

Lectures Honoring Roland Eötvös
and
Celebration of the 50th Anniversary of EPS

Loránd Eötvös and the Foundations of Geophysics

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Many excellent biographies, rememberings have been published in the past

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The history of the 125 year old Eötvös torsion balance

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Abstract The paper is a comprehensive history of Eötvös' torsion balance from the initial experiments of its inventor to the final stages of torsion balance development. It gives a review of the characteristics of the successive types of the instrument and the main features of their development. It covers briefly the contribution of Ferdinand Süss the constructor of the instruments whose mechanical expertise contributed to the success of the torsion balances to a great extent. It appreciates the activity of Hugo Böckh, a well-known Hungarian geologist, who recognised the geological aspects of torsion balance surveys in an early period and initiated their introduction to oil prospecting.

Keywords Eötvös · Torsion balance · Gradient · Curvature · Askania

If you are watching the planet Earth from the space, it appears a quite common celestial body, but from the height of Earth observation satellites and even more from the surface it is a real fascinating one. It is the shelter of life, source of water, hydrocarbon, ores, other raw materials and geothermal energy. On the other hand the Earth is vulnerable and dangerous at the same time, and its harmony may collapse.

If you are watching the planet Earth from the space ...



A grayscale satellite image showing a large, dark, irregularly shaped lagoon or bay on the left side. The surrounding land is densely packed with agricultural fields, appearing as a complex grid of various shades of gray. The coastline is jagged and irregular. The text "from the height of Earth observation satellites" is overlaid in white on the right side of the image.

from the height of Earth
observation satellites

SEA



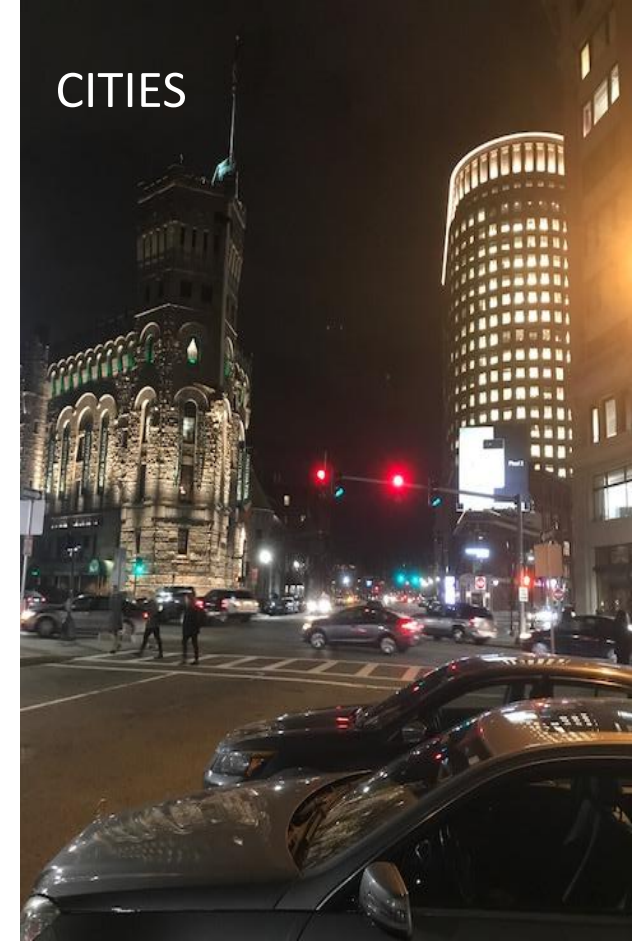
MOUNTAINS



MEADOWS



CITIES



It shelters life, source of water, hydrocarbon, ores, other raw materials and provides geothermal energy.



Earth is vulnerable and dangerous at the same time. Its harmony may collapse suddenly.

The Earth is active, dynamic planet with ever forming landscape, tectonics, volcanic eruption and devastating, destroying earthquakes and changing climate. The secret of that is hidden mostly deep beneath the surface. Much have been learned about it but our knowledge is still of unsatisfactory kind. No one can forecast the magnitude and the hypocenter of the next earthquake or assess the secular variation of the Earth's magnetic field and its forthcoming reversal. Earth sciences are facing many challenges.

What is geophysics about

Geophysics is a composition of physics, and quantitative earth science, which **is concerned with the physical processes and properties of our** amazing and unique **planet**.

Application of geophysical methods for civil engineering, environmental protection purposes, and dominantly for detection of underground natural resources is called exploration geophysics or in other words geophysical prospecting.

Milestones of understanding of the Earth - brief history

Study of the physics of the Earth dates back to many centuries.

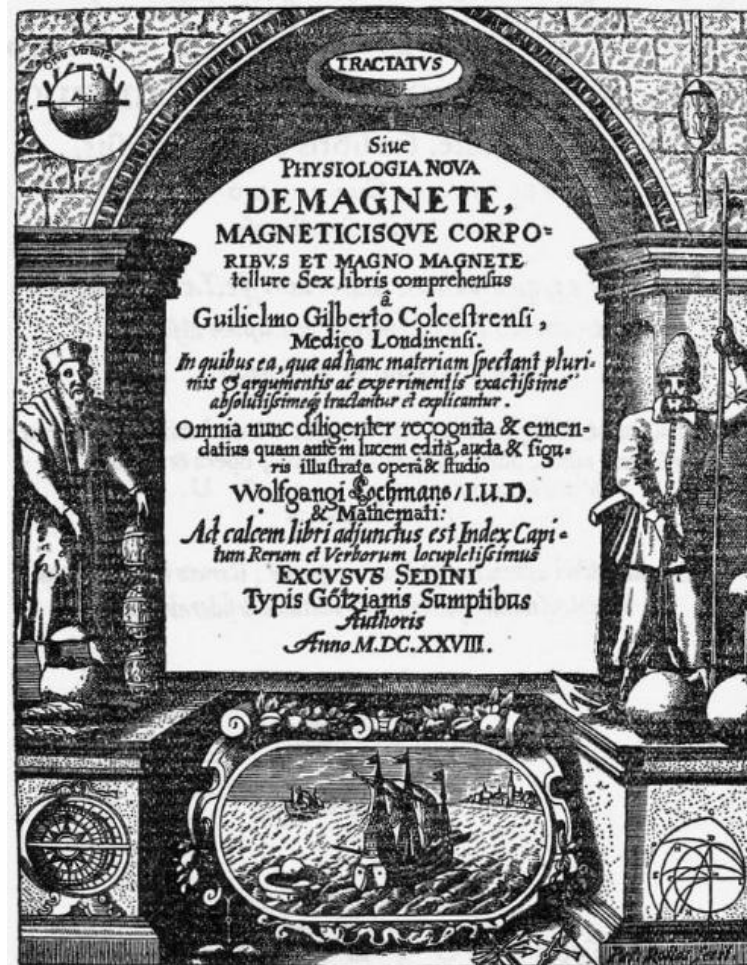
There are historical evidences from the ancient Greece and China, that the magnetic property of lodestone was known and applied for navigation and detection of iron ore deposits already more than 2000 years ago.

In 1600 William Gilbert published his work, titled *De Magnete*, in which he stated that the Earth is a giant magnet.

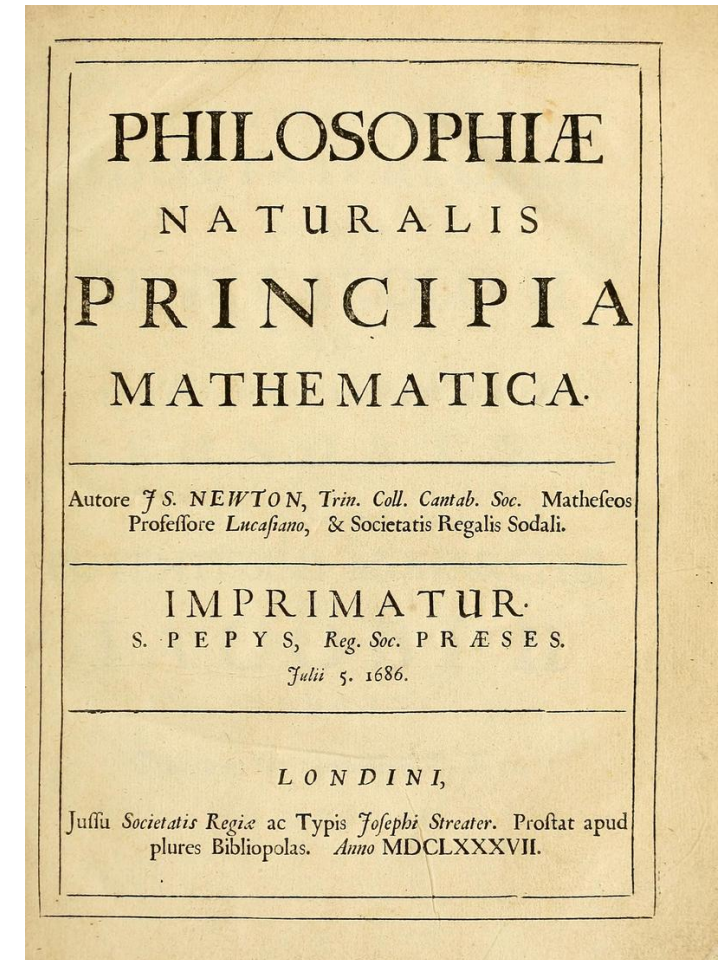
87 years later Isaac Newton published his work in which he described the law of gravitation. This works laid down the foundations of the study of the Earth interior through gravity and geomagnetic fields.

Milestones of understanding of the Earth - brief history

Start of new way of looking at the Earth system



Title page of 1628 edition, wikipedia.org



Title page of *Principia*, first edition (1687), wikipedia.org

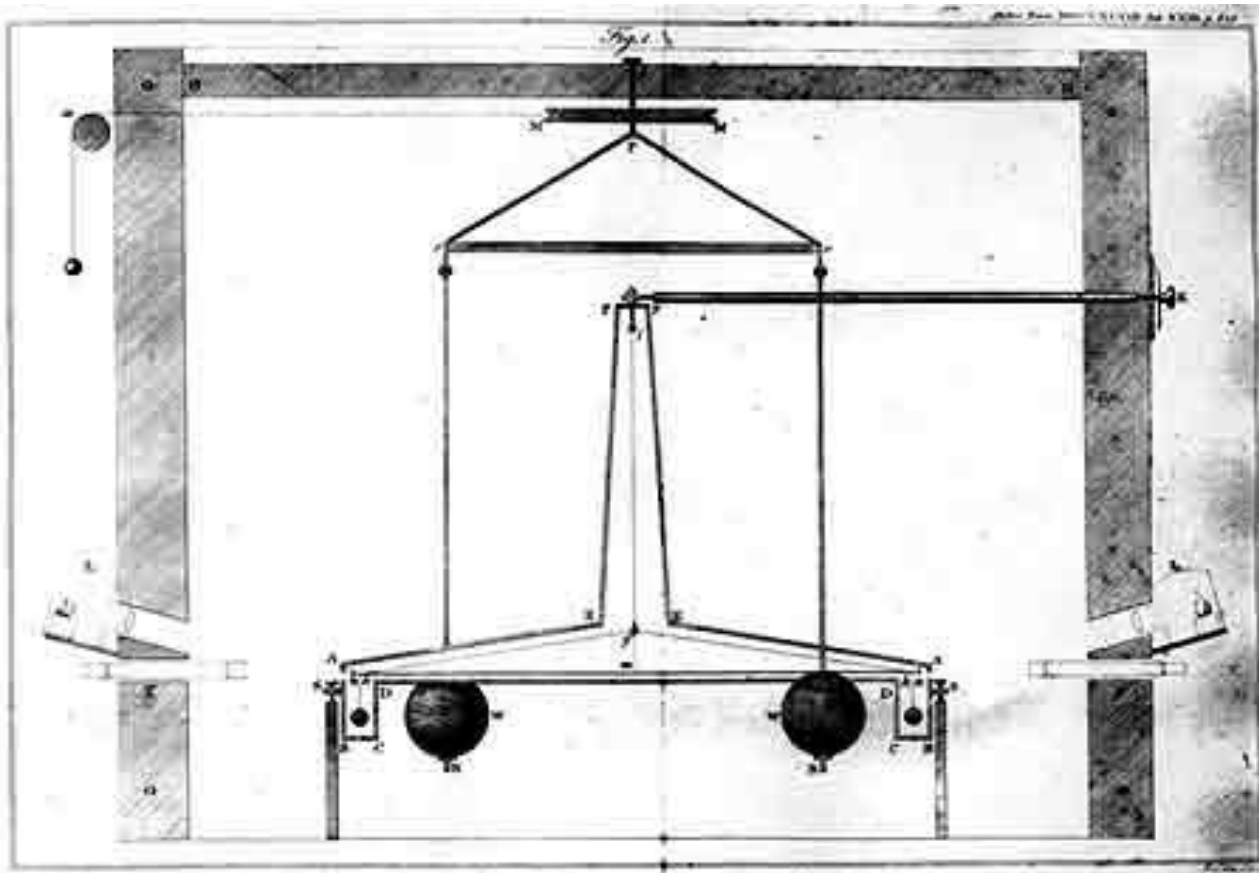
Milestones of understanding of the Earth - brief history

A great earthquake occurred in Lisboa in 1755 with an estimated magnitude of 8.5-9. The city was totally destroyed along with the colonial ambitions of the empire.

As a geophysical consequence, intense seismological instrumental development started and somewhat later the theory of seismic wave propagation was elaborated by Cauchy, Poisson, Stokes and others.



Milestones of understanding of the Earth - brief history



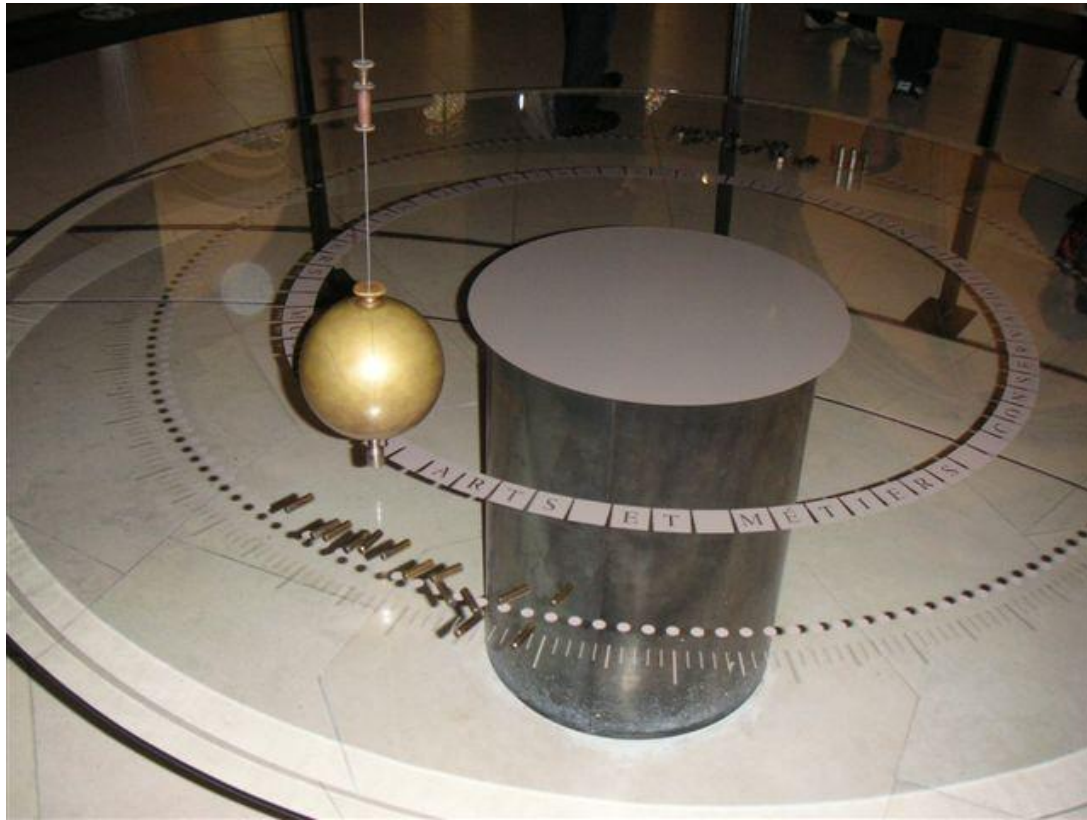
At the end of the 18th century the experiment with the *Coulomb-Cavendish* torsion balance determined the universal gravity constant, the mass and the mean density of the Earth.

Milestones of understanding of the Earth - brief history



Gauss and *Humboldt* made great contribution to geomagnetism by global mapping and by the separation of the internal and external sources of the geomagnetic field. The Göttingen Magnetischer Verein started in 1834 and the global network operated between 1842 and 1864.

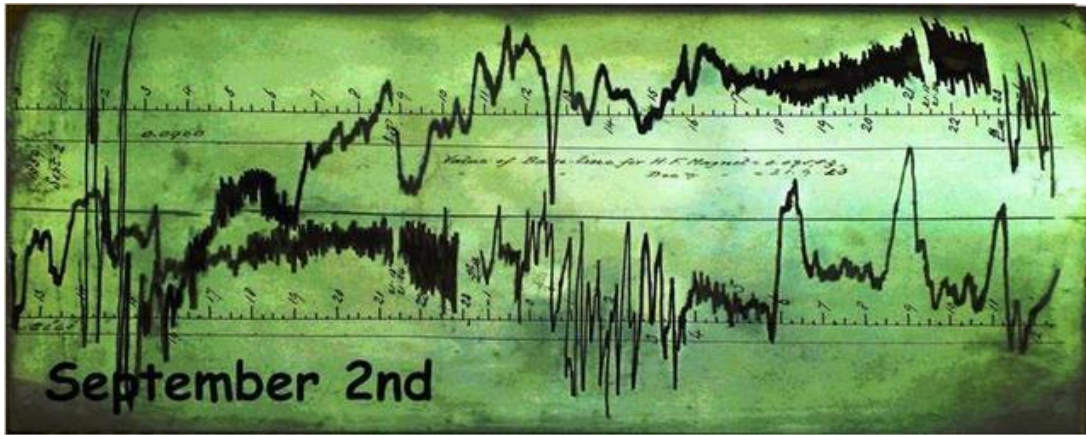
Milestones of understanding of the Earth - brief history



The *Foucault* pendulum
experiment took place in Paris,
in 1851.

Milestones of understanding of the Earth - brief history

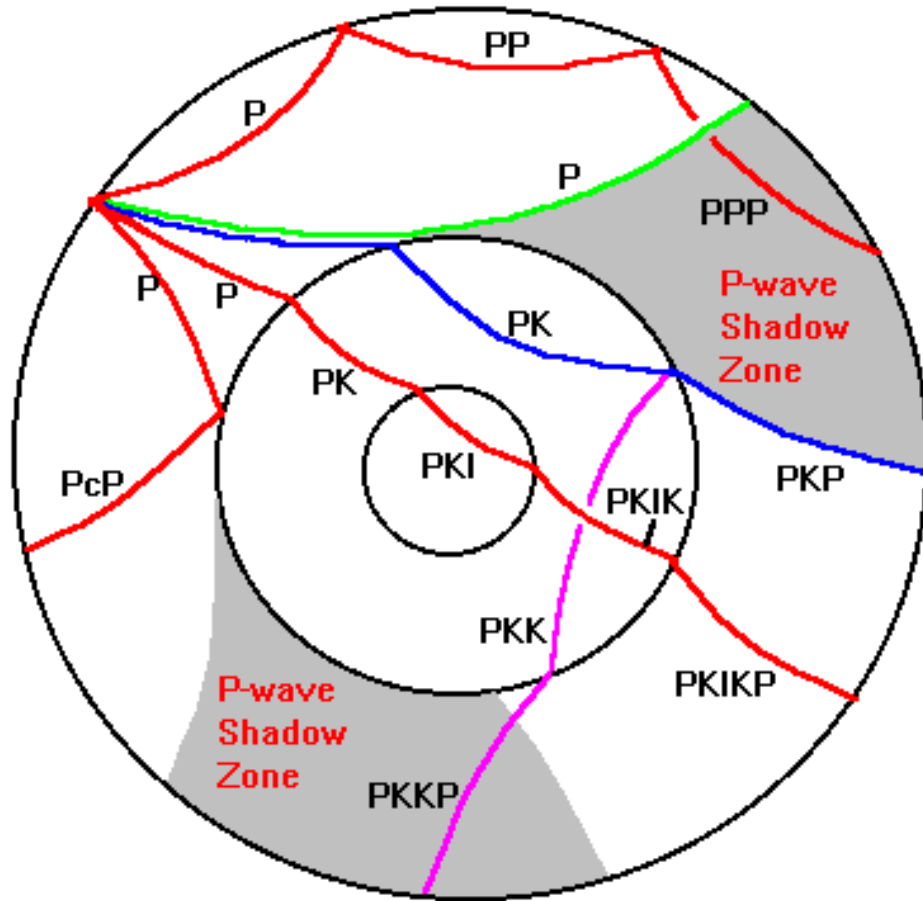
Contemporary observation of the extremely intense solar eruption in 1859, called Carrington event, and the associated geomagnetic storm drew the attention to the solar-terrestrial interactions.



A magnetogram recorded at the Greenwich Observatory in London during the Carrington Event of 1859

A solar storm comparable in magnitude with the Carrington event, has a potential to completely destroy the critical infrastructure, such as electric power transmission, navigation and telecommunication, worldwide.

Milestones of understanding of the Earth - brief history



The layered Earth - the major discontinuities of the planetary interior.

Mohorovicic identified the seismic discontinuity between the Earth's crust and mantle.

Guttenberg estimated the depth of the fluid outer core.

(The solid inner core was found later by Richter in 1936.)

Milestones of understanding of the Earth - brief history



Born of geophysical exploration in 1890-91

In **1890-91** *Eötvös Loránd* constructed the brilliant torsion balance, called **Eötvös torsion balance**. The purpose built device allows studying the gravity field of uneven mass distribution.

Great idea, delicate masterwork of the Hungarian precision mechanics and engineering.

Manufactured by Nándor Süss.



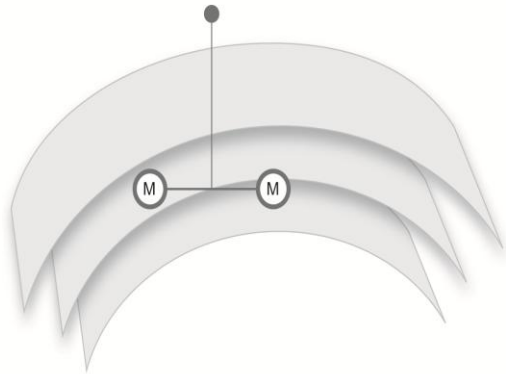
**Properties of the MTA CSFK
Geodetic and Geophysical Institute**



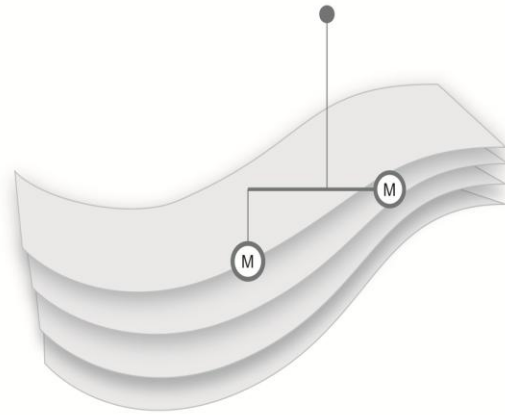
The famous double device (left) and its the younger brother, the Eötvös-Pekár torsion ballance (above). The latter has just entered into service again in the repetition of equivalence experiment.

The principle of the Eötvös torsion balance

Coulomb torsion balance



Eötvös torsion balance



Eötvös torsion balance consists of a torsion fibre and a rod (or beam) suspended on it and balanced by two equal weights. One platinum weight is attached directly to the rod, the other one hangs on it at a lower level.

Suspension and the balanced rod allow only one degree of freedom, the rotation in the horizontal plane. The horizontal component of the local gravity field, if any, twists the torsion fibre from the torsion-less position.

The principle of the Eötvös torsion balance



The whole equipment is encased perfectly against environmental effects and disturbances. Optical reading of the angle of twist is taken in different directions, from which the non-diagonal elements of the Eötvös tensor are derived by applying the Eötvös equation.

$$\mathbf{E} = \begin{bmatrix} W_{xx} & W_{xy} & W_{xz} \\ W_{yx} & W_{yy} & W_{yz} \\ W_{zx} & W_{zy} & W_{zz} \end{bmatrix}$$

Ság volcano experiment

Besides his theoretical work, and laboratory occupation Eötvös was very keen in geography, hiking and alpinism.

He realized, that **the nature offers him a perfect laboratory for testing.**

In 1891 he carried out the first field experiment on the plateau of Ság volcano to check and validate his idea on the vector gravimetry.

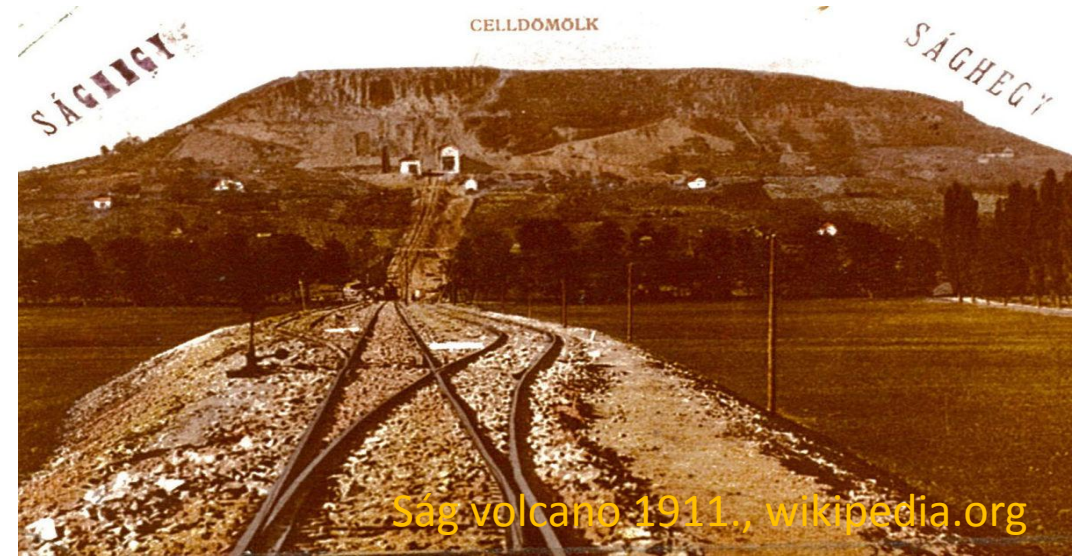


Crater of the Ság basalt volcano today

Ság volcano experiment

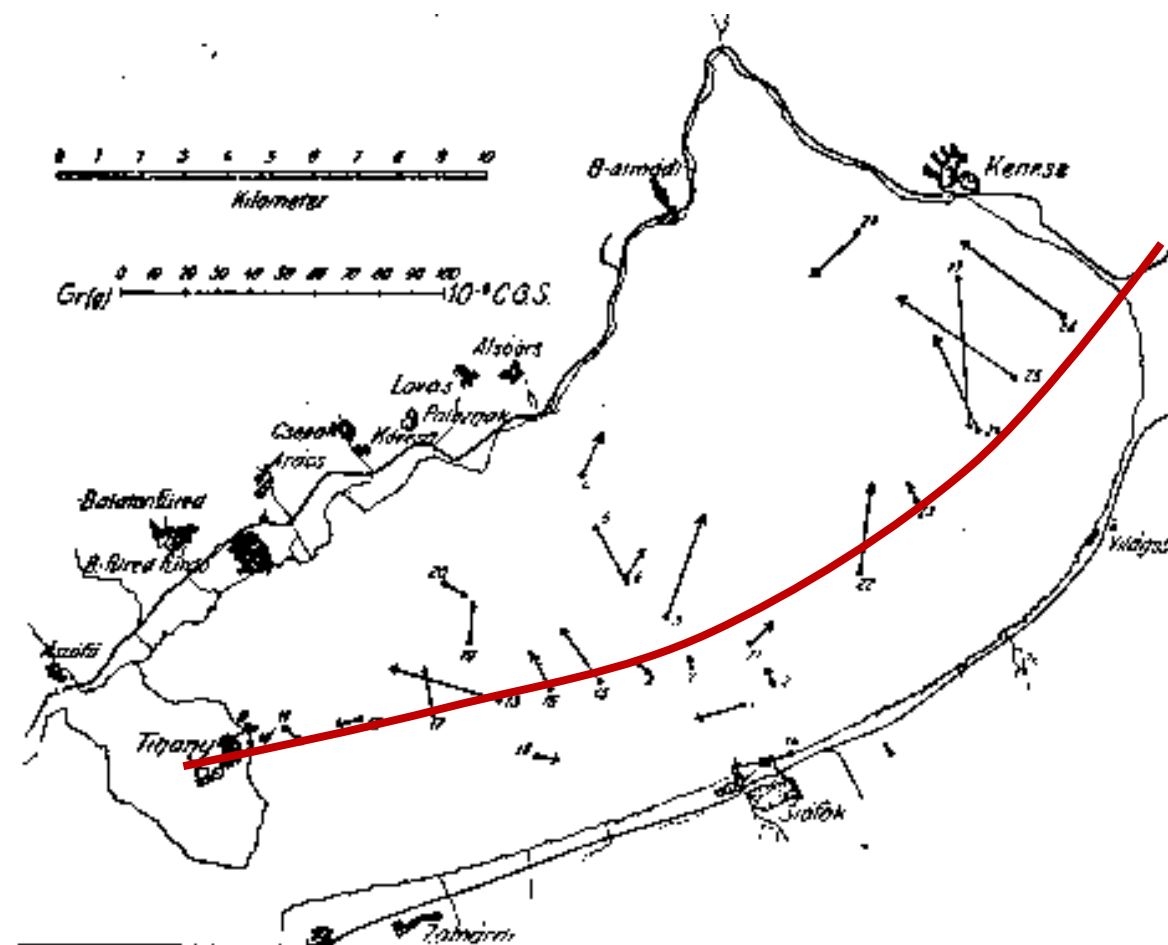
The choice was very well established. The shape of basalt volcanoes is generally very simple, due to the low viscosity of the basalt lava.

The simple cylindrical geometry, and the homogeneous density distribution helped the theoretical calculation on one hand, and the mass/the volume i.e. the expected effect was optimal to the test measurement. (The crater was quarried later.)



Ten years later he carried out a complete and systematic geophysical survey on the frozen lake Balaton. The survey was completed in 1903 with an unprecedented result!

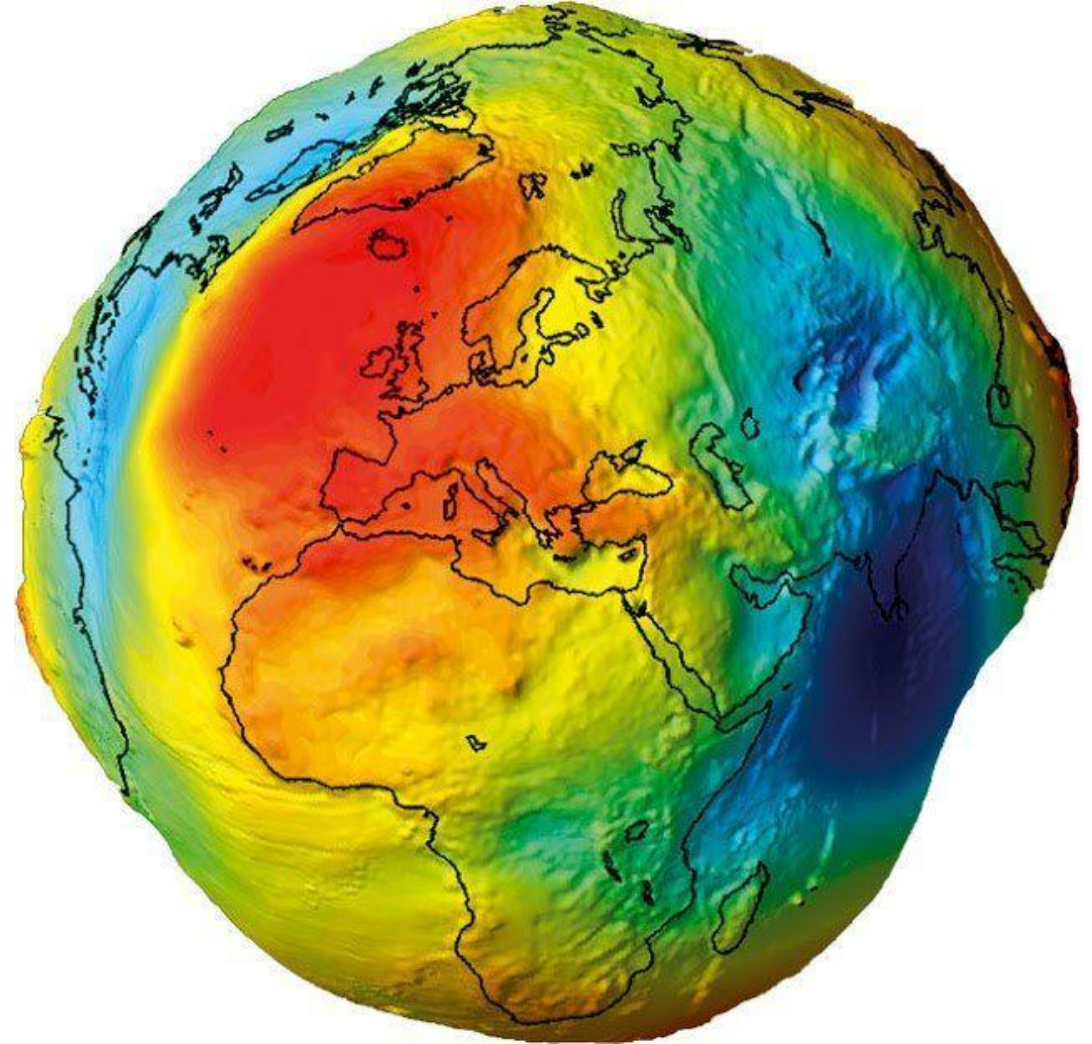
Eötvös and his staff discovered an underground tectonic line. Balaton survey was followed by many geological applications. Most well known are the discovery of Egbell oil field, and the classical hydrocarbon reservoirs in Texas, but many other surveys were carried out worldwide, e.g. in India.



This purpose made survey means the advent of geophysics, born of a new discipline.

Eötvös is cited as the first geophysicist by the earthscience community all over the world.

The Eötvös torsion balance surveys were stopped in the '50ties of the last century. Its role was taken over by effective scalar gravimeters in local, and by satellite gravimetry in global and regional studies very recently. There had been nearly 60000 Eötvös balance measurements were carried out in Hungary until 1960. Data are intensively utilised in structural geology and geodetic reference system calculations. An attempt was also made on the improvement of the Hungarian geoid very recently on the basis of former Eötvös torsion balance measurements.



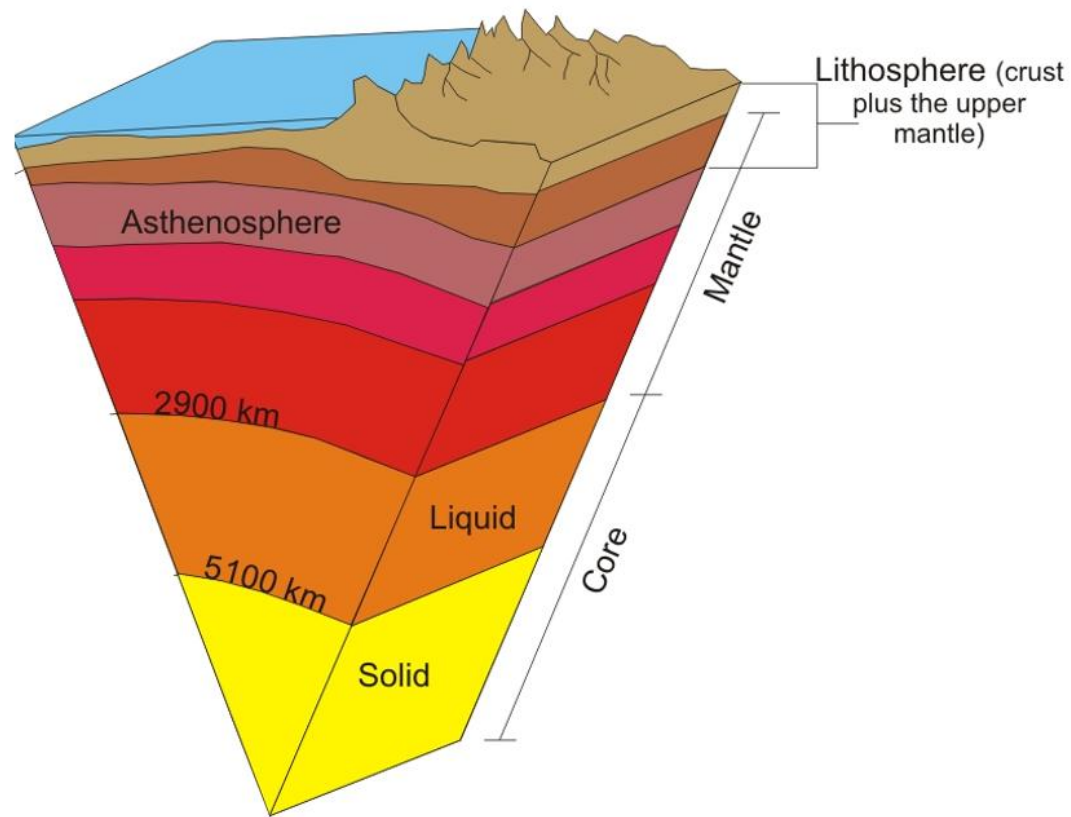
The Earth's gravity still belongs to the active areas of geophysical research and surveys because:

- it is an effective tool for detection of underground geological formation, deposits, reservoirs or simply of buried objects,
- its perfect knowledge is inevitable in the determination of the irregular equipotential surface of the planet which is called geoid. Precise geodetic height positioning is based on the geoid modelling, and the accuracy of the GNSS positioning strongly depends on the reference frame.

The Earth's gravity belongs to the active areas of geophysical research and surveys because:

- and according to or present knowledge the **gravity is the driving force** of subduction and sinking of lithospheric slabs. It governs mantle thermal convection and recycles (mix back) the material of the surface (lithosphere). All in all **it operates the planetary engine**. The planetary engine is responsible for all those things what we call geodynamics at the surface: continental drift, collision of tectonic plates, mountain building, basin formation, volcanism, earthquakes.

Understanding the plate tectonics



Static model of the Earth (internal structure)

The Earth is layered in spherical shells

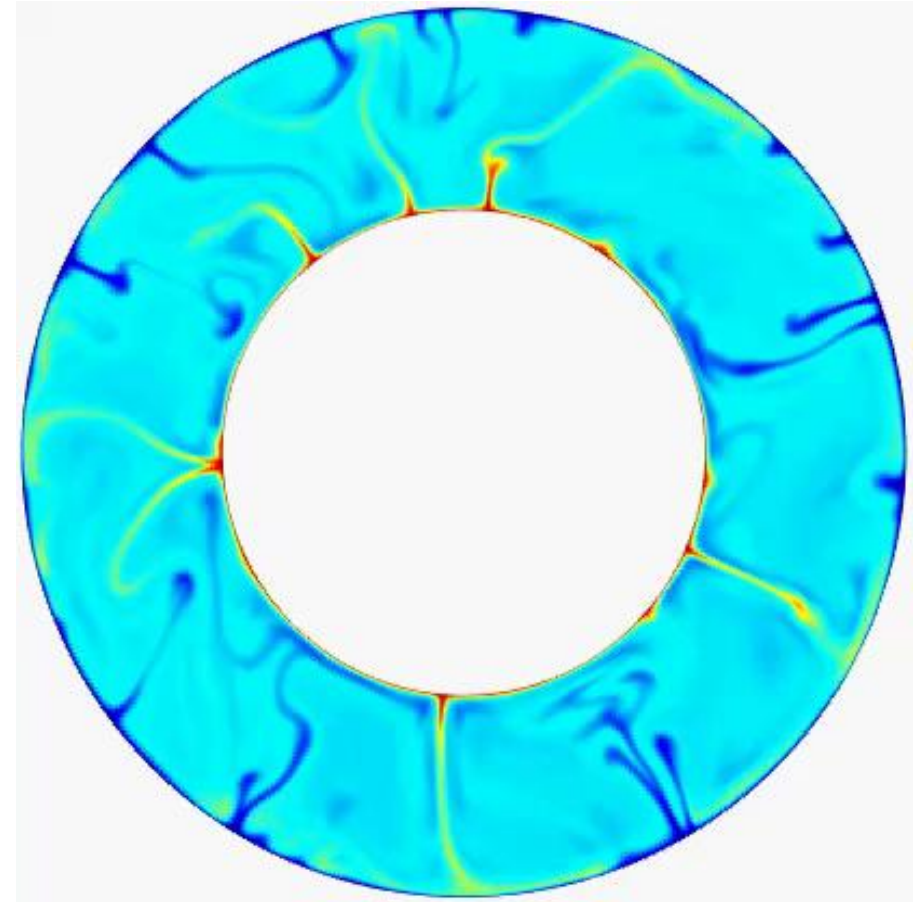
According to the static model of the Earth, the lithosphere, better to say the lithospheric plates are floating on the higher density asthenosphere.

The surface (outer shell) is composed of plates. Oceanic and lithospheric plates are distinguished.

Understanding the plate tectonics

Dynamic model

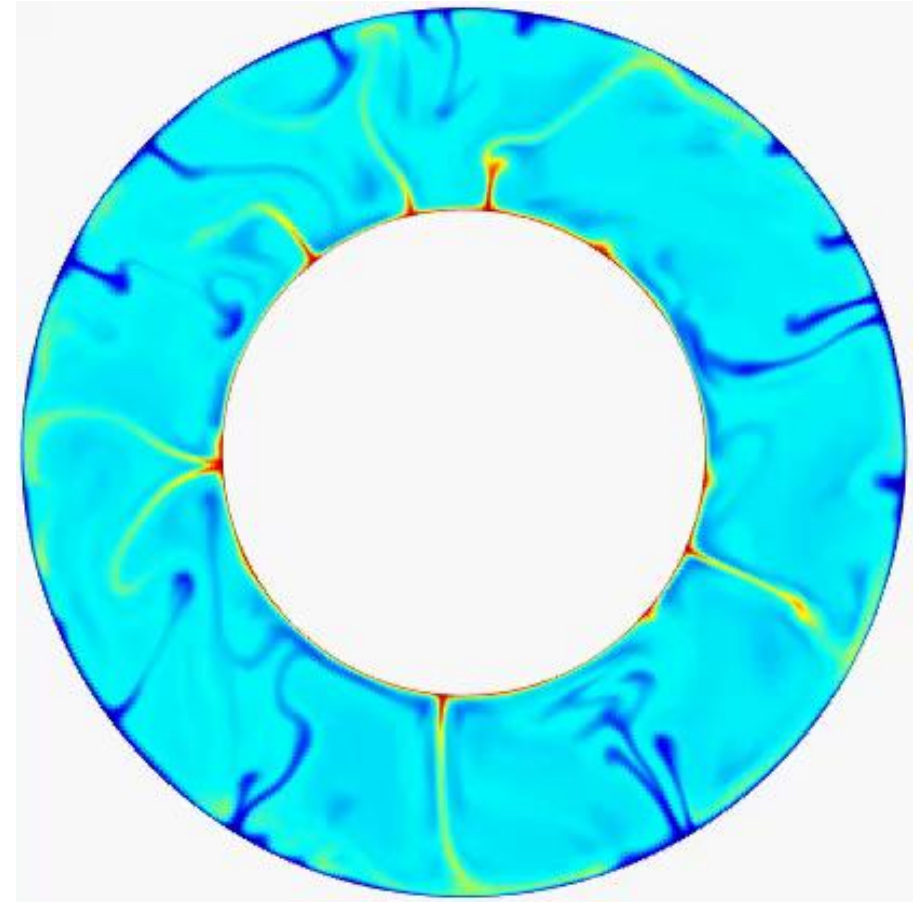
The idea of plate tectonics dates back to *Alfred Wegener*. It became generally accepted in the '60ties of the last century. The first model of plate tectonics stated that relative horizontal movements between lithospheric plates can occur as a result of *thermal convection* (heat upward from the Earth's core).



Understanding the plate tectonics

Criticism of the first dynamic model

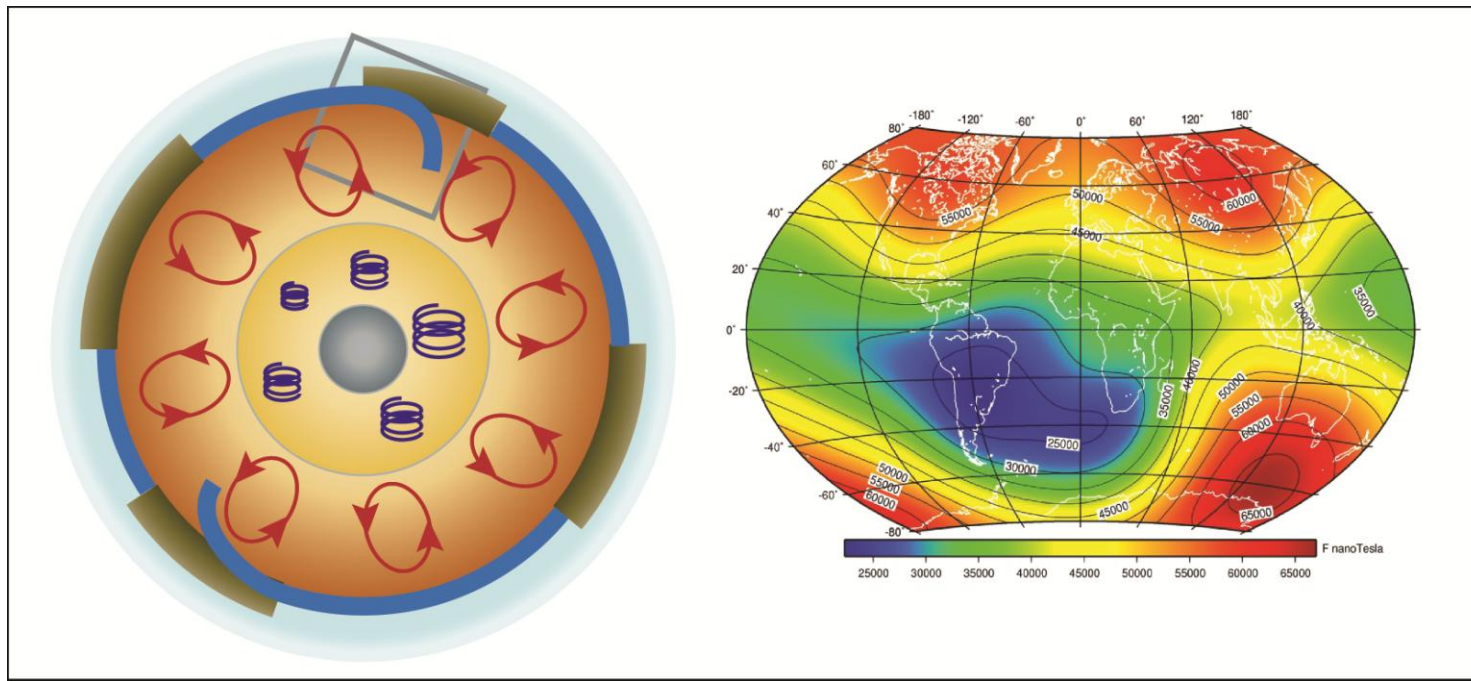
Results of recent geophysical explorations, laboratory experiments and numerical modelling of the geophysical characteristics of the lithosphere-asthenosphere system proved to be inconsistent with the convection engine theory.



Understanding the plate tectonics

Dynamic model - revised

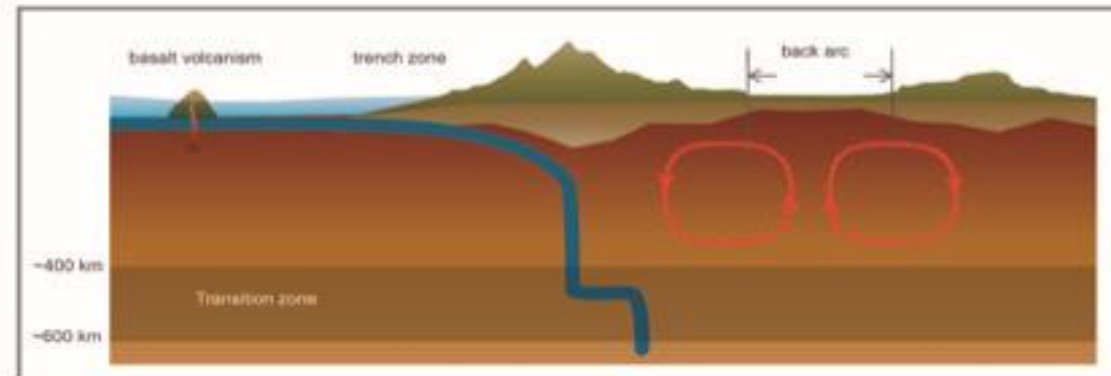
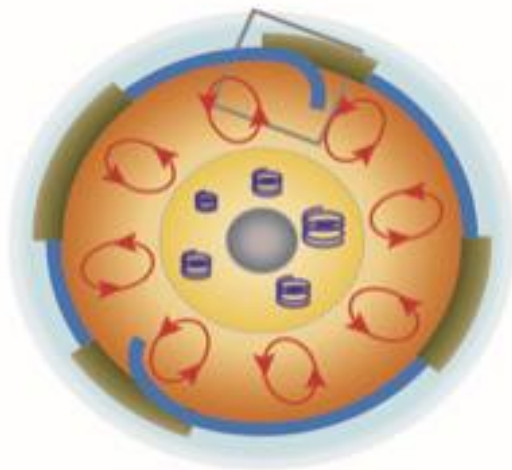
Now we have a new idea! We strongly believe that the main driving force of tectonics is simply the *GRAVITY*, it governs mantle convection and recycles (mix back) the lithosphere at certain conditions.



Understanding the plate tectonics

Dynamic model - revised

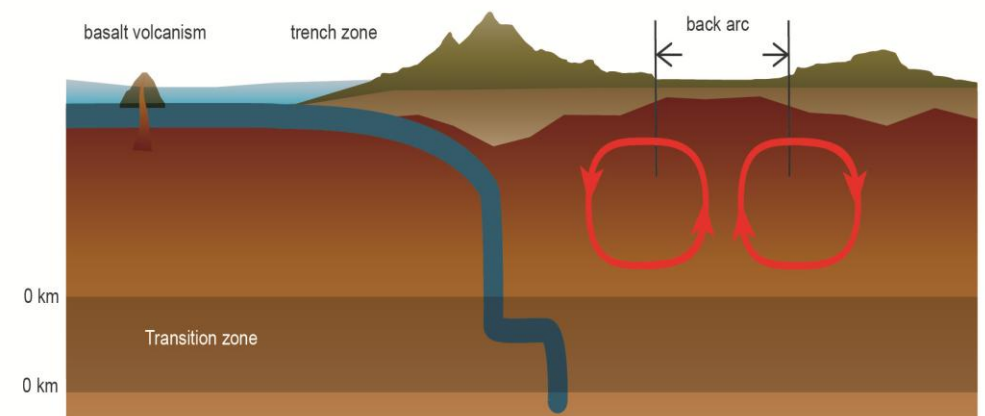
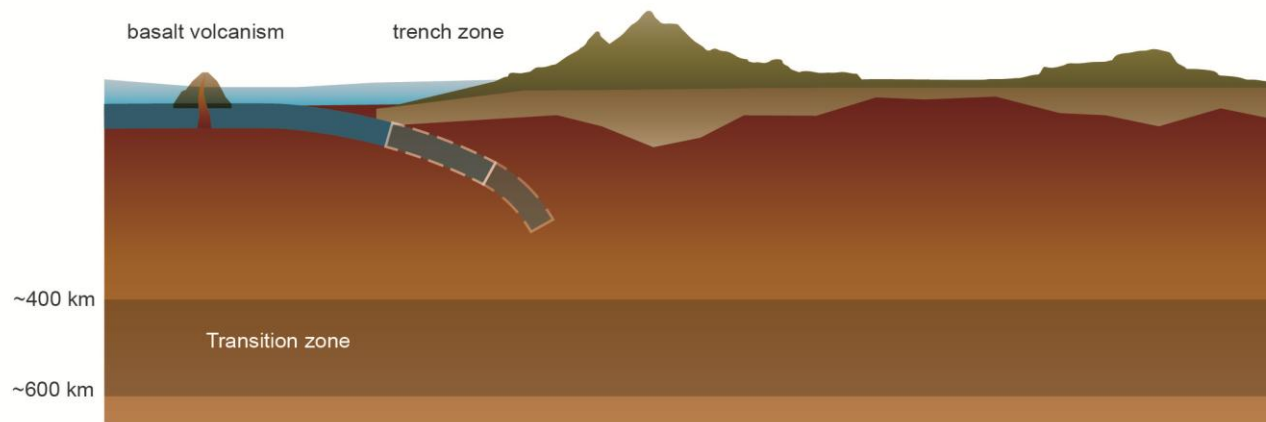
Initiation: Isostatic stability of the lithosphere may fail easily due to internal (raising hot material with mantle convection and or specific mineralogical reason) and external sources (loading of the lithosphere, e.g. due to sedimentation, erosion and extraterrestrial masses) --> The planet becomes dynamic.



Understanding the plate tectonics

Dynamic model - revised

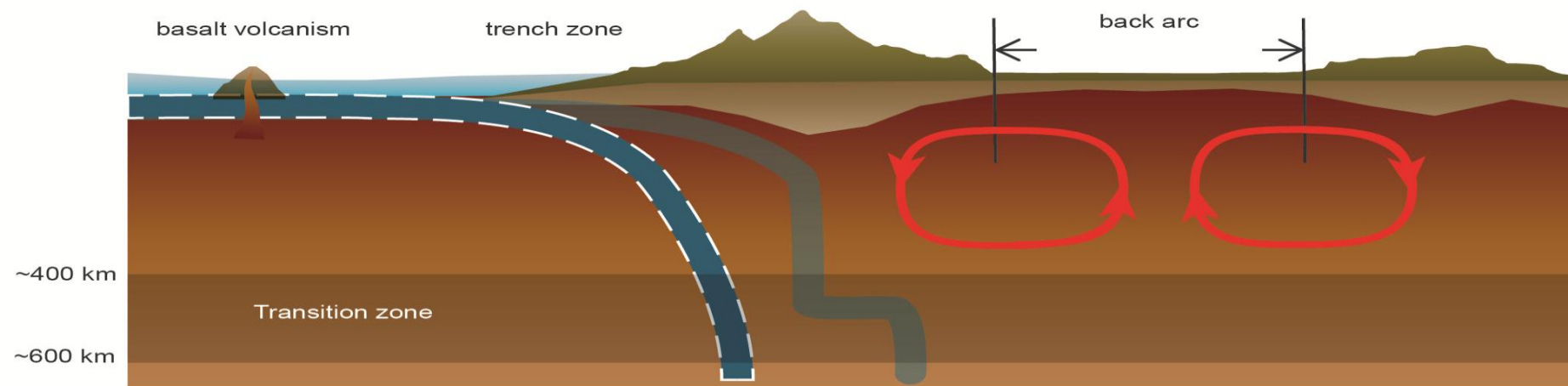
At the convergent boundaries of the tectonic plates the oceanic plate slips/subducts beneath an another plate simply due to its higher density (average density of basalt: 3 g/cm^3 , while that of the granite, which is the main constituent rock of the continental crust, is only 2.6 g/cm^3).



Understanding the plate tectonics

Dynamic model - revised

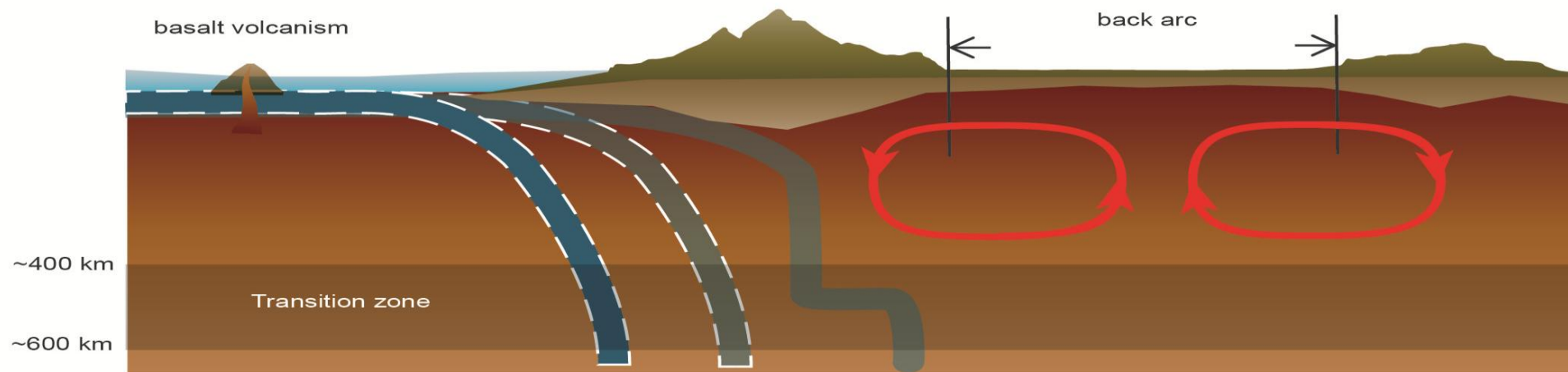
Transformation of basalt to eclogit at a pressure of 1.2GPa and 500-1000 C⁰ (at a depth of 40-60 km) gives a dramatic rise to sinking. (The density of eclogit is 3.75 g/cm³) Eclogit is a very rare rock on the surface, diamond may occur in it as a constituent element



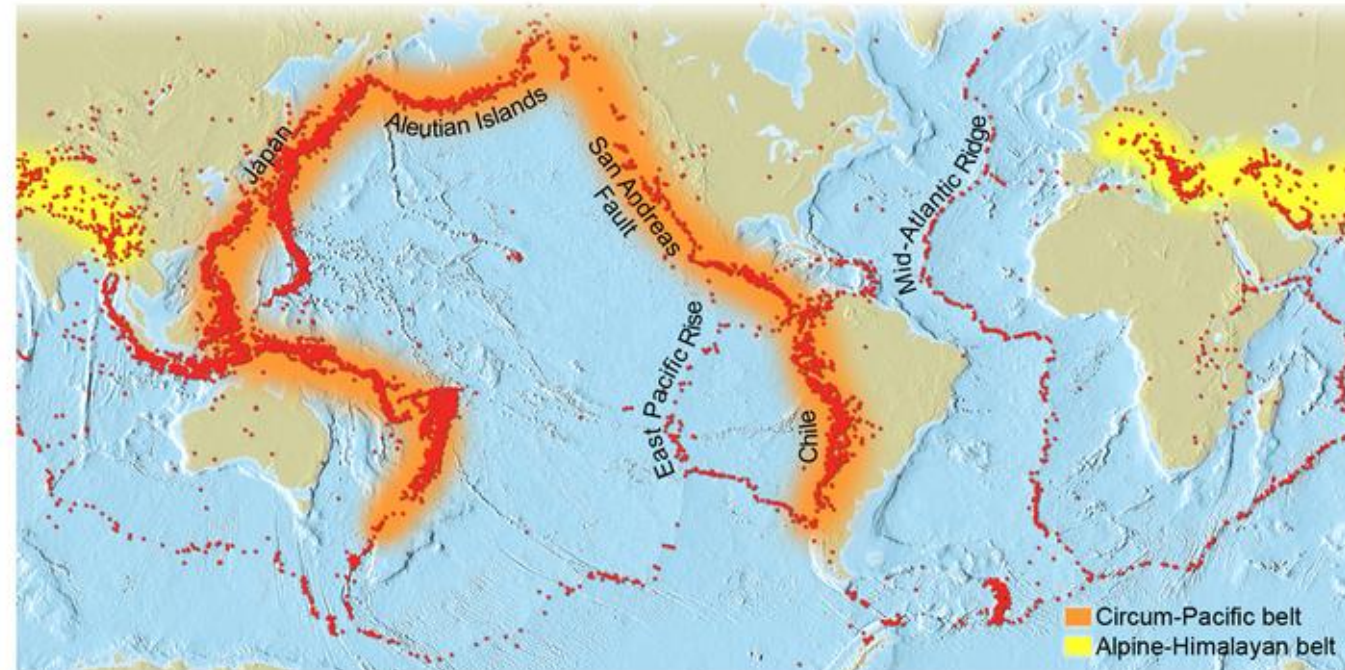
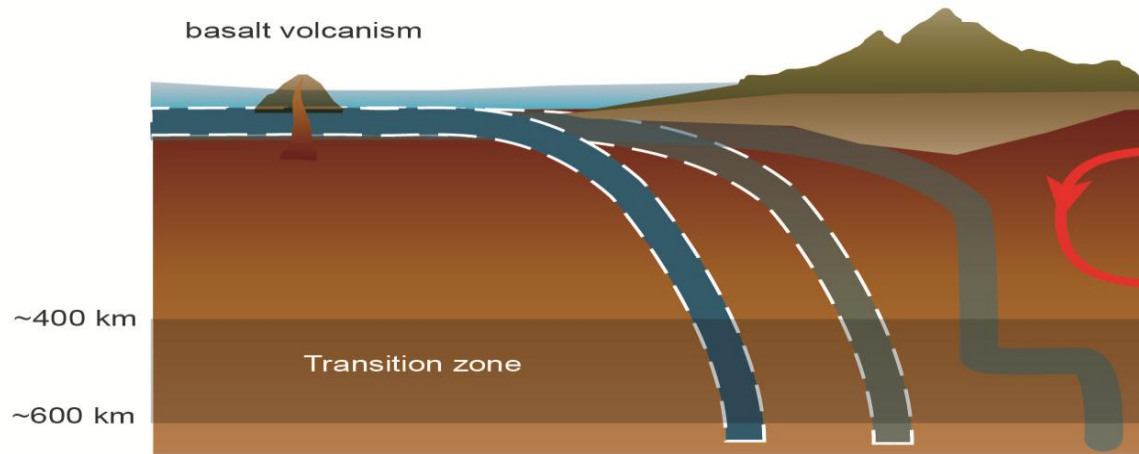
Understanding the plate tectonics

Dynamic model - revised

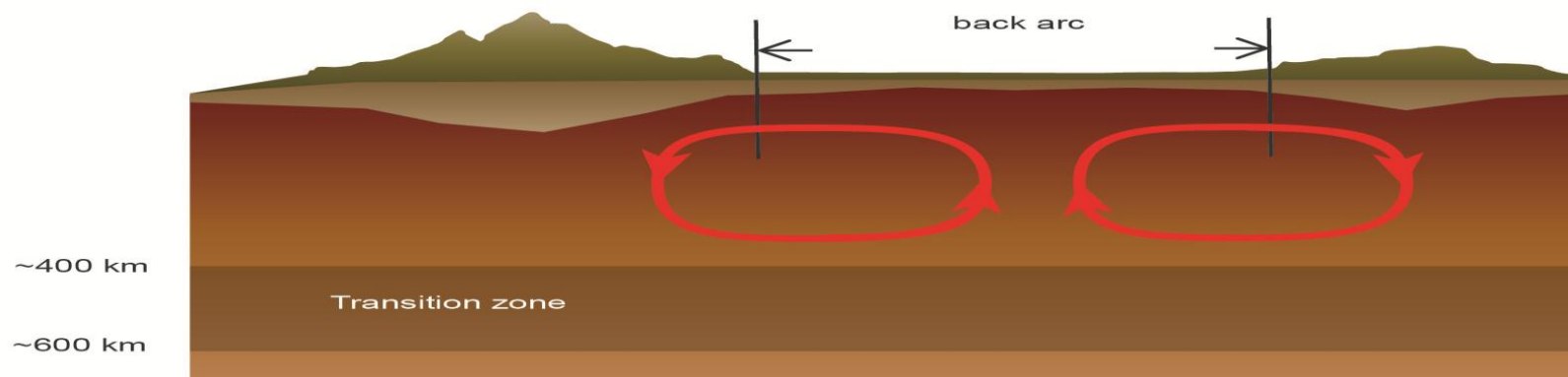
Sinking further into the mantle with a characteristic time of several cm/year is driven by the density difference between the cold and hot mantle material.



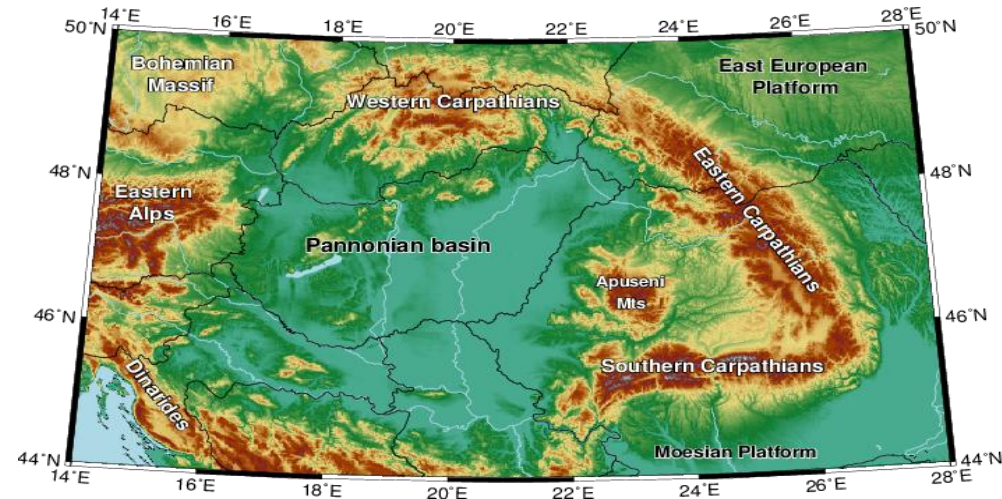
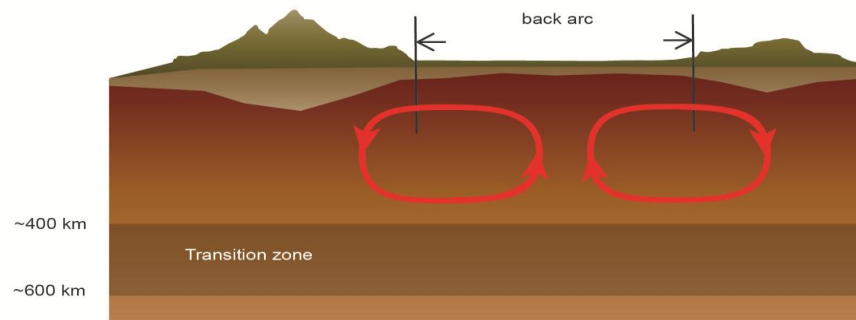
- Colliding plates build mountains, cause deformation and rupture, and earthquakes. The sinking slab is pulling the oceanic lithosphere, feeds volcanoes and recycles its material into the lower mantle.
- Many evidences of that can be observed directly and the slabs are relatively well-known from the deep geophysical tomography.



- How about the intraplate deformation in the continental plate?
- We suppose, that the motion and deformation of the sinking slab results in further deformations and movement of the overriding lithosphere. It is **relatively less understood how the subduction results in extension of the continental plate and in upwelling asthenosphere beneath (basin formation).**
- **Therefore the basin formation is the most challenging question in global tectonics, especially on regional scale.**



The formation of the **Pannonian basin** strongly connected with the Alpin-Carpathian orogeny. The basin is characterized by a very shallow lithosphere (50-80km) and by rather high heat flow ($100\text{mW}/\text{m}^2$). It is a proper place for a **huge natural laboratory to study the intraplate deformations and to prove or disprove the new theory of plate tectonics** by means of theoretical mineralogy, deep seismic tomography, unified gravity mapping and satellite geodesy, in the framework of the largest European geophysical enterprise of the last century.



The Earth's interior has posed mystery for centuries, and our knowledge about it is still unsatisfactory.

We strongly believe now, that we are at the crossing where the intellectual heritage of Eötvös, the power of the modern geophysics and the efforts of the succeeding generation meet in the „**Pannonian basin tectonic experiment**” and this may result in a breakthrough again in understanding of the planet.



Memorial of the Ság hill experiment of *Eötvös Loránd*, 1891. (Built in 1971.)

The monument of the Eötvös experiment is at the foot of the Ság volcanic hill. His name is engraved in the stone, his intellectual heritage is kept in our memory.

On behalf of the Hungarian geodetic and geophysical community I express our gratitude and best compliments here at the unveiling of the EPS Historic Site Plaque.



Memorial of the Ság hill experiment of *Eötvös Loránd*, 1891. (Built in 1971.)