



Model Building in Planetary Science and the NGSS

Dr. Eric Hawker
IMSA Science Faculty
March 4th , 2016

Planetary Science

- Planets are complicated dynamic systems.
- There are many planetary attributes that interact with each other.
- The dynamic changes that planets go through are driven by energy.

Model Building

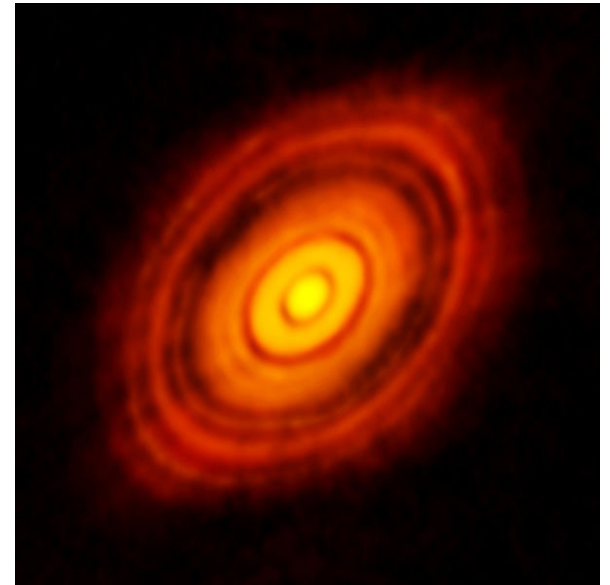
- Usually these are not physical models!
- A set of concepts that describe a system.
- **NGSS Science and Engineering Practices:**
Developing and Using Models: Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to **predict** and **show relationships** among variables between systems and their components in the natural and designed world(s).
 - Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-ESS2-1), (HS-ESS2-3),(HS-ESS2-6)
 - Use a model to provide mechanistic accounts of phenomena. (HS-ESS2-4)

Model Building

- HS-ESS2-1. Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.
- HS-ESS2-3. Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.
- HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

Heat from Planetary Formation

- The initial solar nebula of dust and gas that the Solar System formed from had a lot of gravitational potential energy.
- This gravitational potential energy was turned into thermal energy (heat) during planetary formation.



Atacama Large Millimeter Array image of HL Tauri

Radioactivity

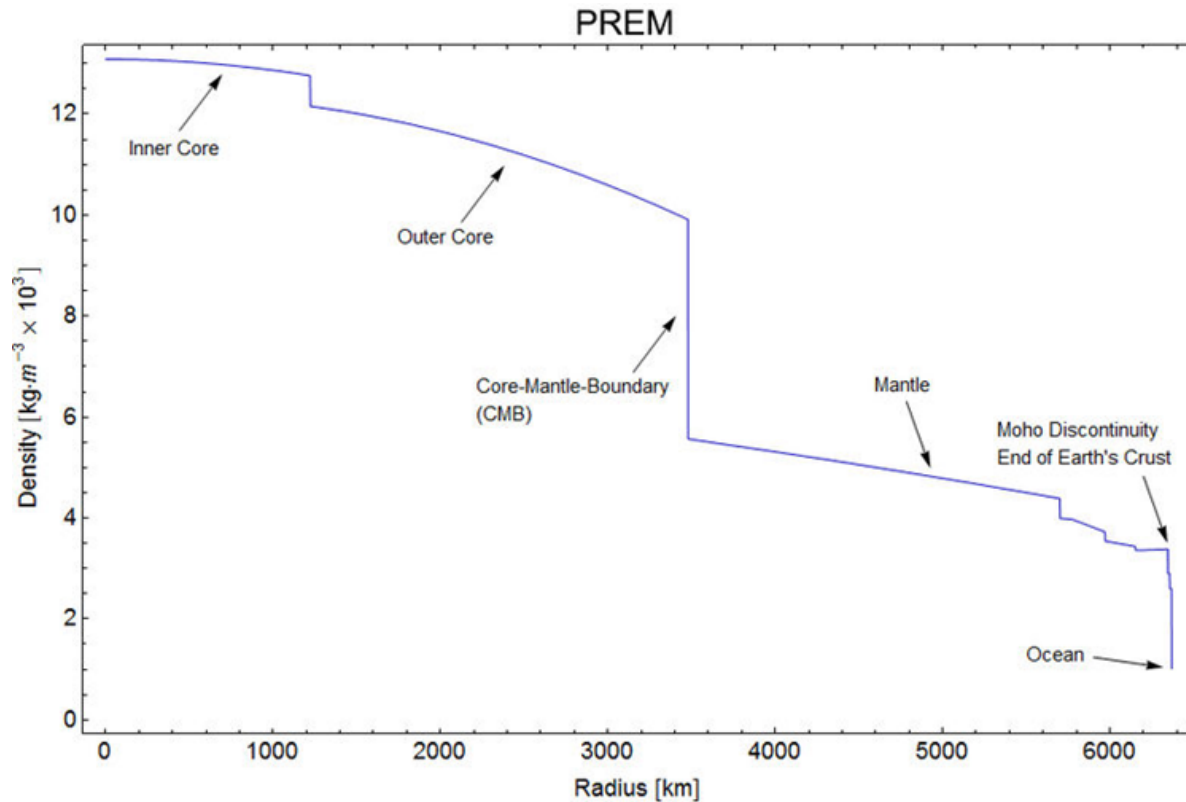
- When the planets formed, radioactive isotopes such as uranium, thorium, and potassium were trapped deep underground.
- When these isotopes decay, they release energy deep under the surface of the planet.
- Over the 4.5 billion years since the planets formed radioactivity has added **a lot** of energy to the planets, all in the form of **heat**.

Density

- Density is how much mass there is per a unit of volume.
- By looking at the density of a planet we can make a rough estimate of what that planet is made of.
- The density of rock is about 3 g/cm^3 while the density of iron is 7.9 g/cm^3 .
- Since Earth has a density* of 4.4 g/cm^3 this means the Earth is about 70% rock and 30% iron.

*This is the uncompressed density, taking out the factor of gravity

The Core

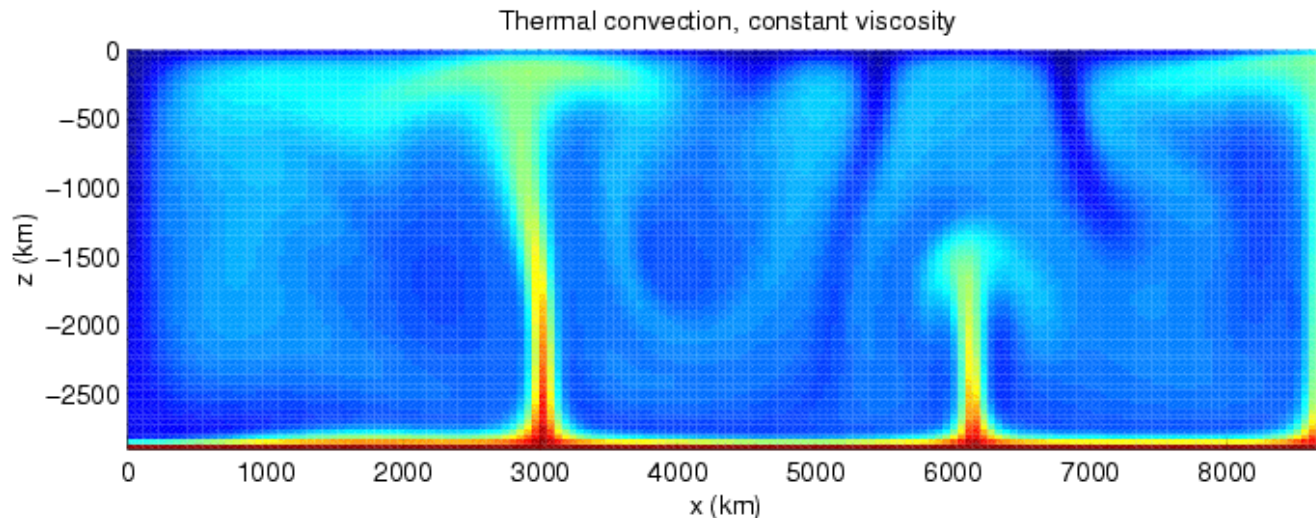
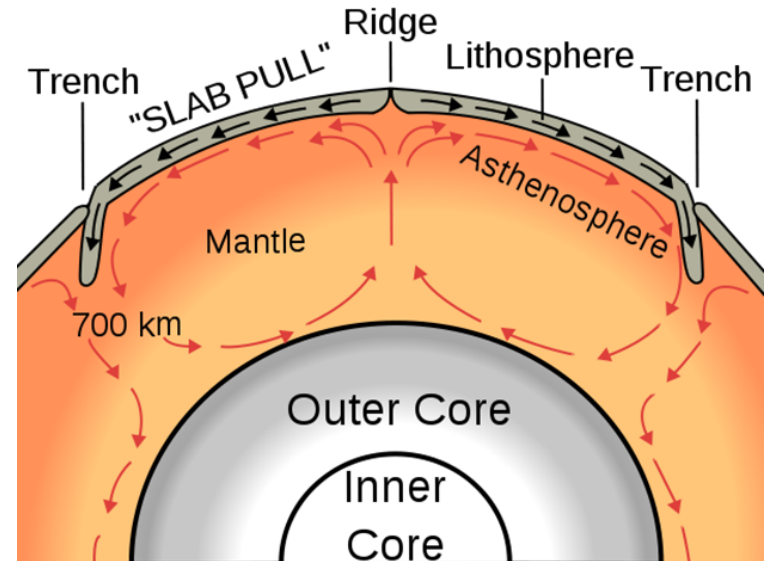


We believe that just after it formed 4.5 billion years ago, all of the heat produced would have melted the planet.

Since denser materials sink in liquid, most of the metal sank to form the core and the planet became **differentiated**.

Convection

- There is a large temperature difference between the center and the surface of the Earth.
- Heat transfer in the outer core and in the mantle occurs through the process of **convection**, with hotter, less dense, and more buoyant material rising upward, and colder, more dense, less buoyant material sinking downwards.



The Core and the Magnetosphere

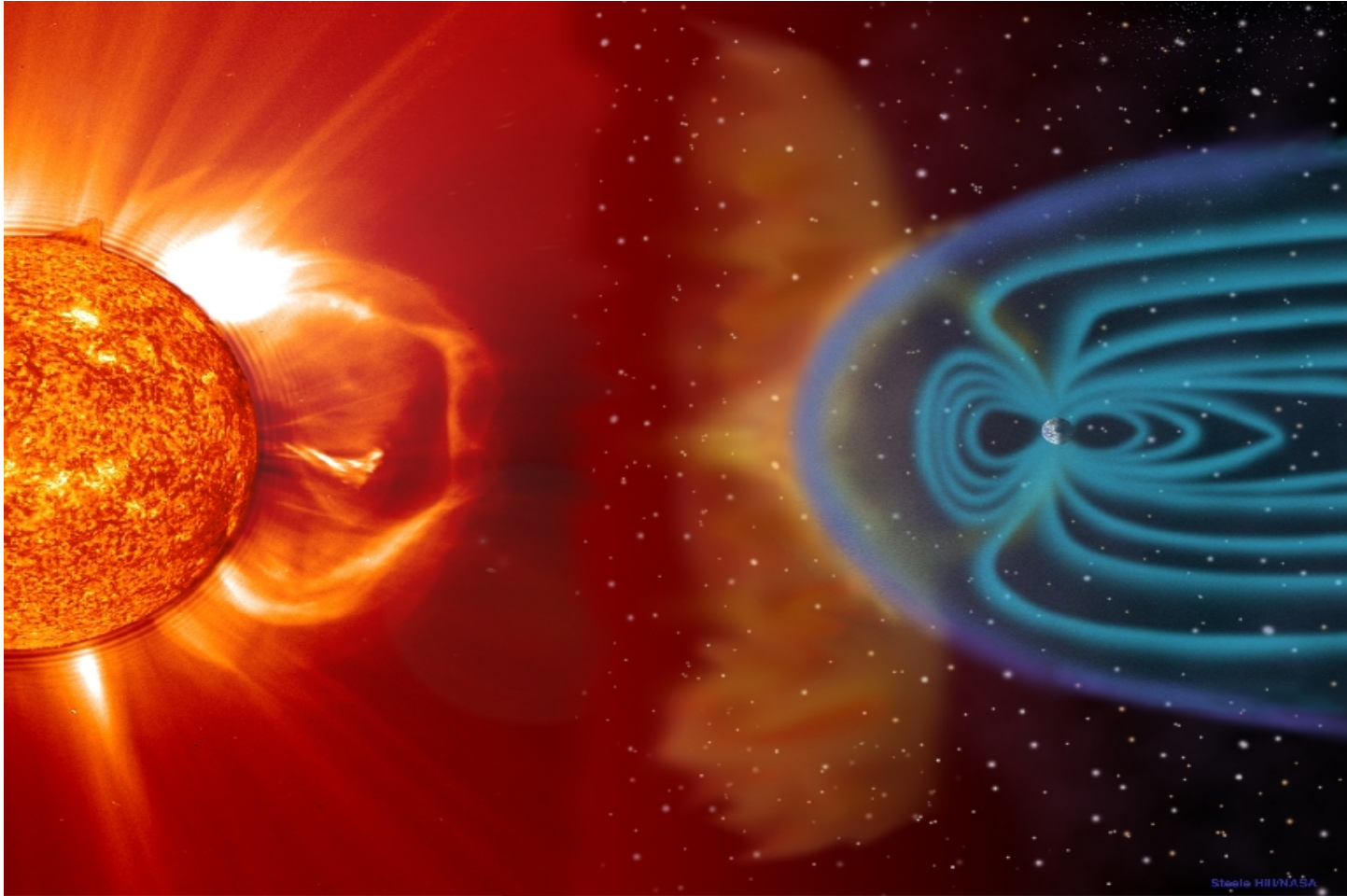
The Earth's magnetic field is produced because the Earth's core has certain properties.

The core is ...

- Electrically conductive (it is made of metal)
- Liquid
- Rotating
- Convection is occurring

If a planet has all of these properties, it will generate a magnetic field, if it is missing any of them then no magnetic field is produced.

The Magnetosphere



The Earth's magnetic field helps protect the atmosphere by deflecting particles of the solar wind.

Tectonics

- Although the mantle is solid the high temperatures and high pressures in the mantle cause it to deform and “flow” in convection.
- The convection of the mantle is a major driving force in plate tectonics.
- If liquid water was not present crustal plates would not be malleable and flexible enough for tectonics to occur.

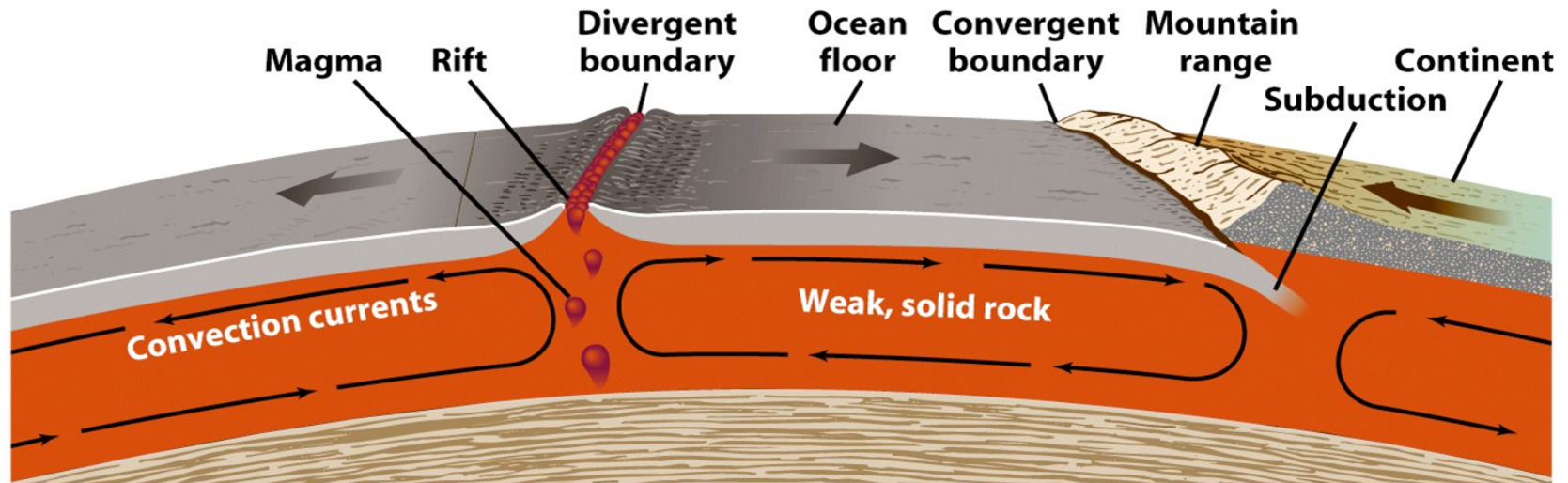
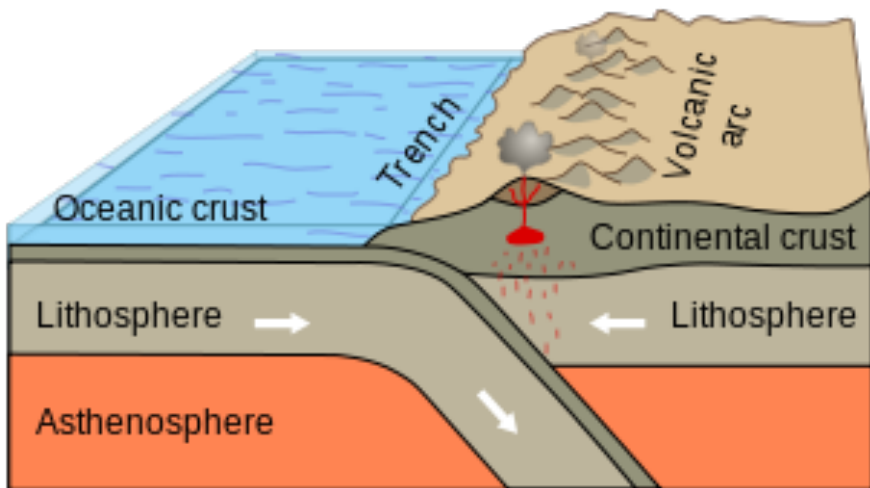
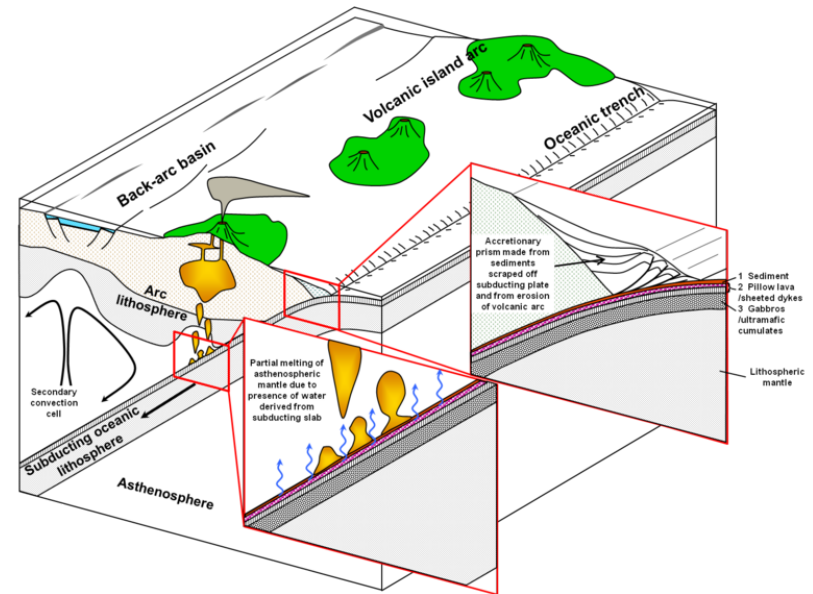


Figure 6-7b
Discovering the Universe, Seventh Edition
© 2006 W. H. Freeman and Company

Volcanism

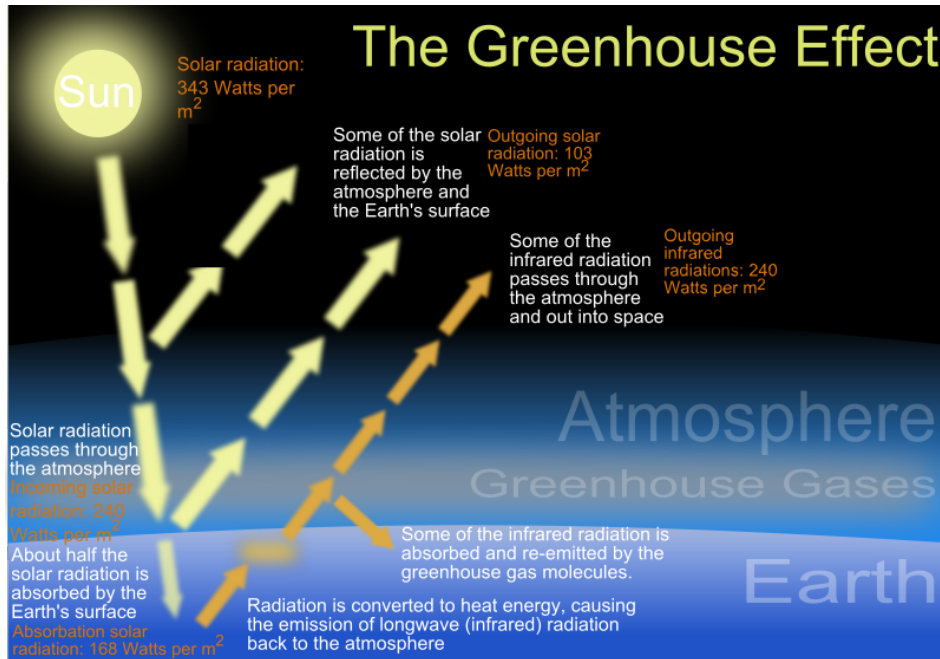
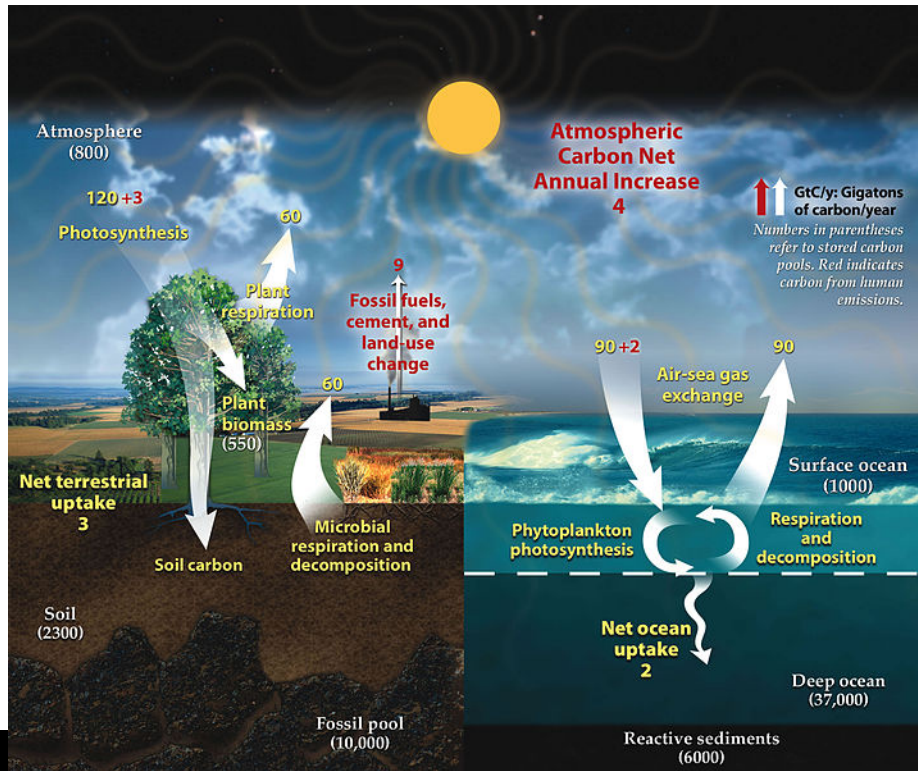
- A major cause of volcanism on Earth is plate tectonics.
- Volcanoes can also be due to convection creating a “mantle plume”



- Volcanoes significantly affect the atmosphere and climate due to the emission of ash, sulfur aerosols, and CO₂.

Atmosphere

The greenhouse effect provides insulation for the surface of the Earth keeping it warmer (by 32 K) than it would be with no atmosphere.

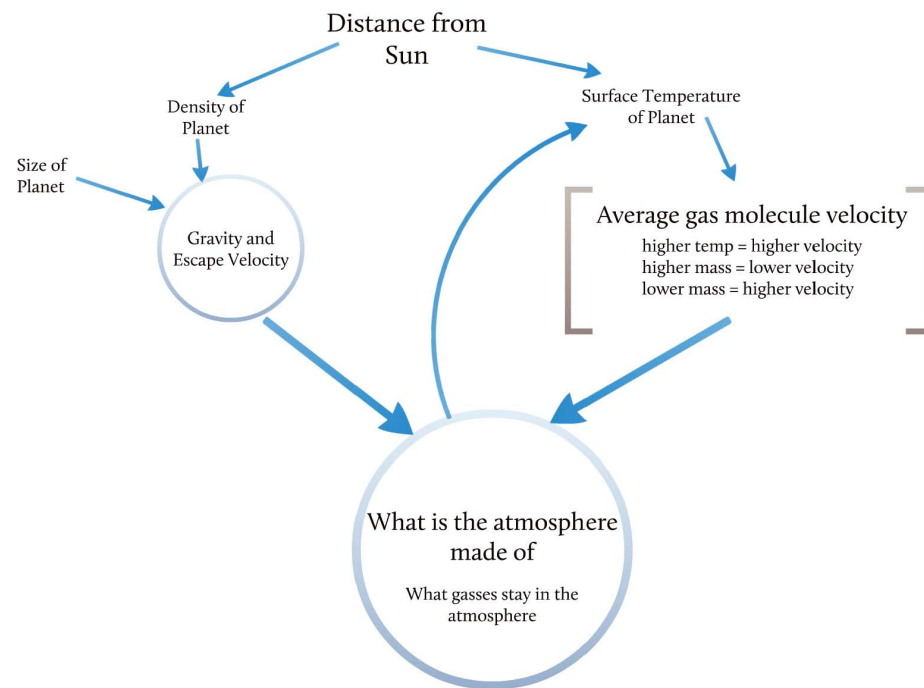
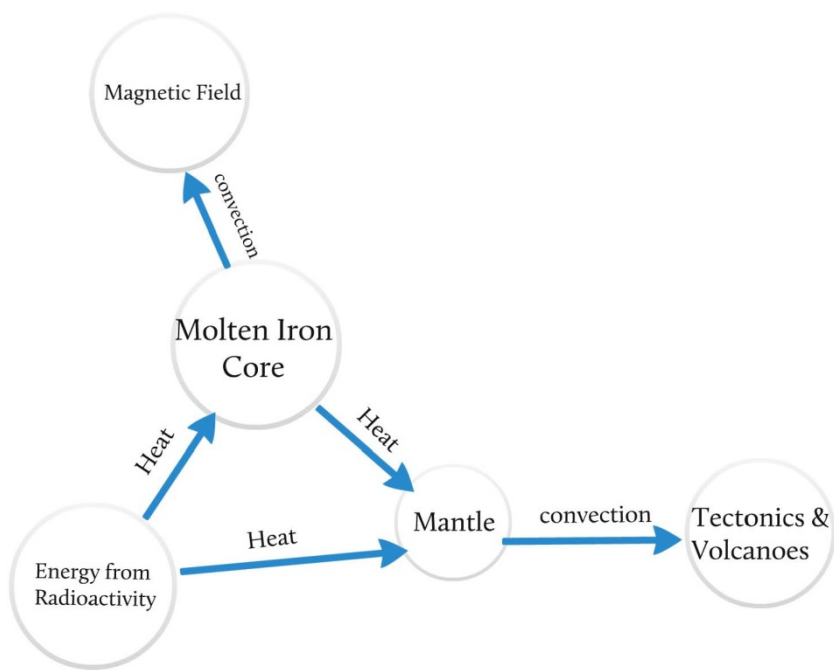


The atmosphere significantly affects life on Earth, but life also significantly affects the atmosphere.

Create a concept map

You should work in groups to construct a concept map that describes all of the main concepts, connections, and interactions that are present when you try to understand the whole Earth and its dynamics.

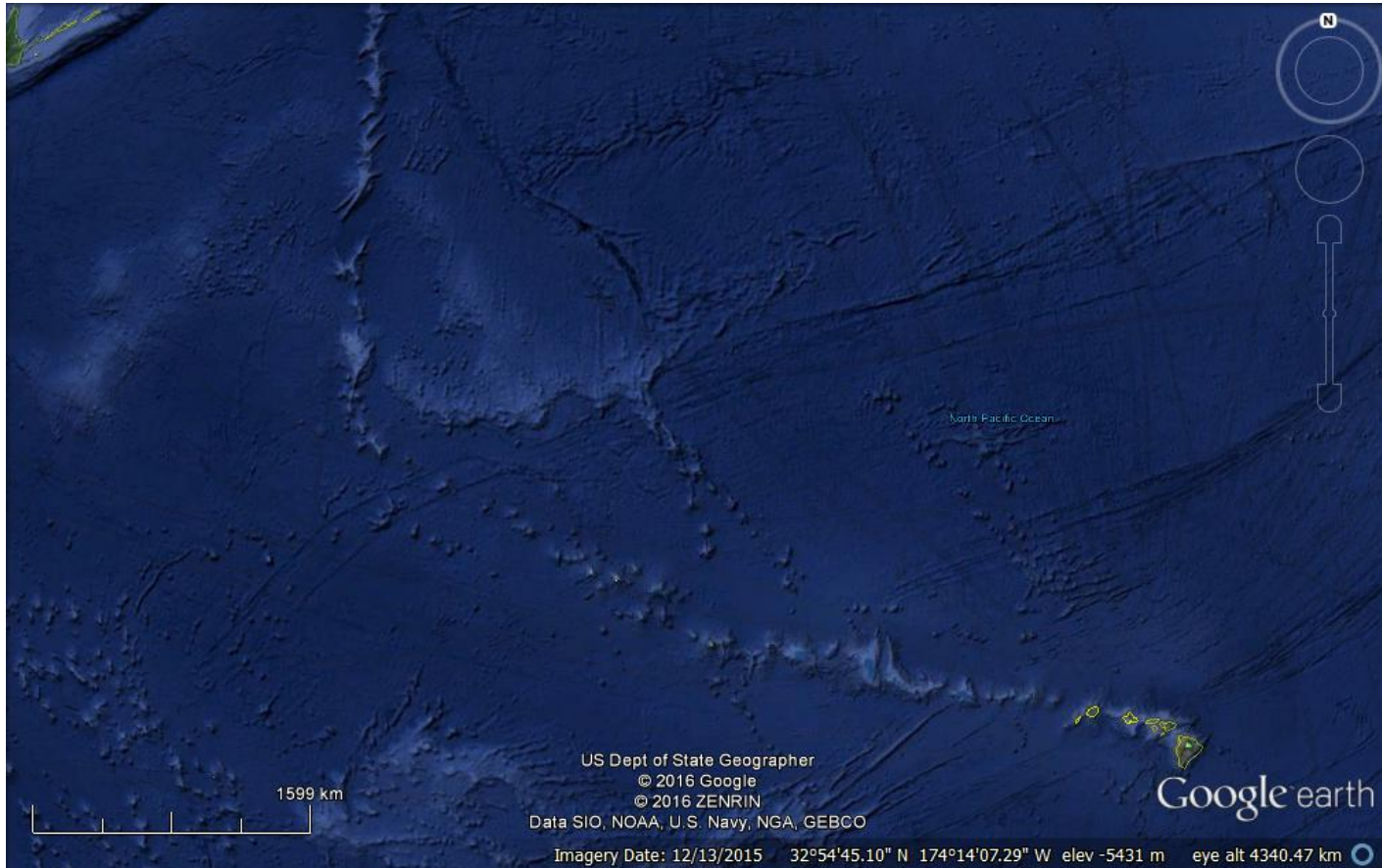
- First make a list of all of concepts, connections, and interactions that you know about.
- Then create a concept map showing how these concepts are connected to each other.



My students use Prezi.com to make their concept maps. These are examples I give to my students showing just a small number of concepts

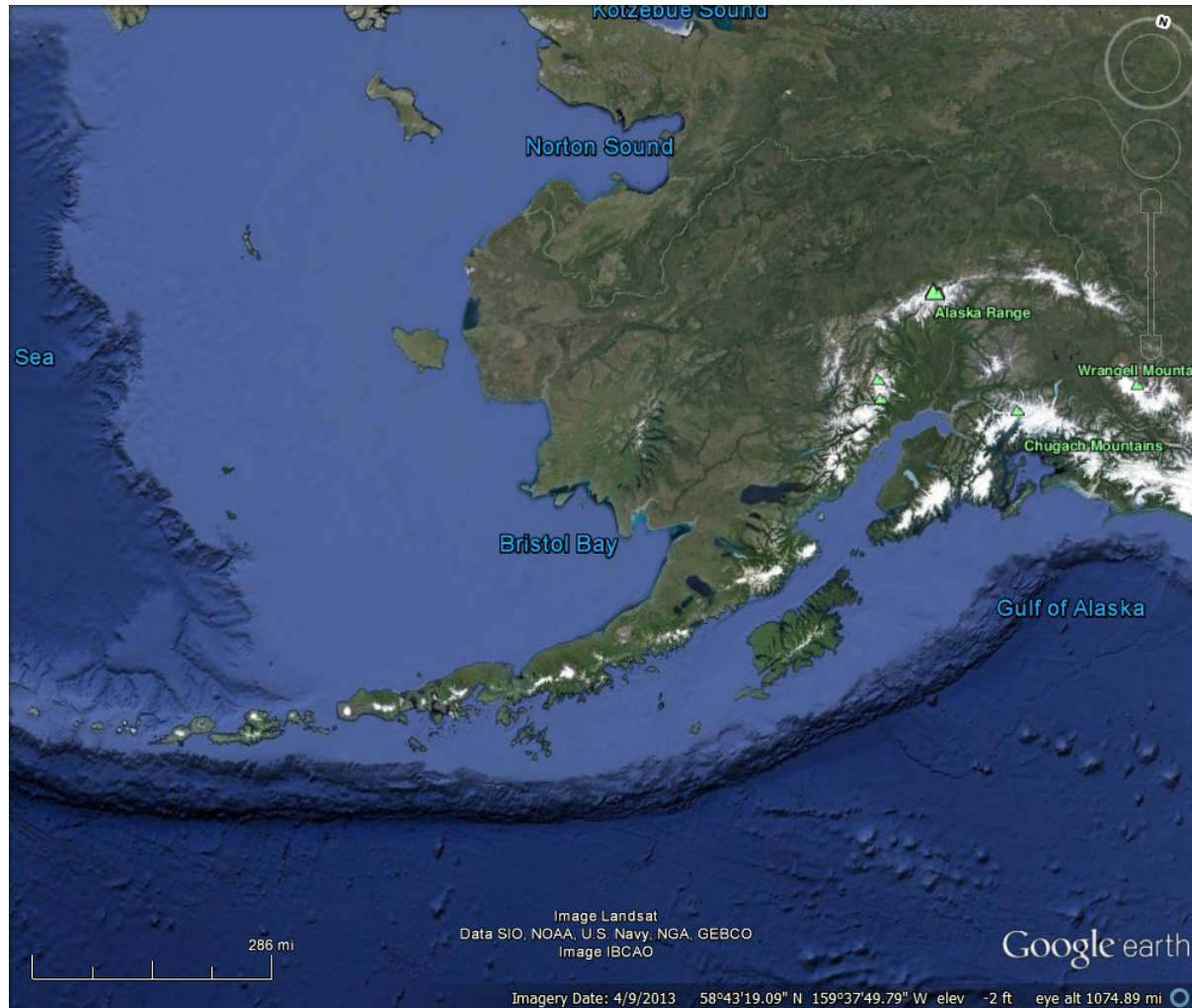
Use your concept map

Use your concept map to answer these following questions....



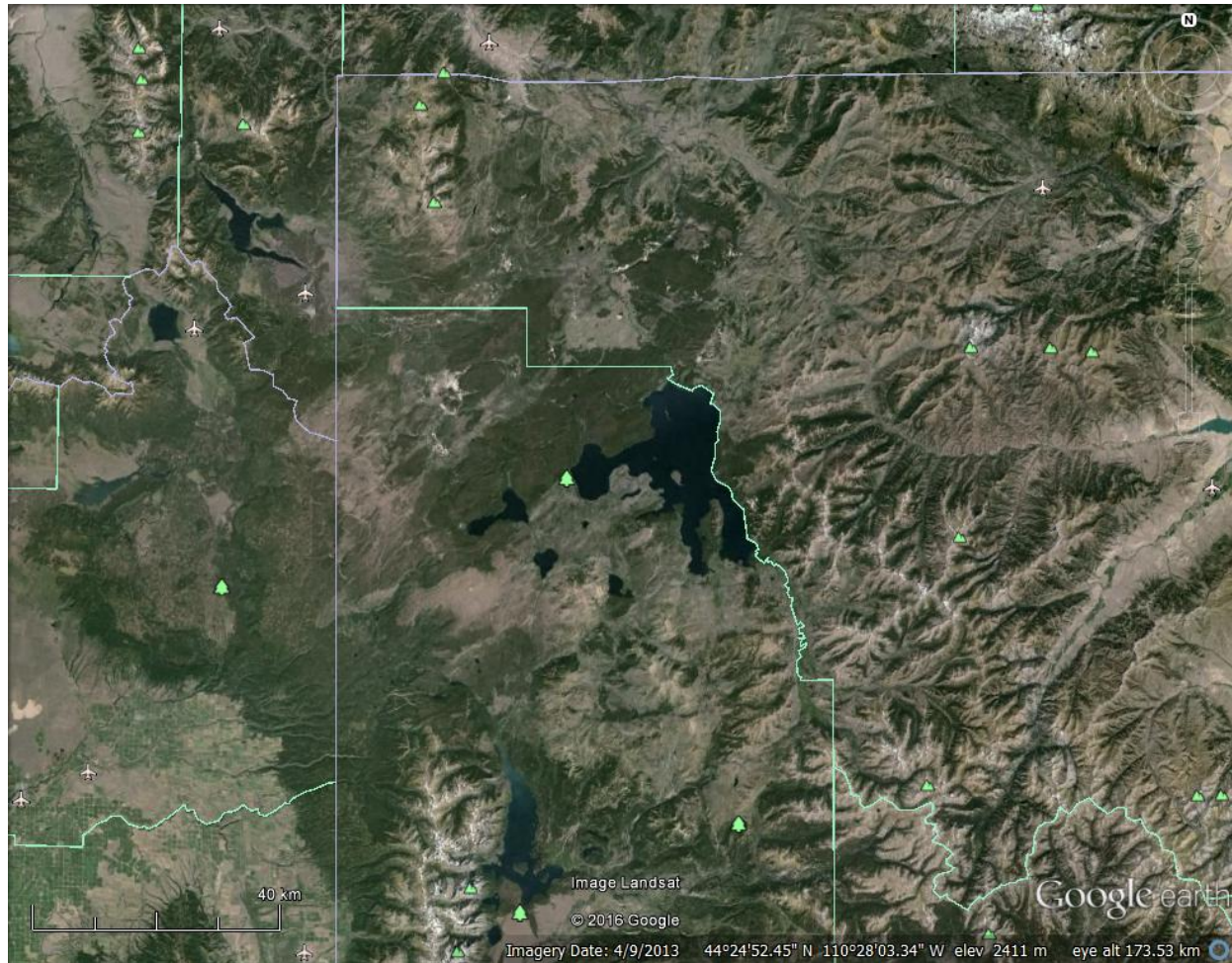
Why is there a line of undersea mountains leading away from Hawaii? Why does the line bend?

Aleutian Islands volcanoes and subduction zone



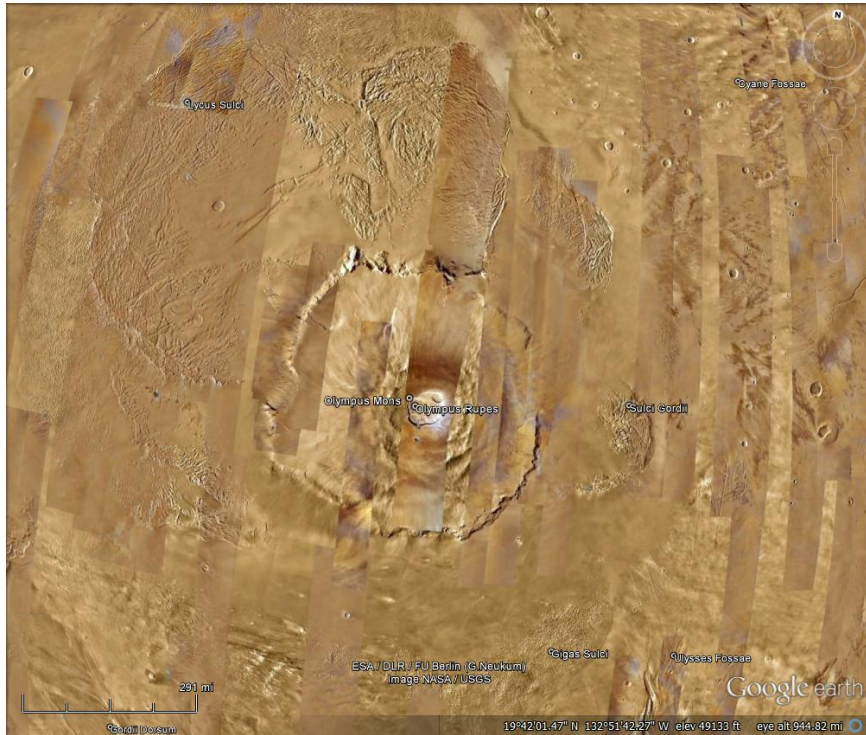
If plate tectonics stopped would that be good or bad for life on Earth?

Yellowstone supervolcano

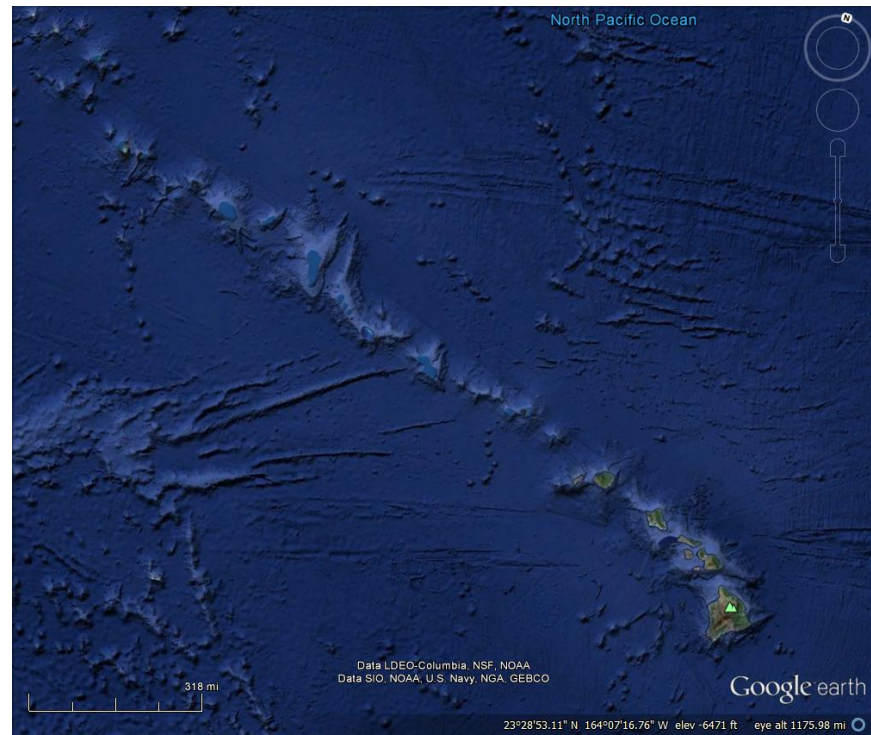


If there was a huge increase in volcanic activity on Earth how could that affect the level of O₂ in the atmosphere?

Olympus Mons, Mars

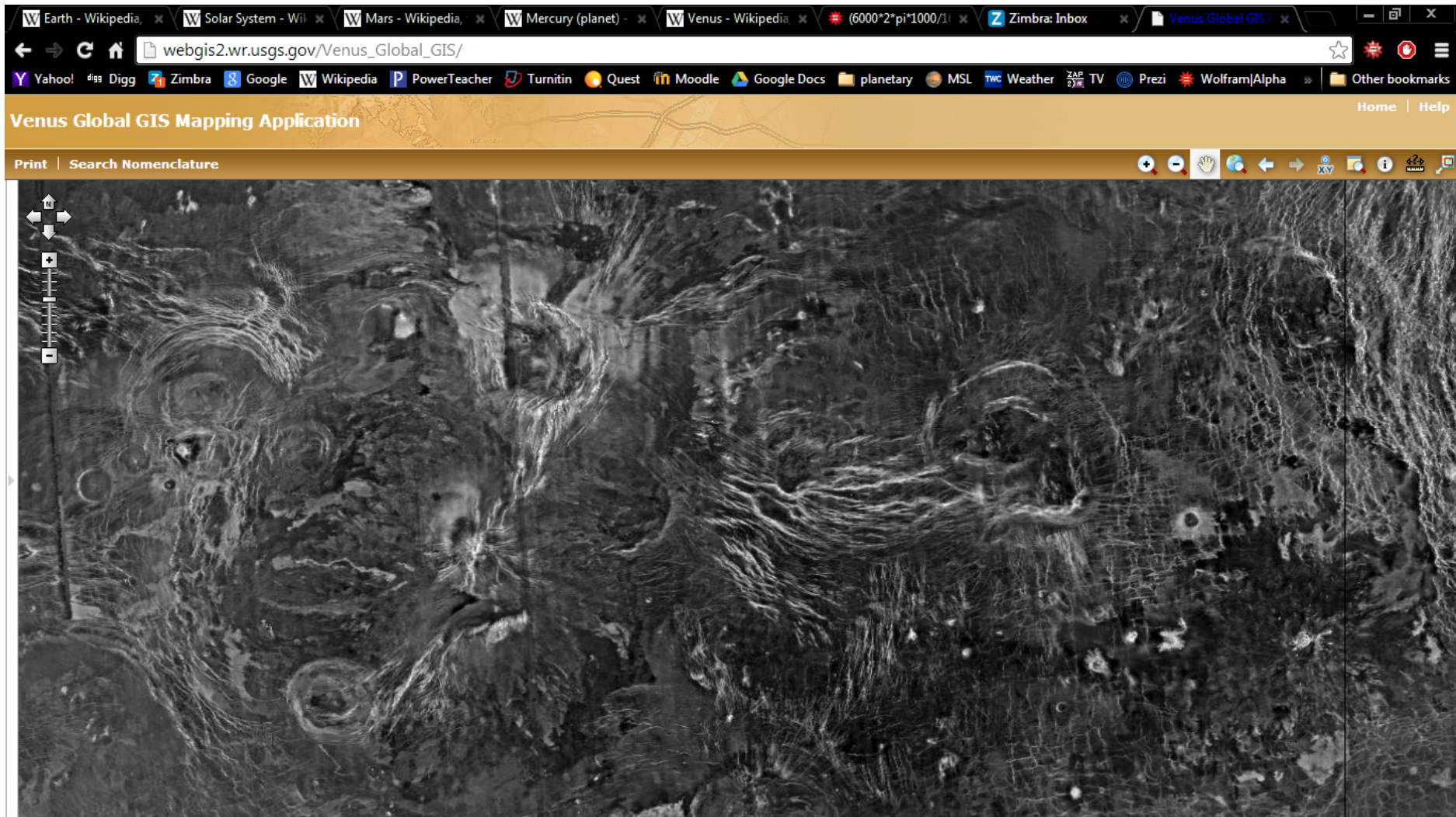


Hawaii



Mars has no evidence of active plate tectonics, yet has the largest volcanoes in the Solar System, why?

Venus



Most of the geologic features seen here are volcanic in origin.

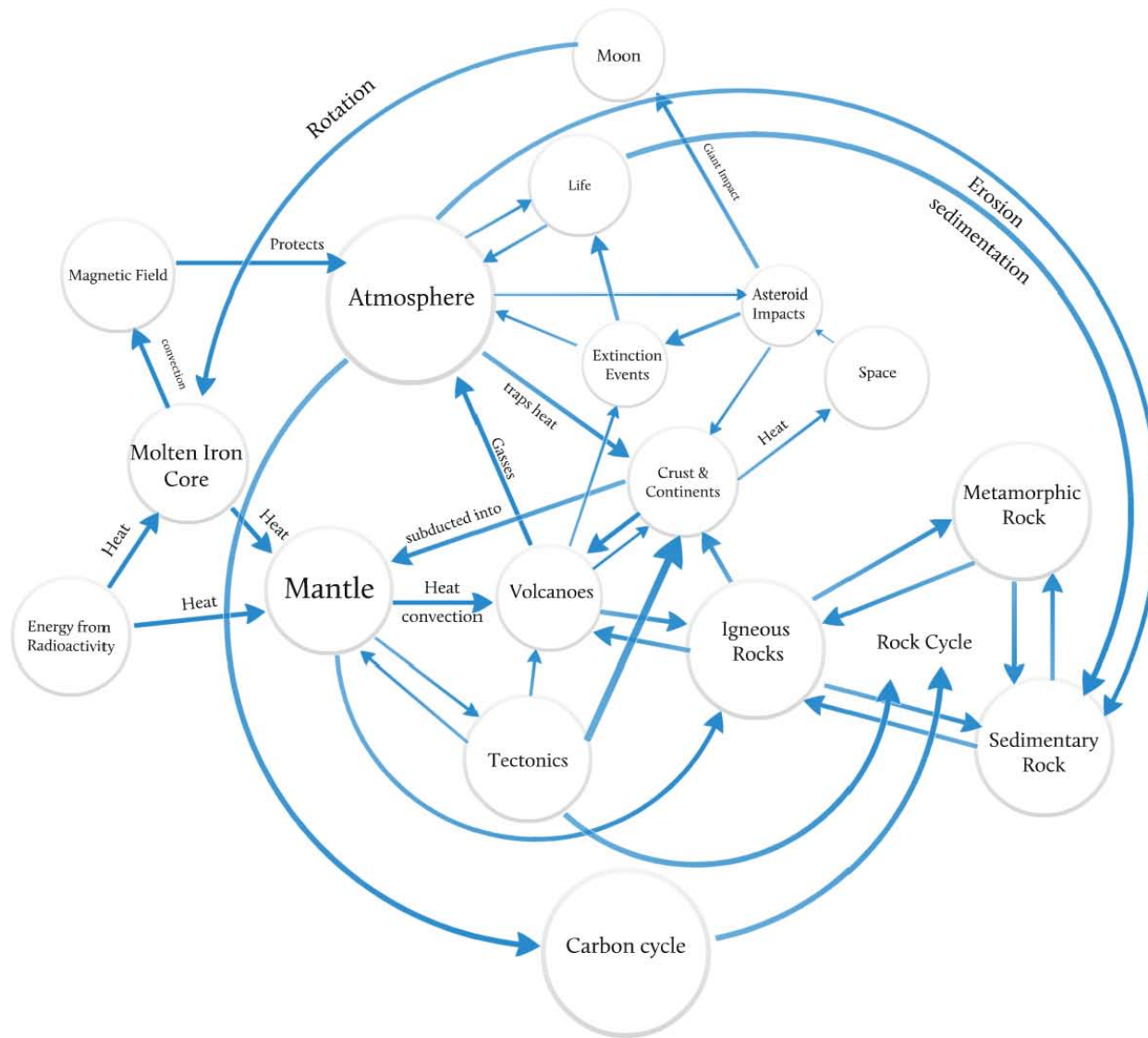
Venus

- Venus has a very thick, very insulating atmosphere.
- Venus has about the same mass and density as the Earth.
- The average age of the Earth's surface is about 100 million years, for Venus it is between 300-600 million years.
- While Venus has lots of volcanoes, we don't know how active they are.
- The core of Venus produces no magnetic field.
- Question: Why does Venus not have a magnetic field?

Exam question that I give my students...

Pretend that astronomers have discovered a planet that has about the same size, density, and rotation rate as the Earth, and this planet orbits a star a lot like our own Sun at about the same distance from the star as Earth does in our own Solar System. The only other thing that they know for certain about this planet is that it has at least one tectonic fault line (it may have more and you do not know if it is an active fault). What predictions can you make about this planet based on these pieces of information? Explain the reasoning behind your predictions.

Callisto is a large moon of the planet Jupiter and it is typical of many of the moons in orbit around Jovian planets. While Callisto is significantly larger and more massive than our Moon, there has never been a robotic probe to land on Callisto, however several missions have flown past the moon and have taken pictures of its surface. Based on these pictures it is believed that the surface has been affected almost exclusively by impacts. There is little or no evidence of any resurfacing processes other than impacts. What predictions can you make about Callisto based on these pieces of information? Explain the reasoning behind your predictions.



This is the full concept map that I share with my students.

Additional supporting slides....

Heat from Radioactivity

- Most of the radioactive isotopes that release energy in planets are from very dense elements like uranium and thorium.
- So higher density means a larger fraction of the stuff the planet is made of is radioactive.
- More mass means more radioactive material.

Density and Mass

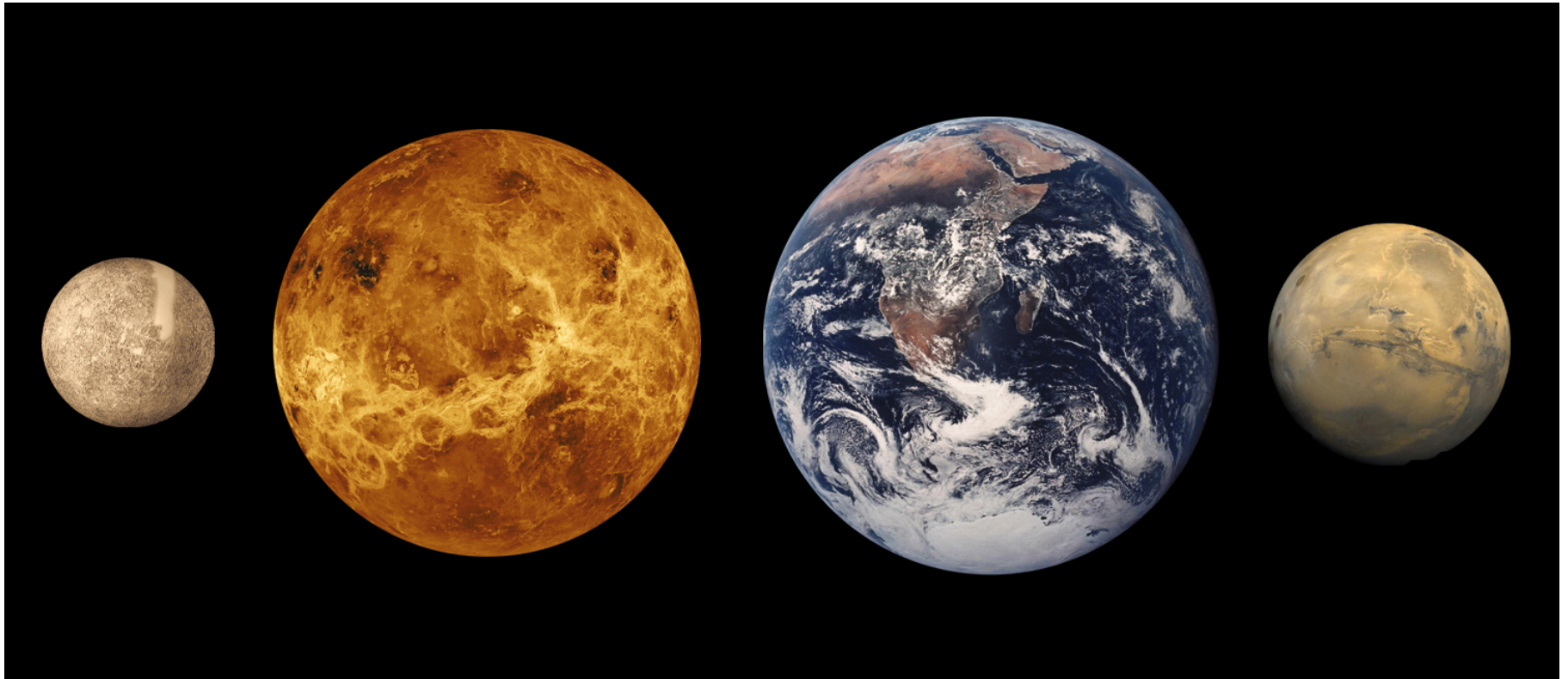
Density is how much mass there is per a unit of volume. By looking at the density of planets we can learn about what it is made of.

Planet	Density*	Mass
Mercury	5.3 g/cm ³	3.3×10 ²³ kg
Venus	4.4 g/cm ³	4.8×10 ²⁴ kg
Earth	4.4 g/cm ³	5.9×10 ²⁴ kg
Mars	3.8 g/cm ³	6.4×10 ²³ kg

The density of rock is about 3 g/cm³ while the density of iron is 7.9 g/cm³

*This is the uncompressed density, taking out the factor of gravity

The Terrestrial Planets



The Core and the Magnetosphere

- Mercury has a magnetic field 300 times weaker than the Earth's
- The core of Venus produces no magnetic field
- The Earth has an average magnetic field
- The core of Mars produces no magnetic field

Heat from Radioactivity

- Mercury has less mass than the Earth but a higher density.
 - Higher percent of its mass is made up of radioactive isotopes, but less mass overall.
 - Less heat
- Mars has less mass than the Earth and a lower density.
 - Lower percent of its mass is made up of radioactive isotopes, and less mass overall.
 - Less heat
- Venus and Earth have about the same mass and density..... So they should have the same amount of heat.

Plate Drift

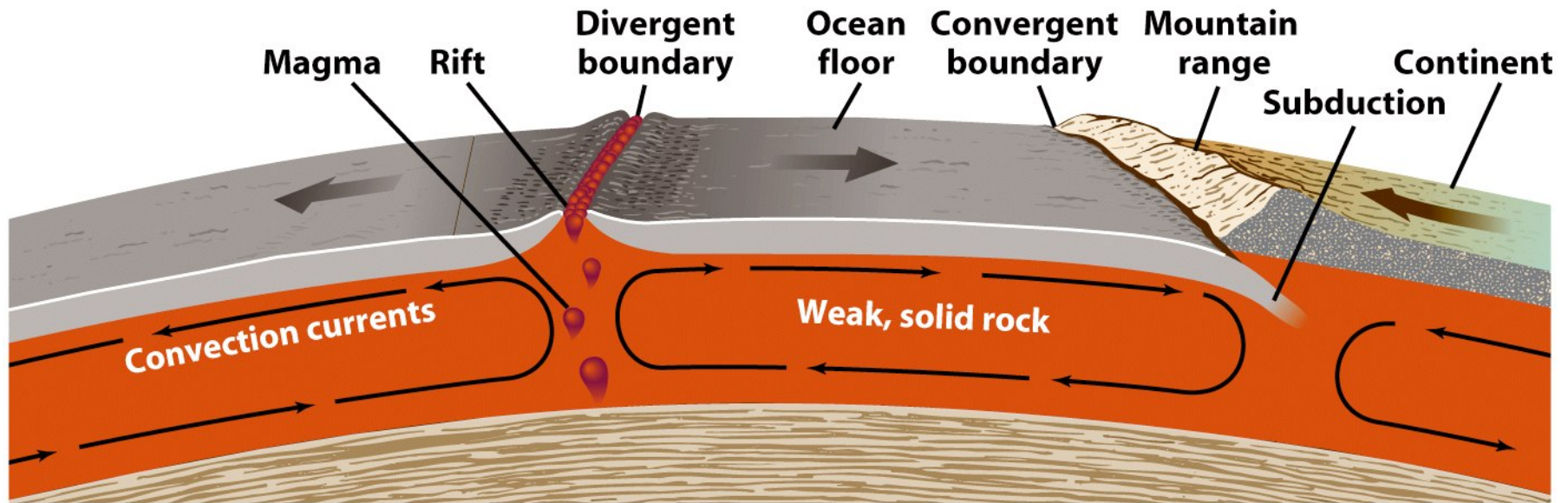
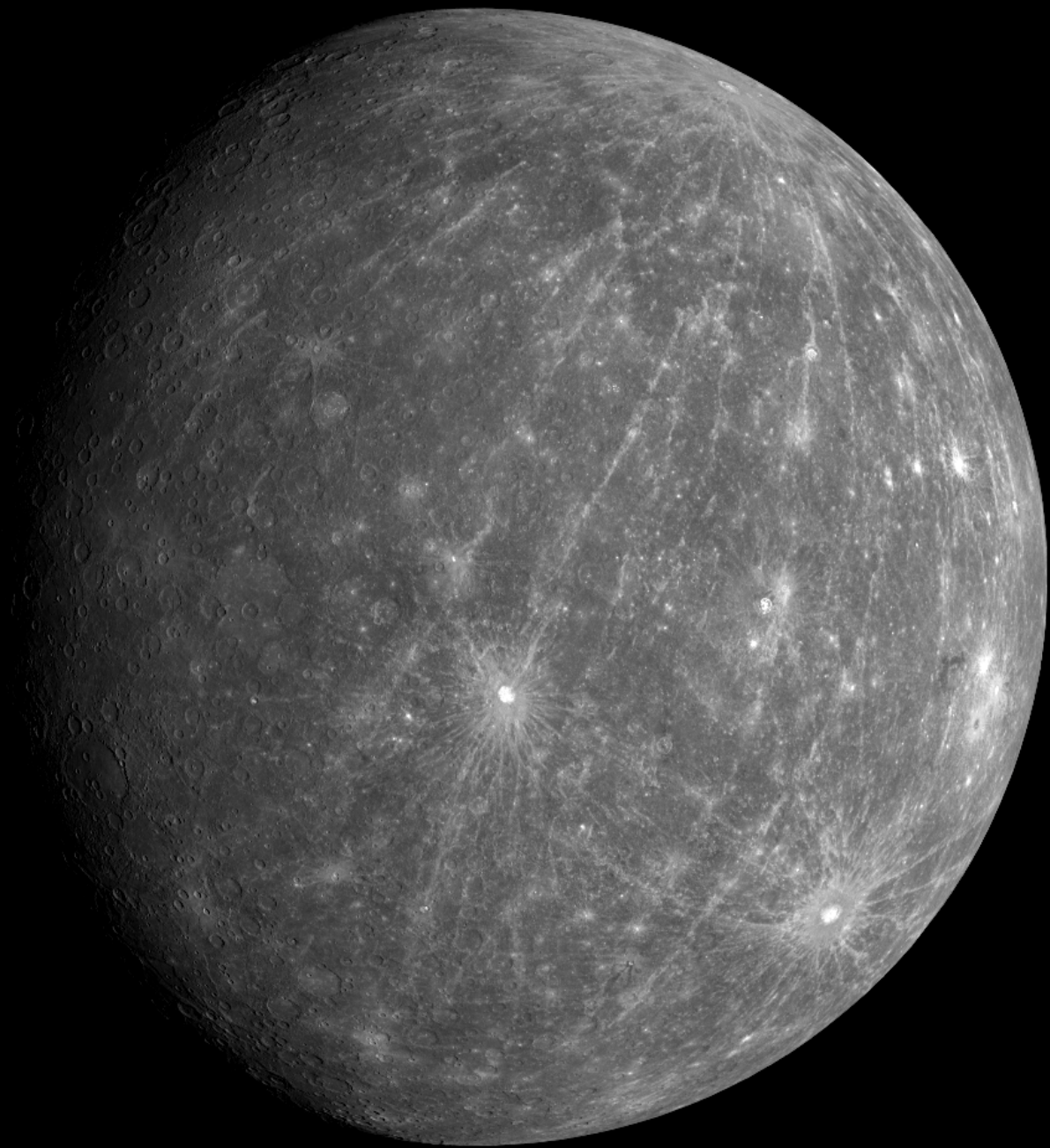


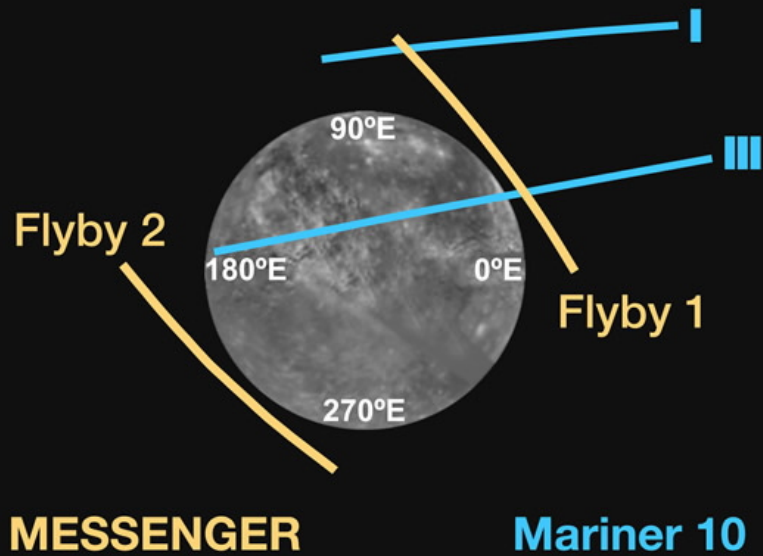
Figure 6-7b
Discovering the Universe, Seventh Edition
© 2006 W. H. Freeman and Company

Earth is a very geologically active place with volcanoes and plate tectonics. The mantle is semi-molten, with convection slowly causing hotter material to rise and cooler material to fall in the mantle. The tectonic plates of the Earth “float” on these convection currents.



Mercury





Because it is so small the core of Mercury is probably mostly solid, meaning that scientists did not expect to find a magnetosphere!

On the scale shown the Earth's field would register at around 50,000nT, so we think that something very different is causing Mercury's magnetic field.

