ARC VOLCANISM AND GRANITE BATHOLITHS

Benioff (1954) was first to note the presence of seismic zones associated with deep sea trenches that appear to dip below the island arc. Earthquakes as deep as 400 km. Mantle is too hot to fail brittlely at this depth, thus earthquakes must be within colder material that has been thrust in from shallower depths.

[Diagram of tectonic processes]

(a) Fore-arc Basin

(b) Subduction Melange

Continental Margin

Andean Arc

Non-Volcanic Arc

Medial Graben

Volcanic Front

Benioff Zone

90-150 km
ARC VOLCANISM AND GRANITE BATHOLITHS

Coates (1962) associated dehydration in underthrust slab with partial melting mantle above to form Aleutian island arc.

3 Volcanic Series Associated with Island Arcs:

1. Arc Tholeiite
   a. Young volcanic arcs, oldest, closest to trench.
   b. Moderate-strong Fe-enrichment, Weak Si, Na, K-enrichment.
   c. Mostly Basaltic-andesite.

2. Calc-alkaline Suite
   a. More mature arcs, farther from trench, overlie arc tholeiites.
   b. Little or no Fe-enrichment, Strong Si, Na, K-enrichment.
   c. Complete series: Basalt, Andesite, Dacite, Rhyolite.

3. Alkaline Suite (Shoshonites)
   a. Youngest series, erupts farthest from trench, not in all arcs.
   b. Generally potassic (shoshonite: K2O > Na2O), may be sodic.
   c. All mafic (basalt, basaltic-andesite), no SiO2 enrichment.
Island Arc Volcanics vs MORB

<table>
<thead>
<tr>
<th></th>
<th>MORB</th>
<th>Arc Tholeiite</th>
<th>Calc-alkaline</th>
<th>Shoshonite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. SiO2</td>
<td>50%</td>
<td>55%</td>
<td>60%</td>
<td>52%</td>
</tr>
<tr>
<td>Dominant Rx</td>
<td>Basalt</td>
<td>Basaltic</td>
<td>Andesite</td>
<td>Shoshonite</td>
</tr>
<tr>
<td>Avg. K2O</td>
<td>&lt;0.25%</td>
<td>&lt;0.5%</td>
<td>1.5%</td>
<td>4.5%</td>
</tr>
<tr>
<td>K2O/Na2O</td>
<td>&lt; 0.1</td>
<td>&lt; 0.4</td>
<td>&lt; 0.8</td>
<td>1.1-1.3</td>
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<tr>
<td>TiO2</td>
<td>0.6-2.5%</td>
<td>0.6%</td>
<td>0.8%</td>
<td>0.7%</td>
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<tr>
<td>LREE/HREE</td>
<td>&lt; 1.0</td>
<td>&lt; 1.0</td>
<td>2-4</td>
<td>4-6</td>
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<tr>
<td>Phenoxtls:</td>
<td>Olivine</td>
<td>Olivine</td>
<td>Hypersthene</td>
<td>Olivine</td>
</tr>
<tr>
<td></td>
<td>Plagioclase</td>
<td>Plagioclase</td>
<td>Plagioclase</td>
<td>Augite</td>
</tr>
<tr>
<td></td>
<td>Augite</td>
<td>Pigeonite</td>
<td>Hornblende</td>
<td></td>
</tr>
</tbody>
</table>

Arc Tholeiites: Tonga-Kermadec, South Sandwich Islands, Izu-Bonin
CalcAlkaline: Marianas, Japan, Fiji, Java-Sumatra
Shoshonite: Fiji

How Do Island Arc Magmas Form?

**Hypothesis 1: SLAB Melting**

Early idea, still supported by many
Problem: Low geotherms make it difficult to exceed melting T
Problem: Experimental melts of Slab don’t match lavas.

**Hypothesis 2: Mantle Wedge Melting**

OK for arc Tholeiites but can’t explain enrichments in K2O, SiO2.
If dry, solidus too high for peridotite to melt.

**Hypothesis 3: Mantle Wedge Melt with Slab Component**

H2O lowers solidus of peridotite.
High PH2O melts SiO2 saturated.
High fO2 early magnetite fractionation.
Alkalis, SiO2 mobile in hot, H2O-rich fluids.
Generally favored by most petrologists.
ARC MAGMATISM  CAUSES

1. Melting caused by reduction in solidus T - H₂O from subducting slab.

   Dehydration reactions with Depth:
   a. Hornblende --> Eclogite + H₂O  (80-100 km)
   b. Serpentine --> Talc + Bruceite + H₂O  (100-120 km)
   c. Talc  -->  Enstatite + SiO₂ + H₂O  (120-150 km)

2. Change in melting relations at high  P⁵ H₂O :
   >> Melts may be Si-Saturated.

3. Water Dissociates, increasing  P⁰₂ :  2 * H₂O --> O₂(g) + 4 * H(g)
   >> Early magnetite fractionation supresses Fe-enrichment.

4. Arc magmas rich in Alkalis, SiO₂  (mobile in H₂O solutions), poor in Ti Nb Ta Hf
   (Immobile in H₂O solutions).
CONTINENTAL MARGIN ARCS -- ANDEAN ARCS

1. Continental crust acts as density filler: primitive melts must fractionate to lower density (lower FeO) before they can rise into low density continental crust.

2. During fractionation, rising magma will assimilate crustal material, increasing K₂O, SiO₂, and other lithophilic elements.

3. Partial melting of lower crust (andesitic in composition) creates large volumes of more felsic magma; rhyolites & granites more common.

4. Batholiths more common in continental arcs, e.g. Sierra Nevada Batholith in California, Coast Range Batholith in British Columbia, Coastal batholith in Peru.

Depth of origin: shallow H₂O-saturated melting of lower crust/upper mantle creates magmas which will freeze (intersect solidus) before reaching surface.

Continental margin arcs vs island arcs

<table>
<thead>
<tr>
<th></th>
<th>Andean Arcs</th>
<th>Island Arcs</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>56-75 wt%</td>
<td>50-66 wt%</td>
</tr>
<tr>
<td>FeO/MgO</td>
<td>&gt; 2.0</td>
<td>&lt; 2.0</td>
</tr>
<tr>
<td>K₂O/Na₂O</td>
<td>0.6 to 1.1</td>
<td>&lt; 0.8</td>
</tr>
</tbody>
</table>
GRANITES

Mostly derived from fusion of lower crust found only in old Andean Arcs or very mature island arcs e.g. Japan with well developed basement.

I-type granites: subduction related
   Melting of older arc volcanics or greywackes derived from them.

S-type granites: Anorogenic, related to continent-continent collisions
   Melting of shales, alumina-rich sediments.

<table>
<thead>
<tr>
<th></th>
<th>I-type Granites</th>
<th>S-type Granites</th>
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</thead>
<tbody>
<tr>
<td>Oxygen fugacity</td>
<td>high fO2</td>
<td>low fO2</td>
</tr>
<tr>
<td>Cause of fO2</td>
<td>H2O dissociation</td>
<td>Graphite (C)</td>
</tr>
<tr>
<td>Dominant Alkali</td>
<td>Na2O</td>
<td>K2O</td>
</tr>
<tr>
<td>Initial $^{87}$Sr/$^{86}$Sr</td>
<td>Low &lt; 0.710</td>
<td>High &gt; 0.710</td>
</tr>
<tr>
<td>Molar Al/(Na+K)</td>
<td>Low &lt; 1.0</td>
<td>High &gt;&gt; 1.0</td>
</tr>
<tr>
<td>Accessory Phases</td>
<td>Sphene, Magnetite</td>
<td>Ilmenite, Garnet</td>
</tr>
<tr>
<td>Ore Deposits</td>
<td>Cu, Mo, Au, Ag</td>
<td>Sn, W</td>
</tr>
</tbody>
</table>