Attached are (1) the equation dictionary project, and (2) the description of the small group project, a discussion of what geophysics teaches us about hot spots and mantle plumes. The major goal of the dictionary is to encourage students to learn to describe the processes inherent in mathematical equations. In so doing, they will learn how the variables in each equation relate to one another, and how they affect the physical processes being described. The goals of the hot spot project are (a) to encourage students to read scientific papers related to the geophysical theories they have learned, (b) to see how different geophysical concepts may be combined for deeper understanding of a single concept and (c) to investigate how science works, how it advances, and how it changes.

Geology 352: Introduction to Geophysics
Winter, 2007
Equation Dictionary Assignment

Geophysics is fundamentally based on mathematics, so you'll be seeing a lot of equations in this class. Many students approach equations simply by memorizing them, rather than focusing on what they tell you. A common question that I hear is "which equation should I use?" or "can I use this equation?" These questions suggest to me that there must be a better way to think about equations. My goal is for you to think of the equation as a story that describes the relationship between variables, or physical parameters. To that end, you will each put together an "equation dictionary" for this class. This dictionary will be yours to bring to exams (and it is the only thing you'll be allowed to bring, other than your calculator), so it is to your benefit to keep it organized and clear.

Each entry in your dictionary will contain 4 columns. The first column will be the equation itself. The second column will explain the variables in the equation. The third column will be a written description of what the equation is telling you, and how it is useful. The fourth column is available for additional comments of your choosing. For example, rather than simply writing down the equation

$$\beta = \sqrt{\frac{\mu}{\rho}}$$

You will have an entry in your dictionary that looks something like this:

Equation and use	Variables	Explanation	Comments
$\beta = \sqrt{\frac{\mu}{\rho}}$ Shear wave velocity	$\beta \rightarrow$ shear wave velocity $\mu \rightarrow$ shear modulus $\rho \rightarrow$ density	The speed of a shear wave depends on the physical characteristics (shear modulus and density) of the material through which it is traveling.	Note that when density increases, seismic velocity *decreases*.

Note that the explanation does NOT read "shear wave velocity is equal to the square root of the shear modulus divided by the density". That would just be turning the equation itself into words. Instead, you're presenting the equation in a way that gives it meaning and relates it to geophysical parameters and processes within the Earth.

Here's another example:

Equation	Variables	Explanation	Comments
$A = A_o e^{-\left(\frac{\varpi t}{2Q}\right)}$ Attenuation of	$A \rightarrow$ seismic wave amplitude at time t $A_o \rightarrow$ initial amplitude of the wave	Describes how much a seismic wave attenuates as it travels for time t. Attenuation	A high frequency wave attenuates more rapidly than a low frequency wave because it

seismic waves	ω → angular frequency of the wave, also = $2\pi f$ t → time that the wave has been traveling and losing energy Q → quality factor; how much a wave attenuates (high Q = low attenuation!)	depends on the frequency of the wave (how many times it oscillates per second), the time it has been traveling and the quality factor Q.	oscillates more times, generating more friction.

In this example you might also include other equations that describe attenuation, such as the version that depend on distance rather than time. This way they'd both be in the same place and you could compare which is most appropriate for a given problem. You might also want to include units in your dictionary.

You'll need to keep your dictionary organized for test days (so that you don't have to hunt through zillions of pages to find the equation you want). You may do this is any number of ways. I strongly recommend making a digital dictionary, since you can easily edit it and don't need to worry about losing it. It is also easier to organize. Equations are easy to write using Microsoft Equation 3.0 (in the text, click "insert/object and click on Microsoft Equation 3.0; I can give tutorials in this if you like). If you write your dictionary by hand, I recommend using a small (e.g. 5" x 7") 3-hole binder. This way you can add or remove equations when you want, and put them in a convenient order. You can divide the notebook into sections based on theme ("earthquake seismology", "refraction seismology", "gravity", etc), or arrange it chronologically.

I will check your equation dictionaries before each exam (please see the syllabus). 5% of your grade in the class will be based on your dictionary, and of course the better your dictionary is, the easier time you'll have on test days.

GEO 352: Introduction to geophysics
Hot spot/mantle plume project and debate

When you took introductory geology, you were probably taught that hot spot volcanoes form from mantle plumes that rise from the core-mantle boundary. You were probably taught that these plumes rise because there are hotter, and consequently less buoyant, than ambient mantle. You probably learned that the plume head produces a flood basalt, and the trailing tail is the source that generates a chain of hot spot volcanoes. You understood that hot spots were fixed in space, indicating that they were rooted deep in the Earth. You may or may not have learned that in fact the mantle plume/hot spot hypothesis is a contentious one that some earth scientists do not believe and are working to disprove.

At issue are several questions about ocean island volcanoes (I'll use that term instead of hot spot volcanoes to keep the observations separate from the model).

1. Do ocean island volcanoes form from mantle plumes? Do mantle plumes exist?
2. Are "hot spots" actually hot?
3. Are hot spots stationary? Or do they migrate? (this ties in to the question of whether or not they stem from a deep source)
4. If not hot spots or mantle plumes, how do ocean island volcanoes form?

Our goal will be to use the tools of geophysics that we've learned in this class to address this debate. We may not come up with a unanimous conclusion as to whether or not we think there are mantle plumes, and whether those plumes are hot. But we will learn more about how geophysics is used to study the solid earth and how different geophysical techniques may be applied to a common question.

To this end, the class will split into 6 groups, each of which will research a single aspect of the hot spot/mantle plume question. Your group will research the issue (some websites and resources are listed below) and will present what you learned in a **15-minute Powerpoint presentation** on Tuesday 6/5 or Wednesday 6/6. Thursday, 6/7 will be devoted to a group discussion of the topic. Class will not meet formally on Thursday 5/31 so that you can work on your presentations as a group. **Each person in your group *must* present part of the Powerpoint, so expect ~5 minutes per person.** In your Powerpoint you should

1. Teach your classmates about how the geophysical technique is used in the study of hot spots/mantle plumes
2. Describe some of the research that has been done using this technique and summarize the results
3. Discuss evidence in favor of, and in opposition to, the hot spot/mantle plume model (if such evidence exists)
4. Include a slide that lists (in proper format) a bibliography of your sources, including journal articles and websites.

All Powerpoints will be handed in to me (I'll copy them to my computer) and I'll post them on Blackboard for others to look at.

Topics will be randomly assigned to the groups. They are

1. Plate tectonics
2. Heat flow
3. Magnetism
4. Seismology
5. Gravity/isostasy
6. Alternative (non-hot spot) models for the formation of ocean island volcanoes (i.e. "if not hotspots, then what?")

A great deal of information on this topic may be found at http://www.mantleplumes.org/, a website put together by some of the leaders in the anti-plume camp. Those in favor of the status quo have no specific website that I know of, but there are a wide range of published papers that discuss the issue. And the website cited above includes many articles by pro-plume scientists. I am happy to help you find papers of interest, and can let you know how to access the Scientific Citation Index, which is a very useful way to

see who cited any given paper and thus how a scientific idea is discussed by the scientific community. Some suggestions for each of the assigned geophysical topics are below. Note that these are just suggestions…you will probably need to look up many more references. These are just jumping-off points. An incredibly thorough (and potentially overwhelming) summary of hot spots and melt anomalies can be found at http://www.geo.lsa.umich.edu/~keken/Papers/ItoVanKeken_Treatise_preprint.pdf.

1. Plate tectonics: Focus on the question of hot spot chains, ages of hot spot volcanoes, etc. There is an interesting paper by Wessel and Kroenke (http://www.soest.hawaii.edu/pwessel/papers/1997/Nature/Nature.html) that uses plate motion to analyze the fixity of hot spots and to determine which ocean island volcanoes are and are not due to mantle plumes. There have been many papers that have referenced this paper in their attempts to deny Wessel and Kroenke's results. In general, Paul Wessel has lots of work on this topic, so a Georef search on his name will probably bring up several articles. There are also two interesting discussions at http://www.mantleplumes.org/TopPages/GTofPT_Top.html, looking at the other side of the coin.

2. Heat flow: There is a classic paper by Von Herzen et al. (Journal of Geophysical Research, volume 94, pages 13783-13799, 1989) that discusses the heat flow anomaly associated with hot spots. Carol Stein also has some PDF's of papers associated with heat flow at her website (http://tigger.uic.edu/~cstein/resice.html). A Google search on "hot spot heat flow" yields a number of possible links.

3. Magnetism: A key thing here is to investigate the results of Ocean Drilling Project legs 145 and 197 (http://www-odp.tamu.edu/publications/197_IR/197ir.htm for the leg summary and http://www-odp.tamu.edu/publications/197_SR/197TOC.HTM for a list of papers resulting from the leg)

4. Seismology: You'll probably be focusing on seismic tomography here…the use of seismic waves to investigate the anomalies in the subsurface. If plumes exist, they should be visible in tomographic data. Wolfe et al. (Nature, v. 385, 245-247, 1997) found seismic evidence for a mantle plume beneath Iceland, whereas Fouger et al. (Geophysical Journal International, v. 146, pp. 504-530, 2001) did not. There's a summary paper at http://geoweb.princeton.edu/people/faculty/nolet/nolet06b.pdf. There has also been work done on the topic of seismic anisotrophy (http://www.sciencemag.org/cgi/content/full/293/5535/1645 or http://www.seismology.harvard.edu/projects/3D/S20A/S20A.html).

5. Gravity/isostasy: A couple of places to start are Pål Wessel's paper that discussed gravity and other geophysical data over Hawaii (http://www.soest.hawaii.edu/pwessel/papers/1993/JGR_93b/jgr_93b.html) and Pablo Canales' discussion of the hot spot swell near the Canary Islands (http://www.blackwell-synergy.com.ezproxy.library.wwu.edu/doi/abs/10.1046/j.1365-246X.1998.00448.x). The Yellowstone hotspot is one for which gravity data have been important, so a search on "Yellowstone geoid" can find you some interesting links. I also found an interesting PDF of a powerpoint on the topic: http://www.goce-projektbuero.de/go_cry_03/marquart.pdf (it might help you find other links as well).

6. Alternative (non-hot spot) models for the formation of ocean island volcanoes and evidence supporting those models. One good starting place is the publications page of Don L. Anderson (http://www.gps.caltech.edu/~dla/#publications), a professor at Caltech who has led the charge against hot spot/plume models. He has many papers that address the question of how ocean island volcanoes form, if not at hot spots. One of those papers (http://www.gps.caltech.edu/~dla/GlobalHotspotMaps.pdf) specifically goes over each proposed hot spot volcano and considers whether there are other sources for its volcanism, and which are the best candidates for true hot spots/mantle plumes. One hypothesis to look up is Edge-driven convection (http://www.mantleplumes.org/EDGE.html).

There are many, many resources for each of these topics, so please feel free to ask me about them.