

Plate Tectonics - GLY 47 / GLY 511 - Spring 2010 Final Exam Review

Subduction Zones

deep ocean trench, outer trench high
(sinusoid of diminishing amplitude)
Wadati-Benioff Zone, double Benioff zones
subduction zone seismicity and type of stress in different parts of subduction zones
depth of penetration of subducting slabs from Benioff zones and mantle tomography
cause of deep focus earthquakes
volcanic arcs and source of the magma - flux melting
pressure-temperature diagrams and subduction zone melts
how mafic magma is produced from ultramafic mantle rock
angle of subduction
accretionary prism and forearc basin
accretionary prisms: controls on characteristics, development
mélange
backarc basins, remnant arcs

Orogenic Belts

Central Andes: Ocean-Continent Orogen

Mesozoic backarc extension
today: compression, some strike-slip
relationship of areas of flat subduction and no volcanism
to subduction of aseismic ridges (hotspot tracks)
thrust belts and foreland basins
(sinusoid of diminishing amplitude)
thin skin tectonics - to - basement involved thrusting
deep structure of the Andes and the Altiplano
orogenic events in the Western Cordillera of North America
and approach and subduction of a midocean ridge

Alpine-Himalayan Orogen

Gondwana rifted apart and the fragments (Africa/Arabia and India) drifted northward
and collided with southern Eurasia
Himalayas began to uplift some 50-60 m.y. ago or more with the collision of India with
southern Asia, which continues today
This was just the last piece of Asia; several other blocks had previously accreted to
Siberia to form Asia
N-S thrusting (expected) mixed with regions of E-W thrusting and N-S extension
parts of Asia are being extruded from between India and northern Asia
-squeezed out to the east and southeast
as India is underthrust beneath overriding Asia, the Indian plate is deflected into a
sinusoid of diminishing amplitude
crustal structure: main thrusts, suture zone, batholiths, foreland basin
escape tectonics
Alpine orogen and the Messinian salinity crisis

Continental Transforms

San Andreas Fault

just one of many faults in the North America-Pacific plate boundary

most are strike-slip, some thrust, some normal faults

San Andreas can be considered a long offset transform connecting the midocean ridge spreading center in the Gulf of California with the Juan de Fuca Ridge off the Pacific northwest

this arrangement follows the subduction of parts of that midocean ridge which was once continuous

features of continental transforms: offset drainage, shutter ridges

pushup ranges at restraining bends

pull-apart basins at releasing bends

Southeast Asia

many strike-slip faults run from eastern Tibet down through southeast Asia

Africa-Arabia - Eurasia collision

transform fault zone runs through the middle east due to northward motion of Arabia

Gulf of Aqaba, Dead Sea, and Sea of Galilee are pull-apart basins

North Anatolian Fault - escape tectonics of the Turkish microplate

Hotspots and Mantle Plumes

the difference between: hotspot, hotspot track, mantle plume

intraplate volcanism

age-progressive volcanism

seamounts and guyots

formation of coral atolls (first explained, generally, by Charles Darwin)

if hotspots are caused by stationary, deep-seated mantle plumes, then you should be

able to determine the absolute direction and velocity of the plate

but mantle convection should deflect rising plumes

So, are mantle plumes stationary?

hotspots in the Atlantic and Indian Oceans may not have moved significantly relative to one another (outside the error limits)

must compare with the Pacific hotspots, especially the Hawaiian-Emperor hotspot track

since it is the longest, best resolved, best studied hotspot track

comparison of Indo-Atlantic hotspots with the Hawaiian-Emperor hotspot has shown a

big discrepancy and therefore motion between them - assuming the plate circuit

connecting them is known accurately enough

the seafloor spreading parameters on intervening midocean ridges are known

reasonably well, but

the connection through Antarctica (the only way to go) was thought to probably be the

cause of the discrepancy because East and West Antarctica appear to have rifted

and moved independently at one time

a paleomagnetic study showed that the Marie Byrd Land portion of West Antarctica (the

most important part for the plate circuit) has indeed moved relative to East Antarctica

since 100 m.y. ago - could that motion account for the apparent motion between the

Indo-Atlantic and Hawaiian-Emperor hotspots???

it is not possible to account for post 100 m.y. Marie Byrd Land - East Antarctic relative motion and the post 65 m.y. hotspot discrepancy
therefore the Hawaiian-Emperor plume has moved relative to the Indo-Atlantic hotspots
therefore, mantle plumes are not, as a general rule, fixed and stationary

large igneous provinces (LIPs)

hotspot tracks often begin with major flood basalt eruptions (LIPs)
numerous LIPs erupted along the line of breakup of Pangea as each part was rifting
laboratory and computer modeling of plumes indicates that they should begin with a large mushroom head that rises through the mantle with a narrow conduit following the mushroom head should spread out when it reaches the base of the lithosphere this gives rise to the initial flood basalt
examples: Rajmahal traps, Deccan traps, Parana-Etendeka flood basalts, Columbia River flood basalts and their trailing hotspot tracks

The Cretaceous Superplume

high seafloor spreading rate, mantle plume activity, high sea level, warm climate of the Cretaceous, and lack of magnetic field reversals may all be the result of a great pulse in the amount of heat coming out of the mantle in the Jurassic and Cretaceous as Pangea was rifting and drifting apart
rapid seafloor spreading results in shallowing of average ocean depth, raising sea level
rapid seafloor spreading and hotspot volcanism releases more CO₂ into the atmosphere, warming climate
much heat may have been removed from the lower mantle (D" layer) by the initiation of many mantle plumes which would have cooled the core-mantle boundary (CMB), increasing the thermal gradient from the bottom to the top of the outer core this should increase the convection in the molten iron outer core (which generates the Earth's magnetic field)
more robust convection in the outer core should mean fewer (or no) magnetic reversals (which are presumably produced by turbulent eddies in the outer core)

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
mid-ocean 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 mid-ocean 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 or 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 within 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”)