Chapitre III : Tectonic shapes

Introduction :

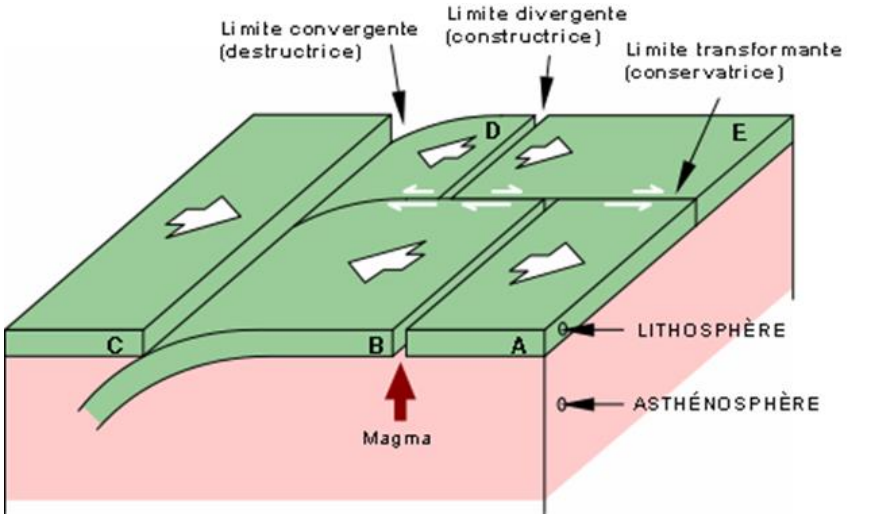
These are the tectonic forces induced by the slow convective movements of the mantle, and the subsequent displacements of the earth's crust. It is essentially a thermodynamics linked to the loss of heat caused by the radioactive disintegration of certain elements.

1/ Plate tectonics : Is a global dynamic model of the Earth's lithosphere. This theoretical model was based on the concept of continental drift, which was developed by Alfred Wegener at the beginning of the 20th century.

The lithosphere, the rigid outer shell of the Earth made up of the crust and part of the upper mantle, is subdivided into plates, called tectonic or lithospheric. Fifteen major plaques were identified, to which were added around fifty minor plaques. These plates have varied relative movements, which generate different types of boundaries between them: convergent, divergent or transforming. At these boundaries many geological phenomena occur such as earthquakes, volcanic activity, the formation of mountain ranges and the formation of ocean trenches. The speed of the relative movement of two neighboring plates varies between 0 and 100 mm/year.

The tectonic plates are made up of an oceanic and/or continental lithosphere, characterized by the crusts of the same respective names, under which is the rigid zone of the upper mantle.

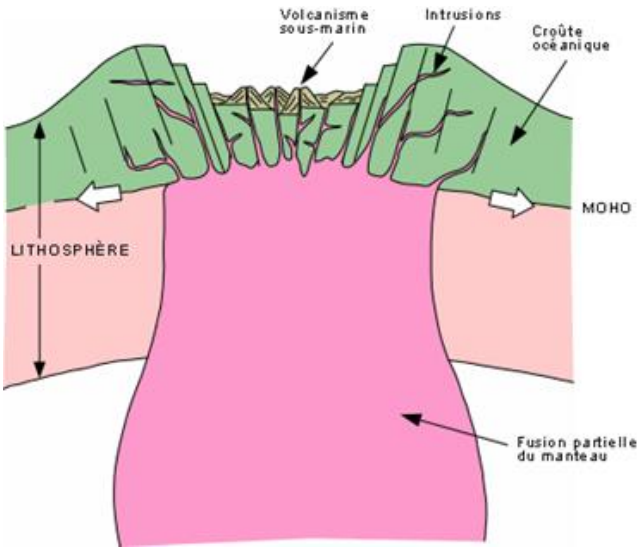
The movement of these plates is possible because the rigid lithosphere rests on the underlying asthenosphere, the ductile part of the upper mantle. This lithospheric mobility is the expression of the convection movements which animate the Earth's mantle, a mechanism allowing the Earth to dissipate its internal heat towards the surface.



2/Type of plate movement :

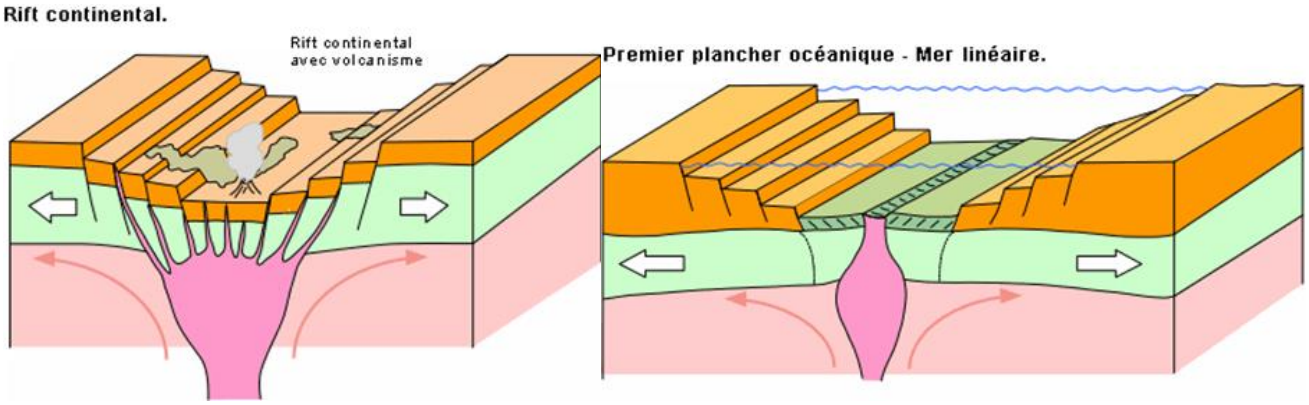
The movements define the three types of boundaries between the plates:

1) Divergent boundaries (tensional stress), the plate(s) move away from each other or there is production of new oceanic crust.

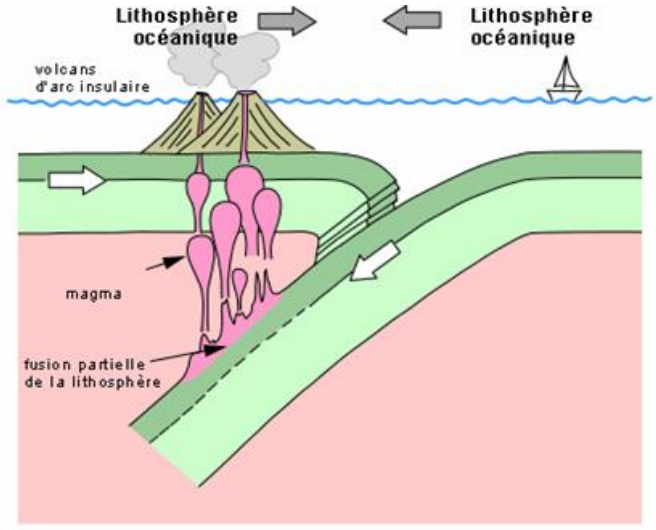


The accumulation of heat under a continental plate causes an expansion of the material which leads to a bulging of the lithosphere. This results in tension forces which fracture the lithosphere and initiate the divergence movement driven by the combined action of mantle convection and gravity. The magma will seep into the cracks, which will cause continental volcanism in places. The continuation of tensions produces a stretching of the lithosphere; there will then be stepped collapse, which produces a valley called a continental rift.

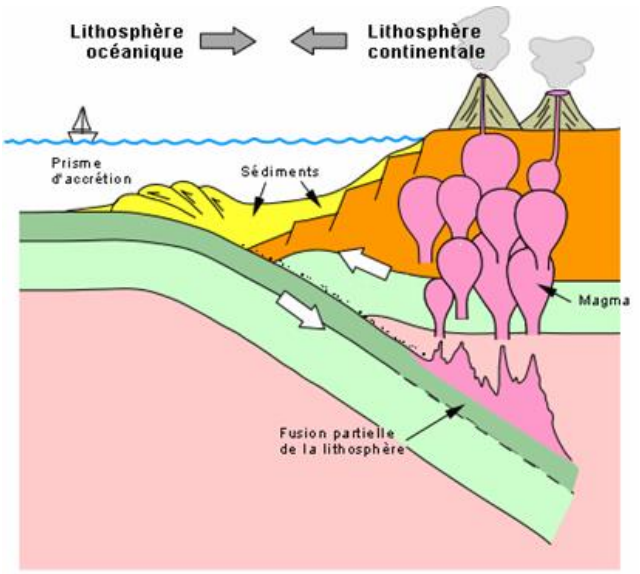
There will be volcanoes and lava flows along the fractures. With continued stretching, the rift sinks below sea level and marine waters invade the valley. Two pieces of continental lithosphere separate and gradually move away from each other. Underwater volcanism forms a first basaltic ocean floor (oceanic crust) on either side of an embryonic ridge.



2) Converging boundaries (compression), movement of two lithospheric plates coming together, one can dive under the other (subduction) or they can collide and thus create a mountain range. The convergence zone is characterized by strong seismicity and rising reliefs. A first type of collision results from the convergence between two oceanic plates. In this type of collision, one of the two plates (the densest, generally the oldest) sinks beneath the other to form a subduction zone.



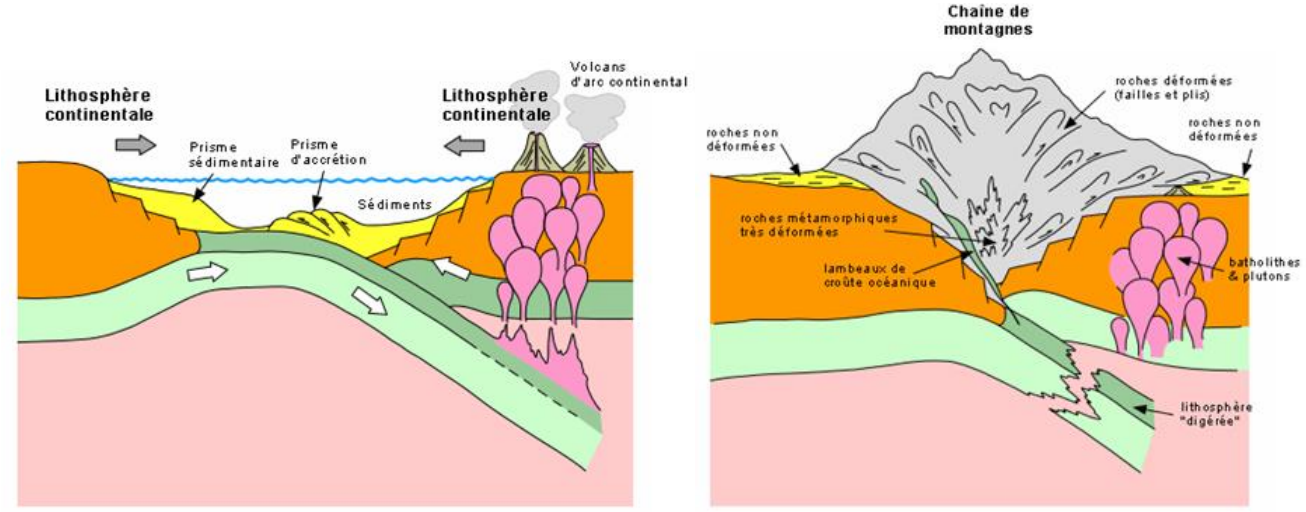
A second type of collision is the result of the convergence between an oceanic plate and a continental plate. In this type of collision, the denser oceanic plate sinks beneath the continental plate.



A third type of collision involves the convergence of two continental plates. As the oceanic space closes as two continental plates come together, the sedimentary material of the ocean floor, more abundant near the continents, and that of the accretion prism become increasingly concentrated; the prism grows.

When the two plates collide, the mechanism gets stuck: the engine of movement (convection in the upper mantle and gravity) is not strong enough to push one of the two plates into the asthenosphere because of the too weak density of the continental lithosphere compared to that of the asthenosphere.

All the sedimentary material is compressed and uplifted to form a mountain range where the rocks are folded and faulted.



3) Transform boundaries (folding), when two plates slide sideways against each other, along faults, correspond to large fractures that affect the entire thickness of the lithosphere; the term transform faults is more often used. They are found most often, but not exclusively, in the oceanic lithosphere.

3/ Convergence of plates :

Convergence zones are the main source of orogeny. The formation of continental mountains from convergence zones is a four-step mechanism.

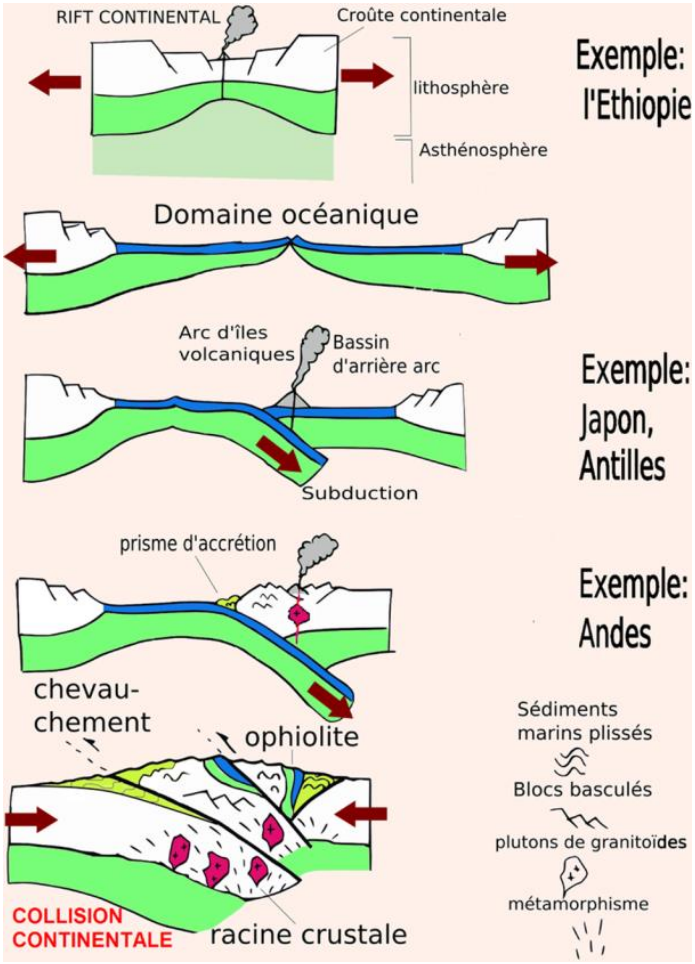
An active continental margin is a convergence zone which brings into contact an upper continental lithosphere and an oceanic lithosphere diving below it in a subduction trench. The subduction of one plate under another leads to numerous consequences, such as andesitic volcanism (generally explosive), numerous earthquakes and especially the formation of folds and faults.

Finally, if convergence along an active continental margin has consumed all the oceanic crust, it leads to a collision zone, where two continental crusts collide. The two plates weld together to form one. alone. This is particularly the case of the Himalayan range, on the border between the Indian plate and the Eurasian plate; this encounter occurred 65 million years ago during migration from the Indian continent. The Alps and the Atlas Ranges are examples of collision chains. It should be noted that during the collision, sedimentary material is transported upwards to form mountain ranges where the rocks are folded and faulted.

4/ Orogeny : or orogeny, characterizes all the geodynamic processes which depend on plate tectonics and which result in the formation of a mountain system in the broad sense. It is called an orogen if it is built on an unstable portion of the earth's crust, and folds and layers of thrust testify to the significant constriction to which it has been subjected. An orogen therefore results from the collision of two continental lithospheric plates of different nature and density.

Orogeny by subduction occurs in particular when an oceanic plate subducts under a continental plate. A volcanic arc then forms in front of the latter, which will gradually increase in volume over the course of geological eras. The added material will then form reliefs and therefore a mountain range...

Finally, relief can form by obduction. This occurs when an oceanic plate passes over a continental plate, rather than subducting.



5/ The deformation :

In structural geology, deformation is a generic term which describes changes in shape, orientation or position of a body (rock, portion of the earth's crust) subjected to stress. When this body is a rock, the deformation essentially concerns the geometric transformation which affects the appearance, texture or properties of this rock. When subjected to stress, the Earth's crust deforms. Stress can be defined simply as a force applied to a certain unit of volume. Every solid has its own strength to resist stress. When the stress exceeds the strength of the material, the object is deformed and a change in shape and/or volume ensues. There are cases where the deformation is however not perceptible to the naked eye but only detected by sensitive devices, and this is the case of the deformation of solid material during an earthquake before it occurs. has broken.

The deformation can be:

• continuous (progressive variation of the transformation) or discontinuous

• homogeneous (initially parallel lines remaining after deformation) or heterogeneous (most common case)

• finite (concers the shape of the final object) or incremental

The deformation can be expressed in the following ways:

• elastic (instantaneous and reversible deformation)

• plastic (non-instantaneous and generally irreversible deformation)

• The first response of a material to stress is elastic deformation. When the stress is released, the material returns to its initial shape and volume. At a given point during elastic deformation, the stress-strain relationship becomes nonlinear: the material has reached its elastic limit. If the stress exceeds this limit, the material is permanently deformed; This results in plastic deformation or brittle deformation (glass breaking). In plastic deformation, all energy is used to deform the material.

With an increase in stress, the material reaches a second threshold, its breaking point, and it breaks; this is the brittle deformation.

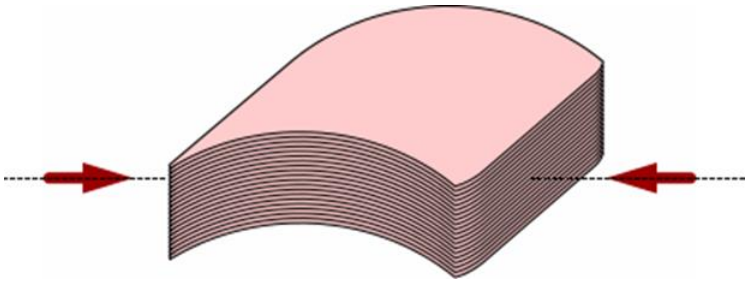
A/ Pleating :

Formation of folds due to the uplift of horizontal layers of the earth's crust under the action of tectonic forces; all of these folds. Deformation of geological layers by lateral pressure, producing a set of folds.

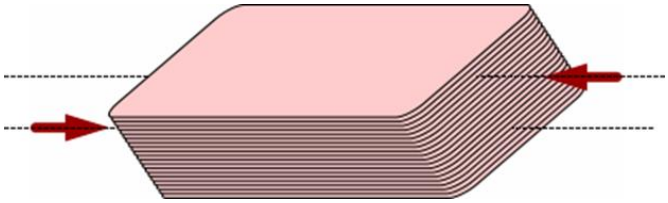
Sedimentary rocks are originally arranged in approximately horizontal layers. But we often find them inclined, deformed, affected by folds and faults, particularly in mountain ranges.

The stresses responsible for the deformation of rocks in the earth's crust have multiple sources. Deformations most often result from movements of lithospheric plates which result in stresses which modify the shape of rocks, their volume and, in certain cases, their chemical and mineralogical composition.

There are basically two types of stresses that deform rocks: compressive stresses and tensile stresses. In compression, forces converge; they can be coaxial or not. The deformation of a deck of cards under compressive stresses illustrates the difference. In the case of a coaxial compressive stress, the boards will arch, as shown here:

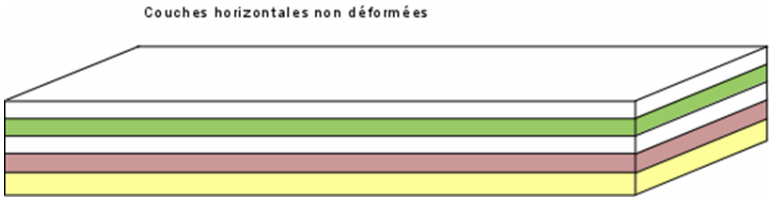


If the stresses are not coaxial, shear will develop; the deck of cards is deformed by the sliding of the cards on top of each other:

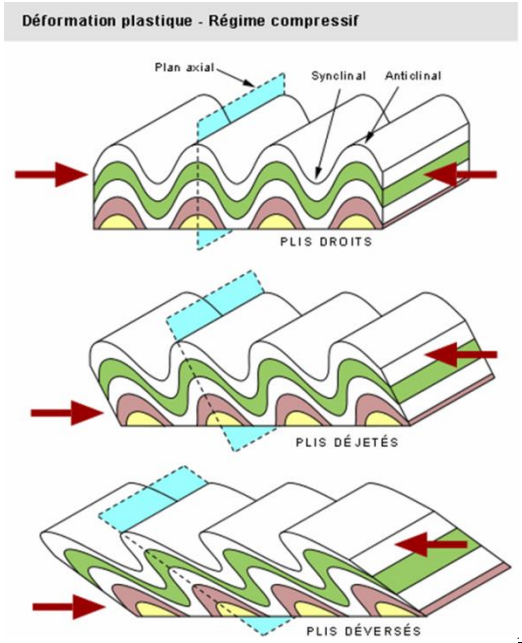


In tension, the stresses diverge and have the effect of stretching the material.

The following diagrams illustrate the deformation of rock layers under compressive and tensile stress regimes. Let's take as a starting volume, a stack of layers of undeformed rocks horizontally.



Folds constitute the manifestation of plastic (ductile) behavior of rocks under the effect of compressive stresses.



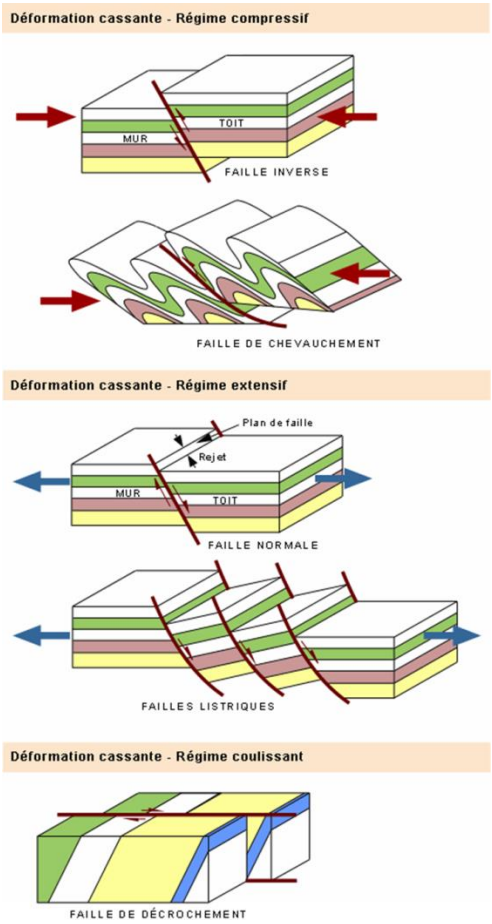
<u>The folds :</u> are undulations of the layers to which we give the name of anticline or syncline: the heart of the fold being on the side of its concavity, an anticline is a fold whose heart is made up of the oldest layers ; a syncline is a fold whose core is made up of the most recent layers. there are recumbent folds, when the axial plane is horizontal. In between, there are

discarded folds and spilled folds. Straight folds result from coaxial compressive stresses, displaced and overturned folds from stresses which are not coaxial

B/ Brittle deformation results in planes of fractures, faults.

A fault is a tectonic structure consisting of a plane or rupture zone along which two rock blocks move relative to each other. A fault is a break in the ground with relative displacement of the separated parts. When the displacement is small, it is easy to measure it. But often, this displacement is so important that it is difficult to know its extent.This plan divides a rock volume into two compartments which have slipped relative to each other in a context of fragile deformation.

This displacement and the shearing deformation are due to the forces exerted by tectonic stresses, which result from plate tectonics or to the gravitational force (gravity instability). The value of the displacement is the fault rejection.



The release is the net displacement of the two compartments. Compressive stresses produce reverse (steep fault plane) or thrust faults (near-horizontal fault

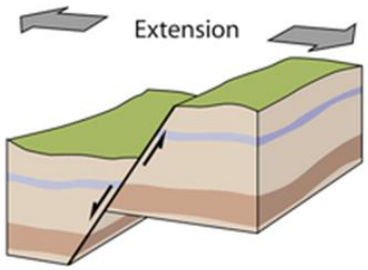
plane). In both cases, the roof rises relative to the wall. Tensile stresses produce normal and listric faults; the roof slopes down relative to the wall. Strike-slip (or slip-slip) faults constitute a special case; they occur by the movement of two compartments relative to each other in a horizontal plane. They are found in compressive or extensive regimes.

Types of vulnerabilities

Depending on the type of relative movement, three main types of faults are defined: normal fault, reverse fault, strike-slip fault.

The 3 main types of faults which correspond to the three types of tectonic movements (transforming, divergent, convergent).

Normal fault

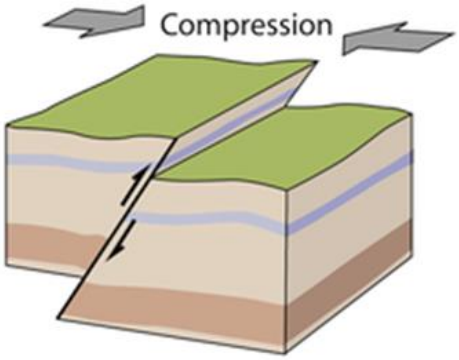


Schematic representation of a normal fault.

A normal fault accompanies an extension; the compartment above the fault ("roof") slopes down relative to the compartment below the fault ("wall"). The geometry obtained between normal faults with opposite convergent dip is called graben. The opposite (normal fault with opposite divergent dip) corresponds to a horst.


Normal fault on the edge of Þingvellir (Iceland).

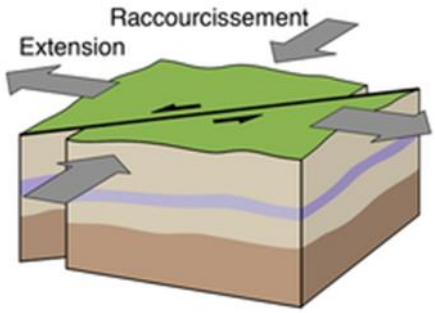
Reverse fault



Schematic representation of a reverse fault

Dropout

San Andreas strike-slip fault



Schematic representation of a strike-slip fault, here a sinistral strike-slip fault.

A shift accompanies an essentially horizontal sliding movement; pure strike-slip faults (vertical fault and horizontal displacement) are not accompanied by any vertical movement. The shifts can be dextral or sinistral, depending on whether the compartment opposite the observer moves to the right or left (respectively).

C/ Fracture : Is a more general term designating any break, with or without rejection, of land, rocks, or even minerals. Faults exist from the microscopic scale (millimeter) to that of tectonic plates (several hundred kilometers).

crack which demarcates a surface of discontinuity within a rock or terrain,

D/ The joint : Is a surface of discontinuity, which is not an abnormal contact with displacement, often straight and perfectly clear, the following types are determined:

 lamination joints;

 tectonic or tension joints.

In the case of this type of rupture, in addition to the characteristics mentioned for the cracks, the geologist will also be interested in:

– permeability (circulation of fluids leading to alteration of the walls)

– the resistance, conditioning that of the materials and the rock mass.

1. Lamination joints

A stratification joint is a discontinuity separating two layers of the same petrographic nature.

Features :

– preferential fracture plane in sedimentary rocks

– sliding of banks on banks: causes sliding streaks, roughness, anisotropy

2. Tectonic joints

The tectonic joint, or tension joint, is a break without rejection. It results from tectonic constraints which cause tensions in the rock. Tension joints can be:

 traction. The tensile stresses acting on the facets oriented in the direction of the tensile stress and the average stress.

Features :

 open

 without genetic filling

 spaced

 rough (shear resistance depends on the opening/roughness ratio)

 permeable

 compression. Fractures occur by shearing along the facets oriented obliquely with respect to the maximum compressive stress.

Features:

 closed

 with or without filling

 frequent

 roughness of the lips

 not very permeable unless it is limestone

 thickness of the affected zones depending on the plasticity of the rocks in contact

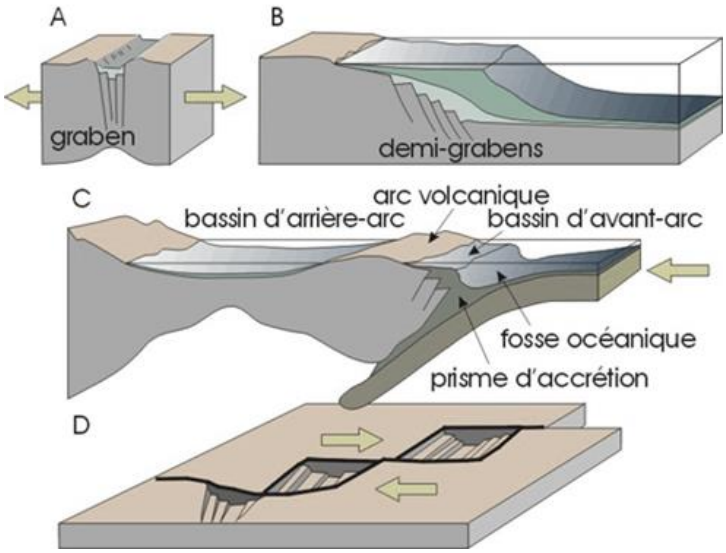
3. schistosity : Schistosity describes a family of sub-parallel and regularly spaced planes along which schistosity rocks are easily cut (or cleaved) into more or less thick sheets. These sheets mark the flattening of the schistosose rock, generally during a deformation phase. The schistosity plane opens easily because it is a mechanical discontinuity. 

As a reminder, any rock subjected to mechanical stress undergoes deformation which can be continuous or discontinuous.

In the case of continuous or plastic deformation, this takes place without visible breakage and the body keeps its shape when the stress stops, unlike elastic deformation where it returns to its initial shape.

On the other hand, when the resistance limit of the body is reached, the deformation results in breaks and is discontinuous or clastic. The body retains its deformation after the stress stops.

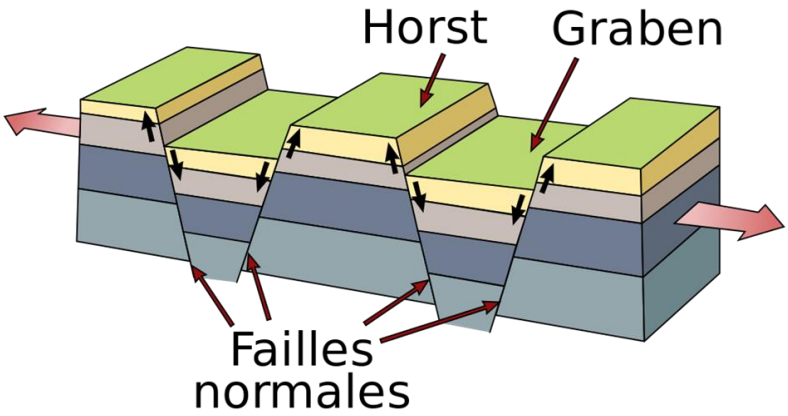
E/ Domes and basins (bowl folds): Circular or elliptical anticlinal structures are called domes. The domes look like upside-down bowls. Sedimentary stratification dips in all directions from the center of the dome Syncline structures of similar shapes, resembling bowls, are called basins (or bowl folds) Sedimentary stratification in this case dips towards the center of the basin (Domes and basins can be small, a few kilometers in diameter or less. However, large dome and basin structures exist, and are caused by bulging (domes) or subsidence (basins) of the continental crust.



F/ Horts and grabens :

Normal faults, in which the roof slides downward relative to the wall). Normal faults result from horizontal tension stresses. Tensile stresses when applied to the

Earth's crust can result in a series of normal faults, where two adjacent normal faults have opposite dip directions. In this case, the sagging blocks are called "grabens" or "collapse ditch" and the raised blocks are called "horsts". Structuring into horsts and grabens is often observed in rift zones.



G/ The Great Rift Valley : Is the name given in 1894 by the Scottish explorer John Walter Gregory1, after his trip to British East Africa2, to a geological unit made up of a series of faults and volcanoes, located in East Africa .

Also called the East African rift or “great East African fault”, this discontinuous fault is made up of several branches divided into fault segments, which are themselves divided into smaller groups, the fault basins. In reality, the entire tectonic fault stretches in Africa and Asia Minor for approximately 7,000 kilometers from North to South, and 30 to 100 km wide, from Lebanon to Mozambique, via the Red Sea and the great African lakes3formed by the accumulation of water in fault depressions, while the eastern branch (Gregory rift) crosses Kenya and Tanzania east of Lake Victoria, where it forms a string of lakes smaller.

Simplified structural diagram of the East African fault system.

Fracturing forming the large African lakes to the west and small lakes to the east of Lake Victoria, to meet further south in Lake Malawi and the Shire Valley, southern Malawi.

The Great Rift Valley, the Red Sea and the Gulf of Aden correspond to the boundaries of three divergent plates. As the fault widens, its altitude decreases due to thermal and tectonic subsidence.

Volcanic activity The Great Rift Valley experiences intense volcanic activity, of great complexity that is not seen anywhere else.

This rift valley in Iceland stretches along the Mid-Atlantic Ridge, where the North American and Eurasian tectonic plates are pulling apart from each other. The body of water to the right, Lake Thingvallavatn, is the largest lake in Iceland and was formed as a result of volcanic activity around the rift. The Thingvellir rift grows about one centimeter (0.4 inch) every year.

H/ The Rocky Mountains, or simply the Rockies (in English: Rocky Mountains or Rockies), are a large mountain range in western North America, in the territories of the United States and Canada.

Location, topography : The Rocky Mountains extend more than 3,000 km from New Mexico in the south to northern British Columbia in the north, where they are known as the Canadian Rockies.

Their altitude ranges from 1,500 m near the High Plains to 4,399 m at Mount Elbert in Colorado. Their width is between 120 and 650 km1. They take an oblong shape, extended in latitude over several thousand kilometers.

The Rocky Mountains are divided into groups and massifs:

The Rocky Mountains were mostly formed during the Cretaceous period during the Laramide orogeny, around 70 million years ago.

However, the Rocky Mountain chain is a complex of metamorphic and magmatic rocks with some sedimentary deposits. Intense erosion, particularly due to glaciations, has leveled basins located in the center of the chain. Glacial erosion has also formed deep, steep-sided valleys

The Rocky Mountain region experienced several phases of glaciation between the Pleistocene and Holocene. The most recent glacial episodes are represented by the Bull Lake Glaciation which began around 150,000 years ago,

I/ The Appalachians : are a mountain range located in eastern North America and extending from Newfoundland (Canada). It culminates at Mount Mitchell (2,037 meters) in North Carolina. The Appalachians separate the Atlantic coastal plain (to the east) of the Mississippi River basin and the Great Lakes (to the west). They stretch over 2,000 km in length.

The Appalachians gave their name to a type of relief, the Appalachian relief, which designates the remains of an ancient heavily leveled mountain. Long corridors extend parallel to rectilinear spines. The name “Appalachia” (Appalachia in English) designates several regions associated with the mountain range. Mostly it is used to refer to the entire range with its surrounding hills and dissected plateau

The Appalachian range was formed in three main stages:

The first phase, called “Taconian orogeny. A chain is then formed by the collision of an island arc with the paleocontinent Laurentia

The Acadian orogeny marks a second phase in the formation of the Appalachians, the paleocontinent Baltica (which corresponds to present-day Western Europe) collides with Laurentia. To the north of the current Appalachians a chain is formed with granite intrusions (for example in Gaspésie). Then this region underwent strong erosion. The Alleghanian orogeny constitutes the third phase of formation of the Appalachians. more precisely the northwest of present-day Africa, This event causes the elevation of the metamorphic heart of the Appalachians, the

formation of faults, and metamorphism. Erosion continues to produce large quantities of sediment, which is deposited in the shallow sea west of the Appalachians.

J/ The Andes Mountain Range (Spanish: Cordillera de los Andes) Is the longest continental mountain range in the world, running north-south along the western coast of South America.

Extending from north to south over a difference in latitude of 65°, or approximately 7,150 kilometers, and 200 to 700 kilometers wide (between 18 and 20° South latitude), The Andes are the highest mountain range in America. Part of the Pacific Ring of Fire, many of its peaks are volcanic. Several of these volcanoes are among the highest mountains on Earth after those in Asia, exceeding 6,000 meters above sea level.

The western slope leads directly to the Pacific Ocean while the eastern slope gives rise to rivers leading to the Atlantic basins and whose successive confluences form large rivers such as the Paraná in Brazil and Argentina

K/ The Alps : Are a mountain range that extends across Europe, spanning the northern border of Italy, southeastern France, Monaco, Switzerland, Liechtenstein, Austria, southern Germany and Slovenia The Alps peak at 4,806 meters

Mountain passes connecting valleys or countries often exceed 2,000 meters in altitude. The Alps form a 1,200 kilometer barrier between the Mediterranean Sea and the Danube. The existence of these orogens is linked to the convergence of the African and European tectonic plates and the interposition of blocks or microplates.

The Alps themselves stretch for a thousand kilometers, with a width of between 100 and 400 kilometers. They can be subdivided according to geographical, geological and topological criteria, into three distinct parts:

• the Western Alps, which form an arc between the Mediterranean Sea and Valais;

• the central Alps, between Valais and Graubünden (eastern Switzerland);

• the eastern and southern Alps, which sink into the Pannonian plain to the west of the Carpathians.

Internal crystalline base (Ambin) stripped of its sedimentary cover and with high metamorphism (metaquartzite, blue and green schist).

The Western Alps arc is classically subdivided into two parts, separated by the crustal Pennine thrust: the external zone and the internal zones. This major overlap juxtaposes distinct paleogeographic units, having had different tectonic and metamorphic histories: overall, the units of the external zone correspond to the proximal parts of the European margin, which were little shortened and little metamorphosed during Alpine history, while the internal units correspond to the more distal parts and to the ocean floor, which have undergone stronger metamorphism and shortening.

Deformations in the Alps, observable thanks to earthquakes and geodesy, are currently low. The Western Alps are, however, rapidly rising, up to 2.5 mm/year in the northwest of the arc. This uplift is an isostatic response to the erosion and melting of Alpine glaciers on the one hand, and to deep processes on the lithospheric scale on the other hand (crustal thickening). Horizontal movements are an order of magnitude smaller

L/ Himalayan range : Is a set of mountain ranges stretching over 2,400 km long and 250 to 400 km wide, which separates the Indian subcontinent from the Tibetan plateau in southern Asia. Strictly speaking, it begins in the west at Nanga Parbat in Pakistan and ends in the east at Namche Barwa in Tibet. This mountainous area, bounded to the west by the Indus River valley and to the east by the Brahmaputra River valley, covers an area of approximately 600,000 km2.

Thus, the Himalayas are home to ten of the 14 peaks which rise to more than 8,000 meters above sea level.

The Himalayas are part of a larger mountain system

Satellite image of the Himalayan range. The Tibetan Plateau is near the center, and the Taklamakan Plain is visible in the light area at the top of the image.

The Himalayas extend over more than 2,400 km. It has three parallel chains arranged in order of altitude and geological era. The youngest of the three ranges is called “sub-Himalayan” (Shivalik Hills) and rises to approximately 1,200 meters above sea level. It was formed by erosion since the formation of the Himalayas. Parallel to this chain is that of the “Lower Himalayas” whose altitude varies from 2,000 to 5,000 meters. Finally, the northernmost range, the “Great Himalayas”, is the oldest of the three. It rises to over 8,000 meters above sea level and contains many of the highest peaks in the world. According to plate tectonics, the Himalayas are the result of the collision of the Indian plate and the Indian plate. Eurasian9 after the subduction of the Neotethys Ocean under Eurasia10.

The portion of the Tethys Ocean which separated them completely disappeared around 50 Ma ago. The summit of Everest is made of marine limestone from this sea12.

A precise dating was obtained in 2020 by the stratigraphic, sedimentological and geochronological study of the sediments superimposed on the Indian passive

margin, which come first from India then from Asia: between 62.7 and 61.0 ± 0.3 Ma13.