Ge 131 Term Projects, 2001

The fundamental rule with projects is that you must find or do something that is novel; that is in some sense your own. You are NOT permitted to merely review other people's ideas.

You need to choose a term project on or before Friday, April 18. This choice should be communicated to me in an email, referring to one of those listed below or stating something else not listed below (which is fine). You must state in a few sentences exactly what you intend to do (i.e., you can't just say "I want to do x".) You can of course talk to me in advance. In most (but not all) cases I can suggest references.

Most of these projects involve science that you have not yet met in the course. You may need to have the courage to choose something that you find interesting (but don't yet know how to do!) I'm available to guide you to the material that you need, including advance copies of later chapters in the course.

You will be expected to have demonstrated some progress on your choice already by April 5.

Mercury 1: Alone among the terrestrial planets, Mercury does not exhibit basaltic volcanism (or, at least, does not exhibit evidence for the relatively iron-rich magmas that normally arise from partial melting of a silicate mantle source.) A major piece of evidence for this is the radar data (Jeanloz, R., Mitchell, D. L., Sprague, A. L., *et al.* Evidence for a basalt-free surface on mercury and implications for internal heat *Science* **268** 1455-1457, 1995). Develop a model to explain this. (For example, if Mercury steadily cools and does not convect then there will be no process for generating basalt. Or maybe basalt is not sufficiently buoyant to get through the older crust.)

Mercury 2: Critically assess the hypothesis that Mercury's magnetic field is *not* the result of dynamo generation. For example, could it be a very large and coherent paleomagnetic feature? A good place to start is the "Mercury" book (Un. Arizona Press.)

Mercury 3: The preservation of the 3:2 spin-orbit resonance is contingent on a "fossil" B-A (difference between intermediate and smallest principle moments of inertia). However, non-stationary mantle convection can cause these moments to change through geological time. Estimate the probability that Mercury was previously in 2:1 and then slipped out (i.e., B=A at some instant) to fall down to the current 3:2.

Venus 1: One popular view of the interior of Venus is that it is dry (i.e., has less water than Earth's mantle). Is this reasonable? That is, under what circumstances could Venus have been so effectively outgassed? Or did it not get water in the first place? [A hint of the problem: On Earth, and presumably Mars, outgassing is accomplished by making CO_2 bubbles in magma which the steam then partitions into; but on Venus it is harder to make CO_2 bubbles once the atmosphere has high CO_2 pressure. If water outgassing is accomplished over a long period of time into magma or crust (but not atmosphere!) then the residue of melting may indeed be dry but the mantle as a whole may not be.]

Venus 2: Scaling arguments suggest that Venus' convection should be much more strongly affected by the "660km discontinuity" (the upper-lower mantle boundary, which will actually be at about 800km depth in Venus). So maybe Venus has an upper mantle heated from below (good for making lots of plumes) and this might also affect whether the core is ever cold enough to nucleate an inner core and thus have a dynamo. So the project would consists of marshaling the arguments and assessing the consequences of layered convection in Venus.

Venus 3: Venus shows no evidence of a global magnetic field. However, it may once have had a dynamo (like Earth's current dynamo though somewhat smaller field). And perhaps some of the rocks on the surface are old enough that they were formed in that epoch. And perhaps the blocking temperature of relevant magnetic minerals is above (though not much above) the actual surface temperature of Venus, so permanent magnetism could persist in a thin layer. It is therefore conceivable that Venus has a small detectable (Mars-like though smaller) magnetic field. Assess the likely magnitude and the challenge of detection.

Earth 1: It has recently become popular (with some) to suppose that D'' (the lowermost 200km of the mantle) might be "primordial" (i.e., a layer of different composition that was left over from an early magma ocean phase of

Earth evolution). Develop plausible phase diagrams that could test the likelihood and nature of such a layer.

Earth 2: By an amazing "coincidence", Earth's mantle regulates its temperature so that it only barely melts (e.g., shallow regions beneath mid-ocean ridges) and yet conventional convection theory would argue that the mantle temperature regulates at a value that does not depend on whether melting occurs (i.e., depends only on the rheology of olivine). By constructing a model in which the operation of plate tectonics depends explicitly on melting, explain the "coincidence" and its consequences for Earth evolution.

Earth 3: Seismological evidence indicates that the inner core is strongly anisotropic. One consequence of this is that the thermal conductivity will be a tensor. This means that even if the outer boundary condition of the inner core is spherically symmetric (i.e., constant temperature), the temperature distribution within a conducting core may have lateral temperature gradients. This is convectively unstable... the inner core must convect. Assess.

Moon: Our companion has a gravity field that seems to have "excess" power at degree 2 in the gravity field. (The same is not true in topography). This has been attributed to fossilized rotational and tidal effects. How significant is the "excess" at degree two? Could it be just the chance outcome of a process (e.g., impacts or convection) that does not favor degree 2? This can be assessed by simulations: Create mass and density anomalies (or crustal thickness anomalies, etc) and then calculate the resulting spherical harmonic representation. By doing this many times you get an idea of the spectrum of possibilities. (A relevant paper is Lambeck and Pullan, *Phys. Earth & Planet Int.* **22**, 29, 1980. Also a paper I gave at last LPSC: extended abstract available)

Mars 1: Discussions of Mars CO_2 usually omit consideration of the large amount that could have been outgassed in the last few billion years associated with volcanism (but long after any hypothesized warm wet phase of early Mars). By "large", I mean relative to the current atmosphere which is a tiny reservoir cosmochemically speaking. Assess the expected outgassing, based on models for Mars thermal history, likely melt production and hypotheses for carbon content, etc. One relevant paper is Weizman, A., Stevenson, D. J., Prialnik, D. and Podolak, M. Modeling the volcanism on Mars. *Icarus* **150** 195-205, 2001

Mars 2: Tharsis sits at the equator and is a major geoid contribution. Is this just a coincidence or did it migrate there by True Polar Wander (TPW)? Many years ago (~1980) Willemann & Turcotte assessed this and concluded that it could not happen because the Martian lithospheric stresses resist True Polar Wander. But what if the lithosphere is fragmented (perhaps as a remnant of a plate tectonic era). Then the TPW could be accommodated by slippage on pre-existing faults. Assess this. How would TPW affect the observed Martian magnetic anomalies? (For this and any Mars topic, I have many copies of a bound set of papers published very recently in *Nature.*)

Mars 3: MOLA data (aided by gravity) tell us that there is both a gradational transition in crustal density from South (thick) to North (thin) as well as a "jump" across the crustal dichotomy boundary between North and South. Could the gradational variation simply arise from the age variation (South is old, North is younger) together with a temperature decline (South formed when the mantle was hotter and gave a thicker crust, etc.) The following papers may help (although they don't directly address this hypothesis): Nimmo, F. and Stevenson, D. J. The influence of early plate tectonics on the thermal evolution and magnetic field of Mars. *J. Geophys. Res.,* **105**, 11969-11979, May 25 , 2000; Nimmo, F. and Stevenson, D. J. Estimates of Martian crustal thickness from viscous relaxation of topography. *J. Geophys. Res.* **106**, 5085-5098 , 2001.

Mars 4: As part of the Netlander mission (2006 or 7), the French will place a seismic network on Mars. (Check out the special issue of *Planet. Space Sci.* **48** 1143-1420, 2000). By use of parameterized convection schemes (for example) make estimates of the total Marsquake activity and expected frequency of quakes and detectability, earthquake premiums for habitation, etc.

Mars 5: What is the expected "geothermal" heat flow difference between North and South on Mars? (This can be tackled by noting that the crust is different, hence the geotherms are different, also the propensity for mantle melting may be different between North and South. This is also very important for assessing hydrothermal activity, large scale mantle flow, habitats, etc. Some day it may be measured.)

Generic Giant Planet: Does carbon want to be diamond or metal (dissolved in hydrogen) at high pressures in a giant planet? A relevant starting point is: Benedetti LR, Nguyen JH, Caldwell WA, et al., Dissociation of CH_4 at high pressures and temperatures: Diamond formation in giant planet interiors? *Science* **286** 100-102, OCT 1 1999.

Generic (Extra-solar system) Planet: Estimate the expected magnetic field and detectability of such a body using radio waves.

Jupiter 1: Recent Jupiter models (Guillot *et al*) suggest little or no heavy elements (ice and rock) core. Yet models of Jupiter formation generally require nucleation by such a core. Assess the possibility that convection through billions of years could have dredged up material from the core and mixed it into the overlying metallic hydrogen. A rough calculation on this was done (but not fully described) in: Stevenson, D.J. Cosmochemistry and structure of the giant planets and their satellites. *Icarus* **62**, 4-15, 1985.
Tristan Guillot maintains a good web site: http://www.obs-nice.fr/guillot/

Jupiter 2: The proposed polar mission to Jupiter (INSIDE Jupiter) will measure the tidal response of Jupiter to the Galilean moons to about one percent or better. Assess the extent to which this could be used to detect a first order phase transition deep within Jupiter. (I can provide more stuff on this than you would ever want.)

Io: Why does Io get such high temperature magmas to the surface? Assess the relative merits of conventional models (Earthlike) vs. Io-specific models (e.g., runaway heating on faults due to tidal friction). Relevant references include: Keszthelyi L, McEwen AS, Taylor GJ Revisiting the hypothesis of a mushy global magma ocean in Io *Icarus* **141**, 415-419 OCT 1999.
[If you're interested in this, talk to James Dennedy-Frank; he may have already laid claim to this topic.]

Europa 1: What is the likelihood of seeing (in the laser altimetry from the proposed Europa Orbiter spacecraft) real time faulting of the surface of Europa due to the eccentricity tide? ("Real time" means days).

Europa 2: Using parameterized convection recipes with tidal heating, assess whether the core of Europa will be volcanically active (essential for life on the ocean floor!) Using these estimates of tidal heating and what you can learn from hydrothermal circulation on Earth's ocean floor, assess how the chemistry of Europa's putative ocean has been affected by deep sea vents and what implications this has for observational strategies (including spectroscopy of water that might reach the surface through cracks in the overlying ice).

Europa 3: Did Europa have a *surface* ocean (i.e., no ice!) when it first formed? For some background on formation, etc., see Stevenson, David J. Jupiter and its Moons. *Science* **294** 71-72, 5 Oct., 2001.

Ganymede: The observed magnetic field of Ganymede appears to require a dynamo. At least on Earth, such a dynamo frequently reverses. Can you think of an observational strategy for deciding whether Ganymede's dynamo actually reverses? Should it reverse (given that it resides in a bias field provided by Jupiter)? Or could you detect evidence that *Jupiter's* field undergoes reversals?

Callisto: Using the magnetic field data and thermodynamic data for salty water as a constraint, assess how thick and/or salty the ocean must be and what this implies for formation scenarios (specifically, where does the salt come from?)

Saturn: The standard picture is that Saturn's magnetic field is spin-axisymmetric (i.e. has no dipole tilt). But the data on which this is based is mostly collected near the equator. Assess how much non-axisymmetry is permitted by the data and consider how this influences the radio emission and ring particle behavior.

Titan 1: Recent work at Keck and HST suggests very dark well-defined patches on Titan's surface, possibly evidence for lakes of liquid hydrocarbons or organic crud. If, as seems likely, part of this comes from the sky (raindrops of ethane) and part from below, explain why or whether a lake morphology rather broadly distributed liquid filling ice pore space is reasonable. (Or whether both are possible). I have copies of a relevant paper:
Stevenson, D.J. Interior of Titan, *Proceedings Symposium on Titan*, publ. European Space Agency (Noordwijk, Netherlands) pp. 29-33, 1992.

Titan 2: Titan may possess a sub-ice crust water-ammonia ocean. Assess whether or in what circumstances this could be detected by Cassini (by magnetic field measurements for example.) The equivalent successful approach was used for Europa and Callisto (but in the case of Jupiter the magnetid dipole is tilted): Khurana, K. K., Kivelson, M. G., Stevenson, D. J. , Schubert, G., Russell, C. T., Walker, R. J., and Polanskey, C. Induced magnetic fields as evidence for subsurface oceans in Europa and Callisto. *Nature* **395**, 777-780, 1998.

Uranus/Neptune: One view of these planets is that they are like onions (i.e., possess separate layers of gas-rich stuff, ice-rich stuff, and rock-rich stuff.) By considering the fluid dynamics and thermodynamics (i.e. solubility) at these interfaces, assess whether this makes any sense.

Triton/Pluto: Crater densities on Triton suggest a young surface. See: Stern SA, McKinnon WB Triton's surface age and impactor population revisited in light of Kuiper belt fluxes: Evidence for small Kuiper belt objects and recent geological activity *Astron J.* **119** 945-952 FEB 2000. Maybe this is because the interior is thermally active. Assess (e.g. for water-ammonia mixtures) the likelihood that these bodies possess an internal ocean. Fran Bagenal (Un. Colorado) has a nice Pluto web site: http://dosxx.colorado.edu/plutohome.html

Generic Kuiper Belt, Oort Cloud and Beyond: What determines whether Mars or Moon mass objects in this region are bright or dark? What determines whether they have or do not have (or ever had) a hydrogen atmosphere and what consequences will this atmosphere have?

Superganymedes Construct models of bodies that have the mass of Earth but the composition of Ganymede. (Our solar system has none of these but there is no reason to think that they are uncommon in the universe). Note that these objects could have dense atmospheres [Stevenson, D. J. Life-sustaining Planets in Interstellar Space? *Nature* **400** p 32 (July 1), 1999].

Differentiation Fluid Dynamics: When Earth's core forms, it may do so through downward migration of large iron blobs that equilibrate poorly by diffusion with the mantle through which they descend (look at relevant chapter in the *Origin of the Earth* book). Assess the extent to which some equilibration might occur through a more careful consideration of the fluid dynamics including partial melting, mixing, etc.