Hartai Éva,

Geology

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Új Magyarország Fejlesztési Terv

A Műszaki Földtudományi Alapszak tananyagainak kifejlesztése a TÁMOP 4.1.2-08/1/A-2009-0033 pályázat keretében valósult meg.

IX. Convergent and transform fault plate margins

1. Convergent plate margins

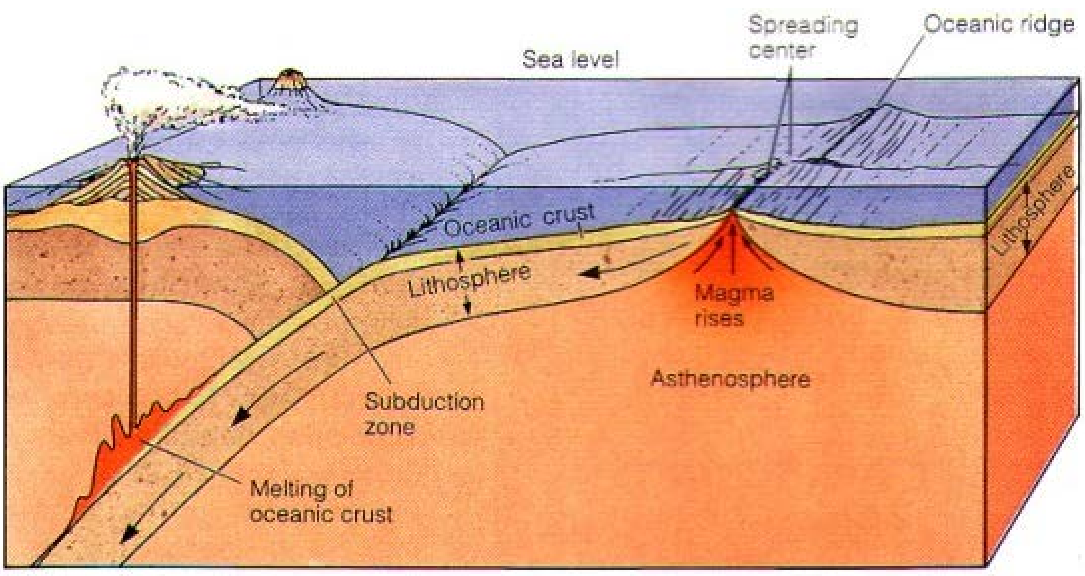
Convergent (in other terms destructive) **plate margins** are formed when two lithosphere plates move toward each other. Along these margins one plate sinks (is subducted) under another. The location where the sinking of a plate occurs is called a **subduction zone**. The type of convergence that takes place between plates depends on the kind of lithosphere involved. Convergence can occur between an oceanic and a largely continental plate, or between two largely oceanic plates, or between two largely continental plates. It is only the oceanic lithosphere that can be subducted. When two continents arrive at each other and collide, the subduction ceases and along the **collision zones** folded mountain ranges are formed.

The physical features of the subduction zone

Thinner and thicker oceanic lithosphere

Near the spreading centre, the lithosphere is thin and its boundary with the asthenosphere comes close to the surface. This thinning happens because rising magma heats the lithosphere and only a thin layer near the top retains the hard, rigid strength properties.

As the lithosphere moves away from the spreading centre, it cools and becomes denser. Also, the boundary between the lithosphere and asthenosphere becomes deeper, and as a result, the lithosphere becomes thicker and the asthenosphere-lithosphere boundary moves deeper. Finally, about 1,000 km from the spreading centre, the lithosphere reaches a constant thickness and is so cool that it is denser than the hot, weak asthenosphere below. As a consequence, it starts to sink downward.



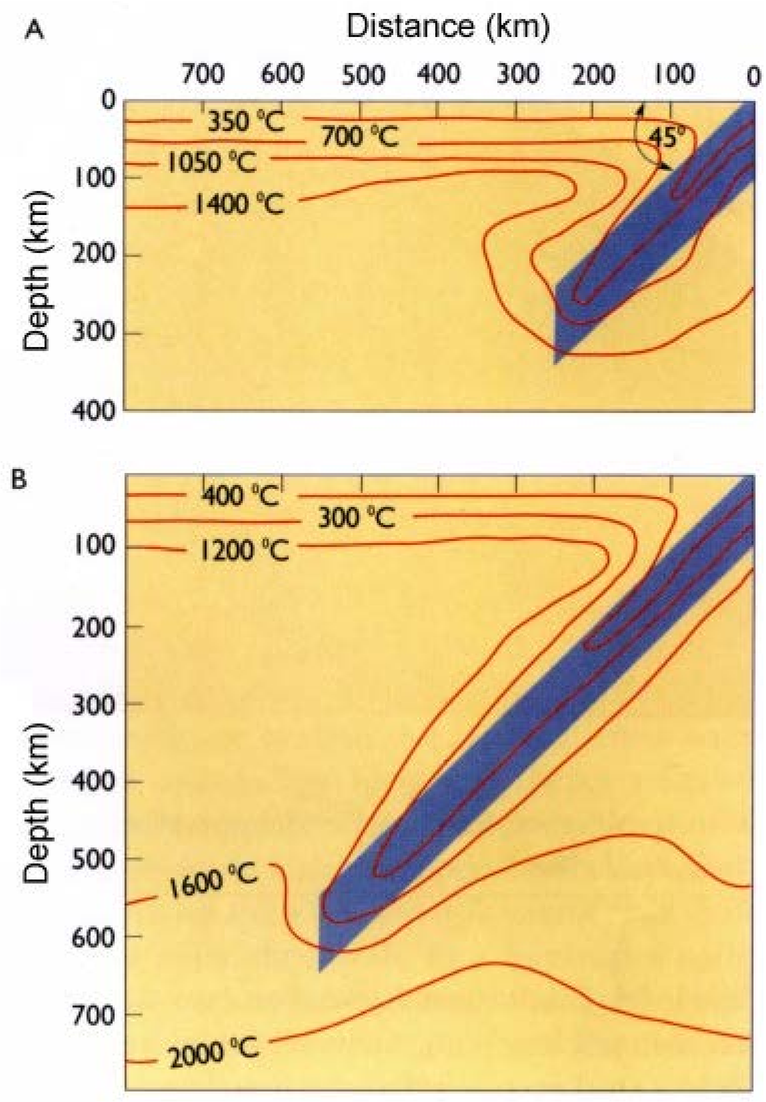
Schematic diagram showing the spreading centre and the subduction zone [i]
Where the temperature is high near the spreading edge, the lithosphere is thin. Away from this area the lithosphere cools and becomes thicker and starts to sink. At depths of about 100 km the oceanic crust starts to melt and the magma rises and forms an arcuate belt of volcanoes parallel to the subduction zone.

Subduction and temperature change

Old lithosphere with its capping of oceanic crust sinks into the *asthenosphere* and eventually into the *mesosphere*. The process by which the lithosphere sinks into the asthenosphere is called **subduction**, and the margins along which plates are subducted are **subduction zones**. They are marked by deep trenches in the seafloor.

We can get information about the subducting plate through earthquakes. The earthquake hypocentres are situated in the **Benioff Zone**, along the contact of the lithosphere and the asthenosphere, or at the inner shear zones of the subducting lithosphere, since it is colder and denser than the surrounding asthenosphere and undergoes brittle deformation.

As the lithosphere sinks, it must heat up. Earthquakes can occur in the subducting slab as long as it is cool enough to be brittle. With a rapid sinking rate of 8 cm/ year, calculations show that the lithosphere retains some brittle properties down to a depth of 700 km. This is probably the reason that a few earthquake foci are as deep as 700 km.



The temperature in the surroundings of the subducting plate
Computer-aided calculations indicate the temperature changes with time in 5 and 10 million years after the start of subduction.

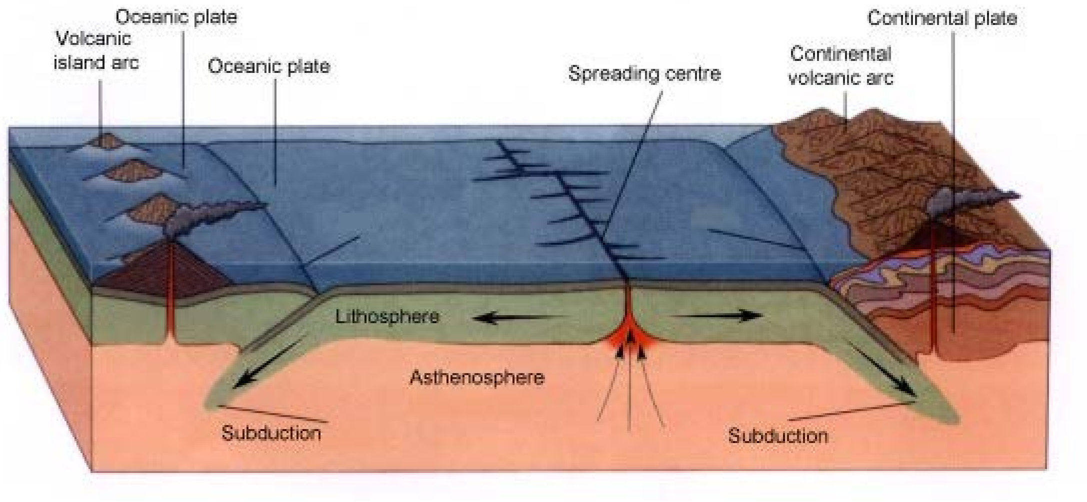
Topographic features at convergent plate margins

Along the convergent plate margins a large variety of topographic units can be found. These units are formed when both plates have *oceanic crust* and also when the overriding plate has *continental crust*. The characters of the topographic units are detailed below.

Volcanic arcs

Andesitic magma is formed by the partial melting of the subducting basaltic crust. Rising to the surface, the magma forms a chain of *stratovolcanoes*. The arc-shaped region of the magmatic activity is called an **island arc** if both converging plates are covered by oceanic crust. If the overriding plate has continental crust, and the stratovolcanoes are built on the continent, the magmatic arc is called a **continental volcanic arc**. The Japanese islands and the Aleutians are modern-day island arcs. The Andes Mountains in South America or the Cascade Mountains in North

America are a continental volcanic arc. The arcs are curved because they are parts of a circle with a radius, which indicates the angle at which the lithosphere is plunging back into the mantle.

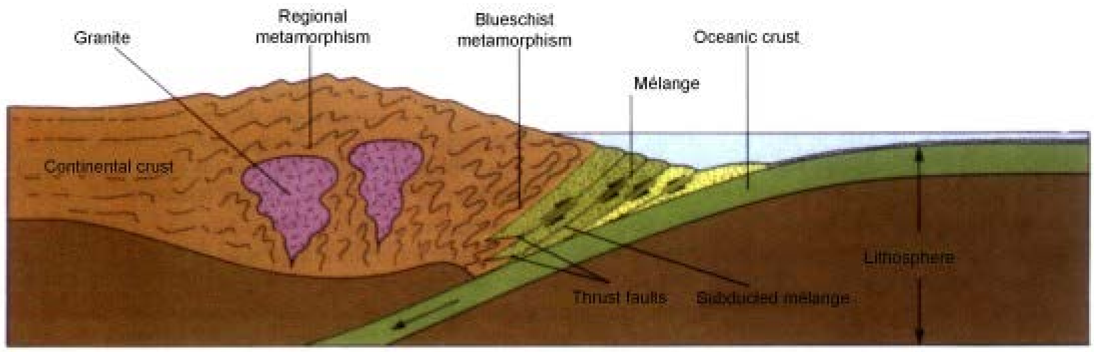


Oceanic island arc and continental volcanic arc

When the subduction occurs along an oceanic plate, an oceanic island arc is built up. If it occurs along a continental plate, the volcanic mountain chain is called a continental volcanic arc.

Mélange

Along the convergent plate margins rocks suffer intense *fragmentation* and *metamorphism*. A distinctive feature of some margins is the development of a **mélange**. A mélange is a large scale *breccia*, characterized by a lack of continuous bedding and the inclusion of fragments of rock of all sizes, contained in a fine-grained deformed matrix. The mélange typically consists of a jumble of large blocks of varied lithology. Large-scale mélanges generally consist of altered oceanic crustal material and blocks of continental slope sediments in a sheared mudstone matrix.



Formation of a mélange [ii]

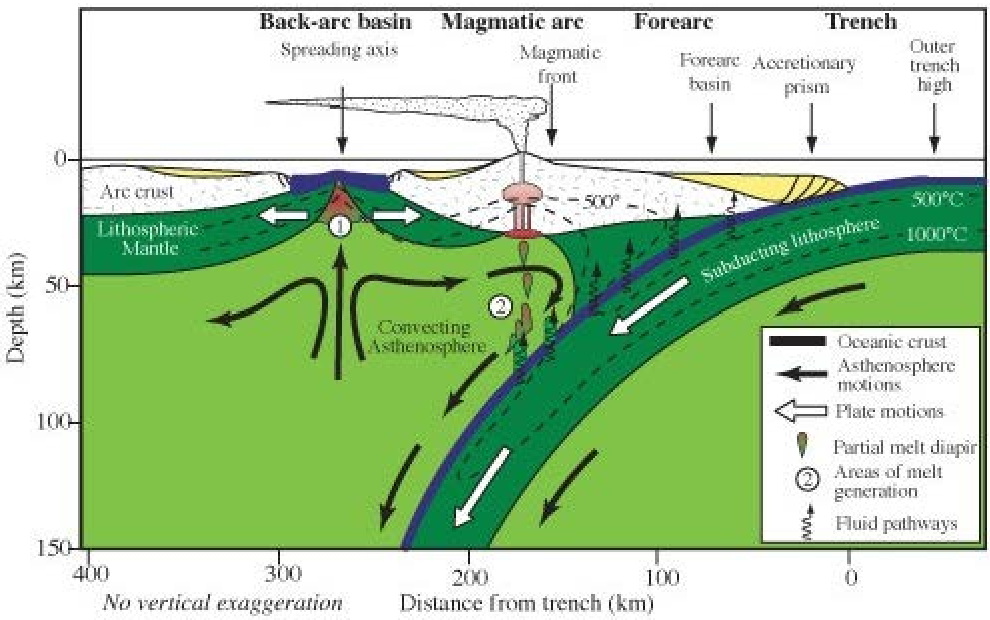
A mélange is formed when young sediment in a trench is smashed by moving lithosphere and dragged downward in slices bounded by thrust faults.

Mélange is formed when a sinking plate drags the sedimentary rocks downward beneath the overriding plate. Caught between the overriding and the sinking plate, the sediment becomes shattered, crushed, sheared and thrust-faulted. The kind of metamorphism that is common in many mélange zones is a high-pressure, low-temperature metamorphism, called **blueschist metamorphism**.

A chaotic mixture of rock masses in a mélange zone at the coast of Trinidad [iii]
The green rock is serpentinite.

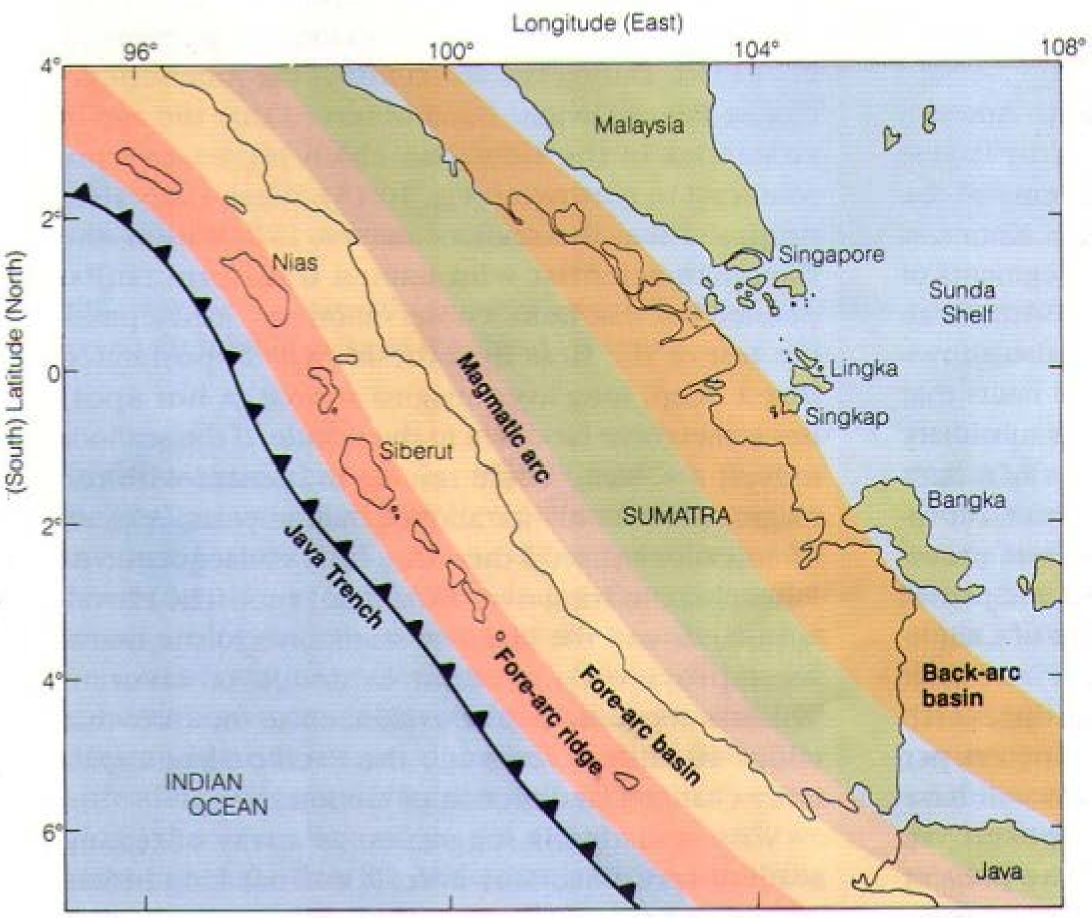
Fore-arc ridges and fore-arc basins

Between the trench and the magmatic arc, both of which are prominent topographic features, two less prominent features are present along many convergent margins: the **fore-arc ridge** and the **fore-arc basin**. A fore-arc ridge is commonly underlain by mélange and is caused by a local thickening of the crust due to thrust faulting at the edge of the overriding plate. A fore-arc basin is a low-lying region between the fore-arc ridge and the volcanic arc.



Cross section of a subduction zone showing the situation of fore-arc and back-arc basins [iv]

The best example is the island of Sumatra in Indonesia, where the island itself is the volcanic arc and it is flanked by a fore-arc ridge and basin.

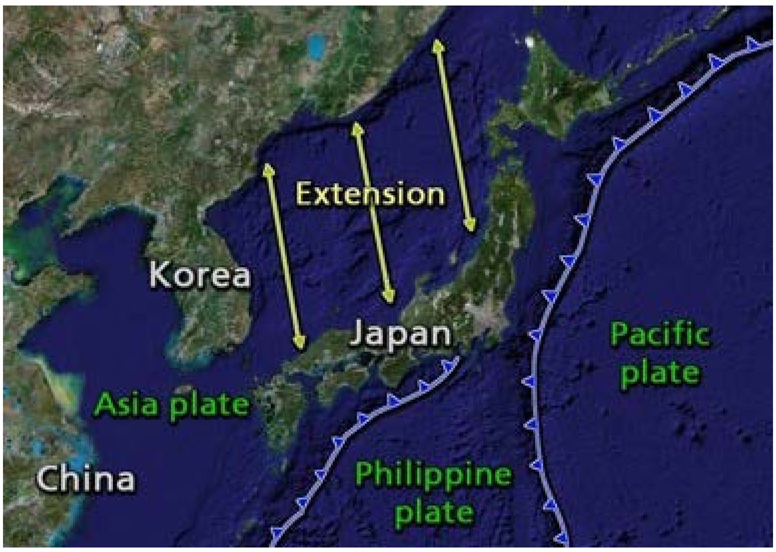


***Map of a portion of Sumatra* [v]**

The map shows the positions of the major topographic features at convergent plate boundaries.

Back-arc basins

Back-arc basins are formed as a result of a process termed **trench rollback**. This term describes the backward motion of the subduction zone relative to the motion of the plate which is being subducted. As the subduction zone and its associated trench pull backward, the overriding plate is stretched, thus thinning the crust, in which a back-arc basin is consequently formed. Sedimentation in the back-arc basins is strongly asymmetric. Basaltic magma may rise into such a back-arc basin, and a small region of new oceanic crust may even form.



***Japan is separated from Asia by the opening of a back-arc basin* [vi]**

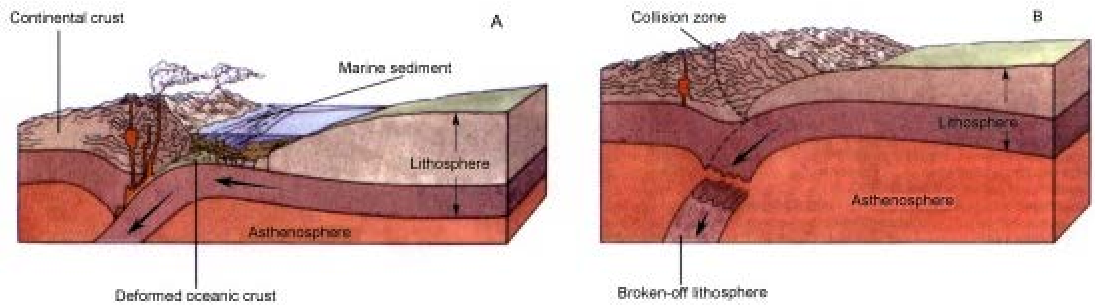
It is a special situation that the deepest and the highest areas of the Earth are found along convergent plate margins and were formed by the collision of plates. The deep-ocean trenches can be as deep as 11 km and the height of the mountains at the convergent plate boundaries can exceed 8 km.

Collision and formation of mountain chains at convergent plate margins

When continental crust is carried on a subducting lithosphere plate and the overriding plate carries also a continent at the margin, the two continents must eventually *collide*. The collision sweeps up and deforms any sediment that accumulated along the margins of both continents and forms a *mountain system* characterized by intense *folding* and *thrust faulting*.

All modern continental collision margins are young *orogenic belts*. These belts can reach several thousand kilometres in length. In these mountain systems the strata are compressed, faulted and folded, usually in an exceedingly complex manner. Igneous activity and metamorphism are always present. The Alps, the Carpathians, and the Himalayas are young fold-and-thrust mountain systems, formed in the Late Mesozoic and the Cenozoic eras.

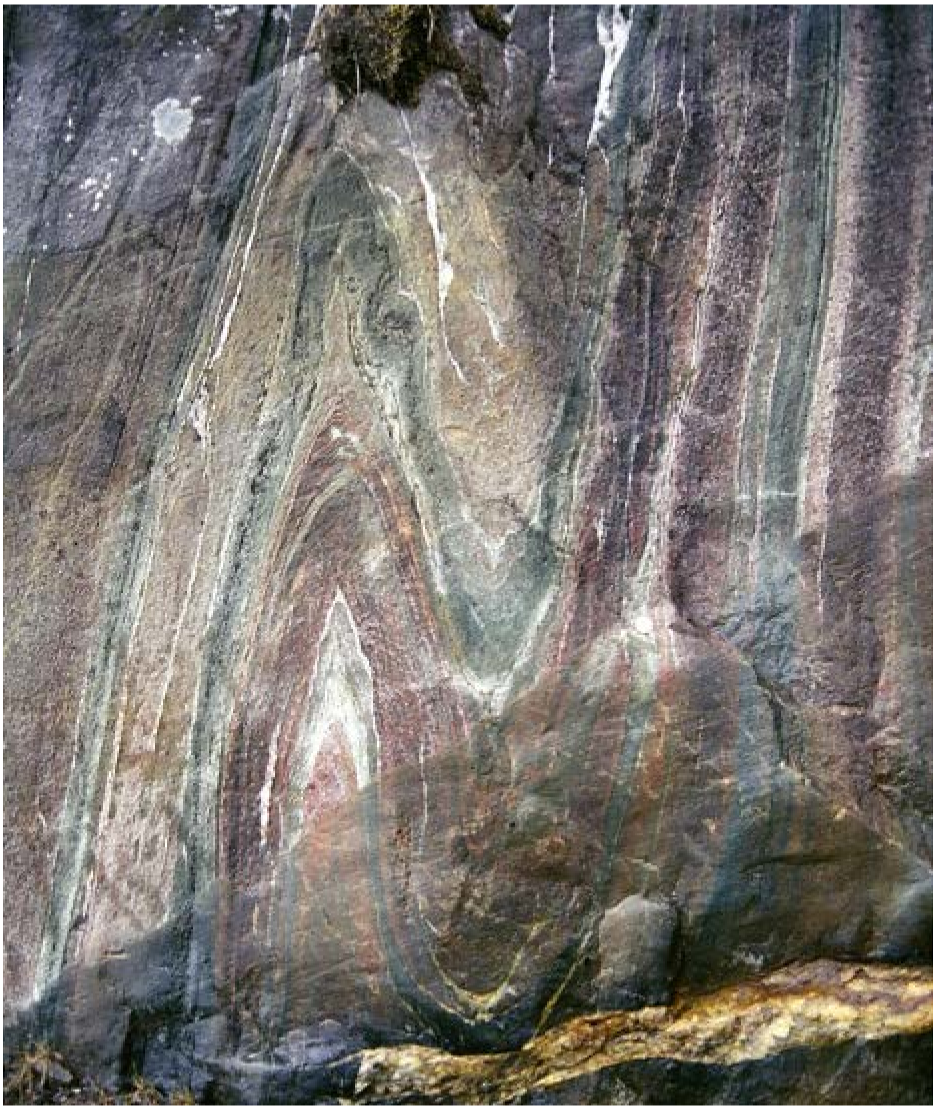
The strata from which the mountain systems are folded up are predominantly marine sediments. The original thickness of the sedimentary layers can be 15 km.



***Formation of mountain chains by collision* [vii]**

A : The subducting lithosphere compresses and deforms sediments. B: Collision is complete. The descending slab of lithosphere is broken off and sinks into the asthenosphere. Along the collision zone a mountain range is formed with strongly deformed sediments.

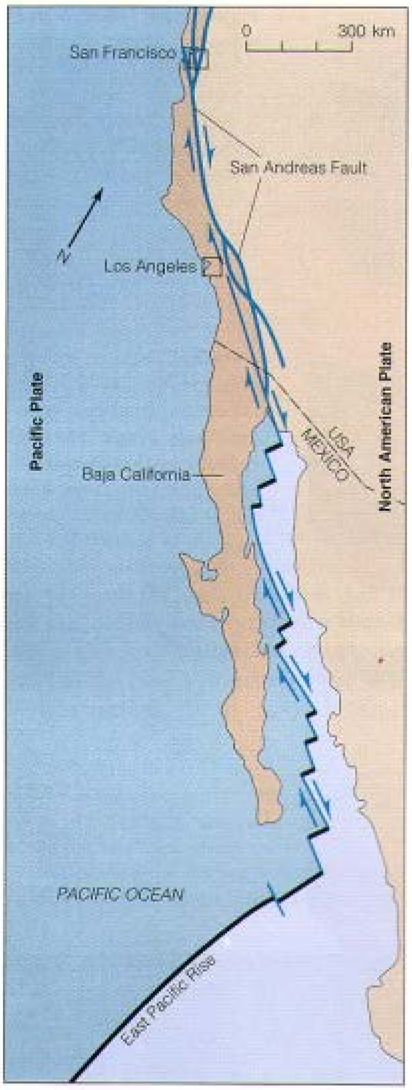
The collision line between the two masses of deformed sediment caught up in a continental collision is commonly marked by the presence of **serpentinites**. These rocks consist mostly of the mineral serpentine and are formed by the metamorphic alteration of highly deformed fragments of oceanic crust and bits of the mantle rock beneath the Mohorovičič discontinuity that were caught up in the collision.



Strongly folded serpentinite (green) and other metamorphic rocks at Nordfjord, Norway [viii]

2. Transform fault plate margins

Transform fault plate margins are formed where two plates slide past one another. The fracture zone that forms a transform plate margin is known as a transform fault. Along the transform fault the rocks are strongly brecciated. Most transform faults are found in the ocean basin and connect offsets in the mid-ocean ridges. A smaller number connect mid-ocean ridges and subduction zones.



The San Andreas Fault as a typical example of a transform fault plate margin [ix]

The fault separates the Pacific plate from the North American plate. Directions of movements are shown by the arrows.

Transform faults are different from the common strike-slip faults. A strike-slip fault is a simple offset, but a transform fault is formed between two different plates, each moving away from the spreading center of a divergent plate boundary. A smaller number of transform faults cut the continental lithosphere. The most famous example of this is the San Andreas Fault zone on the western coast of North America. The San Andreas Fault connects a divergent boundary in the Gulf of California with the Cascadia subduction zone.

A seismic creep (curve in the pavement) caused by the movement along the San Andreas Fault near Hollister, California [x]

In the surroundings of transform faults earthquakes with usually shallow depth and high magnitude occur, and volcanic activity is not present.

http://geology.com/plate-tectonics.shtml

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[i] Skinner & Porter, 1995

[ii] Skinner & Porter, 1995

[iii] http://edmedley.com, photo: Edmund Medley

[iv] http://en.wikipedia.org

[v] Skinner, Porter & Botkin, 1999

[vi] http://en.wikipedia.org

[vii] after Skinner, Porter & Botkin, 1999

[viii] http://www.geol.ucsb.edu

[ix] Skinner, Porter & Botkin, 1999

[x] http://en.wikipedia.org