HARTAI ÉVA,

GEOLOGY

10

Új Magyarország FEJLESZTÉSI TERV

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

X. The speed of moving plates and the causes of plate motions

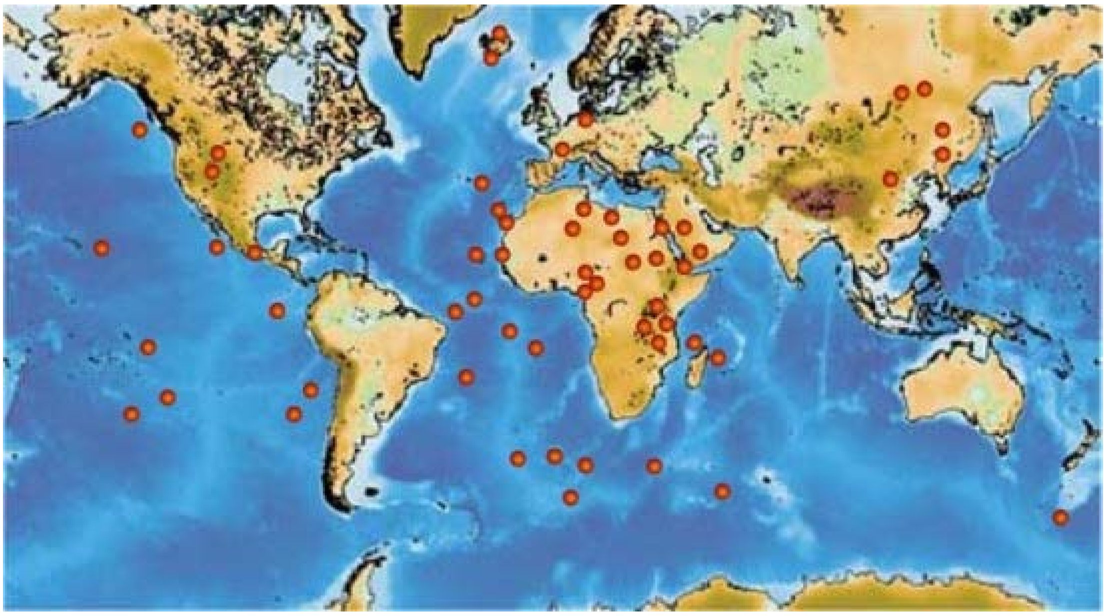
1. Determination of the velocity of plate motion

As was mentioned earlier, the speed of plate motions can be calculated from the magnetic pole reversals is a relative velocity. In order to determine absolute motions, an external frame of reference is necessary.

Hotspots

Recently Global Positioning System satellite measurements give exact data about plate motions. However, we can have a reference framework without these measurements by using hotspots.

Hotspots are volcanic regions, which are thought to be fed by mantle plumes (abnormally hot, rising rock masses originating from the deep mantle). The diameter of hotspots can be several hundreds of kilometres.

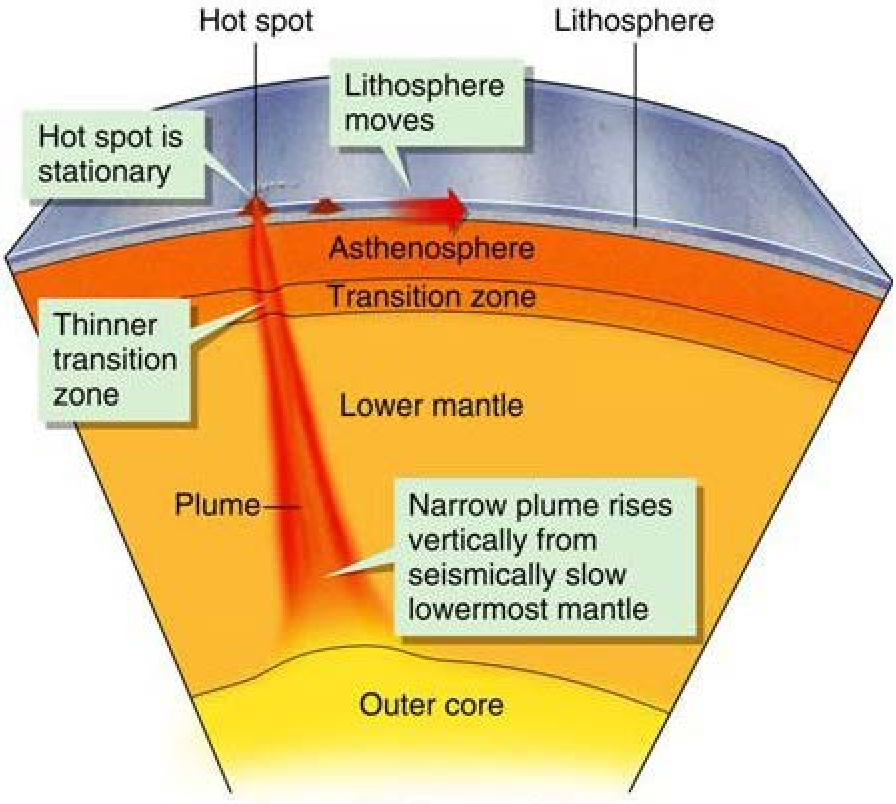


Distribution of hotspots on Earth *[i]*

Mantle plumes

Some scientists state that mantle plumes are generated in the lower levels of the asthenosphere by the decay of concentrations of radioactive isotopes. However, there are other opinions, stating that the plumes are generated at much deeper levels in the lower mantle, perhaps even at the boundary of the mantle with the outer core. One of the reasons for this is that the plumes seem to have remained in the same position over very long periods of geological time (as long as 200 million years). About 70 hotspots have been identified on the Earth's surface, and they can occur on both continental and oceanic crust.

As the plume rises towards the base of the lithosphere, the reduction in pressure allows partial melting of the mantle material within the plume to form basaltic magma.

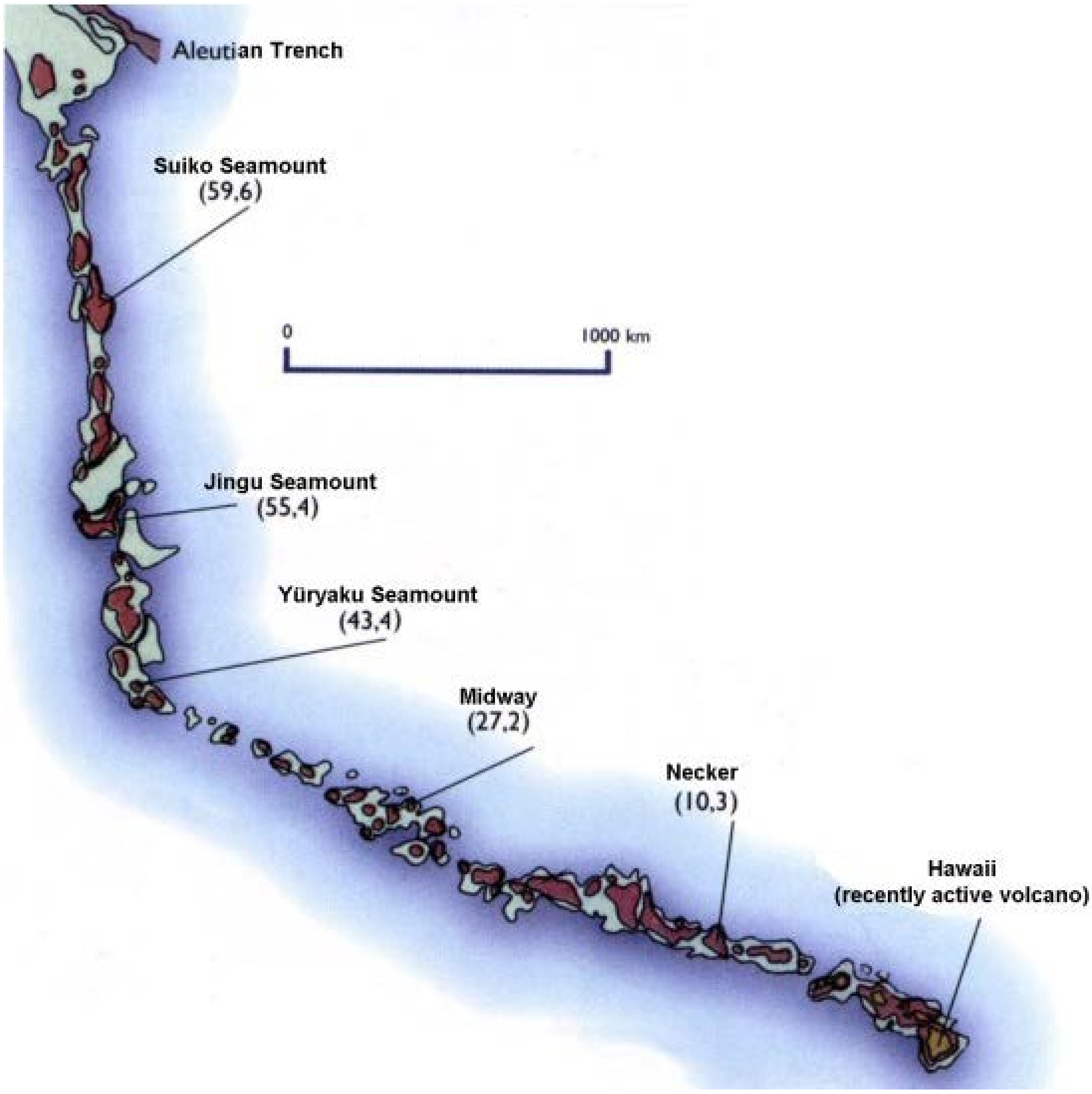


Schematic section of the Earth showing the origin of mantle plumes [ii]

Where hotspots occur on continental crust, the crust becomes domed and extensive volcanic activity exists. The huge volumes of *flood basalts* are thought to be caused by the eruption of a **mantle plume** head at the surface.

Basaltic island chains and the speed of plate movement

In the oceanic areas, the magma melts its way through the oceanic crust and erupts onto the ocean floor to build up an active volcanic island. As the plate carries on moving over the plume, the original island is carried away from the magma source and becomes extinct. The plate acts as a conveyor belt so as the old island is carried away a new volcanic island is formed in its place above the hot spot. This process builds up a **chain of islands**, with the age of each increasing with distance away from the currently active island. As the old islands are carried away from the hot spot, they subside (sink down into the crust) and are eroded by the sea, so that many of the older islands are now under the sea surface and form *guyots* (isolated underwater volcanic mountains).



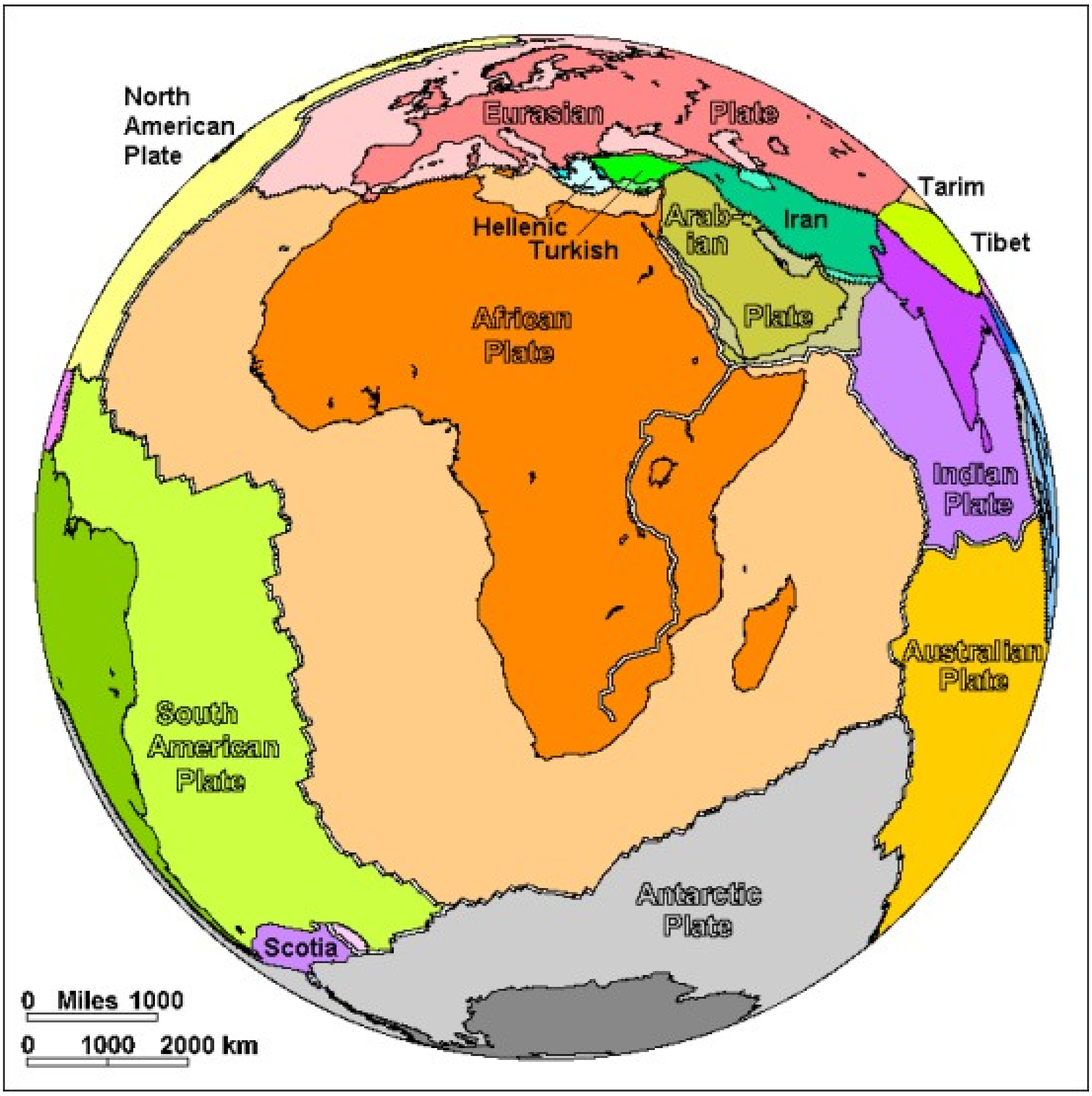
The Hawaiian-Emperor island chain

The numbers show the ages of the basaltic rocks that build up the island. If we know the distance between the two end members of the chain, and the time necessary to cover the distance, the speed of movement can be calculated.

The best-known example of the formation of an island chain above a hotspot is the *Hawaiian Island*. Each of the islands in the chain was formed as the Pacific plate drifted slowly in a north-west direction over a long-living mantle plume.

Plate motion velocities

Using several hotspots as a reference, geologists have found that the *African Plate* is very nearly stationary (evidence from the fact that volcanoes there seem to be very long lived).

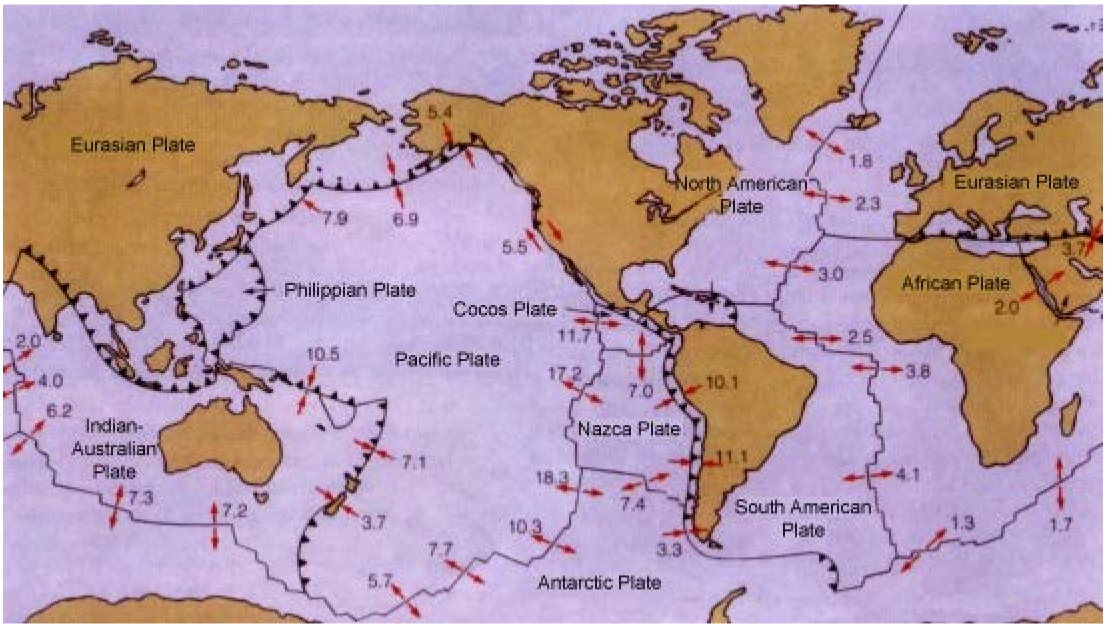


***The African Plate* [iii]**

The plate is shown by the orange colour. The continent is marked by the darker orange. Almost all margins of the plate are spreading edges.

Because the African Plate is almost surrounded by spreading edges, and because the relative velocities along the encircling ridges are closely matched, we must conclude that the *Mid-Atlantic* ridge is moving westward, and that the oceanic ridge that runs up the centre of the Indian Ocean is moving to the east. If the absolute motion of the African Plate is zero or nearly so, the Mid-Atlantic ridge in the southern Atlantic Ocean must be moving westward at the rate of about 2 cm/year.

The *Australian-Indian Plate* is moving almost directly northward. All other plates, with the exception of the nearly stationary Africa Plate, are moving approximately eastward or westward.



Velocity of the motion of the larger plates

The red arrows show the direction of movement. The direction of the subduction is shown by the small black triangles along the convergent plate boundaries.

Several plates do not have convergent margins and must therefore be increasing in size. Most of the modern subduction zones are to be found around the Pacific Ocean, along the *Pacific Plate*, and thus much of the oceanic lithosphere now being destroyed is in the Pacific. Consequently, the Indian Ocean, the Atlantic Ocean and most other oceans must be growing larger, while the Pacific Ocean must be getting smaller.

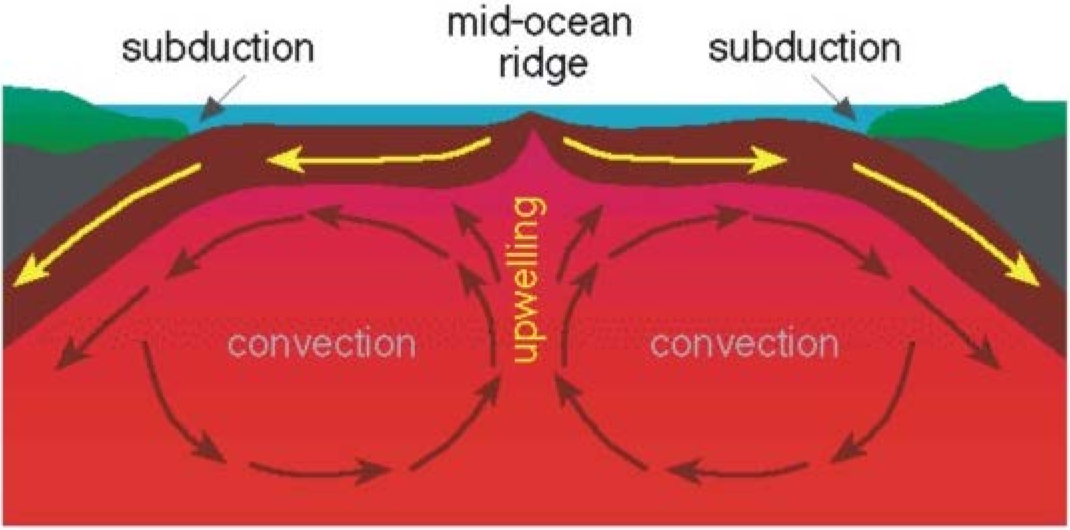
2. The causes of plate movements

Convection in the mantle

The mantle is solid rock. However, from seismic wave velocities we know that the asthenosphere behaves in *ductile* manner, that is even though it is solid it can flow under stress and behave like a liquid. If this is the case, convection can occur in it.

Convection – a type of heat transfer in liquid and gaseous material – is caused when material that occurs at a deeper level is heated to the point where it expands and becomes less dense than the material above it. When this happens, the hot, less dense material rises. In a confined space, rising hot material will eventually cool and become denser than its surroundings. This cool dense material must then sink. This gives rise to convection cells, with hot rising currents and cool descending currents.

The discussion about the convection in the mantle is speculative. Evidence from seismic tomography and heat flow simulation indicates that convection of some sort occurs beneath the lithosphere. Even so it is so difficult to see how plate motions can be due entirely to convective motions. For this reason most scientists believe that lithosphere motion is due to a combination of processes and that convection is only one of the processes.



Schematic section of mantle convection showing the effect on lithosphere motion [iv]

Forces of lithosphere motion

In the movement of lithosphere plates three forces might play a role: (1) convectional currents in the asthenosphere, (2) the weight of the subducting slab, (3) the topographic factor.

The role of convectional currents

As it was discussed before in the formation mantle plumes play an important role in the formation of the convectional currents.

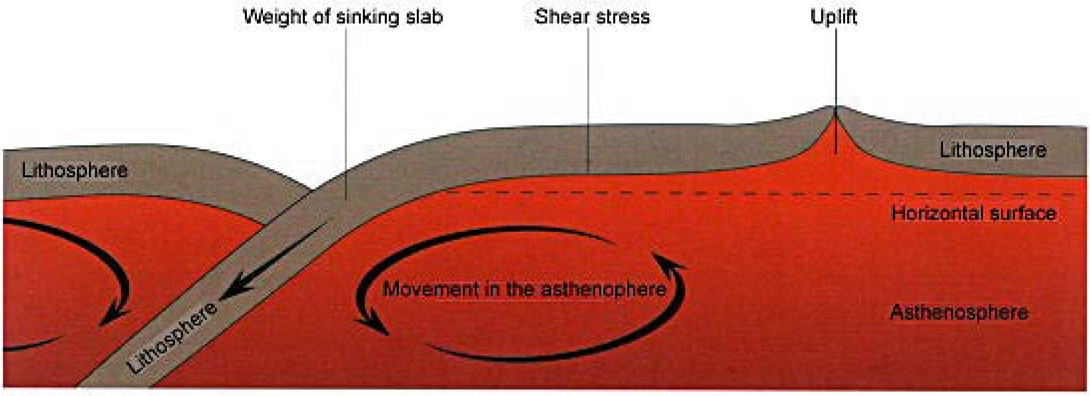
When the ascending heat flow arrives at the base of the lithosphere it spreads radially and causes tension in the rocks above. When several uprising heat flows are arranged in a line, the dominant spreading takes place away from this line into the two opposite directions. The shear stress coming from the movement of asthenospheric material increases, and at a critical point the lithosphere breaks and the two fragments start mowing away. Rising magma at a spreading centre creates new lithosphere and in the process pushes the plates sideways. Once the process started, it tends to keep itself going.

The effect of subduction

The composition and material of the oceanic lithosphere and the asthenoshere are almost the same. However, the subducting lithosphere can be denser than the asthenosphere at greater depth. The reason is, that rock is a poor conductor of heat, and at the depth of 400-500 km the temperature at the central part of the descending slab can be as much as 1000° cooler than the asthenosphere. The dense slab of the lithosphere must therefore sinks under its own weight and exerts a pull on the entire plate. As lithosphere sinks and pulls the plate downward, it places the sinking slab in tension.

The topographic factor

In the centre of the convectional heat uprising the lithosphere becomes thinner and arches upward. Away from the spreading centre it becomes cooler and thicker. As a consequence, there will be a slight difference in height, and the boundary between the lithosphere and the asthenosphere slopes away from the spreading centre. The slope is only 1 part in 100, but its own weight can cause the lithosphere to slide downward on the top of the viscous asthenosphere at a rate of centimetres per year.



Forces of lithosphere motion

The three mechanisms by which lithosphere plates move: (1) shear stress caused by convectional current, (2) topographic difference by the uplift of the spreading edge, (3) weight of the singing plate

The plate tectonic cycle

The plate tectonic cycle involves the cycling of material through the mantle via the oceanic crust. Hot magma rises from the mantle and form new oceanic crust at the mid-oceanic ridges; the oceanic crust moves laterally away from the ridge and finally sinks back into the mantle at a subduction zone. The rate at which new oceanic crust is created is equal to the rate at which it is consumed. The energy source that drives the plate tectonic cycle is the Earth' internal heat.

As a result, the *oceanic lithosphere is completely renewed* time by time. The age of the oldest oceanic crust is 180 million years. However *the continental lithosphere is almost unchanged*, the oldest continental rocks are more than 4 billion years old. In a minor amount, continents can lose material by erosion, or their mass can be increased by volcanic eruptions. In the collision zones the continental material can be also increased by the folded, compressed oceanic sediments or the obducted oceanic crust fragments.

3. The isostatic movements of the lithosphere

Isostasy is the gravitational equilibrium between lithosphere and asthenosphere. In the common sense, isostasy is the principle of buoyancy where an object immersed in a liquid is buoyed with a force equal to the weight of the displaced liquid.

On a geological scale, isostasy means that the Earth's strong lithosphere exerts stress on the weaker asthenosphere which slowly flows laterally.

Continents and mountains have lower density rocks (2.7 g/cm3), and they stand high because they are thick and light. The ocean basins are topographically low because the oceanic crust is composed of denser rocks (2.8 g/cm3). The mantle part of the lithosphere and the asthenosphere have a density of 3.3 g/cm3.

Lithosphere acts as if it were "floating" on the asthenosphere at an elevation which depends on its thickness and density.

Isostasy can be experimented on the following webpage:

http://geoinformatics.sdsc.edu/doe/student/topography/isostasy.html

This concept explaines how different topographic heights can exist at the Earth's surface. When a certain area of lithosphere reaches the state of isostasy, it is said to be in isostatic equilibrium. There are high mountains that are not in isostatic equilibrium e.g. the Himalayas, as they are still rising.

Isostasy is the principal explanation for the vertical motions of the Earth's surface, just as plate tectonics is the principal explanation for lateral motions.

BIBLIOGRAPHY:

[i] http://www.classroomatsea.net

[ii] http://www.geology110.com

[iii] http://www.uwgb.edu

[iv] http://earthscienceinmaine.wikispaces.com