Ocean Islands and Plume Magmatism
Wilson p. 245-285

- In this lecture:
  - Definition, ideas, distribution of “Hotspots”
  - Crustal structure
  - Partial melting
  - Petrography, mineralogy
  - Major elements, shallow level crystallization of OIB
  - Trace element, isotopic composition of OIB
  - Integrated petrologic model

What are “Hot Spots”? 
Most igneous activity concentrated at plate margins
10% within plate interiors
Small seamounts vs. immense ocean Islands

“Hot spot” model of Wilson (1963)

Observations
Linear chains of volcanic islands in Pacific
Age progression established through K-Ar dating

Model
1. Fixed magma source, or “hot spot” in mantle over which oceanic plate moves
2. Surface volcanism fed by mantle plume
3. Volcanoes carried away from plume center, magma supply cut off
4. Forms chains of volcanoes parallel to direction of sea floor spreading

Explains most, but not all intraplate volcanism (riifting + extension important)

Upwelling deep mantle plume hypothesis of Morgan (1972)
1. Secondary mode of mantle convection to plate tectonics
2. Plumes arise from base heating within a boundary layer
   From 670 km seismic discontinuity?
   From CMB? If so, this is a major mode of mantle convection!
   Do plumes incorporate recycled crust, or tap undisturbed primordial mantle?
Where are “Hot Spots”?  
122 Hot spots active over the last 10 Ma

The Big Question: Where do Plumes Originate?  
Origin at 670 km boundary layer?  
layered mantle convection  

vs.

Origin at CMB?  
whole mantle convection
**The Big Question: Where do Plumes Originate?**

Slice through the center of the Earth. The cut of the slice is along the great circle that is marked by the blue circle in the center of the plot. One of the most prominent features is a seismically fast slab-like anomaly that extends from the surface beneath the Continental US well throughout the whole mantle. This is thought to be the image of the subducted Farallon plate.

Other marked features include two large slow anomalies under Africa and the central Pacific Ocean that originate at the CMB (core-mantle boundary) and extend well up into the lower mantle. Also prominent are the seismically fast continental shields in the upper mantle: the South and West African Cratons, the southern extension of the Canadian Shield and the Australian Shield. Mid-ocean ridges are associated with slow anomalies in the upper mantle. The black circle marks the 670km discontinuity between upper and lower mantle.

**Crustal structure, magma plumbing system**

Seismic evidence
- low density volcanic complex
- requires high density “root”
- may be ultramafic cumulates?

Gravity profile
- low density volcanic complex

Crustal magma reservoirs
- defined by earthquake hypocenters
- shallow reservoir extends down 14 km to primary conduit/feeder dike

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Scripps Institute of Oceanography
Partial melting processes

Decompression melting similar to MORB

Main constraints from experimental petrology
- Tholeiitic basalt: extract melt <15 kbar
- Alkali olivine basalt: extract melt 15-25 kbar
- Alkali basalt: extract > 25 kbar

Need to know
1. Composition of primary basalt
2. Mineralogy of mantle source
3. Degree of melting
4. Melting mechanism
   (batch/fractional; modal/non-modal)
5. Depth of melting and melt segregation
6. Importance of mixing different mantle sources
   (plume vs. depleted upper mantle vs. lithosphere)

Crustal contamination is not severe, near primary magmas may erupt

Magma series, crystallization, mixing

Two magma series:
- Tholeitic and Alkaline

Two Alkaline differentiation trends
- under- and over-saturated wrt SiO₂
Mineralogy of ocean island basalts

### Contrasts With MORB

#### Oceanic Tholeiites vs. Alkali Basalts

<table>
<thead>
<tr>
<th></th>
<th>Tholeiitic basalts</th>
<th>Alkali basalts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenocrysts</td>
<td>Intense plagioclase, commonly zoned — may show reaction rims of orthopyroxene</td>
<td>Medium sized olivine phenocrysts common — often strongly zoned with more iron-rich rims</td>
</tr>
<tr>
<td>Ultraphyric phenocrysts may occur</td>
<td></td>
<td>Orthopyroxene absent</td>
</tr>
<tr>
<td>Regolite phenocrysts often appear early in the crystallization sequence</td>
<td>Plagioclase phenocrysts less common, appear later in the crystallization sequence</td>
<td></td>
</tr>
<tr>
<td>Phenocrysts of pale brown augite</td>
<td></td>
<td>Plagioclase ± augite</td>
</tr>
<tr>
<td>Groundmass</td>
<td>Groundmass usually relatively fine-grained, with an intergranular texture</td>
<td>Groundmass relatively coarse, with textures ranging from intergranular to ophtic</td>
</tr>
<tr>
<td>Groundmass pyroxene is variable, subhedral to euhedral</td>
<td>Groundmass olivine may occur</td>
<td></td>
</tr>
<tr>
<td>No alkali feldspar or biotite in the groundmass</td>
<td>Only one species of Ca-rich clinopyroxene in the groundmass</td>
<td></td>
</tr>
<tr>
<td>Interstitial glass relatively common</td>
<td>Interstitial glass often rare or absent</td>
<td></td>
</tr>
</tbody>
</table>

#### Mantle Xenoliths

<table>
<thead>
<tr>
<th></th>
<th>Tholeiitic basalts</th>
<th>Alkali basalts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Associated rocks</td>
<td>Ultramafic xenoliths very rare</td>
<td>Associated xenoliths are ankerites, rich in olivine and augite phenocrysts</td>
</tr>
<tr>
<td>Associated accumulative rocks are pinotites (oceanites), rich in olivine phenocrysts</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Major and trace element composition of magmas

### Compare Hawaiian tholeiites and alkali basalts to MORB

#### Table 5.6 Major and trace element geochemistry of typical tholeiitic and alkali basalts from Hawaii, compared to N-MORB data from Basin Volcanism Study Project 1980's. MORB data from Schmidt et al. (1982).

<table>
<thead>
<tr>
<th></th>
<th>Tholeites</th>
<th>Alkali Basalts</th>
<th>MORB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kilauea</td>
<td>Mauna Loa</td>
<td>Hawaii Kohala</td>
</tr>
<tr>
<td>SiO₂</td>
<td>50.51</td>
<td>51.03</td>
<td>46.37</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>13.45</td>
<td>13.12</td>
<td>14.38</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1.78</td>
<td>2.58</td>
<td>4.05</td>
</tr>
<tr>
<td>MgO</td>
<td>9.59</td>
<td>9.68</td>
<td>6.91</td>
</tr>
<tr>
<td>CaO</td>
<td>11.18</td>
<td>9.67</td>
<td>10.33</td>
</tr>
<tr>
<td>Na₂O</td>
<td>3.29</td>
<td>2.41</td>
<td>3.26</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.49</td>
<td>0.33</td>
<td>0.35</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.17</td>
<td>0.17</td>
<td>0.18</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.25</td>
<td>0.22</td>
<td>0.25</td>
</tr>
<tr>
<td>H₂O</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

### Elevated LILEs

<table>
<thead>
<tr>
<th></th>
<th>Tholeiites</th>
<th>Alkali Basalts</th>
<th>MORB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sr</td>
<td>355.5</td>
<td>219</td>
<td>45.0</td>
</tr>
<tr>
<td>Eu</td>
<td>6.14</td>
<td>4.40</td>
<td>5.35</td>
</tr>
<tr>
<td>Yb</td>
<td>1.68</td>
<td>1.89</td>
<td>1.88</td>
</tr>
<tr>
<td>Lu</td>
<td>0.88</td>
<td>1.89</td>
<td>1.88</td>
</tr>
<tr>
<td>Rb</td>
<td>9.2</td>
<td>4.7</td>
<td>23</td>
</tr>
<tr>
<td>Y</td>
<td>371</td>
<td>273</td>
<td>500</td>
</tr>
<tr>
<td>Nb</td>
<td>162</td>
<td>75</td>
<td>300</td>
</tr>
<tr>
<td>Hf</td>
<td>4.39</td>
<td>3.24</td>
<td>3.00</td>
</tr>
<tr>
<td>Zr</td>
<td>11.55</td>
<td>11.19</td>
<td>18.6</td>
</tr>
<tr>
<td>Nb</td>
<td>17</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>Y</td>
<td>26</td>
<td>23</td>
<td>21</td>
</tr>
<tr>
<td>Tb</td>
<td>1.27</td>
<td>0.60</td>
<td>1.20</td>
</tr>
<tr>
<td>Sm</td>
<td>5.6</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>
Magma series, crystallization, mixing

**Fractional crystallization** in crustal plumbing systems of Oliv + Cpx + Mt + (Plag)

= Linear variations in Major and Trace element Harker diagrams

Incompatible trace element composition of magmas

LREE, LILE enrichment is distinctive

Ocean Island tholeiites similar to EMORB

suggests similar components

Ocean Island alkaline lavas distinct from MORB
Radiogenic isotope composition of magmas

Sr-Nd isotope array of OIBs
At least 3, perhaps more mantle source end-member components:
1. Depleted mantle (DM)
2. Crustal sediment (modern or ancient?)
   or
3. Primordial bulk earth modified > 1Ga by melting (EM)
4. Saint Helena (SHC)

Pb isotope array of OIBs
Require recycling of continental crust into the mantle:
Pb is highly depleted in DM, enriched in continental sediment. why?

Pb isotope ratios greatly different for DM and Plume source mantle

Mixing of DM and SHC (Plume) sources explains most Pb isotope variation

NHRL defined by MAR + EPR basalt

DUPAL anomaly requires 3rd component
Positive deviation from NHRL in 208Pb/204Pb Band centered on 30-40 °S

3 possibly 4 sources:
DM + EM (lower mantle) + SHC (crust?)
**Petrogenetic model, General**

Transition from voluminous tholeiitic shield stage, to small volume alkaline cap lavas

**Petrogenetic model, Hawaii**

Transition from voluminous tholeiitic shield stage, to small volume alkaline cap lavas