A journey through the core of a mountain

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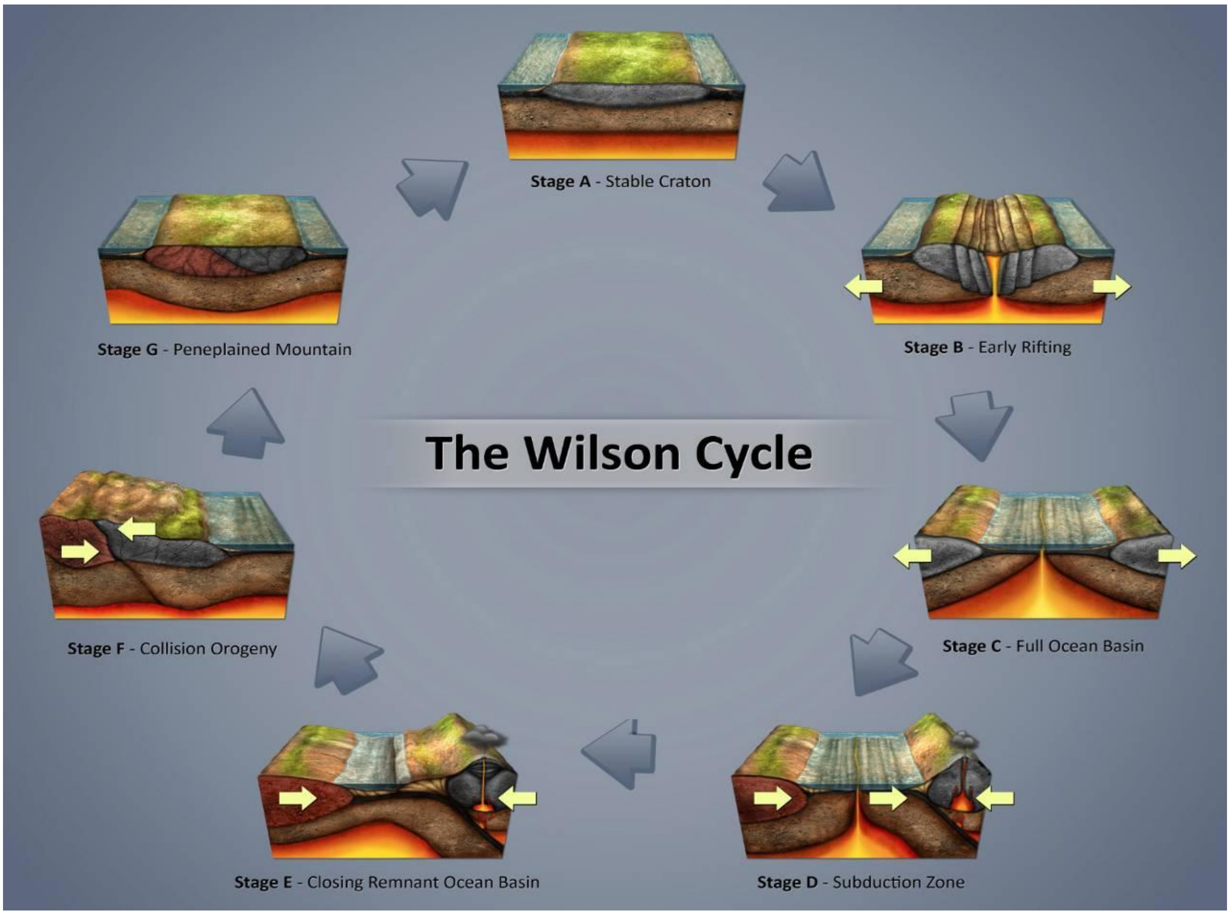
This presentation looked at the Alps, for which the Wilson orogenic cycle (from rifting of a craton, formation of an ocean, subduction at the margins, closure of the ocean, collision and erosion to form a new craton) provides a useful framework. In particular, it looked at the journey a piece of basalt formed at the mid-ocean ridge will take through the cycle using evidence found in the western Alps along a transect roughly from Grenoble to Turin.



Geologically, the western Alps comprise 2 mountain ranges, the Alpine range formed in the Tertiary and an earlier Variscan range, which includes some of the most iconic of mountains, such as the Variscan granite forming Mont Blanc. Molasse basins flank either side of the ranges in depressions caused by loading of the crust by the mountains, with material eroded from the mountains deposited in them, mainly fluviatile with occasional marine deposition. These are termed foreland basins. A section across from the Chainois sub-Alpins through the Dauphinois and Briançonnais to the Piémontain shows folds and faults dipping eastward in the west, while in the east there are fewer folds but faults all dip eastward and between the 2 styles is a ~~sub-horizontal~~ suture which dips at about 30 degrees to the east.

Continental rifting

The Alps were formed not by the collision of Africa and Europe but by the collision of the Apulian-Adriatic micro-plate, a small plate detached from Gondwana, with continental Europe. The collision was tangential to the western Alps, whereas it was full on in the central Alps in

Switzerland. As a result, the early phase of the Wilson cycle is not over-printed by collision. In the south is a failed rift with some associated rhyolitic volcanism.

Failed rift

Jurassic limestones

The rift separated and opened into an ocean about 1,000km wide with passive margins formed on either side of the opening ocean in which sedimentary clastic rocks ranging from fluvial through deltaic to marine turbidites were deposited. Between the Triassic and the beginning of the Cretaceous, the climate was very hot (equatorial) and a lot of carbonates were deposited as reefs and carbonate platform deposits on what was the northern edge of the Tethys ocean. Triassic rock formed at the time of rifting was often terrestrial and evaporates were deposited (mainly gypsum and anhydrite). These are very weak rocks which shear very easily and allow rocks to move past each other; they also produce salt diapirs in other areas, such as the North Sea. The Chartreuse and Vercors massifs are limestones of Jurassic to Cretaceous age with asymmetric folds.

Ocean spreading

The Chenaillet massif is an ophiolite obducted from the ocean floor, where it straddled the mid-ocean ridge, onto the continental crust. Pillow lavas developed as a sausage of lava that cools and quenches forming a crust that then fractures and further blobs of lava emerge. The spreading ridge itself has pillow lavas on their side, with the rounded top on one side and the cusped base on the other. Quenching forms a skin of glass around the outside of the pillows, which devitrifies with time and spherulites form. Beneath the ocean crust pillows are sheeted dykes, then gabbros and peridotite.

Pillow lavas

Pillow lavas on edge at the mid-ocean ridge

The mid-ocean ridge is under tension so cracks form, down which water percolates, often to considerable depth, is heated up and rises again, reacting with the rock and emerging as black smokers with abundant sulphides; this makes them quite important metallogenic provinces. The plagioclase is fairly calcic and the pyroxene in these tholeiitic basalts is also relatively calcic and both undergo ion-exchange with sea water. Plagioclase changes from labradorite to albite and the pyroxenes form amphiboles (hornblende at first, then sodic actinolite) and chlorite. Peridotite also reacts with sea water, with olivine and pyroxene converting to serpentine minerals (lizardite, antigorite and chrysotile). This process is known as sea floor metamorphism.

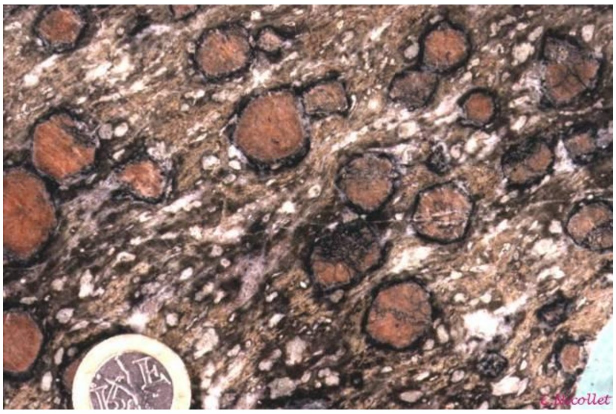
The magma rises at a temperature >1,200^{o}C and solidifies at 1,200^{o}C. It starts off as the equivalent of anhydrous granulite facies and reacts with water to convert to greenschist facies and possibly to zeolite facies in a retrograde metamorphism. The chemical reactions slow with decreasing temperature.

Subduction

Subduction cannot be seen but it can be inferred from geophysical evidence in the form of Benioff zone earthquakes and a distinct dip in heat flow. During subduction, the rock changes from zeolite facies eventually to form eclogite in prograde low temperature-high pressure metamorphism. The grade of metamorphism in the western Alps increases from west to east. The conditions of metamorphism can be determined by thermobarometry from the minerals in the rock and show that a temperature of 750^{o}C and pressure of 35kbar was attained in the Dora Maira mountains in the east. This indicates burial to a depth of in excess of 100km. Given that normal continental crust is only 30km thick and that under mountain ranges around 70km thick, the exhumed rocks must have penetrated deep into the mantle. This poses the question of how rocks can be exhumed from such a great depth.

Spillites are basaltic rocks with albite plagioclase rather than labradorite due to sea-floor metamorphism. As the material goes down the subduction trench, albite, chlorite and actinolite convert to glaucophane, zoisite and quartz. There are still remnants of pillows. Lawsonite and glaucophane are typical of blueschist facies. As it goes deeper, plagioclase converts to jadeite and quartz, zoisite and glaucophane convert to garnet and omphacite plus paragonite and quartz to become an eclogite, as at Monte Viso.

Monte Viso



Retrograde Eclogite

Returning to the surface, there is retrogression with a hornblende and plagioclase ring forming around the garnets coecite and quartz inclusions in pyrope garnets. The rocks had been subjected to very high pressures and they must have come back to the surface quickly, possibly by a process called channel flow.

Collision

Collision involves yet another loop in the progression from basalt through retrograde metamorphism followed by prograde metamorphism and finally retrograde metamorphism again. Collision leads to over-folding and an example was shown of an unconformity with Miocene deposits above it. Compression continues to form a nappe, in which the beds on one side of a fold will be reversed, with the oldest rocks above the youngest.

Inverted beds in nappe

A large fold