Is the Earth's Core Leaking? Background Information

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Earth2Class Workshops for Teachers at LDEO

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Technology has often led to new discoveries

- Telescope
- Microscope
- X-ray machines
- Radar and Sonar
- Satellite multispectral cameras
- Hubble Space Telescope

Understanding the nature of Earth's interior can be considered one of the great discoveries of the past century.

- Entirely hidden by surface rocks and oceans
- Key to understanding how many surface features formed
- Creates Earth's magnetic field, which changes over time
- Better understanding will lead to new questions not yet conceived

- Concepts that were the focus of intense research and scientific debate when today's senior teachers were in school and college are routinely taught today at the high school and even intermediate level.
- Some examples in most Earth Science courses:

--Structure & characteristics of Earth's Layers

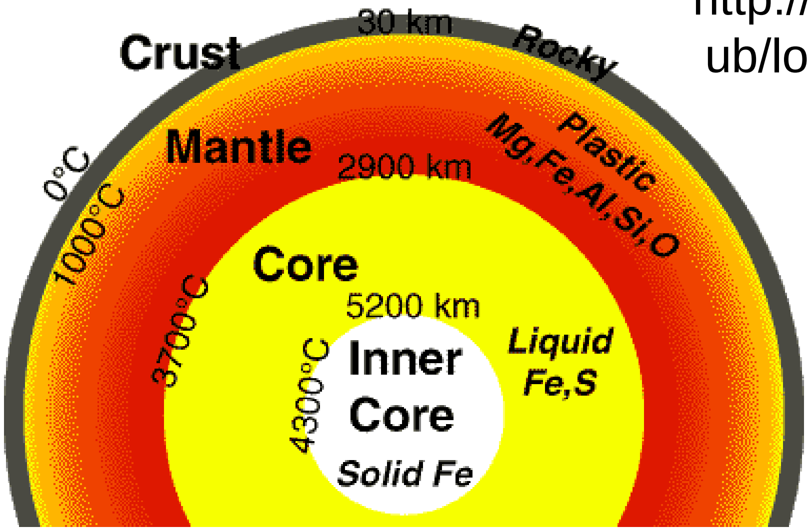
--Locating earthquake epicenters

--Plate Tectonics: boundaries and motions

--Chemical composition of Earth's interior

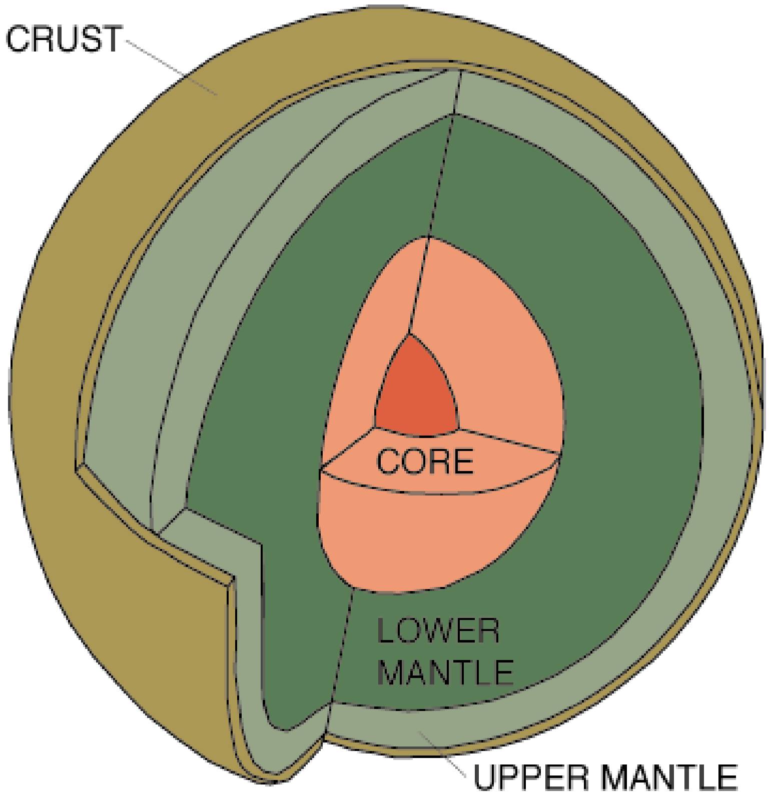
In most college, high school, and middle schools, we routinely (and casually) present models of what lies beneath us such as the one shown in the next slide.

http://www.seismo.unr.edu/ftp/pub/louie/class/100/interior.html



"The earth is divided into four main layers: the **inner core, outer core, mantle**, and **crust**. The core is composed mostly of iron (Fe) and is so hot that the outer core is **molten**, with about 10% sulphur (S). The inner core is under such extreme **pressure** that it remains solid. Most of the Earth's mass is in the mantle, which is composed of iron (Fe), magnesium (Mg), aluminum (Al), silicon (Si), and oxygen (O) **silicate** compounds. At over 1000 degrees C, the mantle is solid but can deform slowly in a **plastic** manner. The crust is much thinner than any of the other layers, and is composed of the least dense calcium (Ca) and sodium (Na) aluminum-silicate minerals. Being relatively cold, the crust is rocky and **brittle**, so it can fracture in **earthquakes**."

How did we gain such understandings?

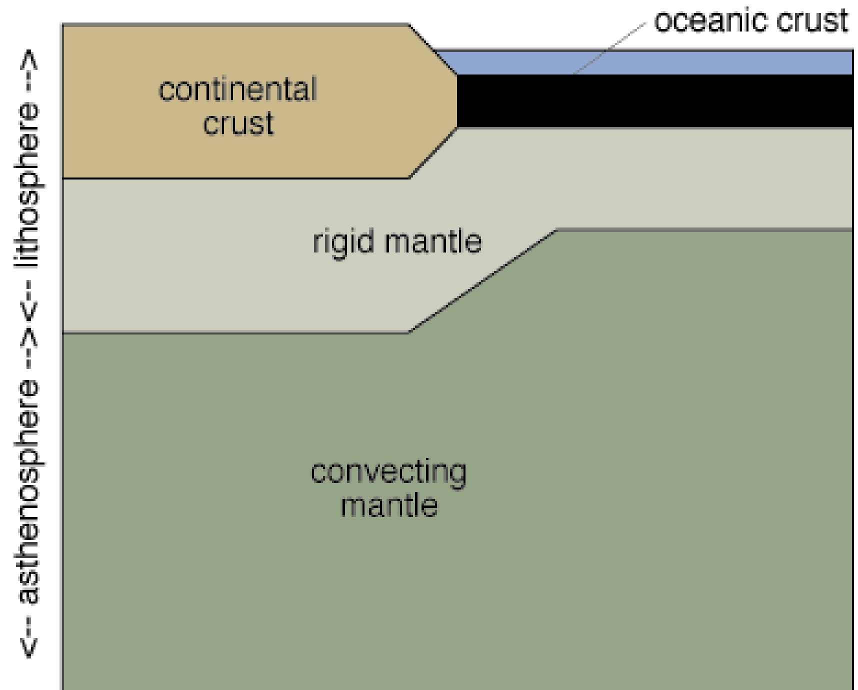


Today, we have a widely held model of an Earth consisting of concentric layers arranged more or less as shown in this diagram.

Source for this and the next few images:
http://volcano.und.nodak.edu/vwdocs/vwlessons/plate_tectonics/part1.html

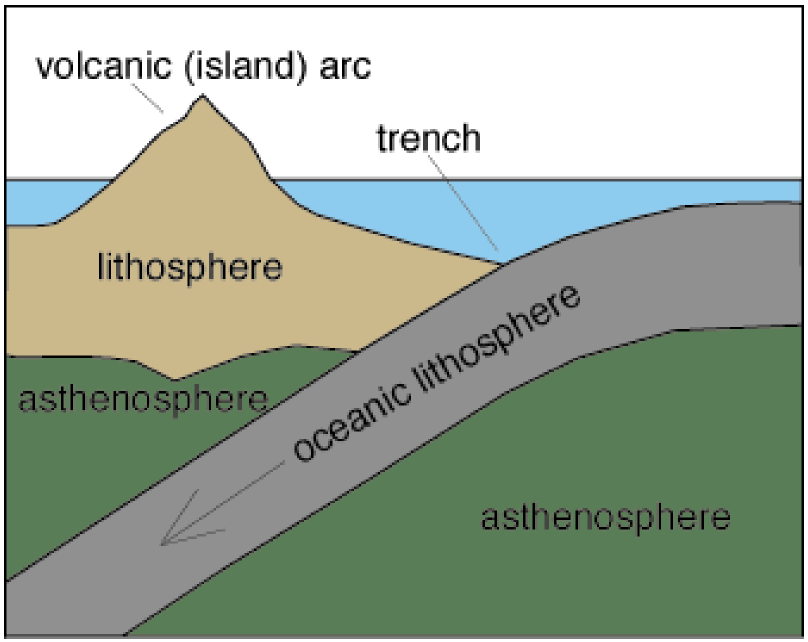
What’s near the surface?

The outer parts of the solid Earth are the **continental** and **oceanic crusts**. Together with the **rigid mantle,** they form the **lithosphere**. Below lies a less-rigid zone, the **asthenosphere**. Within this, convection occurs.

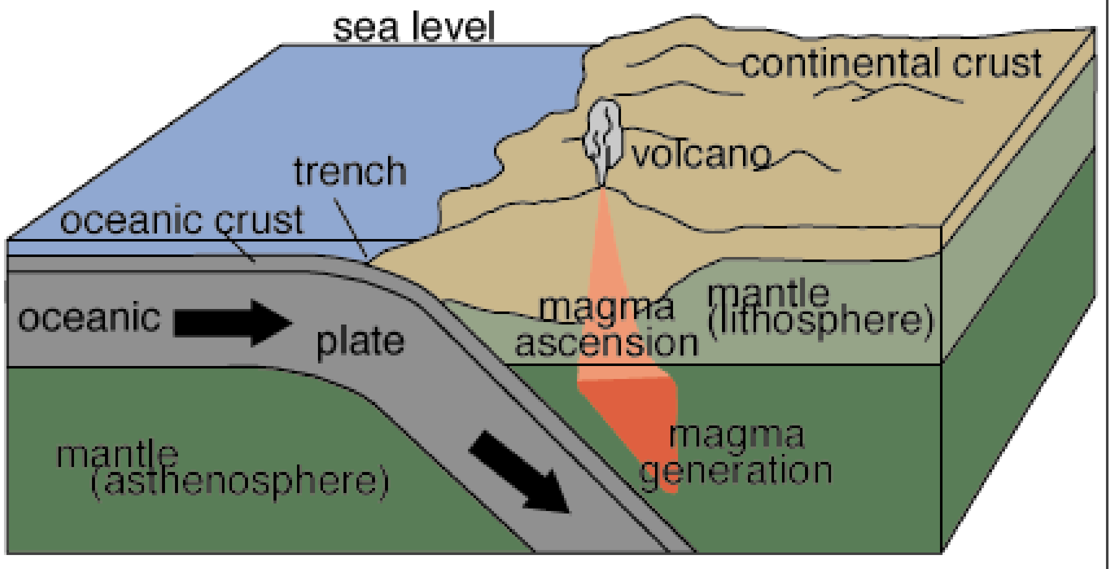


Outer layers of the Earth. Plates are made of crust and rigid upper mantle.

How do these layers interact?

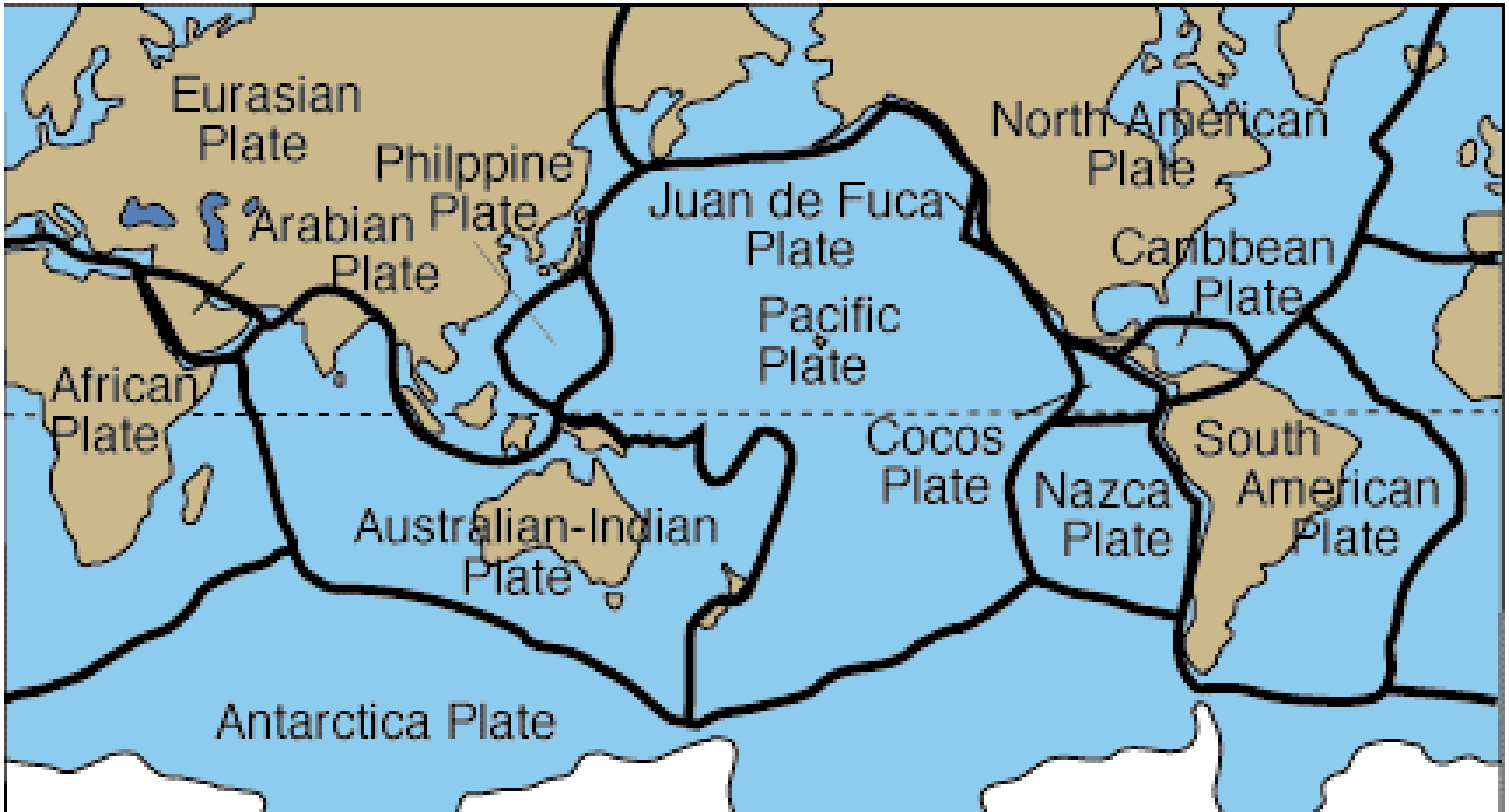


In the early 1960s, Hess proposed that deep-sea trenches were zones where denser oceanic lithosphere plates moved downward through the less-dense asthenosphere.



Magma is generated at subduction zones where dense oceanic plates are pushed under lighter continental plates.

Throughout the 1960s, Vine, Matthews, and many other researchers explored this theory and developed the modern concepts of sea-floor spreading and plate tectonics.



Major tectonic plates of the world.

Representations of the surface boundaries of the tectonic plates are very familiar by now.

Seismology has been the key to understanding Earth's interior

- Careful studies of seismic waves lead to recognition of the mantle and two-part core
- But just as early microscopes could show only some of the complexity in a cell or a drop of pond water, early seismology studies revealed only the largest-scale features of the hidden interior.

Great advances are being made now by IRIS – Incorporated Research Institutions for Seismology

- Consortium of 96 institutions sharing resources and research philosophy
- Global Seismographic Network (GSN)—130 seismological observatories worldwide
- PASSCAL—Program for the Array Seismic Studies of the Continental Lithosphere
- Data Management System
- Education & Outreach Program

IRIS Education and Outreach has useful Internet-based resources for teachers, students, and others

http://www.iris.washington.edu/EandO/

- Among other areas of investigation, IRIS seeks data to solve questions about just why Earth has layers, the variations in composition and motions within these deep layers, and many other important clues to what’s happening inside the planet. These clues combine with what geochemists and others learn through their work to provide higher resolution understandings of Earth’s secrets.

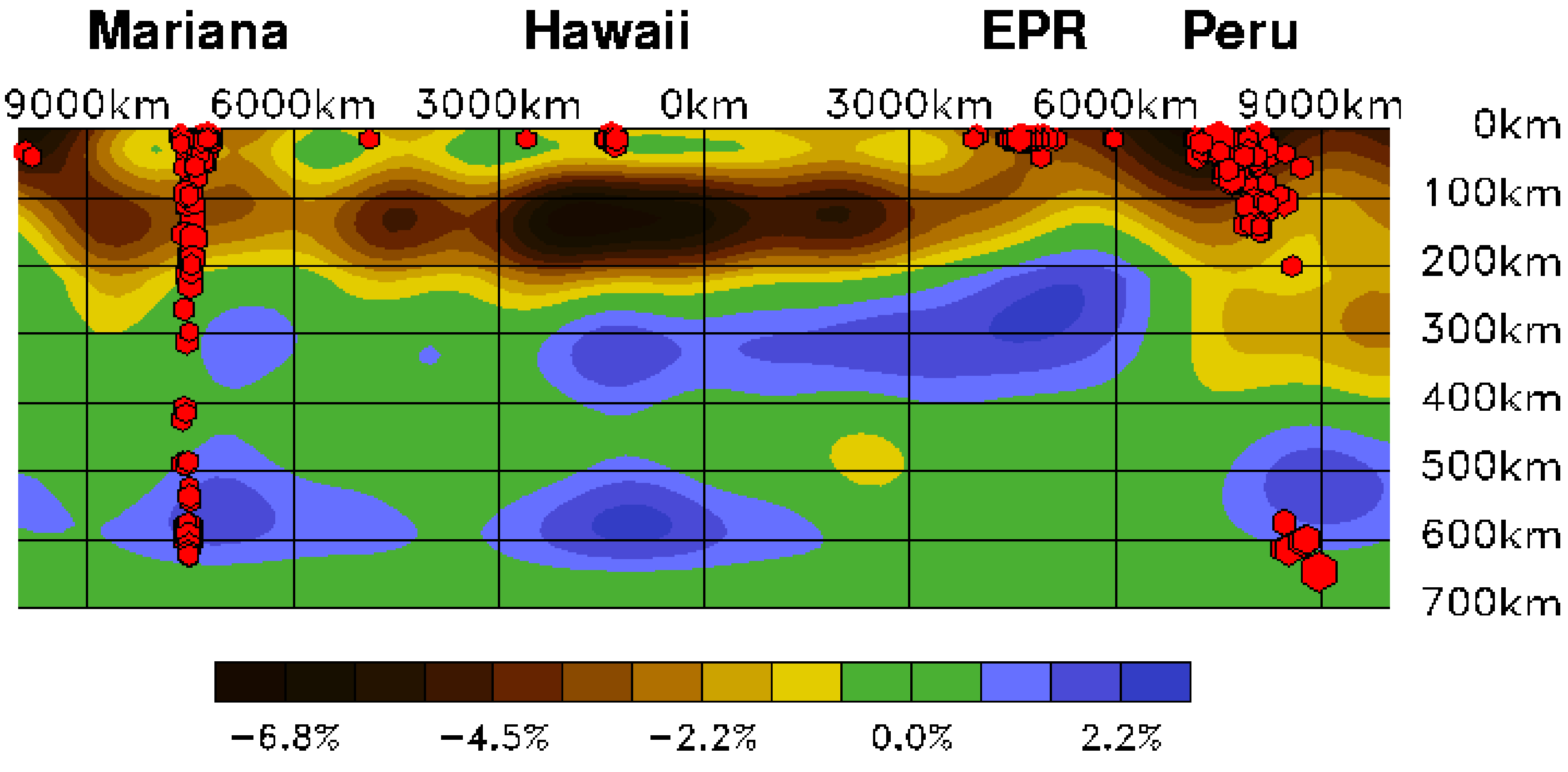
Like everything else, Earth's interior was created by and is still undergoing continuous chemical reactions

- Seismology has revealed that—unlike the attractive, well-defined images shown previously, Earth's interior contains great variations or heterogeneity in its detailed structure.
- Geochemists are gaining new insights into the composition and interactions taking place 10^3s of km beneath our feet.

Global Tomography

Key to much of these new understandings is a technique that utilizes complex computer-based technology to represent convection within the mantle. Global tomography may be compared somewhat to a CAT scan of the brain—it represents a 2-D image of a 3-D environment.

Example of Adam M. Dziewonski's research using global tomography



http://www.seismology.harvard.edu/projects/3D/S20A/S20A.html

In the image, the red “dots” indicate seismic events. The color patterns indicate variations in seismic velocities at different depths.

“The motivation for studying 3-D structure of the Earth's interior is that it may offer the best information on the dynamic processes in the deep interior of the Earth. As the seismic wave speeds change with temperature, it is plausible to obtain 3-D snapshots of the convection pattern in the Earth.”—Adam Dziewonski

http://www.seismology.harvard.edu/projects/3D/

- Dr. Paul G. Richards, Mellon Professor of Geological Sciences at Columbia, is one of the world's experts on the mantle and core. He has given permission to use an article based on his 1998 Jeffreys Lecture as an example of how scientists are making progress in understanding the interior.

"Earth's Inner Core -- Discoveries and Conjectures"

www.ldeo.columbia.edu/~richards/Jefflec.html

(Used with permission.)

What do we now know about the Mantle?

- Much more complex and dynamic than previously able to prove
- Great variation at different depths and locations
- Mapping at various depths may provide essential knowledge needed to predict where and possibly when earthquakes and volcanoes may occur, as well as other useful applications

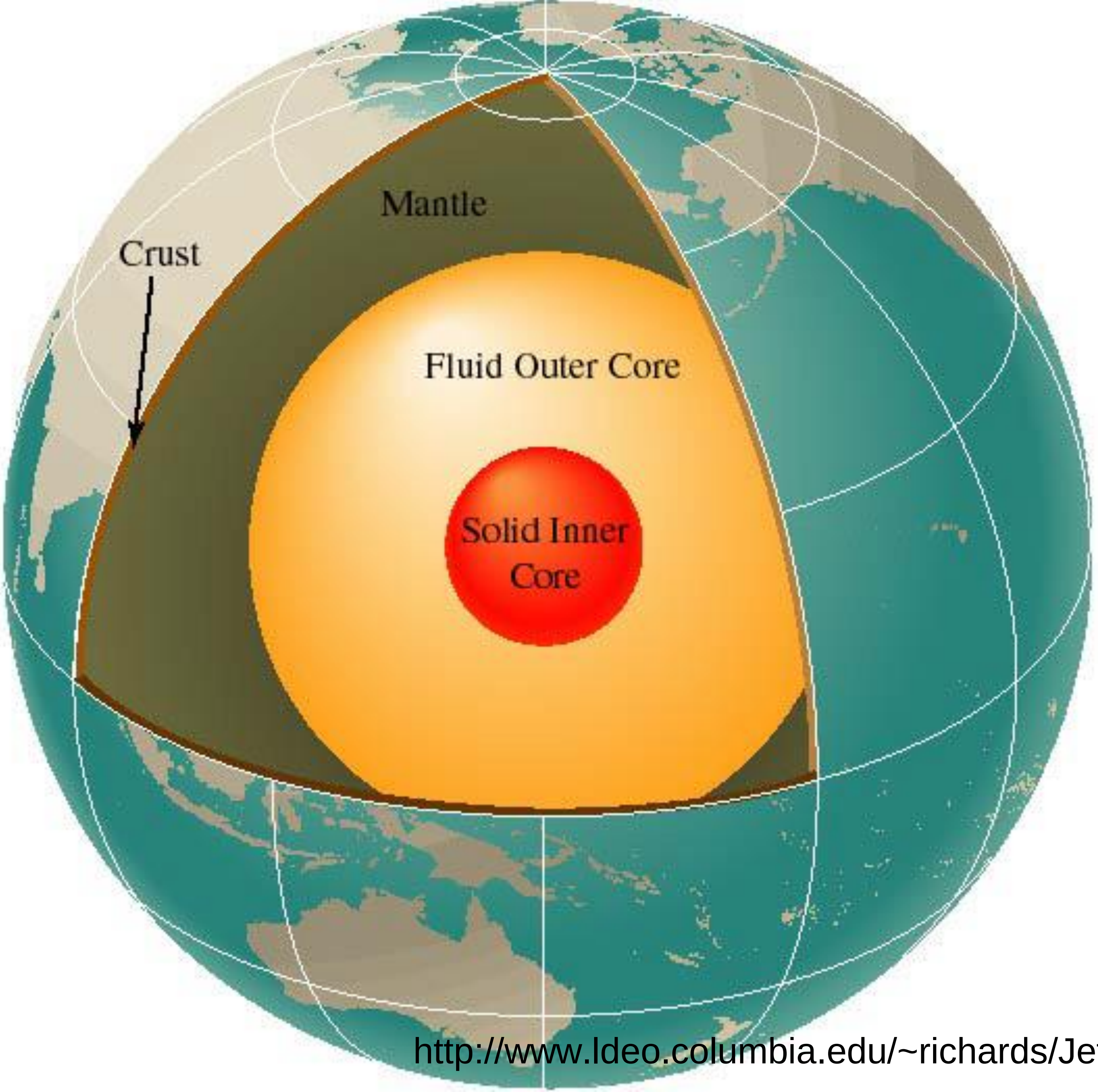
What do we now know about the Inner Core?

- Composed principally of solid Fe
- Radius about 1220 km
- Mass 10**20 metric tons (~30% > mass of Moon)
- Lies at center of larger fluid core (which has ~55% of Earth’s radius)
- Low viscosity, convects ~1 cm/s

- Inner core long recognized as part of process by which fluid core convection maintained, influence on magnetic field
- Recent studies reveal core is not homogenous, with variations in structure and internal velocities
- Rotating in easterly direction relative to mantle at rate fast enough to be perceived on human time scales

Image on next page shows relative sizes of fluid and solid cores

- As deepest interior loses heat through slow convection through mantle, iron at base of fluid core solidifies and solid core grow (~1 cm/100 yr)
- Release of latent heat at base of fluid core drives convection which maintains magnetic field, applying a couple to the inner core (Glatzmaier and Roberts)



http://www.ldeo.columbia.edu/~richards/Jefflec.html

- As might be expected, much popular attention was given to the concept of a Moon-size object inside Earth making revolution on a time scale of centuries
- Attention from scientists focused on the implications concerning dynamo theory, past and present magnetic field, heat flow, and interactions with gravity field

A few important points about chemistry

- More than two centuries of experimental and theoretical investigation have revealed certain general “laws” behind interaction of matter and energy
- These “laws” even appear to function under the extreme pressure and temperature conditions existing within Earth’s interior

4 basic type of chemical reactions

- “Synthesis” or “Addition”

  “A” + “B” → “AB”
- “Decomposition” or “Analysis”

  “AB” → “A” + “B”
- “Single Replacement/Exchange”

  “AB” + “C” → “CB” + A
- “Double Replacement/Exchange”

  “AB” + “CD” → “AD” + “CB”

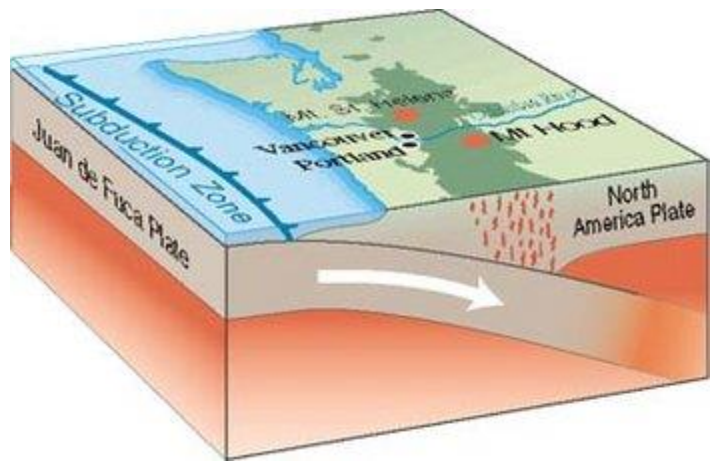
Relative Reactivity

- Whether two elements will react, or whether one element will replace another in a compound, depends on certain well-investigated factors
- Certain elements, such as oxygen, are very reactive and will generally combine with other elements when they meet – this is best exemplified by “rusting” (oxidation of iron)

Starting to put things together

So, if material from the lithosphere sinks into and through the mantle, elements such as oxygen and molecules such as CO_2 may be trans-ported downward and interact with Fe and other matter from the core.

In that case, there may be some exchanges between the core and mantle with interesting implications



•http://en.wikipedia.org/wiki/Subduction_zone

- Our guest scientist, Dave Walker, has been exploring these and many other questions about just what is happening in the Earth’s interior.