Article

Basic Principles of Geology

Earth's Dynamic Engine

This series began with a discussion of the component of geophysics that describes Earth's structural layers. It continues with the processes that drive our ever-changing planet. Earth's dynamo—the foundation of the Theory of Plate Tectonics— incorporates radioactivity, heat flow, magnetism, and more.

In the beginning there was . . . dust!

The solar system began its existence some five billion years ago as a nebular cloud of gas and cosmic dust collapsing upon itself under the relentless influence of gravity. Of course, putting a date on such events as so many years ago is rather meaningless when one takes into consideration several rather important facts.

For one, the Earth—like the solar system—*did not exist* five billion years ago to be any kind of meaningful measuring stick. For another, the Earth's orbit around its star is hardly a universal time clock. And lastly, its velocity has not been consistent over time. In fact, the "year" has gotten longer as Earth's orbit has deteriorated fractions of a second every completed revolution throughout its long history. Yes, she's gettin' old and tired!

Regardless, it's been a long time. And in that time, the gases in that cloud (primarily hydrogen and helium, with a miniscule percentage of heavier elements forged in prior-existing stars) condensed into a star we call the Sun, and the giant gas-rich planets (Jupiter, Saturn, Uranus, and Neptune).

Meanwhile, the dust grains accreted into ever larger lumps, eventually creating planetesimals (celestial bodies up to about 600 miles across) that in turn coalesced to form Mercury, Venus, Earth, Mars, and in my opinion, Pluto (yes, I'm old school, so I still consider Pluto to be a planet, and there is some debate to restore the object back to its former glory), and various moons, asteroids, and comets.

Clouds of dust and gas collapsed under the influence of gravity and other possible contributing factors to form the sun at the center of activity as the temperature and pressure became great enough to promote fusion of hydrogen into helium. Remaining material continued to coalesce to form ever larger bodies that eventually became the planets, moons, asteroids, and comets that we recognize today.

Of all those, Earth stands unique in the universe—as far as we know. It is the only one that supports life, and that life is intimately dependent upon an environment that is created, sculpted, and recycled by geological processes. It is a rocky planet (at least, on its surface) composed of different layers of material in varying states of matter, from liquid to solid (Earth's structure was featured in Volume 2 Issue 1).

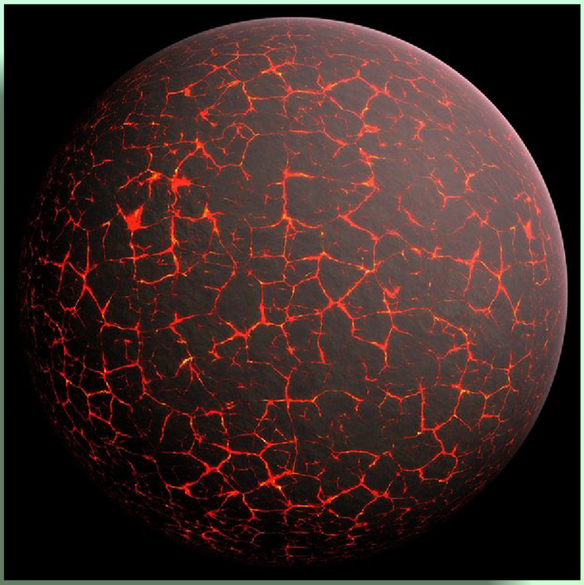
Surely the Sun provides the vast percentage of energy that the planet enjoys. In fact, the Earth receives far more energy on its surface from the Sun than from its interior. However, this energy warms the equatorial regions—surface and atmosphere—considerably more than it does the polar regions. This uneven heating establishes areas of differing atmospheric pressures. As air always moves from regions of higher pressure to lower pressure, this perpetual circulation creates winds. Winds, in turn, play a pivotal role in driving ocean waves and surface currents. In effect, winds and ocean currents spread incoming solar heat evenly around the globe.

But, while the planet *gains* heat from the Sun, it also *loses* a reciprocal amount by radiation into space! Thus, Earth's surface temperature has remained relatively consistent throughout most of its geological history, disregarding comparatively minor cyclic fluctuations.

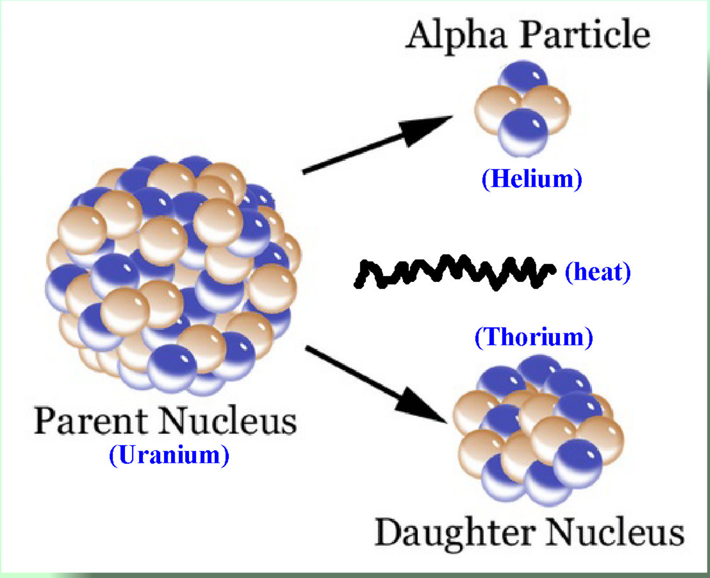
Solar radiation cannot be the force behind crustal movement. Rather, it is the immense heat derived from the *interior* of the planet that is the source of Earth's dynamo, a system geologists now call **Plate Tectonics**. This is the engine that drives all the processes—inorganic and biological—on the surface of our home world. But how is this heat generated?

Earth's reservoir of heat energy has several origins dating from the time of earliest formation. These include impact energy from the colliding planetesimals that coalesced to form the planet, heat radiating from the solid inner and molten outer iron-nickel cores, more heat generated by friction between the different layers of the Earth's interior, additional heat energy emitted by the radioactive decay of heavy parent elements into lighter daughter elements, and a small amount provided by gravitational energy from the Sun and Moon. All of these sources combine to ultimately initiate convection currents within the mantle, which in turn activate movement of the planet's numerous crustal plates.

Primary sources of Earth's internal heat

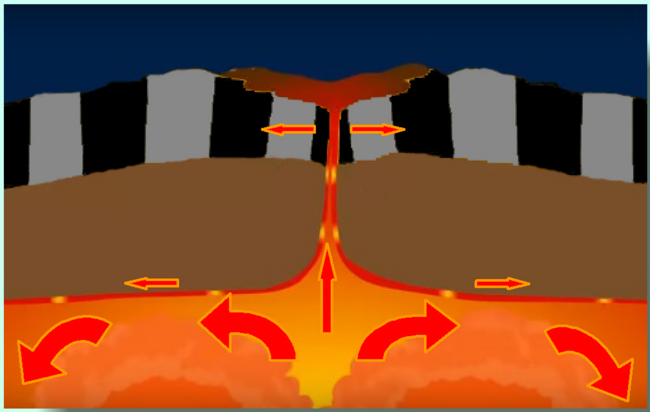


Planetesimals coalesced to form the developing planet during the Hadean Eon.

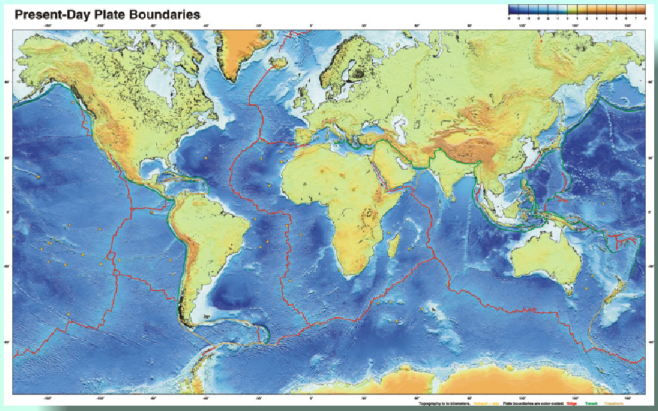


Radioactive decay of heavy elements into lighter ones releases energy in the form of heat.

The mantle is composed of solid silicate rock, but is under such tremendous heat and pressure that it flows, anywhere from about 1 to 3 inches per year—about the rate that human fingernails grow. The lower layer of the mantle is hotter (thus less dense) than the top portion, therefore it rises at the expense of the denser material above that sinks deeper into the planet's interior, gets reheated, rises, and perpetuates the cycle. The result is a network of subterranean convection currents that continuously mold the Earth's upper crust. The relentless tension placed upon the rigid crust above inevitably exploits regions of weakness, cracks the crust, and allows liquified (due to reduced pressure) mantle material to flow out onto the surface of the crust.



Mantle plume pulls crust apart; magma rises through the fault conduits and builds mountain ranges delineating the spreading centers that stretch around the globe.

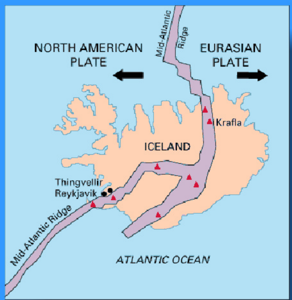


Map of tectonic plates and their boundaries (jagged red lines). Mid-Atlantic Ridge separates North and South America from Eurasia and Africa. (courtesy of NASA)

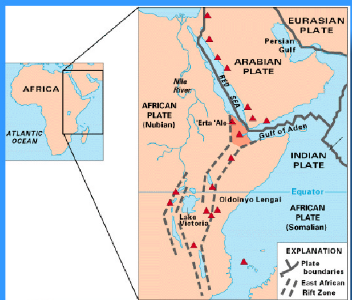
Oceanic crust is the usual victim of this process, because it averages only about 6 miles in thickness. Therefore, it is more vulnerable to fracturing than continental crust, which, being up to about 25 miles in thickness, is less affected. However, the relentless tension below can, and does, eventually rip apart even continents, creating rift zones that allow basaltic lavas to spread out in huge fields that inundate thousands of square miles of land area. These rift zones begin to form as *triple junctions* where the crust has been bulged by rising plumes of mantle below; three boundaries form by radiating out from a central point either as trenches, ridges, and/or transform faults; and finally the crust gives way to allow the basalt to effuse onto the surface. One arm always fails and is then called an *aulacogen*. The rift valley of northeast Africa is a famous and obvious example, where Arabia is being sundered from Africa. The two remaining arms comprise the spreading center. As most spreading centers are hidden below the surface of the ocean, they go unnoticed and unappreciated. Iceland, however, is the exposed summit of the longest mountain range on the planet, the Mid-Atlantic Ridge, separating the North and South American plates from the Eurasian and African plates.

Oceanic Spreading Center

Iceland is the surface expression of an oceanic spreading center, the Mid-Atlantic Ridge, that's pushing Eurasia to the southeast, North America to the northwest.



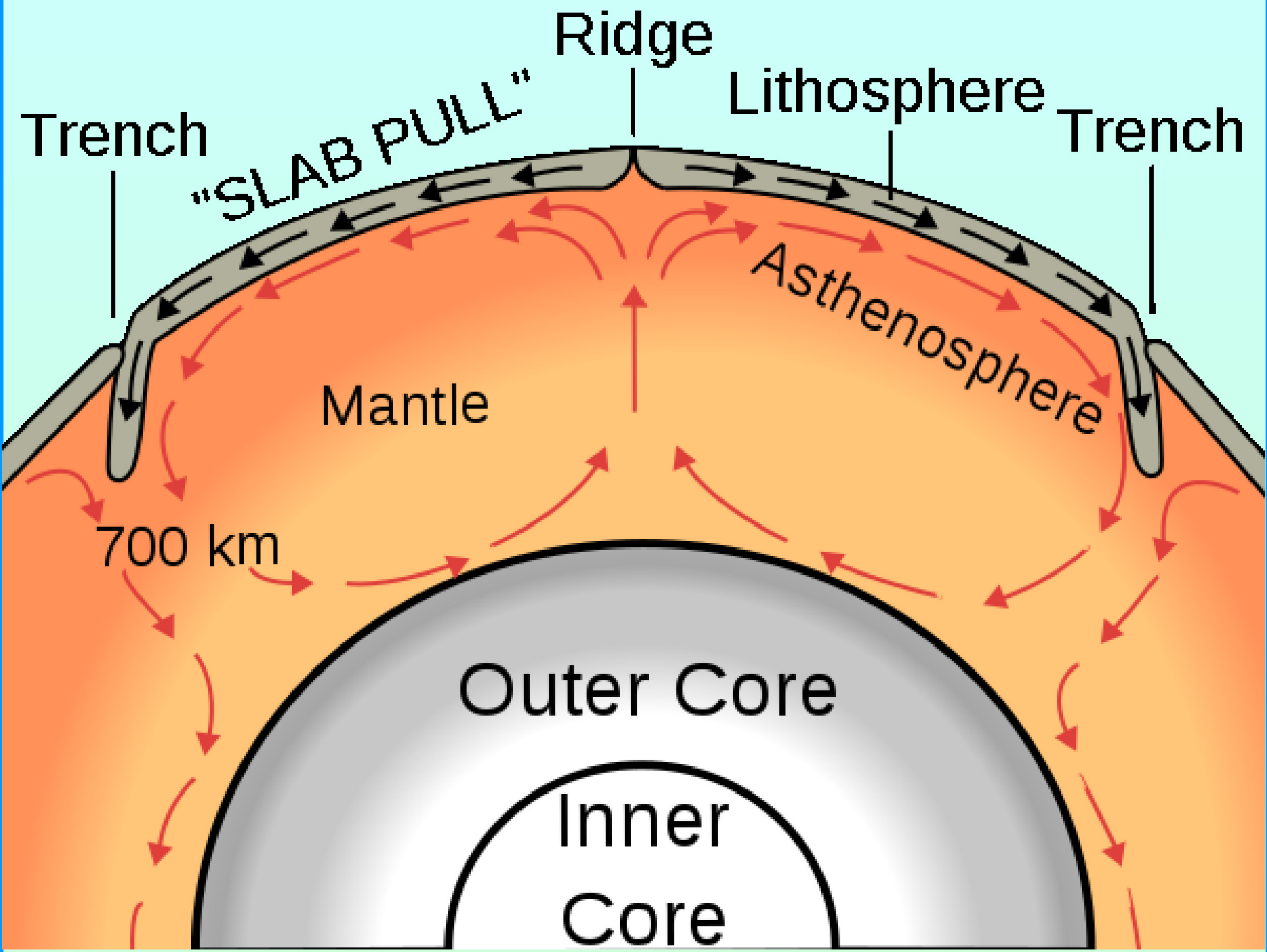
Continental Spreading Center



The Great Rift Valley is an aulacogen that is part of a triple junction that is separating Arabia from Africa. The Red Sea and Gulf of Aden represent the spreading centers.

Artwork courtesy of the USGS

Earth's Dynamic Engine



Mantle Convection Cells

To summarize, nascent heat derived from the accretion of planetesimals that coalesced from a collapsing cloud of dust and hydrogen gas, combined primarily with radioactive decay of heavy elements originally forged in pre-existing stars, provides the energy to initiate and perpetuate convection cells in the mantle.

This is the engine that drives Earth's dynamo, the various consequences of which will be reviewed in the next issue of Discover Minerals that will focus on **Plate Tectonics**.