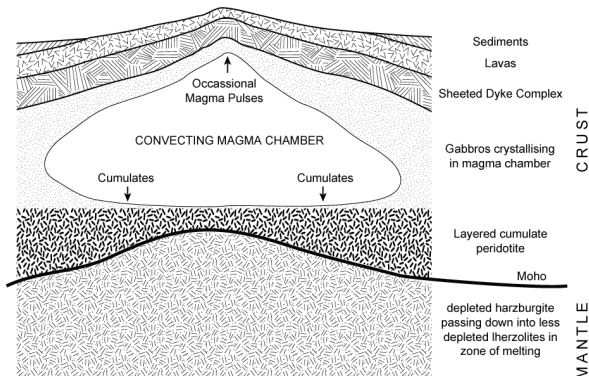


# LECTURE THIRTEEN: Ocean crust, ophiolites and alteration 1

## IN THIS LECTURE

- Overview of Ocean Crust
- Simplified petrogenetic model
- Structure of the ocean crust
- Alteration of the ocean crust
- Petrology of the ocean crust
- Overview of Ophiolites
- Ocean Crust vs Ophiolite
- Distribution of European Ophiolites
- Example of an ophiolite section
- The Troodos and Semail Ophiolites



## OCEAN CRUST AND MID OCEANIC RIDGES

Most conspicuous feature of the ocean floor, rising on average 1000-3000m above the adjacent ocean floor and extend through all the major ocean basins with a total length in excess of 60,000 km.

With the exception of the East Pacific Rise, they occur in the middle part of the oceans and essentially form a submarine mountain range, which slopes to its highest elevation at the ridge crest and slopes away systematically on either flank.

According to Plate Tectonic theory a mid-ocean ridge is a boundary between plates at which new oceanic lithosphere (crust + mantle) is generated in response to partial melting of mantle lherzolite undergoing adiabatic decompression in a narrow zone of upwelling. Essentially the oceanic crust can be divided into two major domains: (1) The accreting plate boundary zone (mid-ocean ridge) at which new oceanic crust is created; and

(2) The passive crust, which after creation at the ridge axis has moved away. In general ocean floor basalts have restricted chemical compositions with tholeiitic characteristics, constant SiO<sub>2</sub>, low K and low incompatible element contents.

However, trace elements and radiogenic isotope ratios vary depending on whether the basalts come from 'normal' segments of the ridges or whether they come from topographic highs or platforms associated with islands astride the ridge axis e.g. Iceland, Azores, Galapagos, Bouvet, Reunion, Tristan de Cunha, Gough

## CONTROLS ON MORB CHEMISTRY

1. **SOURCE** - generally depleted lherzolite in the spinel or possibly even plagioclase lherzolite facies. The trace element geochemistry of MORB shows no evidence for the existence of residual garnet in the source.

2. **DEGREE OF PARTIAL MELTING** - As deduced from a variety of partial melting experiments on synthetic and natural lherzolites a minimum of about 20% partial melting appears to be required to generate the most primitive (MgO-rich) MORB composition. If the primary MORB are more picritic then the degree of melting would be somewhat greater.

3. **DEPTH OF PARTIAL MELTING AND MAGMA SEGREGATION** - Geophysical studies suggest initiation of significant partial melting at depths of 60-80 km. Segregation of magma batches probably occurs at depths of about 20 km.

4. **FRACTIONAL CRYSTALLISATION** - Large magma chambers thermally unstable at slow-spreading ridges so may be different processes operating at fast and slow ridges.

## MID-OCEAN RIDGE ENVIRONMENTS

Different types of mid-ocean ridge environments show different characteristics. In particular the rate of spreading is thought to play an important role in the detailed structure of the ocean crust as it develops.

### Slow Spreading Ridges

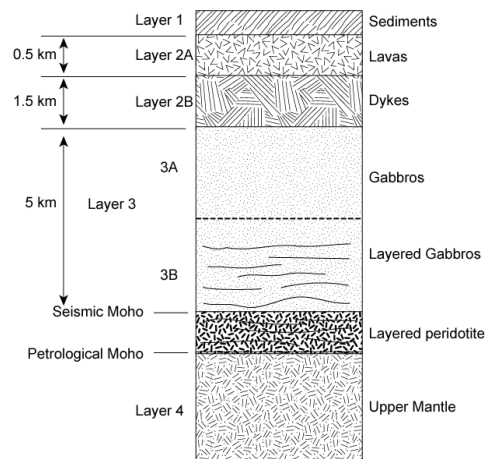
- E.g. Mid-Atlantic Ridge - half rate 1-2 cm per year
- Symmetrical about the ridge
- Well defined central rift valley

### Fast Spreading Ridges

- E.g. East Pacific Rise and Galapagos Rift - half rate 6-7 cm per year.
- Often non symmetrical with respect to plate margins
- Lack of well defined central rift valley

### Aseismic Ridges

- E.g. Iceland - Faeroe, Walvis Ridge - Rio Grande Rise
- Lack seismic activity
- Often have thicker crustal structure (15-30 km) than young oceanic crust (7-10km)



	Vp (kms <sup>-1</sup> )	Average thickness (km)	Average density (gcm <sup>-3</sup> )
Water	1.5	4.5	1.0
Layer 1 - sediment	1.7-2.0	0.5	2.3
Layer 2 - basalt	2.0-5.6	1.75	2.7
Layer 3 - gabbroic ultramafic cumulate layer	6.5-7.5	4.7	3.0
Moho			
Upper mantle	7.4-8.6	7.4-8.6	3.4

## PETROLOGY OF BASALTS

Petrologically basalts can be highly heterogeneous

Generally consists of very fine-grained groundmass with large phenocrysts.

These phenocrysts can be a number of different minerals

Most commonly observed phenocrysts are

Olivine +/- Mg-Cr spinel

Plagioclase + olivine +/- Mg-Cr spinel

Plagioclase + olivine + augite

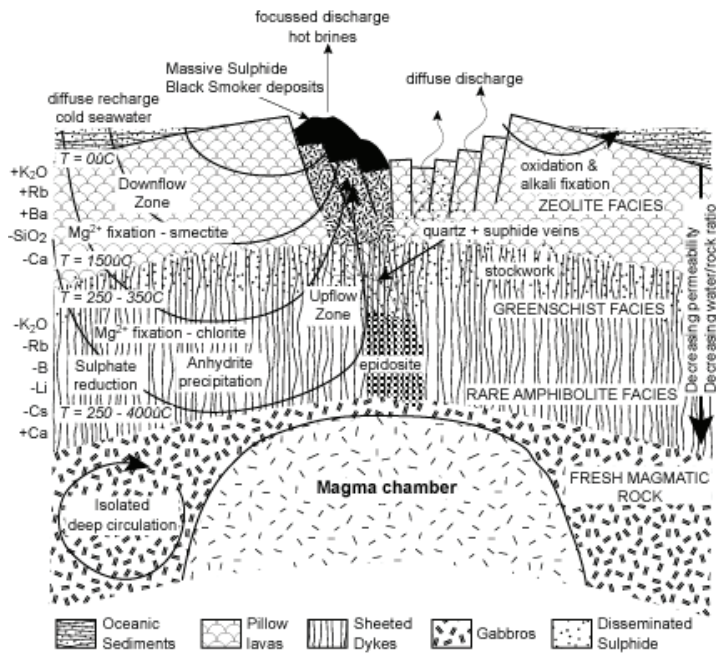
In normal MORB plagioclase is the most common phenocryst, although usually orthoclase poor

Augite phenocrysts are usually rare and confined to rocks with abundant olivine and plagioclase

Olivine, spinel and calcic plagioclase are the first to crystallise followed by augite and then Fe-ti oxides

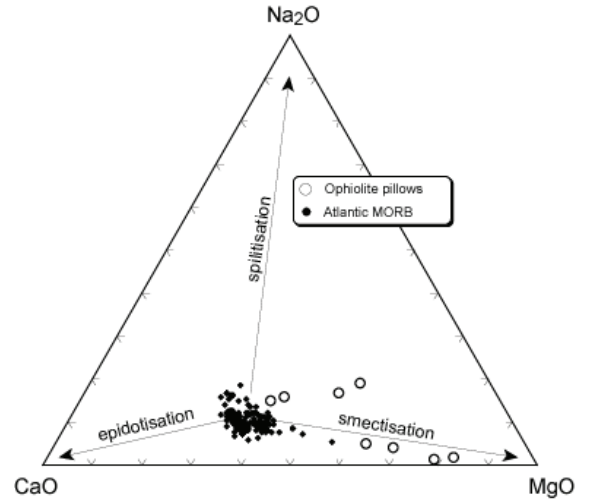
Amphibole is exceedingly rare being observed only in basalts with alkaline affinities and in cumulate gabbros

# LECTURE THIRTEEN: Ocean crust, ophiolites and alteration 2



## ALTERATION OF THE OCEAN CRUST

The ocean crust undergoes a complex sequence of alteration. The degree and type of alteration depends on temperature and the age of the crust. The most well known facies related to alteration of the ocean crust are the black smoker deposits which form massive sulphide deposits.



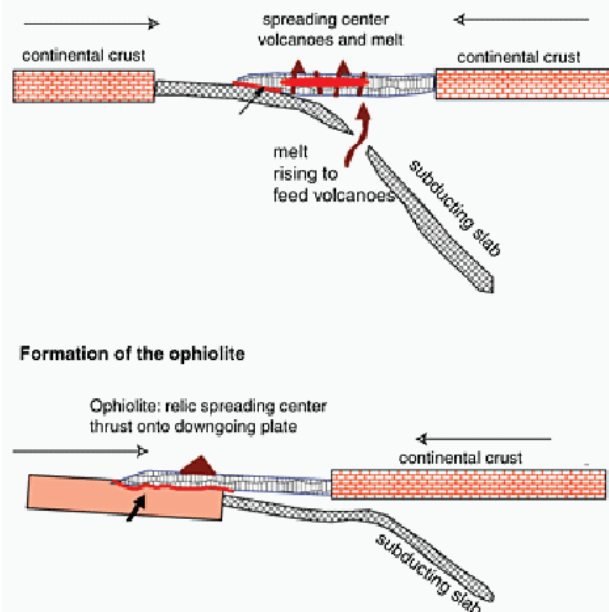
Alteration of the ocean crust involves three main reactions: (1) Splititisation + Na<sub>2</sub>O; (2) Epidotisation + CaO (3) Smectisation + MgO. Carbonates are also deposited during seafloor alteration but during later stages called aging of the ocean crust.. This aging is thought to be responsible for the homogenisation of layers 2A and 2B

## WHAT IS AN OPHIOLITE?

Ophiolites have long been regarded as remnants of ancient oceanic crust formed at spreading centers that have been thrust up on land.

Top diagram shows the spreading center colliding with a subduction zone. As the two plates continue to converge the spreading center is thrust on top of the downgoing plate to form the ophiolite.

### Collision of the subduction zone with the ridge crest



## COMPARISON OF OCEANIC CRUST AND OPHIOLITES

		Typical ophiolite		Normal ocean crust	
		Thickness (km)	P-wave velocity (km s <sup>-1</sup> )	Thickness (km)	P-wave velocity (km s <sup>-1</sup> )
Deep-sea sediments	layer 1	c. 0.3	—	0.5	2.0
Pillow lavas	layer 2	0.3-0.7	3.3	1.7	5.0
Sheeted dyke complex	layer 3	1.0-1.5	4.1	1.8	6.7
Gabbro magma chamber		2-5	5.1	3.0	7.1
Layered peridotite	layer 4	up to 7.0	2.5-4.2	—	8.1
Peridotite, dunite etc (unlayered)					

One of the most well known ophiolite sections is from the island of Cyprus. The ultramafic section in the middle has been mined for chromite. The gabbro complex within the Cyprus Ophiolite shows a complex evolution from relatively ferroan gabbros through to aplitic dykes as the magma chamber evolved.

Another very well known ophiolite sequence is the Semail Ophiolite in Oman. This sequence has exceptional outcrop exposure owing to its desert environment and has been studied extensively for over 40 years.