Lecture 23: Divergent Margins and Transform Margins November 20, 2006

Divergent margins are where most new crust is formed by plutonism and eruptions of oceanic basalt. Oceanic crust has a distinct internal structure reflecting its magmatic origin, metamorphism by hydrothermal fluids and thickening of the oceanic lithosphere by conductive cooling. The organization of oceanic crust can be seen in ophiolites [exposed sections of ocean floor], in transform fault margins, and by deep ocean drilling. Cooling and thickening of the oceanic lithosphere causes a loss of buoyancy that eventually leads to subduction of oceanic lithosphere. In order for seafloor spreading to occur on a nearly spherical Earth, differential rates of spreading between the equator and the poles is accommodated by transform faults that offset the ridge axis. Transform faults may also connect spreading ridges through continental crust or may connect zones of subduction. Although transform fault scars can extend across large distances in the ocean basins, active movement is confined to the zone between plate boundaries.

Sites of ocean crust formation
    No crust older than 180 my;
    Rate of sea floor spreading & topography
Methods of investigating seafloor
    multibeam (swath) bathymetry
    seismic, magnetics, direct sampling
Thermo-Tectonic subsidence curve

Ophiolite model
    Sediments
    Basaltic lavas
    Sheeted dikes and half dikes
    Gabbro and Layered gabbro
    Tectonite peridotite and serpentinite
Hydrothermal activity
    Heat flow
    Water flow and hydrothermal metamoprhism
    Entire ocean cycled every 2-3 million years,
    Greenschist & "greenstone"
    Water may circulate to depths of 2-3 km (outer part of magma bodies)
Transform Faults
    (1) Ridge-Ridge
    (2) Ridge-trench
    (3) Trench-Trench
General Transform Features: mylonite, multiple faults , different elevations, "metamorphic core complex", serpentinite intrusions

Lecture 25: Divergent Margins and Transform Margins November 22, 2004

Mid Ocean Ridges

New crust formed three places: mid ocean ridges, oceanic arcs and continental arcs—each involves more extreme differentiation by partial melting and fractional crystallization

In the case of ocean crust:

No crust older than 180 my;

Since formation of the Earth, igneous activity has created enough crust to cover the entire Earth in a layer 120 km thick (versus an average ocean crust thickness of ~6-10 km)

Spreading rates of ~2-16 cm/year

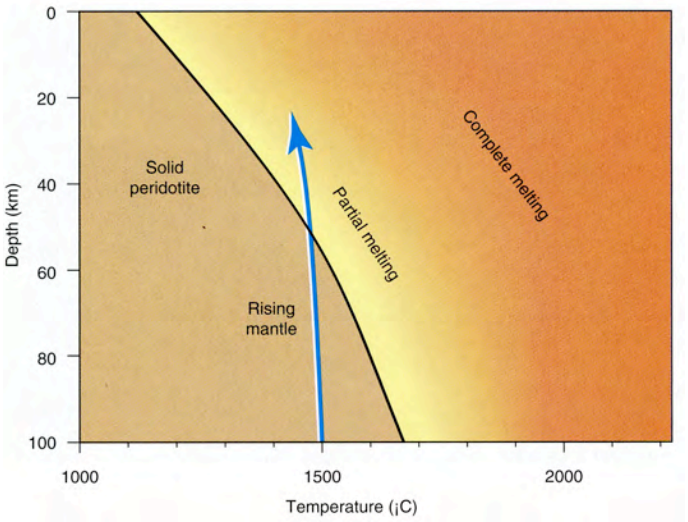
Show pattern of faults parallel with the ridge—mostly normal faults reflecting extension of the thin crust. Typically little earthquake activity owing to ductile crust

Normal faulting produces topographic relief (abyssal hills) that gradually become sedimented as the crust moves off axis.

Major **topographic differences** associated with **rate of sea floor spreading**—fast spreading ridges show little structural relief compared with slow spreading ridges; difference probably due to rate of cooling and increase in brittle fracture of the crust.

Volcanism associated with narrow band 20-30 km across the ridge

Produced by decompression melting as the surface crust slides away from the ridge axis. As rising **mantle crosses the solidus** at 30-100 km depth it begins to melt—still a nearly solid rock but with skins of melt around grain boundaries. Melting occurs near the ridge axis because this is where **the overlying pressure is least**; elsewhere the convectively cooling lithosphere prevents the asthenosphere from reaching the solidus.



The molten liquid rises faster than the solid portion, **accumulating in fractures**

The **zone of partial melting is ~100 km wide** beneath a fast-spreading ridge, perhaps less for cooler, slow spreading ridges.

Magma accumulates into axial **magma chambers that are ~1-5 km across**, several hundred meters to 1 km thick and elongate along the ridge axis.

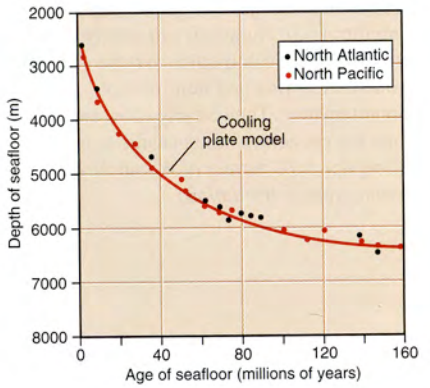
Stretching of the crust above the magma chamber allows magma to escape into the fissures and erupt onto the surface

Within the magma chamber, minerals with high crystallization temperatures settle out to form **layered intrusions**. The first minerals to precipitate are olivine and chromite—form chromium ores. Next to crystallize are olivine, plagioclase and pyroxene to form layered gabbro; the upper part of the magma chamber may crystallize completely forming **massive gabbro**.

Subsidence rates:

Ridges typically elevated to ~2500 m with an axial valley overlying a magma chamber ~several km wide

Ridges follow a **Thermo-Tectonic subsidence curve** governed by cooling history; cooling governed by spreading rate and crust age. But crust of the same age in different ocean basins shows similar age/depth relationships; there is just more crust of a given age in a fast spreading system than in a slow-spreading system. Hence the remarkable thing is that you can fairly accurately **predict the age of crust based upon its water depth!**



Seismicity

Most faulting is due to magma migration and normal faulting near the ridge axis—almost all quakes are of low magnitude and shallow depth (<10 km) Why? Deeper crust is hot and ductile and so does not show brittle fracture. Larger and somewhat deeper Earthquakes are associated with strike-slip motion on transform faults as we will discuss presently.

Heat flow

Is **10X higher at the ridge axis** than elsewhere—associated with thin crust and high fluid circulation

Water flow and hydrothermal metamoprhism

Entire **ocean cycled** through the ocean floor **every 2-3 million years**, hence sea floor hydrothermal fluids are an important means of extracting ions from rock and exchanging seawater borne ions and isotopes with the crust.

Concentration of heat flow at ridges suggests water circulation driven by hydrothermal fluids—set up convection within the crust

Hence seafloor metamorphism is mostly due to low-medium temperature reactions—**Greenschist**—in which **olivine, pyroxene and plagioclase** are converted into **chlorite, epidote, talc and serpentine—all hydrated minerals**. These minerals mostly do not show strong foliation since they are formed in extensional environments; however the sheet silicates—serpentine and chlorite are of lower density than the original minerals and can form intrusions of their own—they commonly intrude up fault planes—particularly in strike slip faults cutting the ridge.

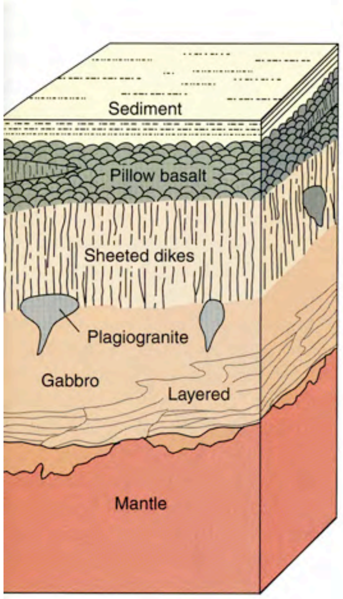
Metamorphosed basalt forms metabasalt or **“greenstone”**

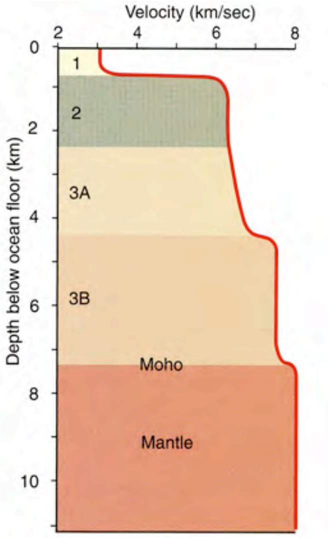
Water may circulate to depths of 2-3 km (outer part of magma bodies)

Vaporizing water in the shallow (low pressure) parts of the crust may create phreatic explosions and hydrofracturing of the surface crust allowing more water to circulate.

Although water circulates throughout young and old crust alike, the presence of hot magma bodies near the ridge greatly **speeds up water circulation** and ability of water to hold ions in solution. Young fractures also create focused outflow form the crust. These hot water springs (hydrothermal vents) can precipitate minerals upon contact with sea water (and often mediated by bacterial films).

Get **variety of hydrothermal systems** (“black smokers, White smokers) that ppt different mineral assemblages depending upon water temperature, chemistry, and bacterial types.



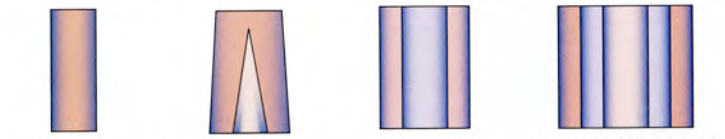


Ophiolite model

Sediments—four major types—(1) umber and other hydrothermal and volcanicalstic sediments; (2) carbonate ooze and chalk—present above CCD; (3) siliceous ooze (radiolarian or diatom ooze and chert)—present below CCD and in areas of high productivity; (4) red clay—present below the CCD, as airborne dust

Basaltic lavas—pillows and flows—shield volcanoes, fissure eruptions, hypabyssal volcaniclastics and flows—rarely extend more than 2 km; typically 1-2 km thick

Sheeted dikes and half dikes—composed of vertical dikes ~1 m thick. Most are "half dikes" with a chilled margin on one side only. Form by progressive splitting of earlier, still hot dikes by later intrusions—presumably the interior of the dike is easier to split (perhaps because they are hotter and more ductile) than the dike margins. Grade into pillow basalts above and gabbros below. Up to 2 km thick

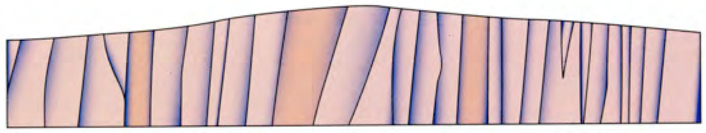


A. Normal dike chilled margins

B. New dike intrudes

C. New dike cools with quenched margins

D. Repeated intrusion creates half dikes thinner and only one chilled margin



E. Troodos sheeted dike complex normal and half-dikes

Gabbro and Layered gabbro—upper part massive gabbro representing cooled walls of magma bodies, lower portion composed of layered gabbros (cumulates) that have settled gravitationally out of the magma chamber—may show cross-bedding indicating directional currents in the magma body! Up to 4.5 km thick

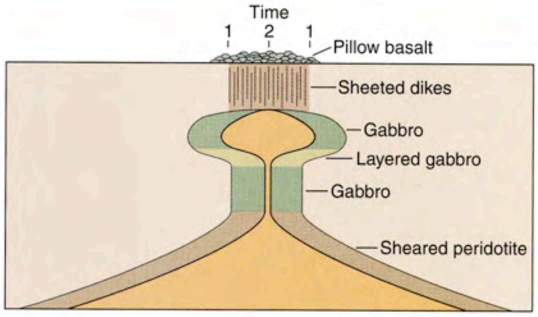
Tectonite peridotite—shows evidence of ductile shearing of olivine and folding—reflects remnant of partial melting extraction and flow in upper mantle. 5-12 km thick.

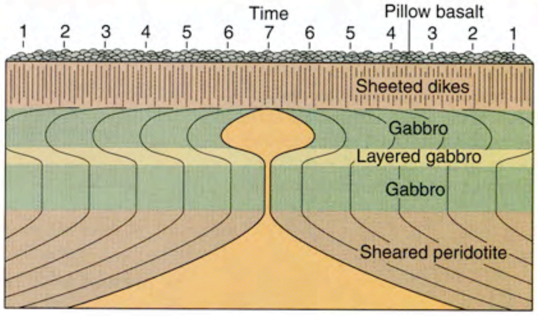
Serpentinite—mantle rocks may have been converted by hydrothermal weathering to serpentinites which may or may not show 'ghost structures' of the original peridotite.

Oceanic Lithosphere Growth at Divergent Margins

Crust grows laterally by magmatism and vertically by cooling and sedimentation.

1. **Lateral growth** occurs because magmatism is always adding material at the ridge with minimal off-axis volcanism or plutonism.
2. **Vertical growth** occurs by sedimentation off axis and by convective cooling of the upper lithosphere that crystallizes the upper mantle





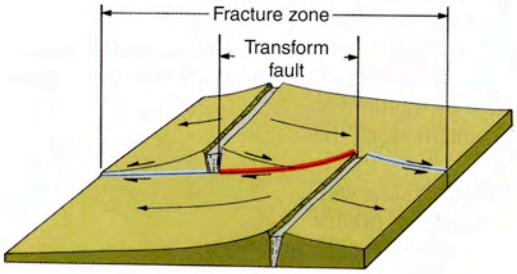
Transform Faults

Transforms are fractures connecting two other types of plate boundaries

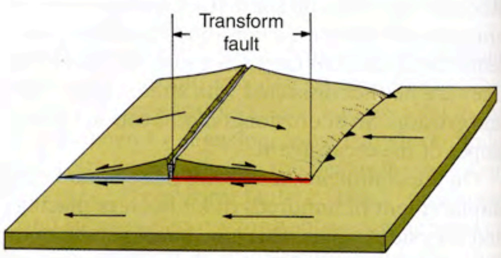
Actual fault is not active along its entire length—only the segment between plate boundaries is active.

Types of Transforms

(4) **Ridge-Ridge**—connects two ridges—common pattern on all ocean ridge systems
(5) **Ridge-trench**—connects a ridge and a trench—The Scotia Arch in the Drake Passage
(6) **Trench-Trench**—the Great Alpine Fault in New Zealand connecting trenches with opposite dip.



(A) Ridge-ridge transform fault.



(B) Ridge-trench transform fault.

General Features

1. Display **mylonite** and shearing features, drag folds and have the most earthquakes of any part of the ridge system.
2. usually consist of **multiple faults** rather than a single strand

3. difference in crust age and buoyancy reflected in **different elevations** across a transform fault; can expose the whole crustal section
4. Can get shearing and crustal thinning across the ductile upper mantle and separation of the mantle and crust along low angle normal faults. In this case the lower crust can rise buoyantly creating a **“metamorphic core complex”**
5. May also have **serpentinite intrusions** along transforms, created by shearing of buoyant serpentine that , in turn, is derived from alteration of the mantle peridotite adjacent to the fault.