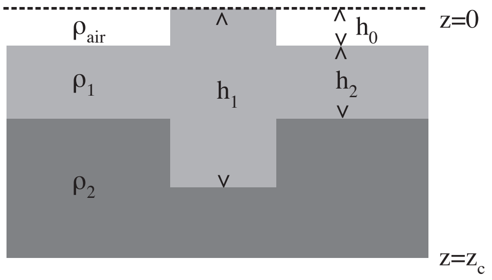
Isostacy is the concept that adjacent "columns" of mass, extending from some reference level at the Earth's surface to some *depth of compensation*, should be equal. Isostacy follows from a balance of buoyancy forces. A number of inferences about the density structure of the earth and the temperature structure of the mantle are based on isostatic calculations. For example, consider the cartoon mountain in the middle of a continent shown here:



In this case, isostatic balance is described by the equation:

$$h_0\, \rho_{air} + h_2\, \rho_1 + (z_c - h_2 - h_0)\, \rho_2 \;= h_1\, \rho_1 + (z_C - h_1)\, \rho_2$$

where the ρ's refer to densities. If the height of the mountain, h_0, is known, and the crustal and mantle densities can be reasonably guessed at, and some depth of compensation, z_c, is assumed, then the thickness of the mountain, h_1, including its "root", can be determined. The compensation depth is the depth below which no lateral variations in density exist.

Problem 1 - Rift Basins

When continental lithosphere is extended, or stretched, it thins, and the surface expression of this is usually the formation of a basin, referred to as a rift basin. Surprisingly, the simple relationship between extension, isostacy, and basin formation was only appreciated in the 1970's, after plate tectonics began to be accepted; this despite the fact the all of the world's petroleum resources are derived from sedimentary rocks deposited in basins formed through extension.

Consider the problem of continental rifting and rift basin formation. Suppose that 150-km-thick continental lithosphere, consisting of 40-km-thick crust and 110-km-thick lithospheric mantle, has been extended by 50% so that the crust and lithospheric mantle are both now 0.5 times their original thicknesses. In addition, suppose that the elevation of the surface was initially at sea level.

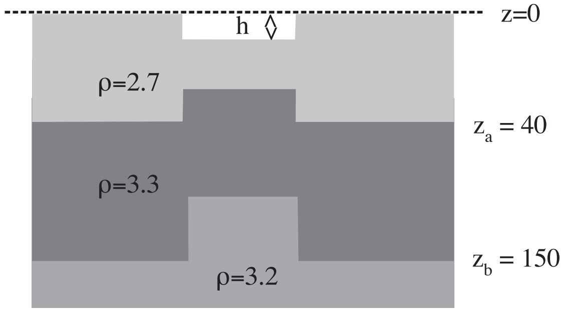
Assume that the density of the air is 0, the density of the crust is 2.7 gm/cm^3, the density of the lithospheric mantle is 3.3 gm/cm^3, the density of the asthenospheric mantle beneath the lithosphere is 3.2 gm/cm^3, and that the rift basin is not filled with either water or sediments.

a) Determine the depth of the basin relative to sea level.

b) Now assume that the basin is filled by sediments with a density of 2.5 gm/cm^3. How deep does the basin become with this additional load?

c) Now suppose that the lithospheric mantle beneath the sediment-filled basin cools and thickens so that the base of the lithosphere attains it's original depth of 150 km, with the entire column still in isostatic equilibrium. How thick does the basin become?

This is basically the situation in Missouri, where the New Madrid fault zone causes lots of earthquates. The New Madrid fault zone is a so-called failed rift, a region of continental lithosphere that thinned through extension but then stopped extending before completely rifting and establishing a new ocean basin. Subsequent cooling of the thinned lithosphere has resulted in ongoing basin subsidence and associated seismicity.



Problem 2 - Thermal subsidence

Consider the problem of oceanic-lithosphere subsidence. Suppose we observe that the depth below sea level of the spreading ridge axis is 2.5 km, and the depth of the sea floor away from the ridge axis above 40-million year-old lithosphere is 3.75 km. We want to estimate the thickness of the 40 m.y. old lithosphere.

Assume that the density of the crust is 2.8 gm/cm^3, the density of seawater is 1.05 gm/cm^3, and that the density of the mantle is given by the equation:

$$\rho = \rho_{1300} (1 - \alpha \Delta T),$$

where ρ_{1300} is the density of the mantle at 1300°C, and α is the coefficient of thermal expansion which characterizes the volume change per change in temperature, ΔT. Also assume that thickness of the crust is 6 km; the average temperature of the lithosphere is 600°C (i.e. assume a constant temperature for the lithospheric mantle of 600°C); there is no lithospheric mantle at the spreading center; the value of α is $\alpha = 3x10^{-5}\ °C^{-1}$; and the density of the "asthenospheric" mantle is $\rho_{1300} = 3.1$ gm/cm^3.

a) Determine the thickness of the 40-m.y.-old lithosphere.

b) What would the depth to the seafloor be if a 1-km-thick sequence of sediments with a density of 2.5 gm/cm^3 was placed on top of this 40-m.y.-old lithosphere?

c) How thick would a pile of sediments with a density of 2.5 gm/cm^3 placed on top of the 40-m.y.-old lithosphere have to be in order to make an island out of these sediments?