Lab 5  Preparation Questions - Tear off this page and turn in at the beginning of Lab

Name ________________________________
Section Day ___________________________
Date _________________________________

(1) a. In your own words, define the concept of isostasy:

b. Draw a picture illustrating your definition of isostasy:

c. Briefly explain why isostasy is important on earth:

(2) a. Define each of the variables in the equation below (using SI units), the use dimensional analysis to calculate the final units.
\[ \rho_1 gh_1 = \rho_2 gh_2 \]

b. What do the final units in this equation represent (e.g., density, viscosity, mass,...) (hint: what is this equation called?). How does this parameter relate to isostasy?
Isostasy is a concept of considerable importance in the Earth sciences. In fact it displaced essentially all earlier beliefs about how topography is maintained and is one of our major tools in understanding the vertical dynamics of plate tectonics. Although its roots arguably extend back to Archimedes, the idea of isostasy was first floated by weighty British surveyors during the great Indian survey of the mid-19th century: a survey of the Indian sub-continent of unprecedented accuracy and density--all accomplished for a really low level of compensation.

The notion of isostasy is cheerfully, even buoyantly, simple. Isostasy is an equilibrium condition characterized by equal pressure within some fluid, in this case the mantle. For the pressure in the mantle to be equal at a given depth, there must be an equal amount of overlying mass everywhere above that depth. If anywhere there is an unequal distribution of mass above a given area of the mantle, this will provoke an isostatic adjustment -- a vertical motion -- whose speed is determined by the viscosity of the mantle and the magnitude of the pressure difference within the mantle. All large-scale topography on the planet is maintained by isostatic equilibrium; the flotation (or sinking) of low (or high) density areas of the lithosphere (the crust plus the ridged layer of the upper mantle) over a fluid interior. This concept is analogous to that of buoyancy in liquids.

In this lab we will simulate different geodynamic environments at isostatic equilibrium to explore the concept of isostasy. Indeed, isostasy doesn't just explain topography---it is also used as a (non-unique, but nevertheless useful) mechanism for inferring the deep density structure underneath continents and ocean plates.

**Using Isostasy to solve a problem**

Many tectonic problems involving vertical crustal dynamics can be solved by setting up a simple pressure balance equation for a system in isostatic equilibrium. Imagine a vertical column extending from sea level or the land surface down to some deep depth within the mantle where lateral density variations stopped. Now imagine another column nearby. Consider the whole of each column as one unit and as such has one mean density. Assume that like most places on the planet they are in isostatic equilibrium. If you were to describe this rather uninteresting situation mathematically you could write an equation that balances the pressure at that compensation depth you picked and it would looks like this:

\[ \rho_1 g h_1 = \rho_2 g h_2 \]

\( \rho_1 \) and \( \rho_2 \) are the respective densities of two layers of material (the Greek letter rho \( \rho \) is often used to denote density) \( h_1 \) and \( h_2 \) are their respective thicknesses, and \( g \) is the acceleration due to gravity (\( g = 9.8 \text{ m/s}^2 \)). You can ignore the area of each column as long as they are the same; we left gravity in there to help the units make sense. **Do not confuse elevation with layer thickness.**
Two nice things about this are that (1) if $\rho_1 < \rho_2$, than $h_1$ had better be bigger than $h_2$---so, lighter layers tend to float higher than denser layers, and (2) you'll notice that the units in this equation are force/unit area (it might be worthwhile to take a moment and work out the units to convince yourself of this)---or, as it's more commonly known, pressure. So, pressure exerted by two different columns of material must be equal to one another. Again, another way of saying this is that a liquid does not tolerate a lateral pressure gradient (which makes it squirt, or move such that the pressure gradient is removed).

A slightly more sophisticated version of the equation above is:

$$\sum (\rho_1 gh_1) = \sum (\rho_2 gh_2)$$

This equation just expresses that the sum of the different layers within column 1 are equal to the sum of those in column 2.

**Example problem setup:** If we say these two columns are in isostatic equilibrium, then they are neither rising nor subsiding, their masses must be equal, and the pressure experienced at their base is the same.

From the above setup you can write the pressure balance equation thus:

$$P @ \text{base of column I} = P @ \text{base of column II} \iff \text{You can start here because isostatic equilibrium is assumed.}$$

$$h_{cc}\rho_{cc} + h_m\rho_m = h_w\rho_w + h_{oc}\rho_{oc} + h_{mf}\rho_m$$

(note that we’ve left gravity off because it cancels)

Now all you need is a little algebra to solve this for whatever variable you are missing.

One key thing---you have to make sure that the columns extend to the same depth. This depth is referred to as the depth of compensation. It’s usually easiest to choose a compensation depth at the deepest level to which lateral density variations are found. **The base of the deepest floating body you are considering usually works** and will negate the necessity to include a term on one side of your equation for the fluid at the
Finally, it's good to note that many Earth materials have different densities (as you should’ve noticed in the bolide impact lab)---basalt (the material of oceanic crust) tends to have a density near 2.9 or 3.0 g/cm³, let’s use 2.95 g/cm³, granite (more or less continental material) near 2.84 g/cm³, and mantle material near 3.30 g/cm³, and water has a density of 1.00 g/cm³. And, temperature tends to lower density. As such, different stacks of material (or of the same material with differing temperatures) are bound to have different elevations.

*For ALL exercises, make at least 3 replicate measurements, then calculate an average and standard deviation for each set of measurements.

Lab Exercise

1) Plain Vanilla - (5 points)
Let's just determine the density of something (in this case, a block of dried Douglas fir) using a puddle of water. Measure the thickness of the block, the height at which it floats, and figure out its density. We'll use this later as a reference point.

At this point, you might be asking yourself why you can’t just measure the volume and get a more accurate measurement of the pressure balance. Why would we make you do the problems this way, instead of just measuring a volume outright (think about the limitations of the geologic record and trying to determine volume in the past)?

2) Let’s add a little fluff – (15 points)
Let’s see what the effect of loading that fir block is with even lighter stuff---measure the amount of wood submerged with the corks on top and the total thickness of the cork and wood. Assume the cork has the same horizontal dimensions as the wood, and calculate a mean density for the cork + wood block column. From this, calculate an approximate density for just the cork. Now, try to turn the whole unit over (cork down, you might have to stabilize it with a finger to keep the cork down). Tricky as this may be, give the measurement your best shot. Measure the amount of wood submerged in this instance, then recalculate the mean density and the density of the cork. If your answers turn out differently, explain why (think both about possible physical reasons for any differences as well as the role of measurement error).

3) Your roots are showing – (30 points)
a) Let's look at the effect of low-density topography and low-density sub-crustal roots on elevation. Float the small and large (without clay) mountain ranges and measure the height of the plain surrounding the mountains above the water. Calculate the hypothetical average thickness (think carefully about what this means) for the mountains above the block. Assume their density is the same as that of the block. How much does the height of the plains decrease (relative to the original block) due to the effect of the additional loads on the underlying crust?
Now, what do you expect to happen when you add the clay mountain (think about why this mountain will float in the mantle differently)? **Think about this BEFORE you do the next step.**

Now that you’ve thought about it, try the mountain with clay and measure the elevation of the plain above sea level. Assume that the clay mountain has the same hypothetical average thickness as the large wooden mountain. Calculate the density of the clay mountain.

b) Once again, invert ALL three set-ups (for the clay mountain, you will need to assume it has the same density you just calculated). In effect, this is almost just like thickening continental crust from below, by adding a root. Measure the elevation of the surface and calculate a hypothetical average thickness for the underplating layer below the block for all three set-ups.

4) **Through thick and thin – (15 points)**

a) Let's make a rift valley (or basin) in our block, and look at its effect on topography—this is just like the East African Rift, except without the scenery and the annoying paleontologists. Measure the height of the valley-bearing block, and calculate its mean density (including the hole), and change (in percent) of elevation relative to the regular old block. How are its change in average density (relative to the un-valleyed block) and elevation change related—simple and obvious math is the key here.

b) Now let's do some crustal thinning—much like the Basin and Range Province. Turn the block over, making sure you get all the bubbles out of that chunk of thinning crust. Again, use the equation above to calculate the mean density of the block (including the crustally-thinned portion). What is the change (in percent) of elevation relative to the regular old block associated with this thinning? Is this in accord with your answer(s) from part (A)? Why or why not?

**Notes on Write-up: (15 points)**

You, as an individual, are expected to provide answers for ALL questions embedded in the above text in a **typed** semi-formal lab write-up. You will have shared data from your group but the write-up must reflect all your own work. This write-up should include for each experiment a brief paragraph explaining the purpose of each experiment, a report of your observations (including diagrams of your setup, measurements you made, and enough narrative to convey your experimental method and results), and enough discussion of your results to answer all the questions posed in the text and convey your understanding of the material.
Isostasy is fun! As we’ve discussed in class, basalt is (presently) the most abundant type of volcanic rock near the surface of the planet—it not only dominates in the shallow oceanic crust (once you get below the sediments), but also occurs sporadically on continents (flood basalt provinces, like the Deccan traps and the Columbia River Basalts are good examples of these). Let’s examine the effect of large basaltic outpourings in topography, and the trade-offs between adding basalt to crust and changing the thickness of continental crust.

A) Assume that the mean density of basalt is 2.9 g/cm$^3$, that of continental crust is 2.7 g/cm$^3$ and the underlying mantle density is 3.2 g/cm$^3$. Assume that normal continental crust is 35km thick. If the system is in isostatic equilibrium, how thick of a flood basalt eruption into normal continental crust (that is, its 35km thickness is preserved—it just gets buried) would be required to generate a basaltic plateau with 1km of elevation above the surrounding normal continent? In short, we want to generate something about the height of Loma Prieta via piling on basalt into continental crust. YOU MUST DRAW A WELL-LABELLED, ACCURATE PICTURE TO GET FULL CREDIT.

B) Now let’s look at the corresponding problem for the ocean floor. Iceland is the one spot on the planet where the mid-ocean ridge system is actually exposed. However, Iceland turns out to be a bit more complicated than just your generic ocean ridge. Assume that normal oceanic ridge basalt has a (basaltic) crust that is 6km thick, and lies 3km below sea-level (we are this comparing with a hot, and thus thermally uplifted, region of the ocean floor). Using the same densities as in part (A) above (and you should know this, but the density of water is 1.0g/cm$^3$), how much additional basaltic thickening of the oceanic crust is required to put Iceland above water? YOU MUST DRAW A WELL-LABELLED, ACCURATE PICTURE TO GET FULL CREDIT.