Lecture 23 Ocean Island Basalts

Thursday, April 21st 2005

Chapter 14: Ocean Intraplate Volcanism
Ocean islands and seamounts
Commonly associated with hot spots

Why are we so interested in oceanic basalts?

- Oceanic basalts are uncontaminated by continental crust
- Therefore their compositions tell us something about their respective mantle sources
- MORB provides information about the upper depleted mantle
- OIB provides information about the lower (more fertile (primitive?)) mantle

Types of OIB Magmas

Two principal magma series

- Tholeiitic series (dominant type)
  - Parental ocean island tholeiitic basalt, or OIT
  - Similar to MORB, but with distinct chemical and mineralogical differences
- Alkaline series (subordinate)
  - Parental ocean island alkaline basalt, or OIA

Some islands are dominated by tholeiitic basalts (and their derivatives) (e.g. Hawaii and Reunion) others by alkali basalts (and their derivatives) (e.g. Tahiti and Tristan de Cunha)
Evolution in the Series
Tholeiitic, alkaline, and highly alkaline

- Alkalinity is highly variable
- Alkalis are incompatible elements, unaffected by less than 50% shallow fractional crystallization, this again argues for distinct mantle sources or generating mechanisms

Table 14-4. Alkali/silica ratios (regression) for selected ocean island lava suites.

<table>
<thead>
<tr>
<th>Island</th>
<th>Alk/Si</th>
<th>Na₂O/SiO₂</th>
<th>K₂O/SiO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tahiti</td>
<td>0.86</td>
<td>0.54</td>
<td>0.32</td>
</tr>
<tr>
<td>Principe</td>
<td>0.86</td>
<td>0.52</td>
<td>0.34</td>
</tr>
<tr>
<td>Trinidad</td>
<td>0.83</td>
<td>0.47</td>
<td>0.35</td>
</tr>
<tr>
<td>Fernando de Noronha</td>
<td>0.74</td>
<td>0.42</td>
<td>0.33</td>
</tr>
<tr>
<td>Gough</td>
<td>0.74</td>
<td>0.30</td>
<td>0.44</td>
</tr>
<tr>
<td>St. Helena</td>
<td>0.56</td>
<td>0.34</td>
<td>0.22</td>
</tr>
<tr>
<td>Tristan da Cunha</td>
<td>0.46</td>
<td>0.24</td>
<td>0.22</td>
</tr>
<tr>
<td>Azores</td>
<td>0.45</td>
<td>0.24</td>
<td>0.21</td>
</tr>
<tr>
<td>Ascension</td>
<td>0.42</td>
<td>0.18</td>
<td>0.24</td>
</tr>
<tr>
<td>Canary Is</td>
<td>0.41</td>
<td>0.22</td>
<td>0.19</td>
</tr>
<tr>
<td>Tenerife</td>
<td>0.41</td>
<td>0.20</td>
<td>0.21</td>
</tr>
<tr>
<td>Galapagos</td>
<td>0.25</td>
<td>0.12</td>
<td>0.13</td>
</tr>
<tr>
<td>Iceland</td>
<td>0.20</td>
<td>0.08</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Spider diagram comparing OIB with MORB

Trace Elements

- The LIL trace elements (K, Rb, Cs, Ba, Pb$^{2+}$ and Sr) are incompatible and are all enriched in OIB magmas with respect to MORBs
- The ratios of incompatible elements have been employed to distinguish between source reservoirs
  - N-MORB: the K/Ba ratio is high (usually > 100)
  - E-MORB: the K/Ba ratio is in the mid 30’s
  - OITs range from 25-40, and OIAs in the upper 20’s

Thus all appear to have distinctive sources
Trace Elements

- HFS elements (Th, U, Ce, Zr, Hf, Nb, Ta, and Ti) are also incompatible, and are enriched in OIBs > MORBs
- Ratios of these elements are also used to distinguish mantle sources
  - The Zr/Nb ratio
    - N-MORB generally quite high (>30)
    - OIBs are low (<20)

Trace Elements: REEs

La/Yb (REE slope) correlates with the degree of silica undersaturation in OIBs
- Highly undersaturated magmas: La/Yb > 30
- OIA: closer to 12
- OIT: ~ 4
- (+) slopes → E-MORB and all OIBs ≠ N-MORB
  - (-) slope and appear to originate in the lower enriched mantle
Trace Elements: REEs


MORB-normalized Spider Diagrams

Isotope Geochemistry

- Isotopes do not fractionate during partial melting or fractional crystallization processes, so they reflect the characteristics of the mantle source.

- OIBs, which sample a great expanse of oceanic mantle in places where crustal contamination is minimal, provide incomparable evidence as to the nature of the mantle.

Simple Mixing Models

**Binary**

All analyses fall between two reservoirs as magmas mix.

**Ternary**

All analyses fall within triangle determined by three reservoirs.

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Sr - Nd Isotopes


Figure 14-6. After Zindler and Hart (1986), Staudigel et al. (1984), Hamelin et al. (1986) and Wilson (1989).
Proposed Mantle Reservoirs

1. DM (Depleted Mantle) = N-MORB source

Figure 14-6. After Zindler and Hart (1986), Staudigel et al. (1984), Hamelin et al. (1986) and Wilson (1989).

2. BSE (Bulk Silicate Earth) or the Primary Uniform Reservoir

The source of many oceanic basalts can be considered as 2-component mixtures of DM and BSE

Figure 14-6. After Zindler and Hart (1986), Staudigel et al. (1984), Hamelin et al. (1986) and Wilson (1989).
3. EMI = enriched mantle type I has low $^{143}\text{Nd}/^{144}\text{Nd}$ and resembles old continental crust (subducted and re-cycled sediments?)

4. EMII = enriched mantle type II has high $^{87}\text{Sr}/^{86}\text{Sr}$ (> .720) well above any reasonable mantle sources. May reflect recycling (subduction) of young upper crust sediments.
5. HIMU – Why do we need a 5th HIMU component? It is not obviously necessary from consideration of Sr and Nd isotopes.

To understand mantle reservoirs further (especially HIMU), we need to look at Pb isotopes.

Pb produced by radioactive decay of U & Th

\[ {\begin{align*}
238U &\rightarrow 234U \rightarrow 206Pb \\
235U &\rightarrow 207Pb \\
232Th &\rightarrow 208Pb
\end{align*}} \]

\(^{204}Pb\) is the unradiogenic Pb isotope and is used as a reference

Pb abundances are very low in the mantle

- Mantle-derived melts sensitive to contamination
- U, Pb, and Th are concentrated in continental crust (high radiogenic daughter Pb isotopes)
- \(^{204}Pb\) is non-radiogenic, so \(^{208}Pb/^{204}Pb\), \(^{207}Pb/^{204}Pb\), and \(^{206}Pb/^{204}Pb\) increase as U and Th decay
- Oceanic crust has elevated U and Th content (compared to the mantle) as will sediments derived from oceanic and continental crust
- Pb is a sensitive measure of crustal (including sediment) components in mantle isotopic systems
- We have seen that several reservoirs (EMI and EMII) appeal to recycling of crustal material through subduction
- 93.7\% of natural U is \(^{238}U\), so \(^{206}Pb/^{204}Pb\) will be most sensitive to a crustal-enriched component
Now we see the need for a HIMU component! Most oceanic basalts in the N. Hemisphere (including MORB) appear to reflect mixtures of DM and HIMU components. (No need for EMI or EMII?)

- $\mu = \frac{^{238}U}{^{204}Pb}$ (evaluates uranium enrichment)
- HIMU reservoir has a very high $^{206}Pb/^{204}Pb$ ratio, suggestive of a source with high U, yet not enriched in Rb, and old enough (> 1 Ga) to develop the observed isotopic ratios
- HIMU is thought to reflect subducted and recycled oceanic crust (possibly contaminated by seawater)
Basalts from the S. Hemisphere and parts of the Indian Ocean have higher $^{208}\text{Pb}/^{204}\text{Pb}$ (relative to $^{206}\text{Pb}/^{204}\text{Pb}$) than basalts from the N. Hemisphere and provide further confirmation of the need for the EMI and EMII components.

CONCLUSIONS

- The mantle source of OIB is highly heterogeneous
- It does not correspond with a primordial, primitive mantle
- Isotopically enriched reservoirs (EMI, EMII, and HIMU) are too enriched for any known mantle process, and they correspond to crustal rocks and/or sediments
- These enriched reservoirs have been introduced into the mantle through subduction
- EMI (slightly enriched) correlates with lower continental crust or oceanic crust
- EMII is more enriched, especially in radiogenic Sr (indicating the Rb parent) and Pb (U/Th parents) correlates with the upper continental crust
- HIMU is enriched in U and Th and probably reflects altered oceanic crust