Khatra Adibasi Mahavidyalaya: Lecture Notes

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Structure of the Earth

The Solid Earth

Solid Earth refers to the Earth's solid surface & its interior including its liquid core. It *does not* include the planet's fluid envelopes- the hydrosphere & the atmosphere, as well as the biosphere. The study of solid earth is called *geology*. The Earth has a mass of $\mathbf{5.972 \times 10^{24}}$ kg and has an average density of $\mathbf{5.52}\,\mathrm{g/cm^3}$.

The shape of the Earth can be approximated as a sphere for astronomical calculations,i.e., for distance scales large compared to Earth's radius. This approximate spherical shape is a natural response to gravitational attraction towards the center-of-gravity. The Earth's rotation leads to an outward centrifugal force, maximum at the equator and reducing to zero at the poles. This produces an *equatorial bulge* with the equatorial & polar diameters being $\mathbf{12,757}$ kms & $\mathbf{12,714}$ kms respectively. This should make Earth an oblate spheroid, but it is not so because of rocks of different density on the outermost layer of the earth- the *crust*.

The Crust

The rocks present in the crust are classified as

(i) *sial:* These are light rocks, primarily granite, with an average specific gravity (s.g.) of 2.7, consisting of silica (SiO_2) and alumina (Al_2O_3) in order of abundance (hence the name sial) & other minerals in smaller amounts. The abundance of silica is about 70%.

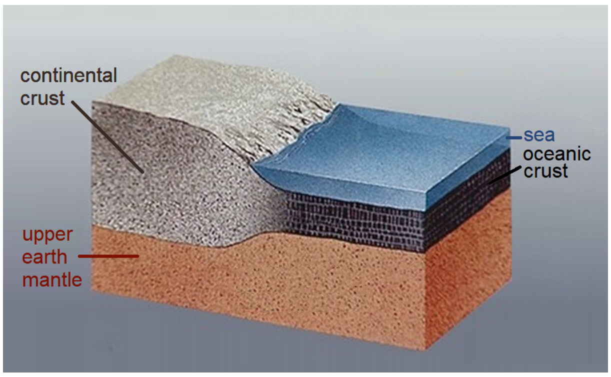

Figure 1: continental & oceanic crust.

(ii) *sima:* These are dark & heavy rocks, with basalt-type rocks having a s.g. of 2.9 & heavier rocks with s.g. upto 3.4. The silica abundance is $40 - 50\%$ & magnesia (MgO) is next in abundance in the heavier rocks (hence the name sima).

As is seen in Fig. 1, the crust surface has two distinct levels- the continental & the oceanic crusts. The continental crust includes an outer border which can be upto 200 m below sea-level & is called the *continental shelf*. At the edge of the shelf, a gradual slope connects the two crusts, called the *continental slope*. Hence, the oceanic crust starts beyond the edge of the continental shelf, not at the visible shore-line.

The level difference of continental & oceanic crusts is explained as follows: The continental crust is dominated by the sial upto an average depth of 25 kms, whereas sima forms the ocean floor and extends beneath the sial layer of the continents. The higher elevation of the continents is because their underlying sial rocks are lighter than the heavier sima rocks of the ocean floor. Just as the equatorial bulge is produced by low gravity at the equator due to the outward centrifugal force caused by the Earth's spin, regions containing lighter sial rocks creates regions of low gravity. The resulting bulges are therefore responsible for the higher elevation of the continental crust. In absence of rotation & differential rock densities, the Earth would have been a sphere. Rotation makes it an oblate spheroid & further irregularities are a result of differential densities of crustal rocks.

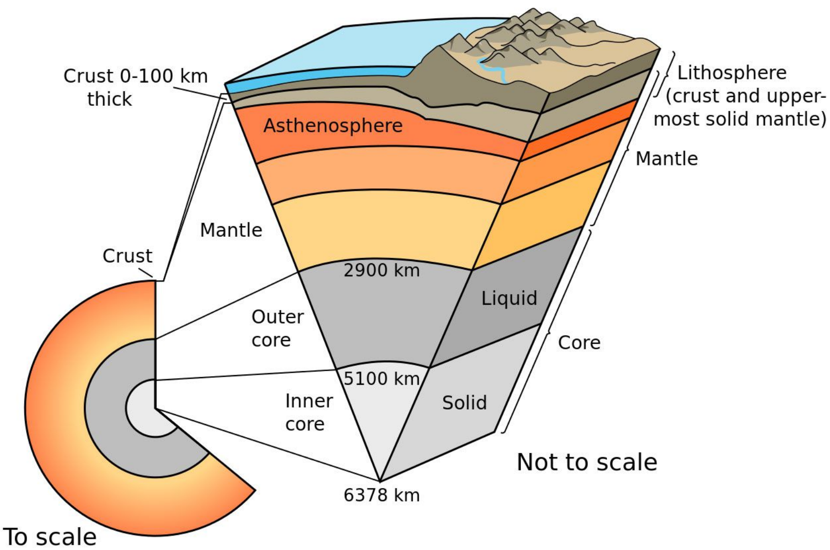

Figure 2: lithosphere is crust & solid part of upper mantle

The continents are essentially rafts of sial surrounded by ocean floors of heavier sima. The material of the sial can be regarded as a light slag which accumulated on the surface during the Earth's solidification from a molten state. Why the sial is not accumulated uniformly over the surface, i.e., the reason for the sial missing in the ocean floor is still an unsolved problem.

Isostasy & the Shape of the Earth

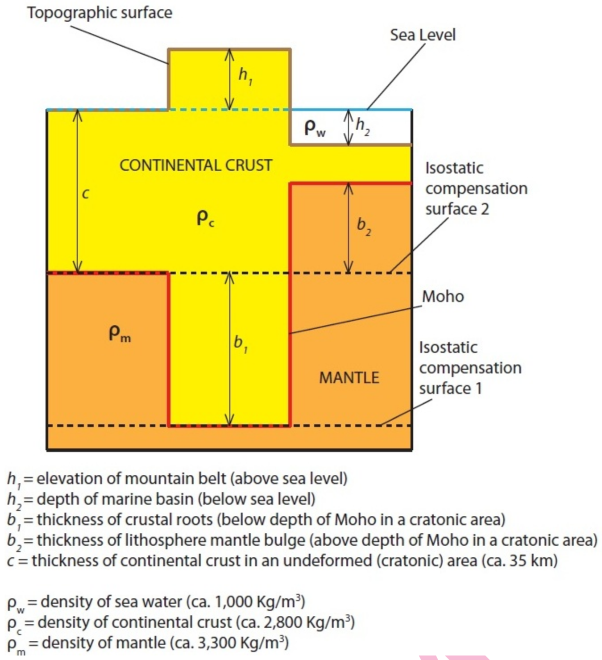

Figure 3: Airy's model of isostatic equilibrium

To understand in more detail about the topographical features on the Earth's surface like mountain's & plains it is necessary to know about the layers below the crust (see Fig. 2). The **asthenosphere** is a shell with thickness in the range $100 - 700$ kms thick, with its upper surface at a depth of 60 kms below the oceans & 120 kms below the continents, where pressure and temperature combine to keep rocks close to melting. The overlying layer, containing the uppermost 50 kms of the mantle under the oceans and uppermost 90 kms under the continents, *plus* the crust, is called the **lithosphere**. The crust & upper mantle (i.e., the lithosphere) have similar mechanical properties in contrast to the asthenosphere which is quasi-molten.

The gravitational equilibrium that determines the various topographic variations on the Earth's surface as well as the different heights of the ocean floors is called **isostasy**. Isostasy describes the physical, chemical, and mechanical differences between the mantle and crust that allow the crust to "float" on the more fluid mantle. Isostasy can be observed if Earth's solid & less ductile lithosphere exerts stress on the weaker mantle or asthenosphere, which over geological time flows laterally such that the load is accommodated by height adjustments. Differences in levels of mountain ranges, widespread plateaus & plains are compensated by difference of densities of underlying matter. Therefore, there exists a certain minimum level below the surface where pressure due to the weight of the overlying crust is everywhere the same. This surface is called the isostatic *compensation surface*. Minor topographical features like individual peaks & valleys are not balanced isostatically, but are maintained by the strength of crustal rocks.

The **Airy** model of isostasy is where different topographic heights are accommodated by changes in crustal thickness, in which the crust has a constant density ρ_c & the mantle has a density ρ_m. The basis of the model is that within a fluid in static equilibrium, the hydrostatic pressure is the same on every point at the same elevation (surface of isostatic compensation), a consequence of Pascal's law.

For example, a feature of height h_1 (+ve topography) must require a compensating crust depth of b_1 determined by the pressure equality (see Fig. 3)

$$(h_1 + c + b_1)\rho_c = c\rho_c + b_1\rho_m$$

which gives

$$b_1 = \left(\frac{\rho_c}{\rho_m - \rho_c}\right) h_1 \approx 5h_1, \text{ for } \rho_c = (2.75\rho_w) \,\&\, \rho_m = (3.3\rho_w),$$

with $\rho_w = 1kg/m^3$, the density of water.

Similarly, a feature of depth h_2 (-ve topography) the condition of isostatic equilibrium gives

$$h_2\rho_w + b_2\rho_m + (c - h_2 - b_2)\rho_c = c\rho_c,$$

which gives

$$b_2 = \left(\frac{\rho_c - \rho_w}{\rho_m - \rho_c}\right) h_2 \approx 3.2h_2$$

Thus, the oceanic crust is *thinner* than the continental crust, & the continental crust is *thicker* under mountain ranges than it is under plains.

The Layers of the Earth

The Earth is layered both **chemically** & **mechanically**. The chemical subdivisions are

(i) *Crust*: the oceanic crust is about 5-10 kms & continental crust about 30-50 kms thick. The former contains mainly basalt, the latter granite.

(ii) *Mantle*: 7 or 35 kms to 2900 kms deep & makes up 84% of the Earth's volume. The mantle is composed of *peridotite* rocks, made of olivine ((Mg^{2+}, Fe^{2+})$_2SiO_4$) & pyroxene ($XY(Si,Al)_2O_6$ with X being Ca/Na/Fe/Mg & Y being smaller size ions like Cr/Al).

(iii) *Core*: 2900 kms to center & is metallic, with Fe(90%) & Ni(9%).

The mechanical subdivisions are

(i) *Lithosphere*: the solid & brittle outer shell comprising the crust & the upper mantle. The chemically distinguishing boundary between them is called the **Moho**. As the depth of the crust is not uniform, the Moho does not exist at an uniform depth.

(ii) *Asthenosphere*: 65 or 120 km to about 200 km in depth & is quasi-molten. As a result, it is weak, viscous & ductile (*ductility* is the capacity of a rock to deform in response to large strains without macroscopic fracturing).

(iii) *Lower Mantle (or mesosphere)*: it is the region from 660 to 2900 km below Earth's surface. It is rigid, unlike the asthenosphere due to high pressure which results in minerals different from the upper mantle.

(iv) *Outer Core*: 2900-4720 kms, it is molten because of the high temperature in the region.

(v) *Transition region*: 4720-5170 kms, it is mushy & leads to the solid inner core.

(vi) *Inner Core*: 5170 km to center. It is not in a liquid state even though te temperature near the center is about 6000° C. The pressure is greater than 1 million times the atmospheric pressure which compensates for the high temperature & compresses it into a solid.