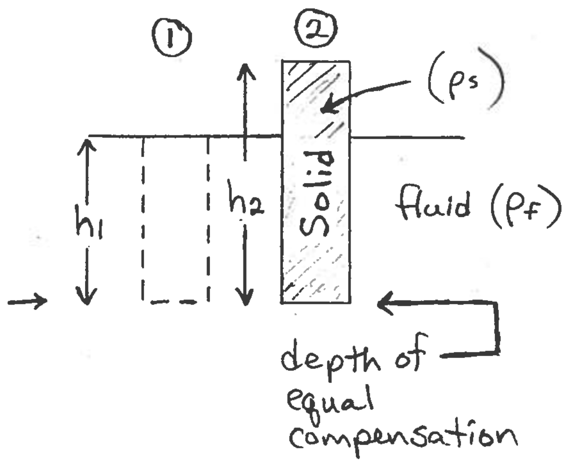
ISOSTASY IN GEOLOGY AND BASIN ANALYSIS:

The concept of isostatic balance is very important in geology. This basically is the application of Archimedes Principle, which states:

* "When a body is immersed in a fluid, the fluid exerts an upward force on the body that is equal to the weight of the fluid displaced by the body" *

This rule applies to all mountain belts and basins which exist under conditions of local (airy) isostatic compensation: the lithosphere has no lateral strength, and thus each lithospheric column is independent of neighboring columns (e.g. rift basins).

To work isostacy problems, we assume that the lithosphere (crust + mantle lith.) are "floating" in the fluid asthenosphere. Always use neat and accurate definition diagrams. A simple, nongeologic example looks like this:



To calculate equilibrium forces, set forces of 2 columns equal to each other:

$F_1 = F_2$ $(F = m \cdot a)$

$m_1 \cdot a = m_2 \cdot a$ (grav. accel cancels out)

$m_1 = m_2$ (mass)

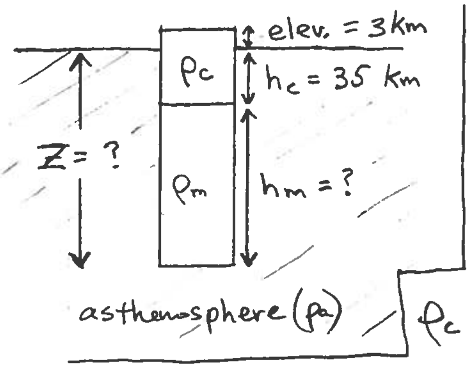
Setting horizontal axes = unity (1 m), and because $m = \rho \cdot V$ (density · volume), Convert to $m = \rho h$, and:

$$\boxed{\rho_f h_1 = \rho_s h_2}$$

← this eqn correctly describes equilibrium isostatic balance in the definition diagram.

* because fluid has no shear strength (yield stress = 0), it cannot maintain lateral pressure differences and will flow to eliminate press. gradient.

EXAMPLE 1 Estimate thickness of lithosphere:



In this example, we have measured the depth to the moho (h_c) using seismic refraction. Elevation (e) is known, and standard densities for crust, mantle lithosphere, and asthenosphere are used:

$\rho_c = 2800\ kg/m^3$; $\rho_m = 3400\ kg/m^3$; $\rho_a = 3300\ kg/m^3$

How deep to base of lithosphere? Solve for Z:

$$\rho_a(Z) = \rho_c(h_c + e) + \rho_m(Z - h_c)$$

$$\rho_a Z - \rho_m Z = \rho_c(h_c + e) - \rho_m h_c$$

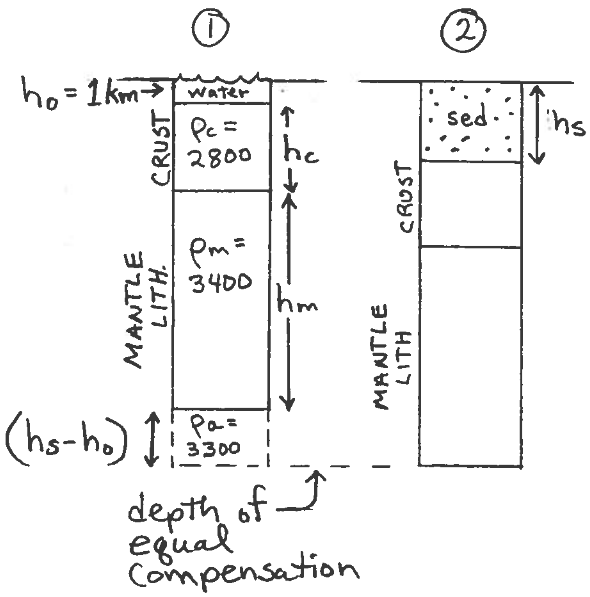
$$Z = \frac{\rho_c(h_c+e) - \rho_m h_c}{(\rho_a - \rho_m)} = \frac{2800(35+3) - 3400(35)}{(3300 - 3400)} = \frac{-12{,}600}{-100}$$

$$\boxed{Z = 126\ km}$$

EXAMPLE 2 Sediment loading

let: $\rho_w = 1000\ kg/m^3$; $\rho_s = 2.3\ kg/m^3$

Consider a basin 1 km deep that is filled only with water. How deep will the basin be after it is filled with sediment?



(= depth below which there is no density contrast between columns)

Remember, force balance must be calculated for entire column down to depth of equal compens.

Also, thickness of crust and mantle lith does not change, so they cancel out of both sides of the equation.

$$\rho_w h_o + \rho_c h_c + \rho_m h_m + \rho_a(h_s - h_o) = \rho_s h_s + \rho_c h_c + \rho_m h_m$$

$$\rho_w h_o + \rho_a(h_s - h_o) = \rho_s h_s$$

$$\rho_w h_o + \rho_a h_s - \rho_a h_o = \rho_s h_s$$

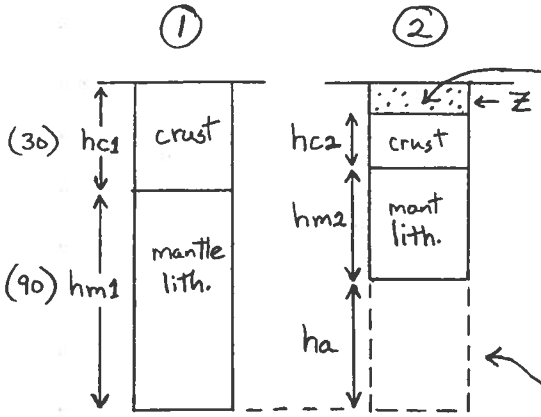
$$h_s(\rho_a - \rho_s) = \rho_a h_o - \rho_w h_o$$

$$\boxed{h_s = \frac{h_o(\rho_a - \rho_w)}{(\rho_a - \rho_s)}} = \frac{1.0\,(3.3 - 1.0)}{(3.3 - 2.3)} = \underline{\underline{2.3\ km}}$$

"rule of thumb"

EXAMPLE 3

Subsidence produced by thinning of crust and mantle lithosphere. How deep?



basin is formed:
A: fill with water
B: fill with sediment

Start with:
$hc1 = 30$ km
$hm1 = 90$ km

Thin crust and m.l. to half of original. How deep is basin? Solve for Z:

Note: $ha = hc1 + hm1 - hc2 - hm2 - Z$

$$\rho_c(hc1) + \rho_m(hm1) = \rho_w(Z) + \rho_c(hc2) + \rho_m(hm2) + \rho_a(ha)$$
$$30\rho_c + 90\rho_m = Z\rho_w + 15\rho_c + 45\rho_m + \rho_a(120 - 15 - 45 - Z)$$
$$30\rho_c + 90\rho_m = Z\rho_w + 15\rho_c + 45\rho_m + 60\rho_a - Z\rho_a$$
$$Z(\rho_a - \rho_w) = 60\rho_a - 45\rho_m - 15\rho_c$$

A: $$Z = \frac{60\rho_a - 45\rho_m - 15\rho_c}{(\rho_a - \rho_w)}$$ ← Filling with water ($\rho_w = 1.01$ g/cm³)

$$= \frac{60(3.3) - 45(3.4) - 15(2.8)}{(3.3 - 1.01)}$$

$$= \frac{3.00}{2.29} = \boxed{1.31 \text{ km}}$$ for water

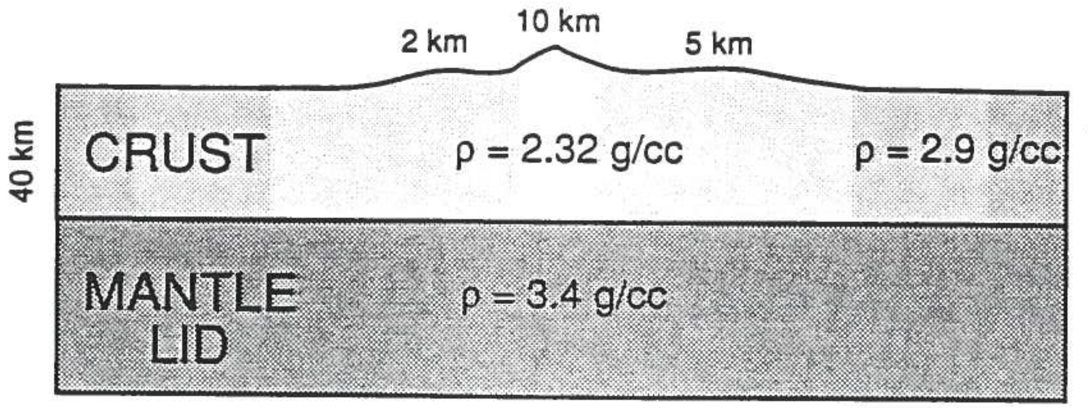
B: $$Z = \frac{60\rho_a - 45\rho_m - 15\rho_c}{(\rho_a - \rho_s)}$$ ← Filling with sediment ($\rho_s = 2.3$ g/cm³)

$$= \frac{60(3.3) - 45(3.4) - 15(2.8)}{(3.3 - 2.3)}$$

$$= \frac{3.00}{1.0} = \boxed{3.0 \text{ km}}$$ for sediment

Note: This example is in Angevine et al (1990), Fig. 2.3

Pratt Isostasy



Airy Isostasy

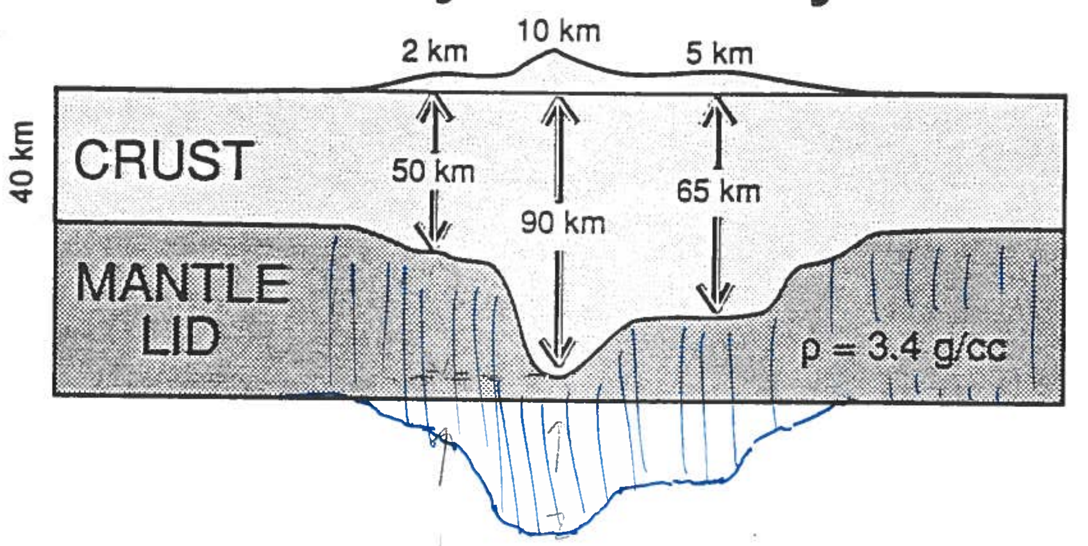


Figure 2.1 Pratt versus Airy isostatic compensation of the crust (modified from Molnar, 1986).

Angevine et al (1990)