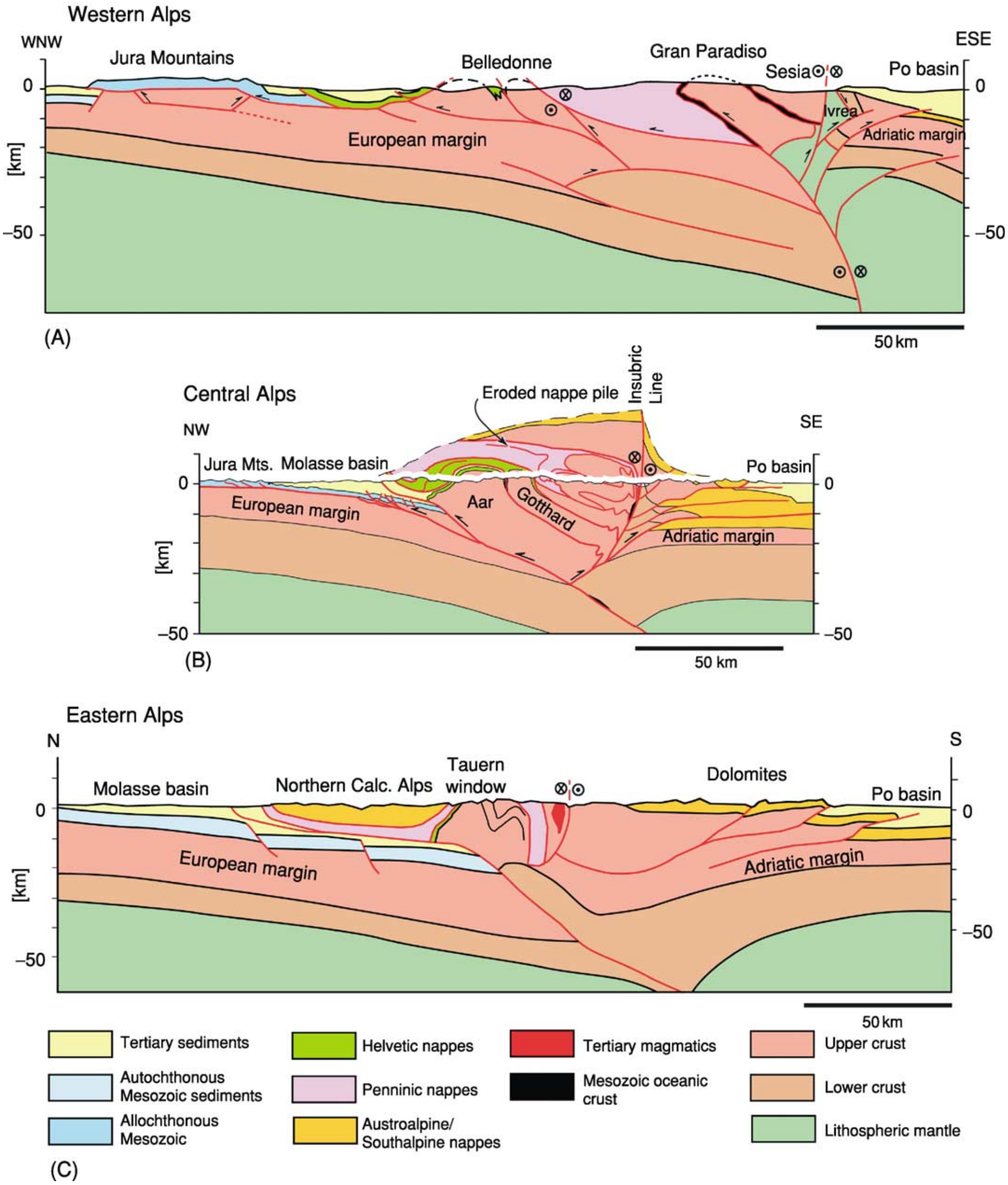

Figure 4 Three profiles through the Alps, showing the deep structure of the orogen. The profile sites are shown in Figure 2. (A) Transect through the Western Alps of France and Italy. (B) Transect through the Central Alps of Switzerland and Italy. (C) Transect through the Eastern Alps of Austria and Italy. See text for discussion.

boundary dips to the east, attaining depths exceeding 50 km beneath the orogen. Much of the crustal root is made up of lower crust, which appears to be tripled in this transect. This stacking was accomplished by thrust faults that moved entire blocks of crustal rocks upward towards the west. On the Adriatic margin, on the other hand, the crust–mantle boundary rises towards the surface, proceeding westward. This rise is accentuated by several thrust faults, which also affect the lower crust. In the case of the Ivrea zone, these lower crustal rocks and pieces of the mantle actually outcrop at the surface. The asymmetric structure of the Western Alps is a consequence of the collision of the Adriatic and European margins resulting from the convergence of the African and Eurasian plates. The ocean basins located between the two margins were highly deformed by these plate movements. The sediments, as well as their crustal substrate, were compressed, shortened, and stacked. These rocks now form the Penninic nappes shown in Figure 4A. The upper crust of the European margin was also shortened and thickened in the process of collision, forming a large-scale basement uplift (the Belledonne massif) within the Alps.

Further out towards the foreland, shelf sediments of the European margin were detached from their substrate, shortened by folding and thrusting, and transported towards the west. They now form the Jura Mountains. In addition to all of the thrusts and folds that represent WNW–ESE shortening, there were substantial movements in and out of the plane of the section shown in Figure 4A. These movements were related to strike–slip motions that displaced the Adriatic margin towards the north relative to the European margin.

Central Alps

Investigation of the Central Alps by the Swiss National Research Project (NRP) 20 has provided results complementary to those of the European GeoTraverse (EGT). The EGT study assessed the continental lithosphere that runs from the North Cape across Europe to Tunisia. Several transects were profiled across and within the Swiss Alps. Figure 4B, a profile along the central traverse of NRP 20, has been extended to include the Jura Mountains and the Po basin. As with the Western Alps, the asymmetric structure of the Central Alps evolved during convergence between Eurasia and Africa. The lower crust of the European margin extends at constant thickness beneath the Adriatic lower crustal wedge. The tip of the latter is exposed at the surface. The centre of the orogen consists of European margin upper crustal rocks that were stacked by thrust faults during plate convergence and collision. The associated heat and pressure transformed the rocks: granites became orthogneisses, sediments became paragneisses, and limestones became marbles. The mineral assemblages "frozen" in these metamorphic rocks allow determination of the temperature and pressure paths these rocks took during collision and the ensuing denudation.

Along one major fault, the Insubric Line, the nappe stack was moved upward and southward, but erosion kept pace with this uplift and removed a large section of the Austroalpine and Penninic nappes. Studies of the rocks outcropping at the surface indicate that they were once buried to depths exceeding 25 km. Strike–slip motion along the Insubric Line moved the Adriatic margin westward relative to the European margin in the later stages of the collision. In the north-western part of the orogen, the thrusting was chiefly towards the north-west. Conversely, thrusting was directed towards the south-east in the south-eastern part of the orogen. In both cases, the sequence of thrusting was from the centre of the orogen towards the forelands. This can be interpreted as the result of the collision of the European and Adriatic continental margins. Deformation of the crust occurred within the zone of contact and the deformed rocks were shoved on top of each other to form an orogenic wedge, similar to the wedge of snow forming in front of a moving snowplough. Shortening related to plate convergence and collision is particularly accentuated along this transect of the Alps. The associated uplift and erosion are indicated by the high degree of metamorphism of the exposed rocks outcropping at the surface. The focused horizontal shortening (and vertical stretching) explain why the Alpine chain is particularly narrow in this transect.

Eastern Alps

The Eastern Alps have been studied in a joint project (TRANSALP) between Germany, Austria, and Italy. A seismic transect through the Eastern Alps and the Dolomites has produced the seismic data and geological interpretations shown in Figure 4C. The crustal structure of the Eastern Alps is rather different from that of the western and central sections. The European margin shows a thin slab of lower crust dipping to the south. The Adriatic lower crust is thicker and has a piece protruding into the European upper crust. The upper crust of the European margin forms a large-scale basement uplift that is exposed in the Tauern window. The Helvetic nappes are virtually absent in this transect and the Penninic nappes make up only a proportionally small volume . The upper crust of the Adriatic margin, on the other hand, is much more voluminous. It is over 30 km thick and is shortened by thrust faults. Important strike–slip motions have displaced the Adriatic margin to the west, relative to the European margin along the Pustertal line.

Alpine Nappe Structures

Collision between the two margins of the Eurasian and African plates, like the crash of two cars, led to severe deformation (folding and fracturing) of the rocks within the zone of contact. Large-scale fractures in a zone of compression led to the formation of thrust faults that transported entire crustal blocks upward on a gently inclined fault surface. The displaced blocks were typically several hundreds of kilometres wide, 50–100 km long, and only a few kilometres thick. These thrust sheets are termed 'nappes', from the French for 'tablecloth', because of their shape. The (horizontal) shortening of the continental crust also led to the folding of layers of rock. The folds, which occur on every scale, from millimetres to kilometres, are an expression of the penetrative deformation of crustal rocks.

Thrust Faults

Geologists in the nineteenth century were puzzled when they saw older rocks lying on top of younger rocks. One of the classic locations where this is readily observed is in eastern Switzerland (Figure 5). The rugged peaks of the Tschingelhore are formed by Permian clastic sediments (roughly 260 Ma), but the rock immediately beneath the peaks consists of Jurassic limestones (formed about 150 Ma). The famous Glarus thrust is the sharp contact between the close proximity of the Permian and Jurassic units. The geographical extension of the Glarus thrust can be seen in a profile across eastern Switzerland (Figure 6). The Helvetic nappes were displaced northward along the Glarus thrust over a distance of 50 km. In order to displace a thrust sheet, a weak, basal lubricating layer must be present. In the case of the Glarus thrust, this lubricating layer is a highly sheared limestone, which was scraped off the footwall and dragged and drawn out along the thrust surface. It now forms a layer roughly 1 m thick and can be traced northward over a distance of some 30 km (in Figure 5 it is visible as a thin, light line along the horizontal contact).

As is evident from Figure 6, substantial internal deformation affected the rocks below and above the Glarus thrust. Highly sheared folds and thrust faults, repeating the various sedimentary layers many times, can be observed in the Mesozoic sediments beneath the Glarus thrust. Similarly, the rocks of the displaced block above the Glarus thrust show thrust faults and folds. One of these thrust faults, the Säntis thrust, displaced the younger Cretaceous strata much further north, compared to the older (Triassic to Jurassic) strata. In this case, the thrust fault was lubricated by a thick layer of shales, which have relatively low shear resistance.

Nappe Internal Deformation

As a thrust sheet is compressed, detached from its substrate, and transported, it undergoes internal deformation. The type of deformation depends largely on the nature of the rocks involved. In the case of a layered sequence of sedimentary rocks, folding prevails, whereas if the mechanical contrasts are low, such as sometimes occurs in a suite of granitic and gneissic rocks, the deformation may be more homogeneous. If mechanically weak layers of rocks are present, the deformation is focused and thrust faults may develop. All of these processes – folding, faulting, and homogeneous deformation – may take place jointly.

Figure 7 shows folded Cretaceous and Eocene limestones (100 to 50 Ma) that form an asymmetric anticline. The folded limestones are overlain by older rocks. Dolomites (~220 Ma) form the yellow cliff beneath the summit and crystalline basement rocks (>300 Ma) make up the dark summit. These older

Figure 5 The Glarus thrust in the Tschingelhore (between Flims and Elm in eastern Switzerland). The thrust fault is visible as a sharp horizontal contact between the older rocks that form the rugged peaks and the younger rocks that form the cliffs above the snowfields.

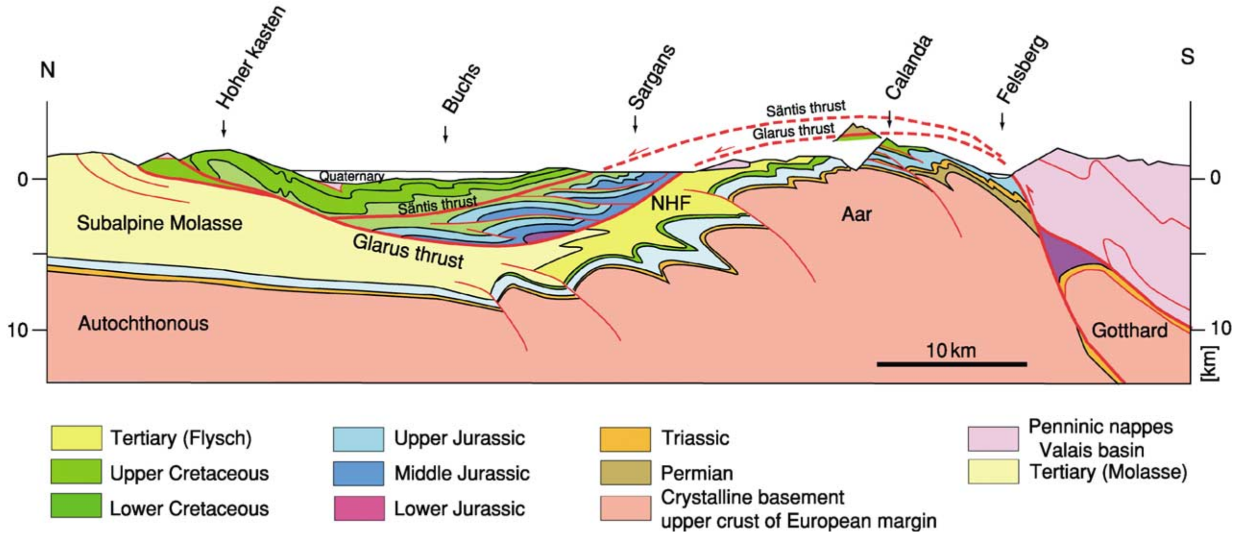

Figure 6 Profile through the Helvetic nappes of the eastern Swiss Alps. The Helvetic nappes were displaced along the Glarus thrust over a distance of around 50 km. But the rocks above and below the Glarus thrust were also intricately deformed, as is evident from the fold-and-thrust structures. The Säntis thrust displaced the uppermost part, the Cretaceous strata, of the Helvetic nappes an additional 10 km to the north. Deeper down, the crystalline basement rocks of the Aar massif now form an anticlinal upwarp. NHF, North Helvetic Flysch.

Figure 7 Folded strata in the flank of Piz d'Artgas ('peak with arcs'), overthrust by older rocks forming the summit and the yellow cliff beneath.

rocks were emplaced along a thrust fault that is located near the base of the yellow cliff. Figure 8 is a profile across the Tauern window, where the upper crust of the European margin forms a large anticlinal fold. In the centre of the upwarp, erosion has removed the higher nappes, thus providing an insight into the formerly deeper parts of the orogen. The crystalline basement rocks in the core of the upwarp were compressed and internally shortened. From the deformed mineral grains of the rocks it is possible to determine how much horizontal shortening and vertical stretching actually occurred and to reconstruct the shape of the upwarp prior to this homogeneous deformation. The present-day shape of the Tauern upwarp (Figure 6), as well as its reconstructed geometry prior to homogeneous shortening, provide a reminder of the ductile behavior that granitic rocks can exhibit in the course of plate collision.

The Klippen nappe, a Penninic nappe in the French–Swiss Alps, is a classic example of a style of internal deformation characterized by fold-and-thrust structures (Figure 9). The lubricating layer (evaporites) at the base of the nappe consists of a thick layer of anhydrite. This rock type, which has a particularly low shear strength, forms when very shallow areas of seawater evaporate. The great thickness of the weak evaporite layer in the northern part of the section shown in Figure 9 facilitated the formation of large-scale folds, and the anhydrite was able to flow into and fill the fold cores. In the southern part of the nappe, the anhydrite layer is thinner and the deformation style is characterized by imbricate thrusting. Each thrust fault is parallel to the strata and followed the weak anhydrite layer.

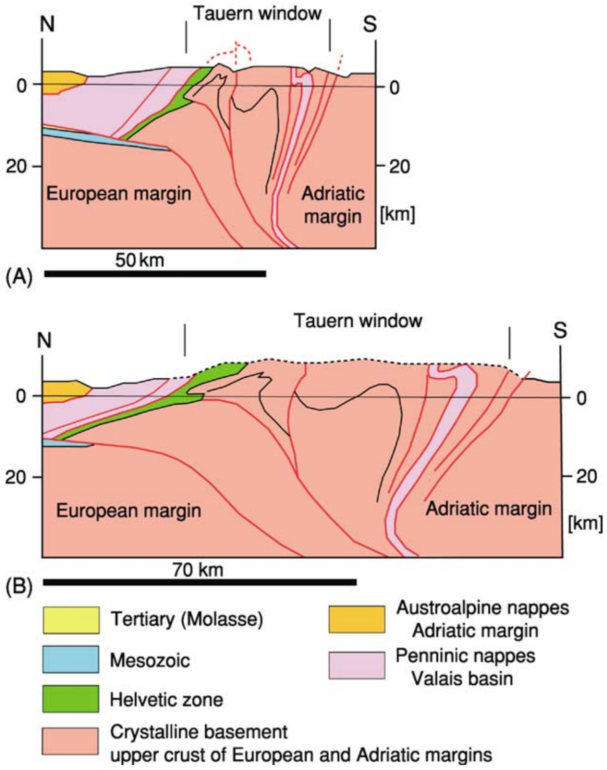

Figure 8 Profile across the Tauern window (Eastern Alps). (A) Present-day geometry; (B) retrodeformed to the configuration that existed prior to homogeneous horizontal shortening and vertical stretching.

The Making of the Alps

Geologists working in the Alps had recognized early on that oceanic sediments occurred within the mountain range and were juxtaposed with rock units typical for continents. The pyramid of the Matterhorn (Figure 10), for example, is composed of crystalline basement rocks that were formed more than 300 Ma and which originated in the former (Adriatic) margin of the continental African Plate. In contrast, the base of the pyramid consists of volcanic and sedimentary rocks that formed in an ocean basin (the Piemont Ocean) 170 to 100 Ma ago. The Piemont Ocean formed in response to divergent motion between the Eurasian and African plates (see Figure 3). The Alpine Orogen evolved in a number of steps associated with relative movements between the Eurasian and African plates. The ocean basins between the two continental plates were closed in the process. The

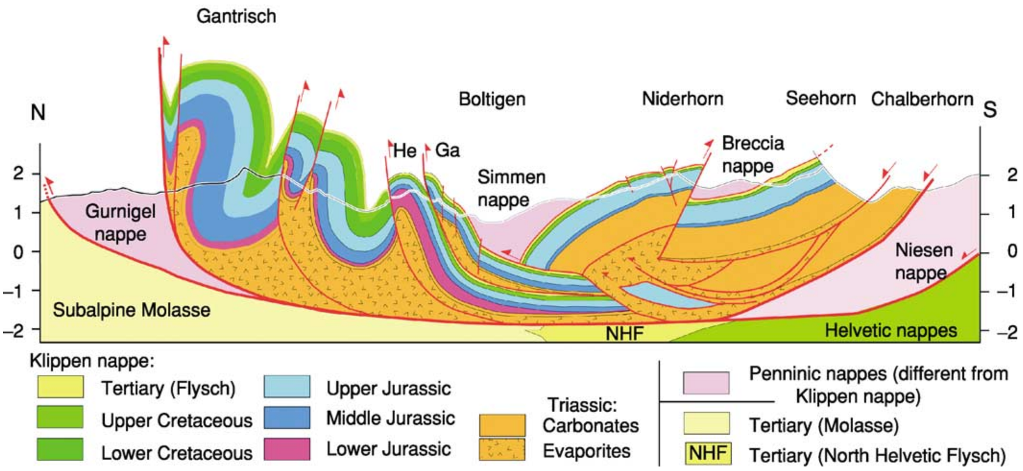

Figure 9 Profile across the Penninic Klippen nappe of the western Swiss Alps. The Klippen nappe consists of sediments of the former Briançonnais swell that have been overthrust onto sediments scraped off of the Valais basin and the Piemont ocean (the Niesen and Gurnigel nappes, respectively). The nappe internal structure of the frontal north-west part of the Klippen nappe is dominated by folding, whereas in the internal south-east part, imbrications stemming from thrust faulting prevail. Ga: Gastlosen thrust, He: Heiti thrust.

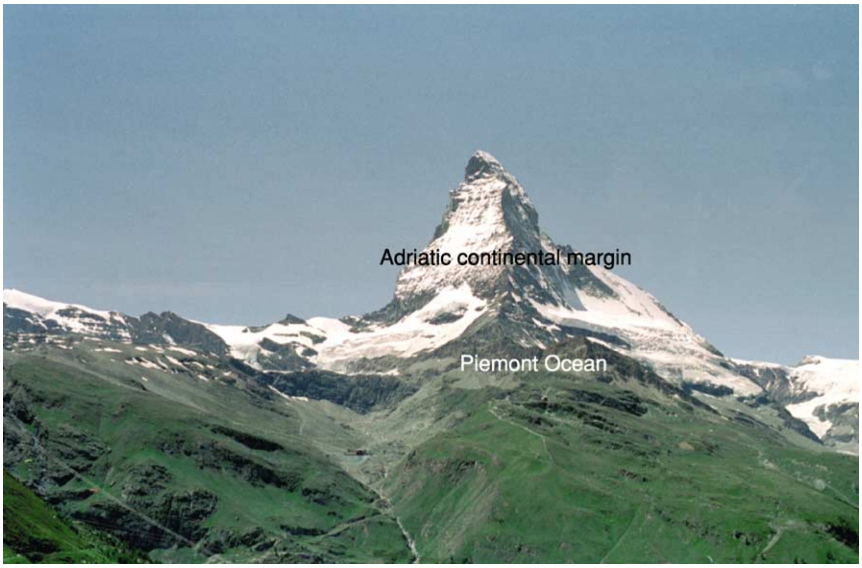

Figure 10 Crystalline basement rocks pertaining to the margin of the African continent build up the Matterhorn peak and overlie the younger volcanic and sedimentary rocks that formed in the Piemont Ocean.

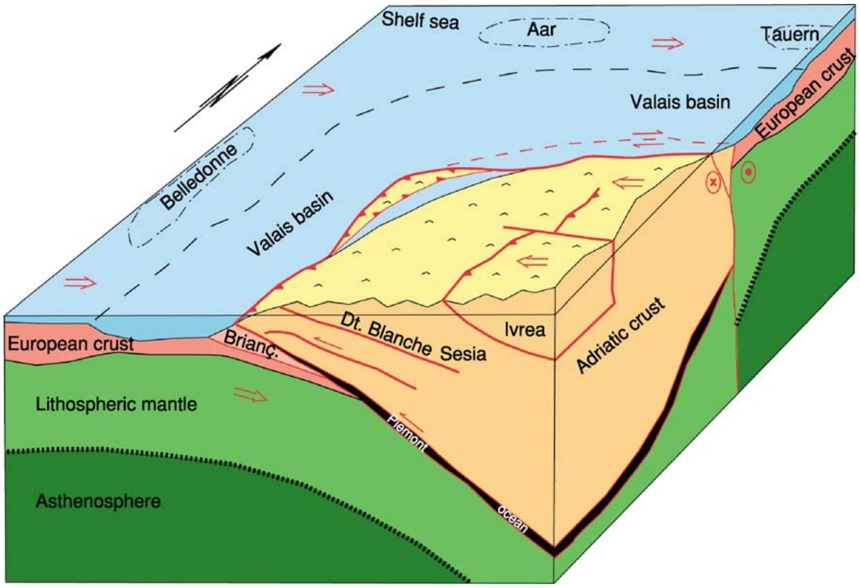

Figure 11 Block diagram showing the three-dimensional geometry of the ancestral Alps at 90 Ma. An east-dipping subduction zone in the Western Alps had consumed the Piemont Ocean. The Briançonnais continental fragment was entering this subduction zone. The Valais basin and the shelf seas of the European margin were the site of ongoing sedimentation.

first basin, the Piemont Ocean, closed in Cretaceous times (~100 Ma). The second basin, the Valais, closed in Tertiary times (~35 Ma). Closure of these basins resulted not only from head-on collision, but also involved strike–slip movements between the European and Adriatic margins.

During Cretaceous times, convergence between the Eurasian and African plates was directed east and west. The European margin (Figure 11) was approaching the Adriatic margin, which had already formed an ancestral mountain range. The Piemont Ocean had already been subducted along an east-dipping subduction zone. Small fragments of this ocean were scraped off of the descending plate and were attached to the upper plate, a process called ‘underplating’. The Briançonnais microcontinent

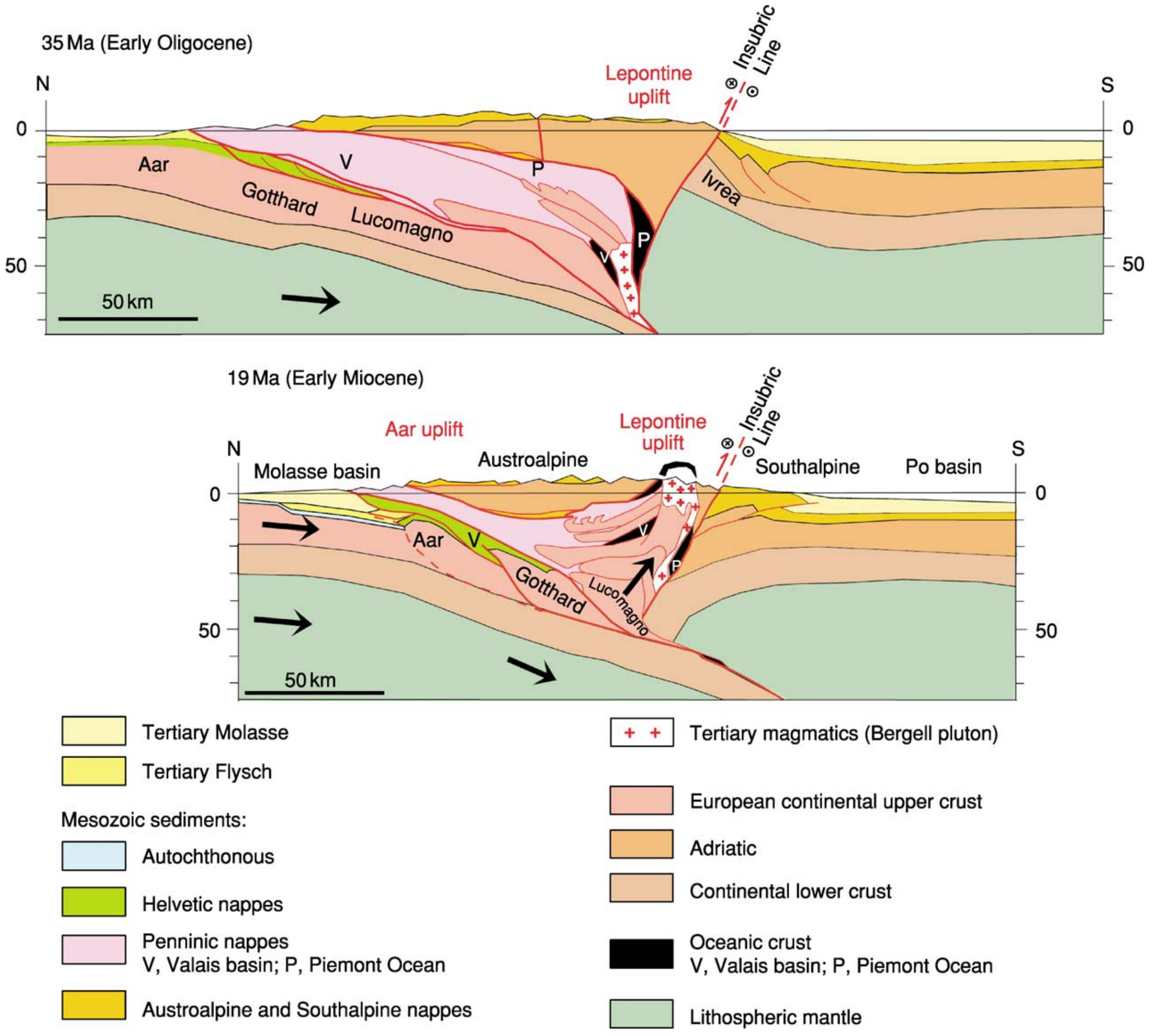

Figure 12 North–south profile through the Central Alps of eastern Switzerland, reconstructed to the geometry at 32 and 19 Ma. Comparison of the two profiles reveals that the orogen grew outward with time on both sides, and that the units in the central part of the orogen were raised to a higher level by the combined action of folding and erosional denudation.

was just in the process of being subducted, but parts of it were also attached to the upper plate. The Valais basin was still the site of sedimentation, as was the shelf of the European margin. In the region of the future Central and Eastern Alps, the east–west convergence was expressed as east–west dextral strike–slip movements. At about 40 Ma, the convergence between the Eurasian and African plates changed to a north–south orientation. As a consequence, a south-dipping subduction zone evolved, into which the Valais basin gradually disappeared. Again, a number of fragments were scraped off of the descending plate and were accreted to the upper plate. About 35 Ma, the two margins started to collide. During this north–south convergence, strike–slip movements took place in the ancestral Western Alps. In the Central and Eastern Alps, the collision phase compressed the two margins and led to the stacking of crustal pieces, horizontal shortening, and vertical stretching. Figure 12 shows two stages of this collision phase in a cross-section trough the Central Alps, reconstructed for 35 and 19 Ma. The deformation of the two continental margins pushed crustal fragments up inclined thrust faults and uplifted parts of the orogen by large-scale folding and vertical stretching. As a consequence, the land surface of the ancestral Alps was uplifted. The ensuing high elevations caused precipitation and triggered enhanced erosion. Rivers built large fan deltas in the foreland of the Alps. As far as known, denudation kept pace with uplift during mountain building. Nevertheless, deep crustal fragments were exposed in the process, bringing to the surface samples of rock that had been at depths of several tens of kilometres during the early stages of the formation of the Alps.

See Also

Europe: Mediterranean Tectonics; Variscan Orogeny; Permian to Recent Evolution. **Moho Discontinuity**.

Further Reading

Debelmas J (1974) *Géologie de la France*. Paris: Doin.

Debelmas J (1979) *Découverte Géologique des Alpes du Nord*. Orleans: BRGM.

Debelmas J (1982) *Découverte Géologique des Alpes du Sud*. Orleans: BRGM.

Krenmayr HG (ed.) (2000) *Rocky Austria: A Brief Earth History of Austria*. Wien: Geological Survey of Austria.

Labhart TP (2001) *Geologie der Schweiz*, 5th edn. Thun: Ott Verlag.

Labhart TP and Decrouez D (1997) *Géologie de la Suisse*. Lausanne: Delachaux et Niestlé.

Lemoine M, deGraciansky P-C, and Tricart P (2000) *De l'Océan à la Chaîne de Montagnes: Tectonique des Plaques dans les Alpes*. New York: Gordon & Breach.

Marthaler M (2001) *Le Cervin est-il Africain?* Lausanne: Loisir et Pédagogie.

Marthaler M (2002) *Das Matterhorn aus Afrika: Die Entstehung der Alpen in der Erdgeschichte*. Thun: Ott Verlag.

Neubauer F and Höck V (eds.) (2000) *Aspects of Geology in Austria. Reports of the Austrian Geological Society, Special Issue 92(1999)*. Wien: Austrian Geological Society.

Nicolas A, Polino R, Hirn A, Nicolich R, and ECORS–CROP Working Group (1990) ECORS–CROP traverse and deep structure of the western Alps: a synthesis. In: Roure F, Heitzmann P, and Polino R (eds.) *Deep Structure of the Alps,* vol. 156, *Mémoires de la Societe Géologique de France,* pp. 15–28. Paris: Geological Society of France.

Pfiffner OA, Lehner P, Heitzmann P, Mueller St, and Steck A (eds.) (1997) *Deep Structure of the Swiss Alps. Results of NRP 20*. Basel: Birkhäuser.

Roure F, Bergerat F, Damotte B, Mugnier J-L, and Polino R (1996) The ECORS–CROP Alpine seismic traverse. *Mémoires de la Societe Géologique de France* 170.

TRANSALP Working Group (2002) First deep seismic reflection images of the Eastern Alps reveal giant crustal wedges. *Geophysical Research Letters* 29(10): 92-1–92-4.

Mediterranean Tectonics

E Carminati and C Doglioni, Università La Sapienza, Rome, Italy

Introduction

It is commonly accepted that Mediterranean geology has been shaped by the interplay between two plates, the African and European plates, and possibly also smaller intervening microplates. The Mediterranean was mainly affected by rifting after the Variscan Orogeny (*see* **Europe:** Variscan Orogeny): during the Mesozoic, oceanic Tethys areas and passive continental margins developed, where widespread carbonate platforms were formed. During the Late Mesozoic, the Mediterranean area was dominated by subduction zones (from east to west, the Cimmerian, Dinarides, and Alps–Betics), which inverted the extensional regime, consuming the previously formed Tethyan oceanic lithosphere and the adjacent continental margins. The composition (oceanic or continental), density, and thickness of the lithosphere inherited from the Mesozoic rift controlled the location, distribution, and evolution of the later subduction zones. The shorter wavelength of the Mediterranean orogens relative to other belts (for example, the Cordillera and the Himalayas) is due to the smaller wavelength of the lithospheric anisotropies inherited from the Tethyan rift.

The Mediterranean basin was, and still is, a collector of sediments derived from the erosion of the surrounding continents and orogens: the best examples are the Nile and Rhone deltas. In the past, other deltas deposited sediments in the bottom of the Mediterranean, and their rivers were later disconnected or abandoned: an example is the Upper Oligocene–Lower Miocene Numidian Sandstone, which was derived from Africa, deposited in the central Mediterranean basin, and partly uplifted by the Apennines accretionary prism. It is well known that, during the Messinian eustatic lowstand, the Mediterranean dried up several times, generating a salinity crisis during which thick sequences of evaporites were deposited in the basin. This generated a pulsating loading oscillation in the Mediterranean, because the repetitive removal of the water led to significant isostatic rebound across most of the basin, particularly where it was deeper, as in the Ionian, the Provençal, and the central Tyrrhenian seas.

The direction of the relative motion between Africa and Europe since the Neogene is still under debate.