GLY 47/511 - Plate Tectonics
Mantle Convection and Driving Forces Lecture Summary
Summary of Lecture on 3/21/10

Mantle Plumes, Mantle Convection, Driving Forces of Plate Motion

The Source of Hotspot Lavas

Hotspot Chemistry

ocean island basalts are enriched in incompatible elements
    incompatible elements are trace elements that prefer to go into any melt that forms rather than staying behind in the residual solid crystals
midocean ridge basalts (MORB) are depleted in incompatible elements due to the long history of partial melting of the upper mantle source for ridges
therefore hotspots have long been thought to derive from another (presumably deeper - lower mantle) reservoir that has not been depleted in incompatible elements by continuous midocean ridge processes
hotspot lavas from different parts of the world have differences in trace element and isotope geochemistry, thought to indicate that different lower mantle reservoirs, perhaps due to variable enrichment from subducting slabs

Mantle Tomography - Method

mantle convection (including mantle plumes) is caused by differences in density, resulting primarily from differences in temperature since the mantle is believed to be essentially all the same composition
the exact seismic velocity for individual points in the mantle can be determined by measuring the total travel time for all seismic waves passing through that point from many different earthquakes (from different directions and angles
this is determined for a gridwork of boxes filling the mantle to evaluate areas of higher from lower velocity compared to the average velocity for that depth
higher velocity is presumed to result from higher density and lower temperature rock
lower velocity is presumed to result from lower density due to higher temperature rock
lower density regions should rise and higher density regions should sink
P & S waves plus various reflected and refracted waves may be used for tomographic studies to improve the coverage or resolution
depending on the type of waves used (and the amount of available seismic data), either the depth resolution or the resolution of small structures (plumes) may be limited

Mantle Tomography - Observations

low density regions (of rising mantle rock) underlie midocean ridges but only extend several hundred km down, within the upper mantle

MOR source is convection within the upper mantle

The Pacific Superswell and the African Superswell (two areas of anomalously high topography) are underlain by large low density areas near the bottom of the mantle which must drive significant mantle upwelling and apparently exerts a dynamic upward swell at the Earth's surface

several studies have shown low density regions extending below Hawaii, Iceland, and other hotspots well into the lower mantle, in some cases all the way to the CMB while a few hotspots may be fed from shallower levels

Mantle Convection

idealized mantle convection with a cold upper thermal boundary layer and a hot lower thermal boundary layer plus some internal heating (radioactive decay) should produce hot plumes rising from the lower thermal boundary layer and cold plumes sinking from the cold upper boundary layer

Paleozoic age structural domes and basins in the stable interior of North America have been proposed to have resulted from rising and sinking plumes

Based on tomography and geochemistry there appears to be a combination of separate upper mantle convection and also whole mantle convection

midocean ridges derive material only via upper mantle convection

some subducting slabs appear to remain with in the upper mantle

many subducting slabs appear to sink into the lower mantle

many hotspots appear to be fed by plumes extending deep into the lower mantle

the D" layer just above the CMB may be the source of many mantle plumes

Driving Forces of Plate Motion

Dana previously proposed cooling contraction of the Earth to account for "geosynclines" but whole Earth must be in compression/convergence if that were the case

others proposed that Earth might be expanding (thereby accounting for drifting apart of continents) because the universal gravitational constant (G) must decrease as the universe expands thereby allowing Earth to expand (less gravity)

- but the small reduction in G couldn't allow enough expansion to account for the formation of all the world's ocean crust between continents

- paleomagnetic measurement of ancient and modern magnetic inclinations in rocks in widely separated locations on one continent show that the latitudinal distances have remained the same and therefore the Earth's circumference has not changed

Holmes (1928) and later Hess (around 1960) proposed mantle convection to drive drifting continents and midocean ridge spreading

Forsyth & Uyeda (1975) determined that the traction is too weak between the weak asthenosphere and the flat lithosphere for mantle convection to drag ocean plates Slab Pull and Ridge Push produced by gravity and density differences were found to be the most important driving forces, with the asthenosphere producing a drag on the moving oceanic lithosphere

the greater the proportion of a plates edge that is subducting the faster it moves

the greater the proportion of a plate that is continental the slower it moves

slight directional differences in the velocity of S waves indicates alignment of olivine crystals in the mantle in the direction of movement of tectonic plates, presumably due to shearing by the plate movement (or some have proposed it is really active mantle flow pushing the continents, with their deep “keels”)