TOPIC: THE TECTONICS OF PLATES

1. HISTORICAL BACKGROUND

THE FIRST HISTORICAL DATA - LEAVING ASIDE THE GREEK REFERENCES - THAT SERIOUSLY REFLECT THE POSSIBILITY THAT THE CONTINENTS MOVE, COME FROM THE CARTOGRAPHERS OF THE 16TH AND 17TH CENTURIES, WHO NOTICED THE SIMILARITY OF THE COASTS OF SOUTH AMERICA AND AFRICA. THEY CONSIDERED THAT THE AMERICAS HAD BEEN SEPARATED FROM EUROPE AND AFRICA BECAUSE OF EARTHQUAKES AND FLOODS. IN THE NINETEENTH CENTURY ALEXANDER VON HUMBOLDT SAID THAT NOT ONLY DID THE GEOGRAPHICAL BOUNDARIES COINCIDE, BUT SO DID SEVERAL GEOLOGICAL FORMATIONS.

IN THE FACE OF THESE MOBILIST THEORIES, THE FIXIST THEORIES WERE OPPOSED AS THEY DENIED THE MOBILITY OF THE CONTINENTS. THE LATTER WOULD DISAPPEAR THROUGHOUT THE NINETEENTH CENTURY.

AT THE END OF THE 19TH CENTURY, AUSTRIAN GEOLOGIST EDWARD SUESS MANAGED TO PUT THE PIECES OF THE PUZZLE TOGETHER AND PROPOSED THAT THE CONTINENTS THAT ARE NOW IN THE SOUTHERN HEMISPHERE IN THE PAST WERE UNITED IN A SINGLE SUPERCONTINENT, GONDWANA.

2. VERTICAL MOVEMENTS: ISOSTASY

THE VERTICAL MOVEMENTS OF THE CONTINENTS WERE KNOWN SINCE ANCIENT TIMES AND WERE ACCEPTED BY FIXISTS AND MOBILISTS.

OLD WATERFRONT LINES WERE KNOWN INSIDE THE CONTINENT AND THAT THE ESTUARIES AND FJORDS ARE FORMED BY FLOODING VALLEYS BY SINKING THE CONTINENT.

A SIMPLIFICATION COULD BE MADE BY STATING THAT THE LITHOSPHERE "FLOATS" OVER THE ASTHENOSPHERE SO THAT:

IF IT INCREASES ITS MASS, DUE TO SEDIMENT ACCUMULATION, FORMATION OF A GLACIER LAYER ... IT "SINKS" INTO THE ASTHENOSPHERE.

IF IT DECREASES ITS MASSES, BY EROSION, MELTING OF GLACIERS... IT “ASCENDS” AND “RISES” OVER THE ASTHENOSPHERE.

ISOSTASIA IS CALLED MOVEMENTS THAT SEEK GRAVITATIONAL BALANCE WITH THE MANTLE, SO THAT IT RISES WHEN IT IS DISCHARGED AND SINKS WHEN IT IS OVERLOADED. THEY ARE SLOW MOVEMENTS THAT STOP WHEN THE ISOSTATIC BALANCE IS REACHED.

ALFRED WEGENER: THE CONTINENTAL DERIVA

At the beginning of the 20th century, Alfred Wegener developed the theory of continental drift that was the beginning of the plate tectonic paradigm, although due to its revolutionary character it was not accepted in its time.

In 1915 he published The Origin of the Continents and the Oceans, in which he points out the basic ideas of his hypothesis about continental drift. In this work it is proposed that in the past there had been a single supercontinent, which he called Pangea, which 200 million years ago began to dismember giving rise to a series of smaller fragments that suffered a series of horizontal displacements, "drifting ", which caused continental collisions, these being responsible for the folding and elevation of the mountain ranges.

The evidence provided by Wegener to support his theory is explained below.

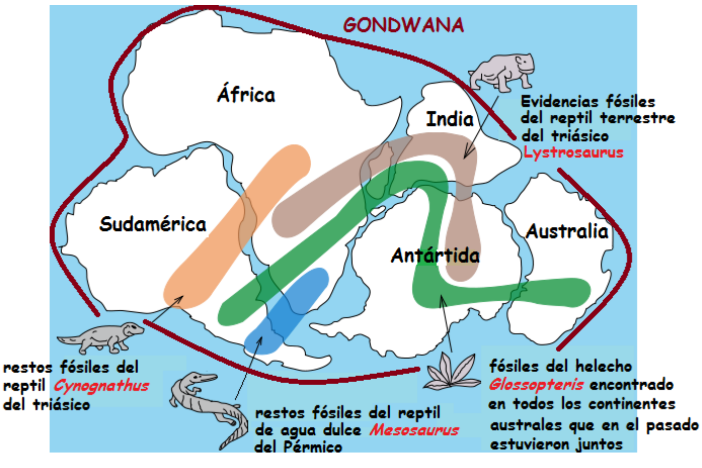
A) GEOGRAPHICAL TESTS

The lace of the continents or their coastline was one of the arguments in favor of a previous supercontinent. If the adjustment was not perfect, it was due to erosion and remodeling of the coastal strip. Before his detractors, Wegener argued that the union of the continents, distant in the past, could only be approximate.

B) GEOLOGICAL TESTS

In his reconstruction of Pangea, Wegener was able to verify the similarities in the structure of the rocks on both sides of the Atlantic. For example, the Appalachian chain in the western United States has a northeast orientation and disappears on the coast at the height of Newfoundland. Well, it turns out that mountains of similar age and structure emerge in the British Isles and on the Scandinavian peninsula. When reassembling all the land masses mentioned around the Appalachians, they are presented as a single and continuous belt.

C) PALEONTOLOGICAL TESTS



These students of the fossil remains of living animals of the past had established that the fossils of animals and plants in some areas of the coasts of Africa and South America were identical, but attributed this coincidence to pilgrim explanations, such as intercontinental bridges, aligned islets, etc.

D) PALEOCLIMATIC TESTS

The distribution of the Glossopteris fern and its preference for cold environments led Wegener to conclude that the lands where the plant lived had been united under a subpolar type environment. As a meteorologist, he was interested in obtaining evidence of ancient climates in support of its continental drift. Thus, he came to deduce that the continents of the southern hemisphere had together formed a large ice cap. Their deductions were based on the existence of glacial tillitas of the same age in South Africa, South America, India and Australia; Traces of glacial abrasion, stretch marks and grooves were detected under these sediments.

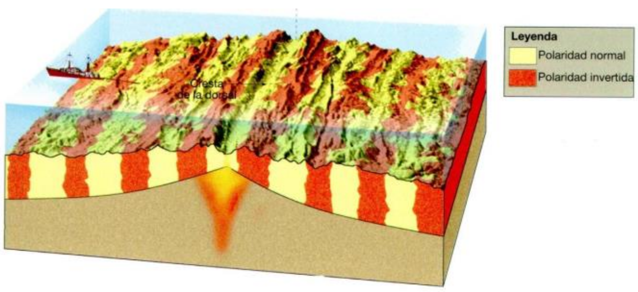
2. THE SCIENTIFIC REVOLUTION

However, Wegener's theses were not accepted because he did not explain what the cause of the movement of the continents was.

However, throughout the twentieth century, four major scientific and technological advances promoted the formulation of a new theory, **plate tectonics:**

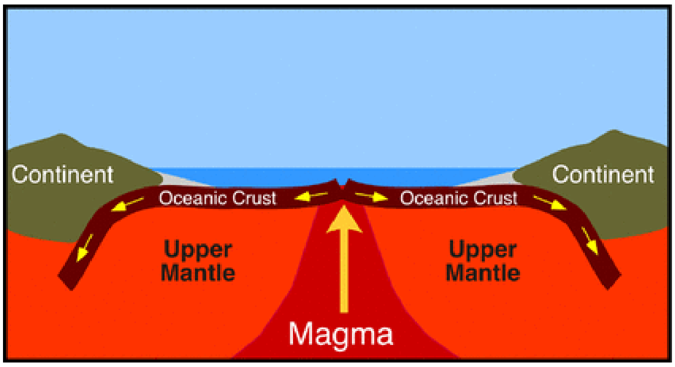
1. The location of seismic foci and volcanic activity along ocean ridges and underwater trenches. The seismic foci inclined between 40 and 60 degrees with respect to the horizon in a plane called the Wadati-Benioff area. Now we know that it is the place where one plate is inserted under another.
2. The study of the ocean floor. The discovery of sonar, military interest (submarine war in World War II) and the economic one promoted the investigation of the seabed. It was discovered that this presented:

- The same type of roughness as the continental crust, but also contained an immense underwater mountain chain, with more than 70,000 km in length and more than 1,000 km in width, zigzagging between the continents and surrounding the entire globe. Additionally, in the center of this mountain range, a depression or rift valley with tectonic and volcanic activity was detected.



- The age of the oldest rocks found in the oceanic crust did not exceed 200 million years. In addition, the rocks of the dorsal and its surroundings indicated that they were very young and progressively increased their age as they moved away from the dorsal.
- The confirmation of successive magnetic investments in the geological past and their relationship with the patterns of symmetry bands on both sides of the ocean ridges. The rocks of more recent age had normal magnetic polarity, while the rocks of more distant areas alternated their magnetic polarity: inverted, normal, inverted, etc. In this way, the oceanic crust was revealed as a recording tape of the history of the investments of the Earth's magnetic field.

These findings led **Harry Hess** to propose the <u>hypothesis of ocean floor expansion and recycling in subduction zones.</u> According to this hypothesis, the numbers are the place where magma from the lower mantle rises, expanding laterally; As the new oceanic crust grows, it moves away from the dorsal, moving like a conveyor belt. With the passage of time the "excess" of oceanic crust is being recycled and gradually consumed in the depth of the oceanic trenches.



All the exposed considerations ended in a new scientific revolution, already anticipated by Wegener - for many with sufficient arguments - that was baptized with the name of Plate Tectonics Theory, as will be studied in the next section.

3. PLATE TECTONICS: LITHOSPHERIC PLATES

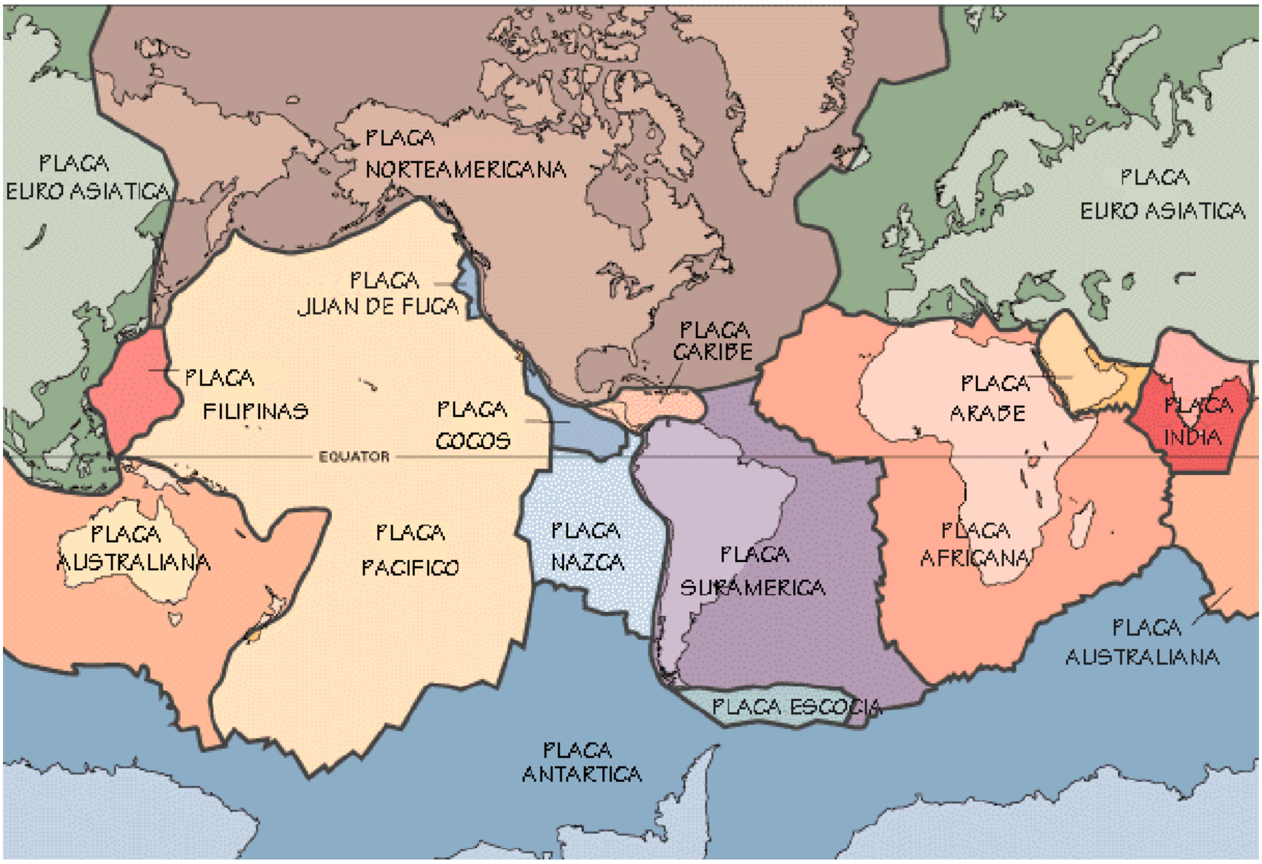
Plate tectonics can be considered as a global theory that serves to explain most of the geological processes that take place on Earth. The mechanisms of expansion of the ocean floor, of subduction in the ocean trenches, as well as the volcanic manifestations, the seismic shocks and the tectonic processes related to the lifting of mountains and the deformation of the rocks, receive their explanation within the context of tectonics of plates and allow us to understand globally the configuration of our planet.

The model of tectonic plates is anchored, on the other hand, in the geophysical studies carried out to unravel the layers of the Earth's interior and its mechanical behavior. Thus, the lithosphere, compact and rigid layer, rides on top of another, weaker and softer, called asthenosphere, which allows its displacement.

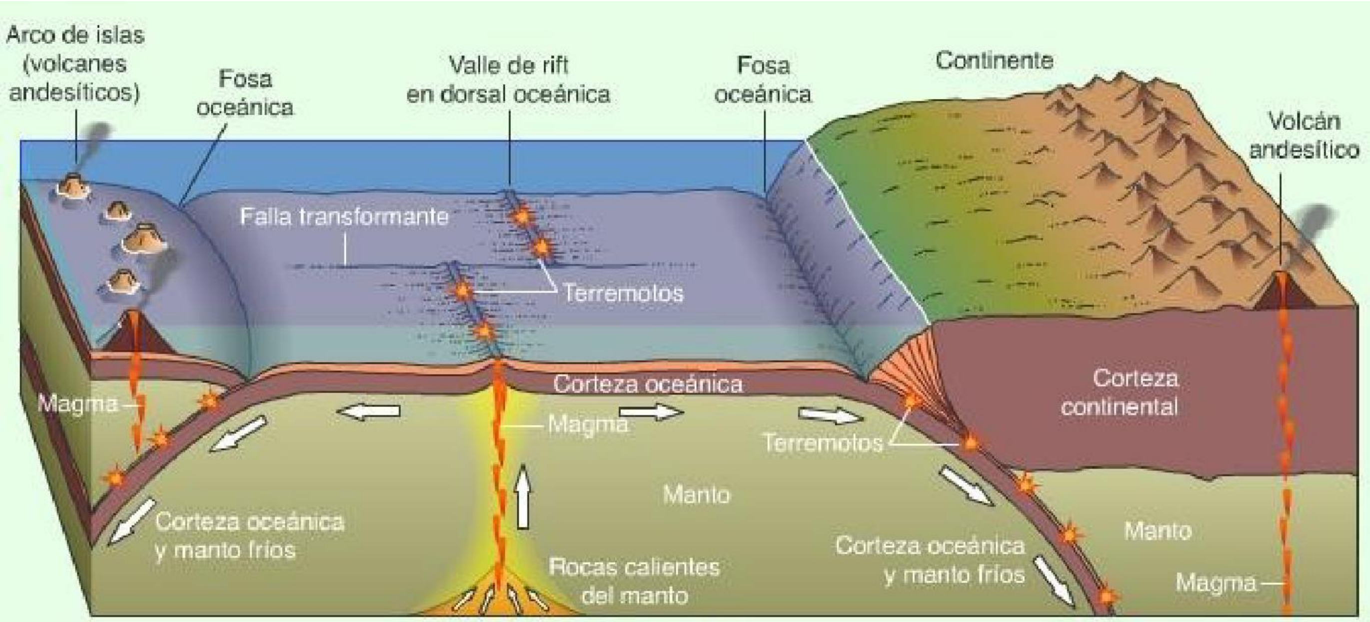
3.1. *TYPES OF PLATES AND THEIR DISPLACEMENT*

The lithosphere is fragmented into a series of plates, of different sizes, that are in slow but continuous movement and whose limits are the ocean ridges, ocean trenches and transforming faults.

There are seven **main plates,** the North American, the South American, the Pacific, the African, the Eurasian, the Australian and the Antarctic. The Pacific plate is the largest and the only one that is formed only by oceanic lithosphere. The other six have part of the oceanic lithosphere and part of the continental lithosphere. Other plates are medium in size, such as the Nazca, the Caribbean, the Philippine and Cocos plates. In addition, other smaller plates or microplates have been identified (the Iberian Peninsula functioned in the past as an independent microplate separated from Europe).



- The plates move interacting with each other along their boundaries or edges, where the greatest deformation develops. The plates have three types of edges in which a particular type of contact is manifested and, therefore, a characteristic geological activity, as described below.
- Divergent or constructive edges: the plates separate and new lithosphere is formed.
- Convergent or destructive edges: the plates collide and lithosphere is destroyed.
- Passive edges or transforming faults: the plates move laterally, neither lithosphere is created or destroyed.



3.2. DIVERGENT EDGES. THE FORMATION OF AN OCEAN

They correspond to plates that separate in opposite directions creating new ocean floor. Pos that are also called constructive edges. This limit coincides with the ocean ridges, these ocean ridges extend longitudinally across all oceans over more than 70,000 kilometers, with an average width that can be around 1,000 kilometers. In the upper part is a large crack or elongated valley, called rift, where magma emerges from the lower mantle.

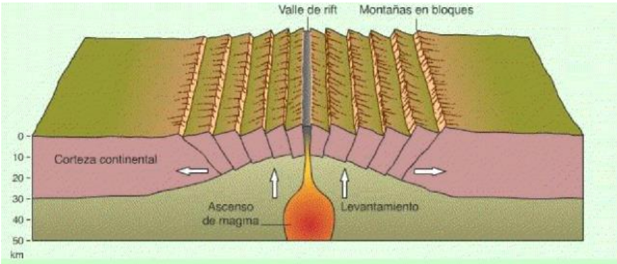
The dorsals are regions of high thermal flux. Upon separation of the two plates, a pressure drop occurs in the rocks of the mantle. Said pressure drop, in turn, lowers the melting temperature of these rocks, inducing partial melting. The partial melting of the mantle rocks forms large amounts of magma that rises to fill the cracks resulting from the divergence of the plates. In this way, the ocean floor grows continuously.

Occasionally, magma emissions are so abundant that the dorsal can emerge from the surface of the ocean. This occurs in Iceland, where the thermal anomaly is even greater due, it seems, to the existence of a hot spot. Here, the Central Atlantic dorsal emerges and bifurcates into two branches, constituting a natural laboratory where to study in detail the processes of divergence of plaques.

The formation of divergent edges on the continents explains how continents break (like Pangea) and how oceans (like the Atlantic) are formed. This process occurs in a series of stages:

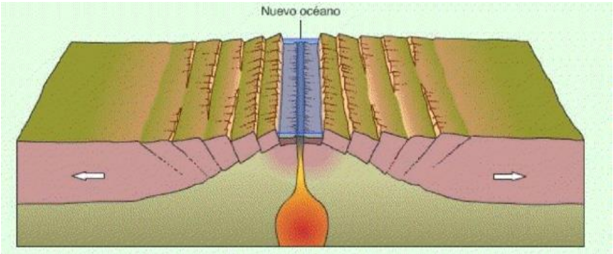
A) TRAINING STAGE OF A THERMAL DOME

Under a continent a hot spot develops that causes the bulge of the lithosphere and a dome is formed. This stretching leads to a triple point with three cracks, called rifts, which are enlarged and begin to emit material from the mantle. It's happening at the triple point where the Red Sea meets the gulf*de Adén y la depresión de Afar.*



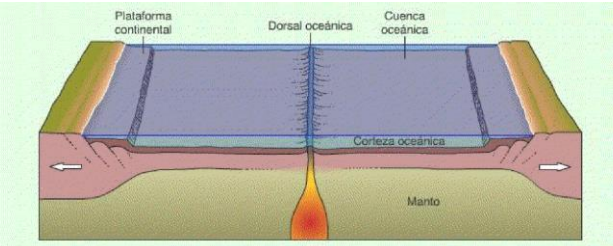
B) RIFT-VALLEY STAGE

A series of domes - more or less aligned - are connected in a chain and connected to form a single large opening that laterally will form two differentiated plates. Magma emerges from the lower mantle widening the crack. The blocks slide in favor of normal faults forming a central valley, called rift valley, from whose bottom sprout lava emissions and elongated volcanic buildings are constructed. The example, or the Great Rift Valley.



C) RED SEA STAGE

When the separation of the plates has deepened enough the rift valley, the waters of the nearest ocean invade it originating a young and narrow sea. This situation currently occurs in the Red Sea.



D) ATLANTIC STAGE

As the plates separate and move away from the dorsal, a continental shelf is installed, close to the continent, which through a slope gives way to the abyssal plains. An ocean basin has been developed whose examplemás característico es el océano Atlántico.

3.3. *CONVERGENT EDGES*

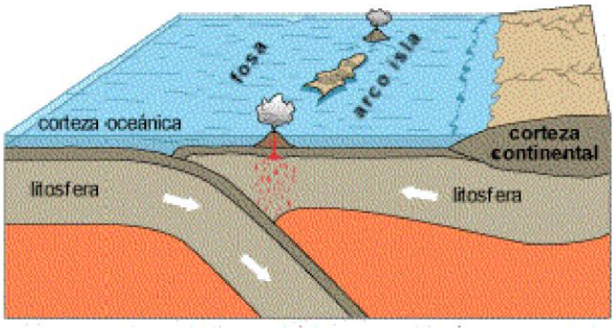
These regions, where an oceanic plate converges or collides with another plate. They are areas where lithosphere is destroyed, they are called subduction zones, and in them the oceanic lithosphere is subducted and somehow absorbed into the mantle. This means that the subducting plate bends and enters into the Earth, forming an oceanic pit in the inflection zone.

Subduction only occurs when one of the converging plates is oceanic. The subduction plane is called the Benioff plane or zone. It is determined by the location of seismic foci at different depths, depending on the oceanic plate that subducts interacts with the other plate or with the mantle materials.

When the plates that converge are continental, no subduction occurs.

Convergence can respond to three different situations or types of shock:

A) OCEAN-OCEAN CONVERGENCE

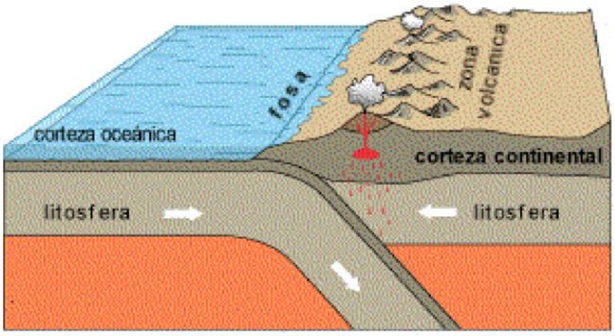


When two oceanic plates converge, one of them sinks or subducts beneath the other, forming an oceanic pit during the process. Normally the oldest and therefore densest plate is the one that bends and is introduced into the depths of the mantle.

The plate being subducted, causes intense seismic activity with the seismic foci located in the Benioff plane. It also carries with it water that hydrates the wedge wedge between the two plates, lowering its melting point and causing basic magmas that tend to ascend to the surface.

When magma reaches the bottom of the ocean, underwater volcanoes form. That if they emerge they form a set of aligned volcanic islands. This area is called the insular arc type or island arc. The curved shape they present is due to the fact that the plates are not flat and that their intersection is made outside a spherical surface such as the Earth.
When subduction occurs at a certain distance from the mainland, a marginal sea or trans-basin is usually formed, such as the Sea of Japan or the South China Sea.
Examples are the Aleutian Islands, the arch of the Antilles, the island arches of Japan and the Philippines. Parallel to these volcanic arches are the graves of the same name, the Mariana Trench with more than 11,000 meters being the largest gap in the oceans.

B) OCEAN-CONTINENT CONVERGENCE



When an oceanic plate and a continental plate converge, a subduction zone is also produced. The oceanic plate, being thinner and having greater density, slides under the continental one, promoting the formation of an oceanic pit.

According to the oceanic plate it descends, it causes intense seismic activity with the seismic foci located in the Benioff plane.

In addition, part of the sediments dragged by it, and sometimes fragments of the oceanic crust itself, are separated from the subductive complex and piled on the edge of the continental crust forming an accretion prism.

On the other hand, when the oceanic plate is sinking, it releases water by inducing partial melting of the rocks of the overlying mantle. Basaltic magma thus formed migrates slowly to the surface. In its ascent it can be contaminated with silica-rich rocks of the continental crust and, by processes of assimilation and magmatic differentiation, become a magma of andesitic or granitic composition. Upon reaching the surface, magma gives rise to volcanic eruptions that usually present a high explosiveness. At the same time, a series of volcanic buildings are being constructed that will form a continental volcanic arch.

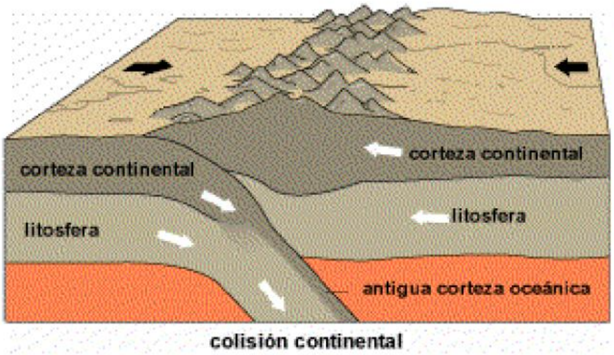
The generated magmatism raises the temperature of the entire subduction zone. This together with the directed pressures caused by the movement of the plates produces an intense regional metamorphism. All these processes, together with a high tectonic activity, with the presence of numerous deformations (folds and faults), ends up configuring an orogen

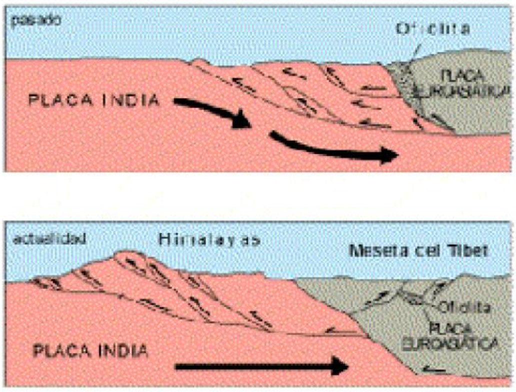
Andean volcanic type. These regions, also called active continental margins, are represented in the west of the American continent, from the Las Cascadas mountain range, through Sierra Madre and the Central American mountain range, to the Andes.

C) CONTINENT-CONTINENT CONVERGENCE

When the collision of plates involves two continents none of them tends to sink. This is because its density is lower than the rocks of the mantle and, therefore, its buoyancy is high. The clash of the subcontinent of India with South Asia, which led to the rise of the Himalayan mountain range, is one of the most dramatic examples of the consequences of plate tectonics.

Prior to the continental collision, the plates are separated by an ocean basin whose lithosphere is subducting under one of the continents. Insular arches or continental volcanic arcs are generated that once the basin is closed they will be embedded in the resulting suture. The sediments of the continental margins are imprisoned at the edges of the plates along with some fragments of oceanic crust attached to the continental mass.





The compression that occurs between the two plates results in intense metamorphism and significant deformations (reverse faults, riding ...). The seismic activity continues to be important, but the magmatism decreases until it is almost canceled once the basin is closed. There is talk, therefore, in this case, of cold mountain ranges.

The final product of all this generalized compression is a shortened and thickened continental lithosphere. This type of continental collision is called an Himalayan or Alpine type intracontinental orogen.

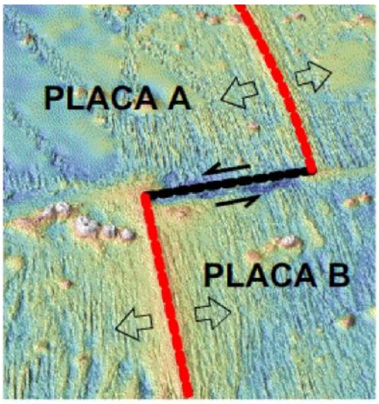
In the case of the Himalayas, the edge of the Asian plate is partially riding on the Indian plate, a duplication that explains the great height of this mountain range and, above all, the high plain of Tibet located to the north.

Also the Eurasian belt (the Alps, the Pyrenees, the Carpathians, the Caucasus, the Zagros Mountains and the Hindu Kush mountain range) has been lifted by approach towards the Eurasian plate of the plates located south of it.

3.4. *PASSIVE EDGES: THE TRANSFORMING FAILURES*

There are zones of contact between plates where neither construction nor destruction of bark occurs. There is talk, only in this sense, of passive edges since they are fracture zones where tensions accumulate and eventually discharge an important seismic activity.

Transforming faults are failures in direction or tearing, large, along which the two plates that travel in opposite directions slide horizontally.



The majority are found in ocean basins by sectioning the dorsals, to which they confer a staggered or zigzag appearance, as a result of the differential expansion in the different sections of the ocean floor.

In some places the transformation zone is located in the continental crust, assuming a serious risk for the population since the frequent earthquakes that they give rise to are of superficial focus and very destructive. Such is the case of the failures of St. Andrew, in California, and the fault of Northern Anatolia, in Turkey, whose movements in the century we have just left have been devastating.

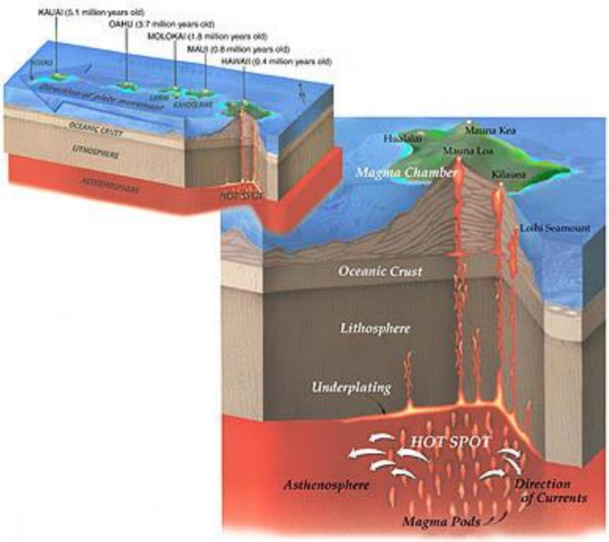
4. OTHER PROCESSES INSIDE OR AT THE LIMIT BETWEEN PLATES

4.1. *AULACOGENS*

When a thermal dome is established under a continent, the formation processes of a rift originate a triple point. The branch of the same that is not going to join to form the dorsal degenerates, stops its progression and remains as a depressed area and delimited by major failures. Sometimes these graves are invaded by large rivers, as is the case in the Amazon basin.

Benué's depression in Nigeria, caused by the opening of the Atlantic and separating Africa and South America, is the most characteristic example. In the Iberian Peninsula, the sedimentary groove in which the Iberian mountain range was installed and subsequently erected has been interpreted as a *Aulacogen*

4.2. INTRAPLACY MAGMATISM: THE HOT POINTS



Proposed by Tuzo Wilson, hot spots or hot spots, are regions of the earth's surface where there is a rise of magma in the form of feathers or plumes from very deep areas of the mantle. Probably, this material comes from the mantle-core interface, layer D ".

Thus, the location of the surface at which the hot spot emerges turns out to be stationary and independent of the movement of the plates. On the surface the outcrop of magam generates volcanoes. As the lithospheric plate moves, they move with them the volcanoes that when they move away from the hot spot lose their activity and cool and in the lithosphere that is on the hot spot a new volcano originates. The result is an aligned series of more active and younger volcanoes the closer they are to the hot spot. This is the case of some volcanic archipelagos, such as the Hawaiian Islands, which are aligned in the direction of plate movement.

Most often, the hot spots are inside an oceanic plate like in Hawaii or Tahiti, although they are also located near the ocean ridges, such as the Azores, Galapagos or Iceland. In the continental lithosphere, the most characteristic have been described in Yellowstone National Park, United States, and in the Afar region in Africa.

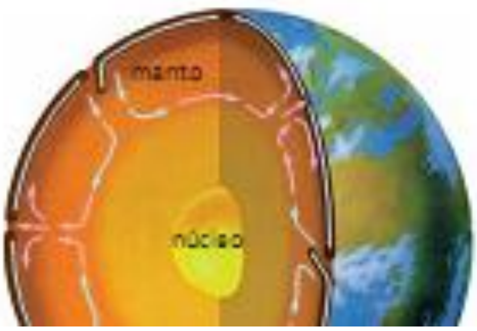
5. CAUSES OF PLATE MOVEMENT

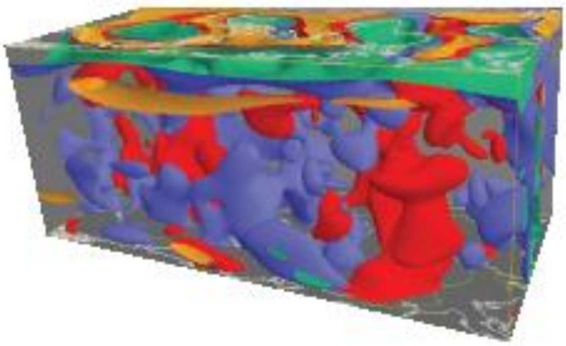
The explanation of the causes that produce the movement remains one of the weak points of the theory. Several processes that can participate, to a greater or lesser extent, in the global dynamics of our planet have been invoked.

5.1. CONVECTION CURRENTS

Convective processes are based on heat currents, more or less circular, that involve dragging material from the hottest to the coldest areas and vice versa. They are possible in solid materials when they can warp when heated.

This possibility seems to occur inside the mantle where the heat of disintegration of the radioactive elements is added to the high temperatures, and this contributes to the upward and downward movements of the mantle rocks. The ocean ridges would correspond to the areas where there is





an increase in heat currents and subduction zones to the zones of descent of cold materials. The movement of the mantle would act as a fluid that causes the drag of the lithospheric plates.

5.2. *TRAIL AND PUSHING OF THE PLATES*

These mechanisms involve, in part, the gravitational force.

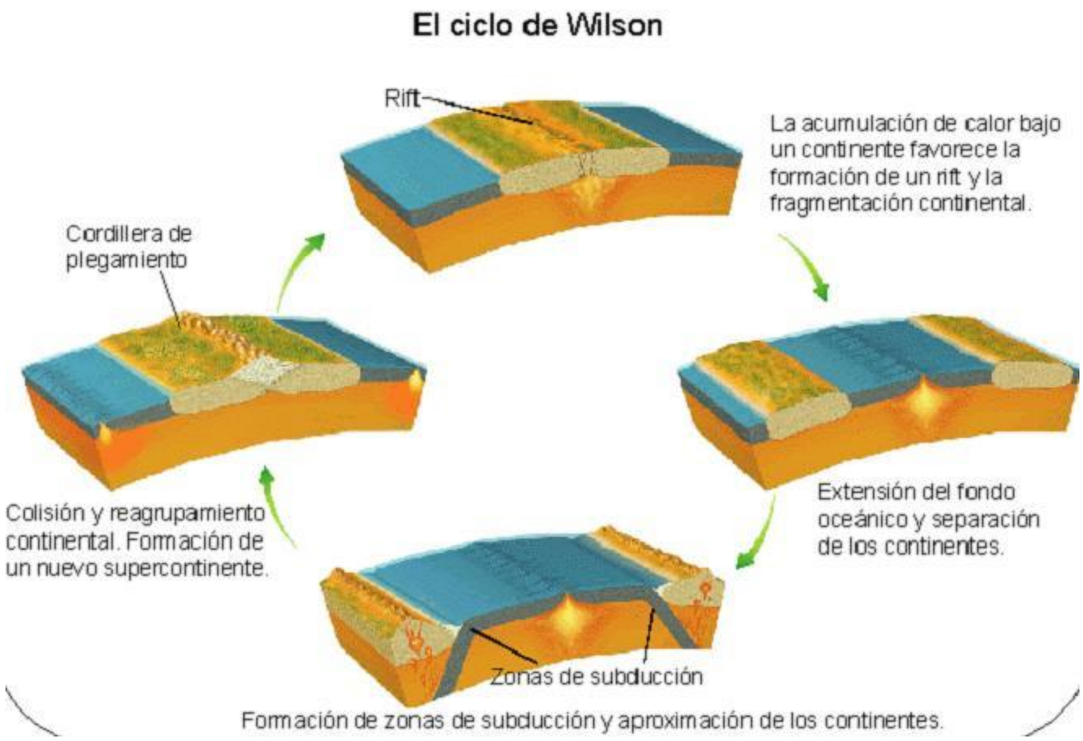
The ridge of the dorsal is in an elevated position, so that when the magma cools, it presses and pushes laterally the plates whose sliding is favored because the movement is descending. In a graphic way this process could be referred to as "wedge effect".

On the other hand, the oceanic plate as it moves away from the dorsal gradually cools and increases its density. Finally it sinks into the pit, "downhill", in favor of gravity. Once subduction begins, the weight of the sunken plate is able to progressively drag the rest of the plate. This mechanism has been called “gravitational pull” or “towel effect” since if a towel is spread in the water it initially floats, but if one of the edges is soaked it sinks and drags the rest with it.

Although none of the proposed mechanisms explain the plate tectonics engine alone - probably all contribute to some extent - there is no doubt that the unequal distribution of heat inside the Earth is responsible for thermal convection in the mantle . And this is, in short, what promotes the movement of the plates.

6. WILSON CYCLE

The thermal phenomena of the interior of the Earth, which periodically give rise to processes of fragmentation and continental collision, were studied by Tuzo Wilson. This cycle presupposes that all continents come together in a single land mass, the supercontinent, approximately every 500 million years.



7. OTHER CONSEQUENCES OF PLATE TECTONICS

- Plate tectonics is responsible for the distribution of the continents, the appearance of mountain ranges and the formation of the oceans. This has huge repercussions for the Earth:

- GEOGRAPHICALLY: The rupture of continents and formation of new oceans increases the volume of the dorsals and causes the rise in sea level. This decreases the continental surface and increases that of coasts.

- IN THE CLIMATE: The existence of fragmented continents or pangeas influences ocean currents, the presence of continents at the poles favors the cooling of the poles and the formation of glaciations, the elevation of the mountain ranges affects the atmospheric circulation. All these factors directly influence the weather.

- IN THE BIOSPHERE: It is clear that if tectonics influences the climate and distribution of ostas and seas it will have an important impact on the biosphere.

○ The periods of pangeas coincide with the reduction of biodiversity because coastal ecosystems (of great biodiversity) are reduced, continental interiors are desertified and the area usable by living beings decreases, reducing resources.

○ The periods with fragmented continents coincide with an increase in biodiverdity because, they increase the coastline and continental platforms (areas of great diversity), geographical isolation favors the formation of new species that occupy new territories with varied resources and reduces the aridity of the continents.