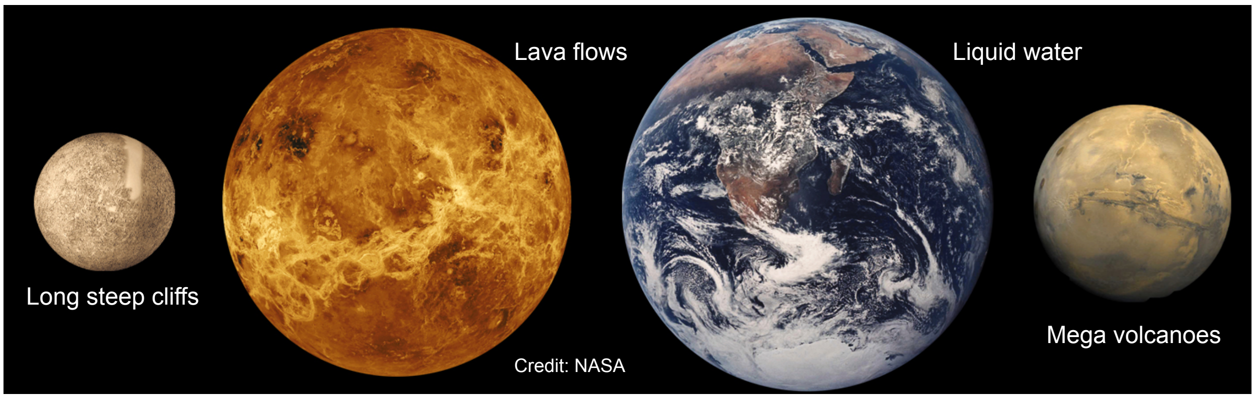
Nothing is rich but the inexhaustible wealth of nature. She shows us only surfaces, but she is a million fathoms deep.

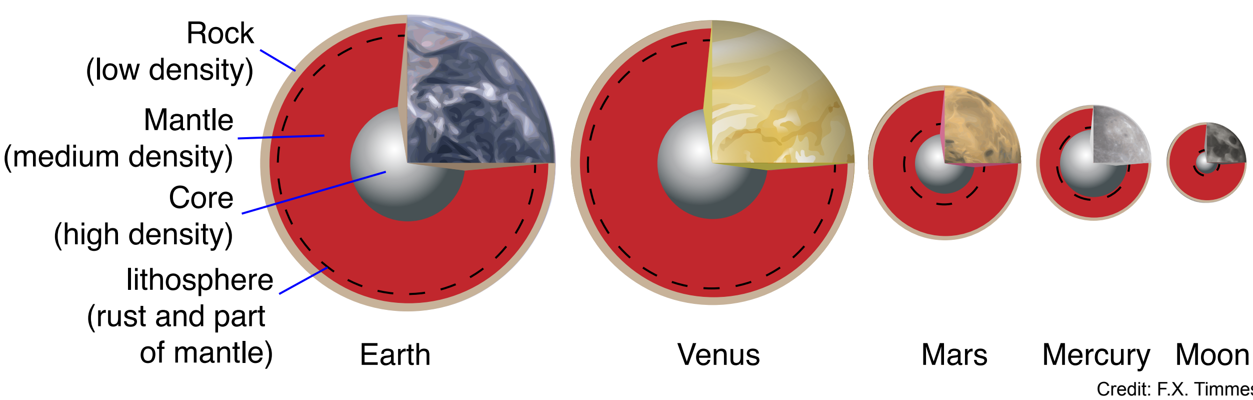
Ralph Waldo Emerson

Below the Surface

Greetings AST 111. In this module we'll explore how the interiors of the terrestrial planets connect with their surfaces and the space around a terrestrial planet.



We're mainly going to be doing a comparative analysis of the terrestrial planets because there's much to be gained by looking globally at similarities and differences. Above is an image of the four terrestrial planets along with a label giving one of their outstanding surface properties.

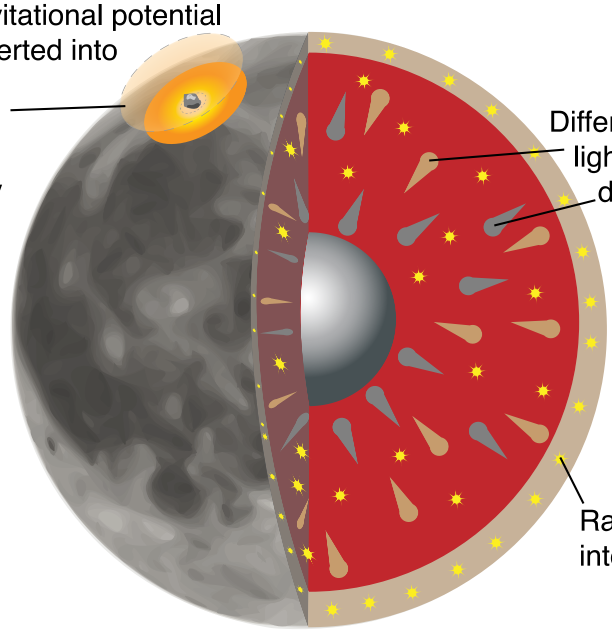


So all of the terrestrial planet's have a similar structure. Because of gravity. Gravity causes heavier stuff to sink to the middle. The lighter stuff floats to the top. Starting from the middle where the density is the highest we have the core, mantle, and the crust where the density is the lowest. The core is mainly metals and rock. The mantle is mainly rock. The crust, the foamy cherry on top, is mostly rock.

Another way to characterize the structure is by the strength of the rock. How malleable, how plastic, the rock is. The lithosphere is the most flexible. Below the lithosphere the material is more stiff, more rigid. Because you can bend and flex the lithosphere you can have more geological activity. A thinner lithosphere means more geological activity.

The image above shows the situation for the terrestrial planets and the Moon, arranged by size from left to right. Earth and Venus, the two biggest planets, have thin lithospheres. Mars, Mercury and the Moon are smaller and have relatively thicker lithospheres. So we should expect more geological activity on Earth and Venus than on Mars, Mercury and the Moon.

Note the relatively large size of Mercury's core - consistent with metal snowflakes being the dominant condensate that close to the Sun when the planet's formed. The Moon on the hand may have a small iron dominated core - consistent with the Moon being born from the outer layers of the Earth in a titanic collision during the ear of heavy bombardment.

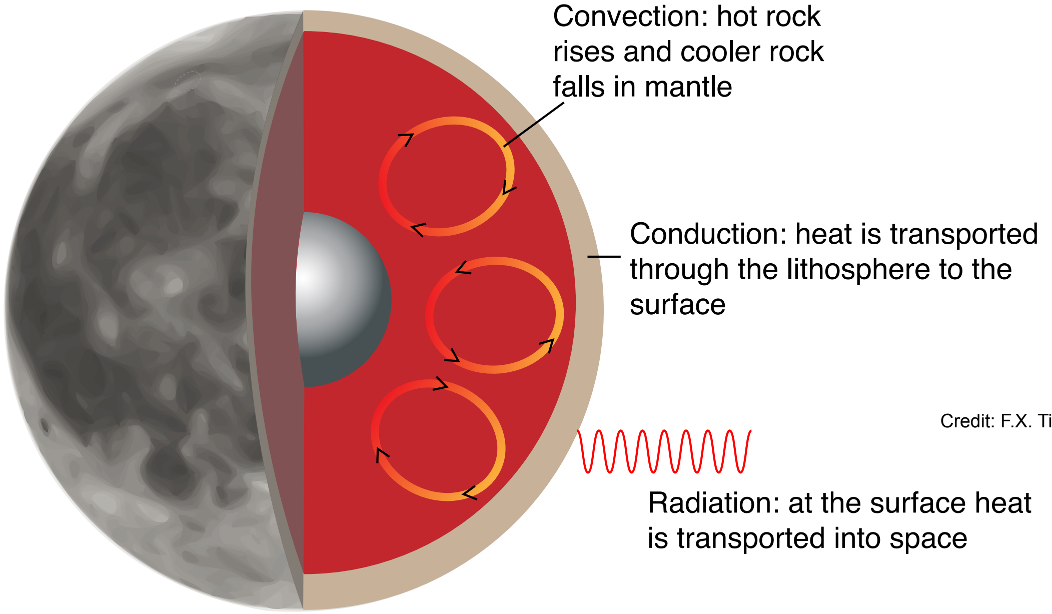


So what drives geological activity on the surface? Well, its the amount of thermal energy that you've got in the inside. There are three ways that a planet gets their thermal energy. And that is accretion, differentiation, and radioactivity, as shown in the illustration above.

In the early days of the solar system's formation, during the era of heavy bombardment, a lot of heat energy was added by accretion. As the impactors came in and smacked the surface, you're converting gravitational energy into thermal energy. And this kept them hot. That thermal energy is now long gone and accretion is no longer a major diver.

Another heat source is differentiation, basically gravity pulling heavy stuff downwards toward the middle. As the heavy stuff falls and the lighter stuff rises, gravitational energy is again converted into thermal energy. Differentiation is still going on, but slower than it was in the past. Differentiation accounts for about half of Earth's internal energy budget.

The third source of heating is radioactive decay. Most important because of their long half-lives and relative abundance are radioactive isotopes of uranium, thorium and potassium. Radioactive decay accounts for about half of Earth's internal energy budget.



Credit: F.X. Timmes

So that's how you heat a planet. How do you cool a planet? Well, there's three ways to cool a planet - convection, conduction, and radiation.

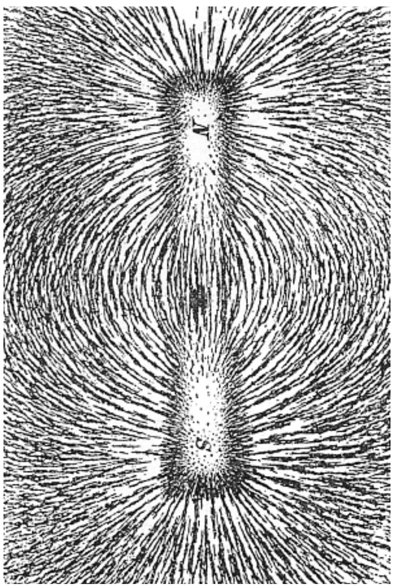
You already know what convection is. Convection is boiling. Convection is turbulence. If you take a pot of water and put it on a stove, initially heat is transported from the bottom of the pot to the top of the pot by conduction. One molecule bangs into another molecule, and they share their energy. Rinse, Lather and Repeat. Energy, when transported from A to B by conduction, basically does a random walk, collision by collision.

But as the bottom of the pan gets hotter and hotter, conduction becomes an inefficient way to move energy. This is when nature uses another mechanism to transport energy from A to B, which is convection, boiling, roiling. You take hot material at the bottom of the pan, you move it up to the top of the pot , where it loses its heat energy. This now cooler material falls back down to get heated again. And the cycle goes around and around.

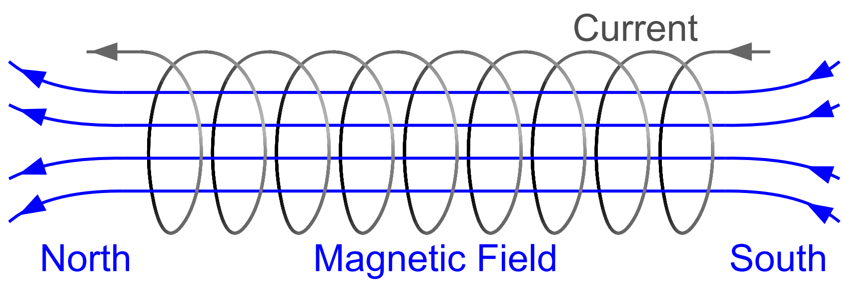
Once you get energy to the surface, weather by conduction or convection, radiation takes over. Photons move the energy from the planet surface to outer space, energy lost forever by the planet.

Surface geologic activity - volcanoes, plate tectonics, quakes and so on - is mainly caused by convection in the mantle, which keeps the lithosphere thin and the interior partially molten.

So, you've got the three ways to heat planets and three ways to cool them off. Here is the golden rule: size matters. Larger planets retain their heat longer. The bigger you are, the more material you got, the longer you are going to hang onto your heat, the longer you're going to have geological activity. Size matters on how long a planet stay hot before ultimately, all planets will cool off and become geologically inactive (aka dead).



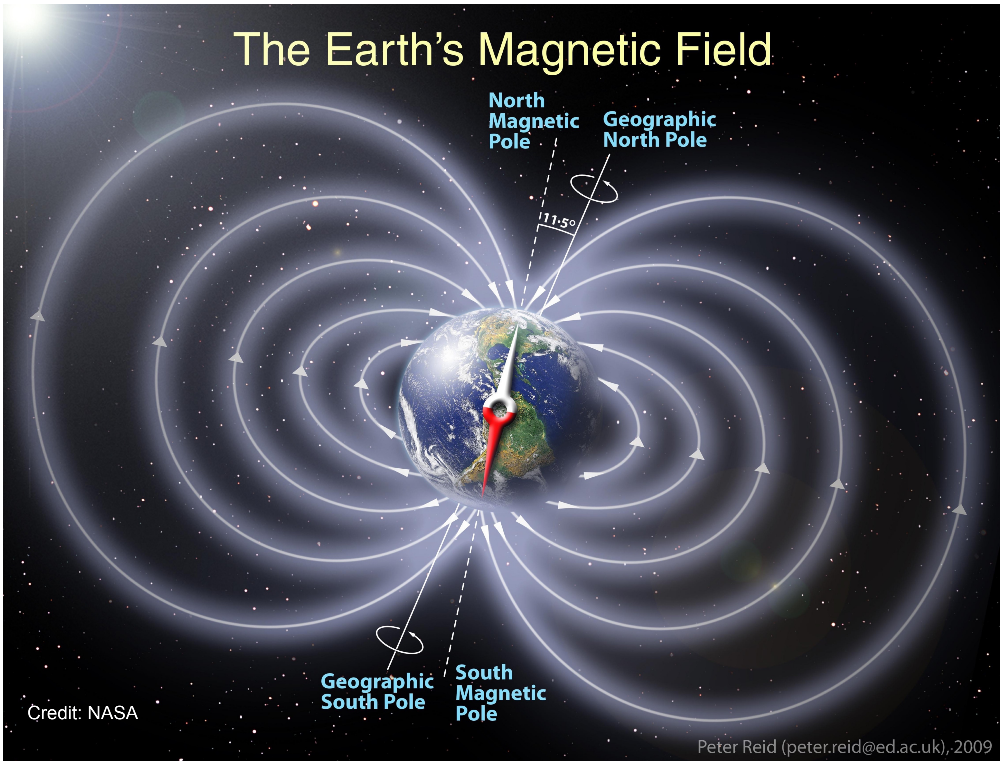
Credit:Wikipedia, Creative Commons



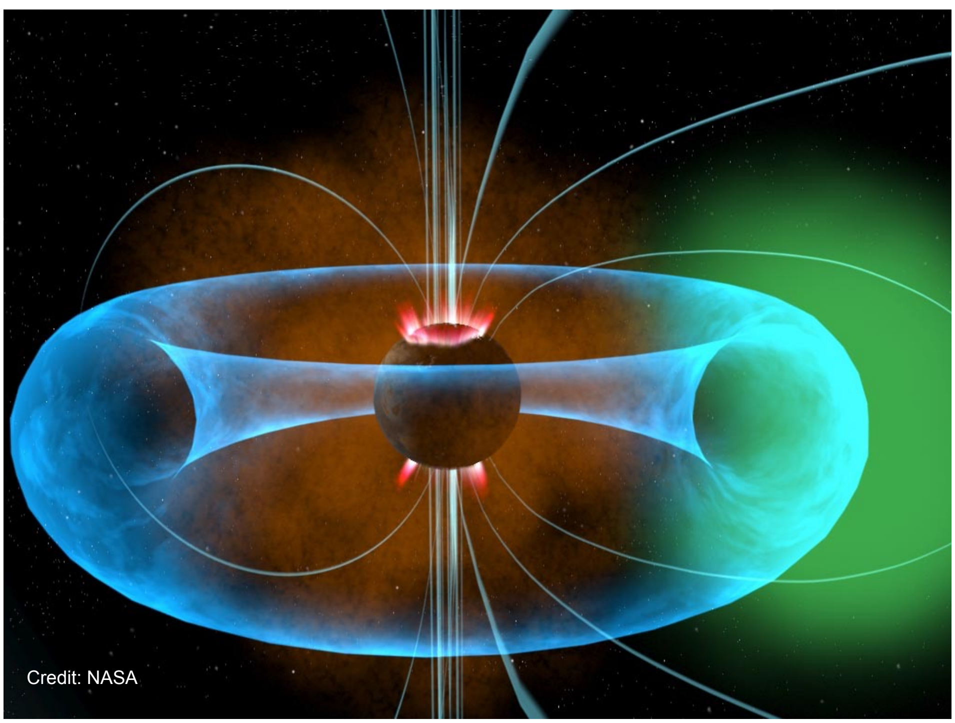
Credit: F.X. Timmes

Some planets have magnetic fields. To have a magnetic field requires three things. It requires an electrically conducting fluid, molten metal in the core, for example. You've also got to have convection so that you're moving the molten metal around around. And finally you also have to have rapid enough rotation to provide kinetic energy and Coriolis forces.

The process is kind of like the bar magnet shown in the image above - but not that simple. Its more similar to the electromagnet illustration shown above. Here the electrons in the wire play the role of a moving electrically conducting fluid in motion and the coils of the electromagnet play the role of rotation. That’s a reasonable but not perfect analogy.



Earth has all three requisite ingredients and thus has a vigorous magnetic field. The illustration above shows the magnetic field axis is currently about 11 degrees from the rotational axis. I say currently because the magnetic field axis wanders around on decade long timescales. The field



can even flip signs - so north becomes south - with the rock evidence suggesting this has happened several times in Earth’s past.

Earth’s magnetic field provides a protective cocoon from the ravaging solar wind, as shown in the illustration above. This is good for saving our atmosphere and for life. It also produces some spectacular light shows known as the northern and southern lights, caused by particles from the solar wind finding their way to our atmosphere through the “weak spots” in the cocoon - the magnetic axis poles.

Venus, the other large terrestrial planet, rotates too slowly to have a magnetic field. Mars and the Moon have very weak magnetic fields because their cores have become solid instead of being liquid. Mercury has a surprisingly large magnetic field, about 1% of Earth’s. While Mercury’s rotation is slow this is counterbalanced by Mercury having a relative large iron core that has not completely turned to a solid.

A million fathoms indeed. Thanks. Bye Bye!