Arc Magmatism

Reading:

Winter, Chapter 16

Island Arc Magmatism

- Activity along arcuate volcanic island chains along subduction zones
- Distinctly different from the mainly basaltic provinces
  - Composition more diverse and silicic
  - Basalt generally occurs in subordinate quantities
  - More explosive than the quiescent basalts
  - Strato-volcanoes are the most common volcanic landform

- Igneous activity is related to convergent plate situations that result in the subduction of one plate beneath another
- The initial petrologic model:
  - Oceanic crust is partially melted
  - Melts rise through the overriding plate to form volcanoes just behind the leading plate edge
  - Unlimited supply of oceanic crust to melt

Subduction Products

- Characteristic igneous associations
- Distinctive patterns of metamorphism
- Orogeny and mountain belts

Structure of an Island Arc

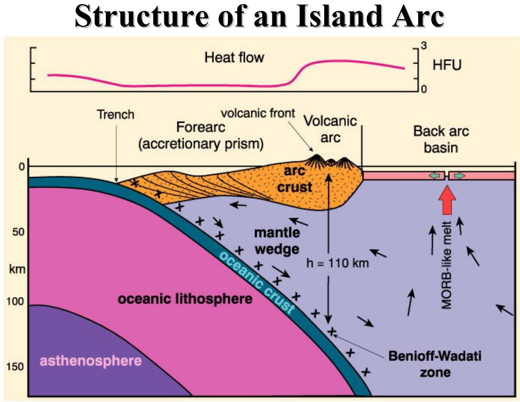


Figure 16-2. Schematic cross section through a typical island arc after Gill (1981), Orogenic Andesites and Plate Tectonics. Springer-Verlag. HFU= heat flow unit (4.2×10^{-6} joules/cm^2/sec)

Volcanic Rocks of Island Arcs

- Complex tectonic situation and broad spectrum
- High proportion of basaltic andesite and andesite
  - Most andesites occur in subduction zone settings

Major Elements and Magma Series

- Tholeiitic (MORB, OIT)
- Alkaline (OIA)
- Calc-Alkaline (~ restricted to SZ)

Major Elements and Magma Series

a. Alkali vs. silica
b. AFM
c. FeO*/MgO vs. silica

diagrams for 1946 analyses from ~ 30 island and continental arcs with emphasis on the more primitive volcanics

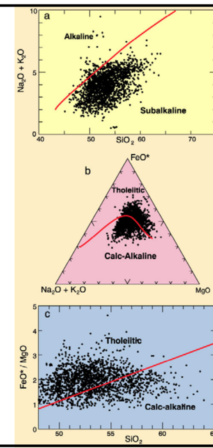
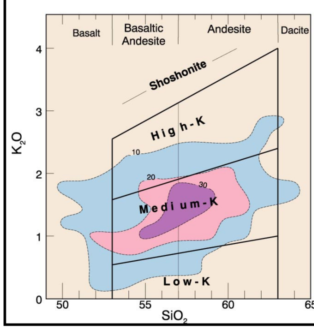


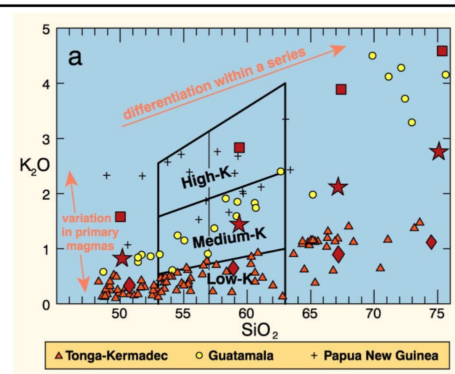
Figure 16-3. Data compiled by Terry Plank (Plank and Langmuir, 1988) ***Earth Planet. Sci. Lett.*****, 90, 349-370.**

Sub-series of Calc-Alkaline

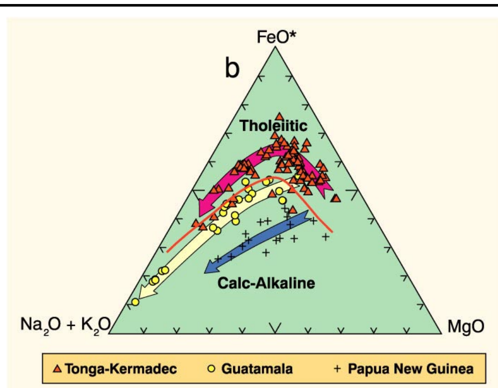
- K_2O is an important discriminator → 3 sub-series



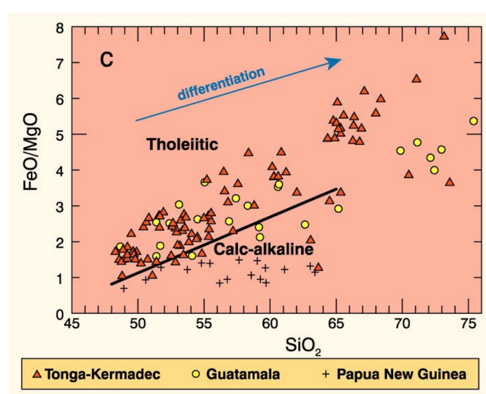
The three andesite series of Gill (1981) Orogenic Andesites and Plate Tectonics. Springer-Verlag. Contours represent the concentration of 2500 analyses of andesites stored in the large data file RKOC76 (Carnegie Institute of Washington).



K_2O-SiO_2 diagram distinguishing high-K, medium-K and low-K series. Large squares = high-K, stars = med.-K, diamonds = low-K series from Table 16-2. Smaller symbols are identified in the caption. Differentiation within a series (presumably dominated by fractional crystallization) is indicated by the arrow. Different primary magmas (to the left) are distinguished by vertical variations in K_2O at low SiO_2. After Gill, 1981, Orogenic Andesites and Plate Tectonics. Springer-Verlag.



AFM diagram distinguishing tholeiitic and calc-alkaline series. Arrows represent differentiation trends within a series.



FeO*/MgO vs. SiO_2 diagram distinguishing tholeiitic and calc-alkaline series.

Calc-alkaline differentiation

- Early crystallization of an Fe-Ti oxide phase
  Probably related to the high water content of calc-alkaline magmas in arcs, dissolves → high f_{O2}
- High water pressure also depresses the plagioclase liquidus and → more An-rich
- As hydrous magma rises, ΔP → plagioclase liquidus moves to higher T → crystallization of considerable An-rich-SiO_2-poor plagioclase
- The crystallization of anorthitic plagioclase and low-silica, high-Fe hornblende is an alternative mechanism for the observed calc-alkaline differentiation trend

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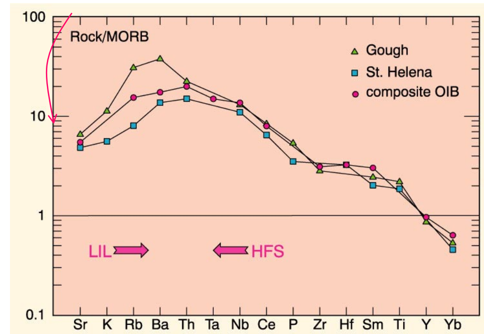
- MORB-normalized Spider diagrams
  - Intraplate OIB has typical hump



Winter (2001)

Island Arc Magmas

The main variables that can affect the isotherms in subduction zone systems are:

1) Rate of subduction

2) Age of the subduction zone

3) Age of the subducting slab

4) Extent to which the subducting slab induces flow in the mantle wedge

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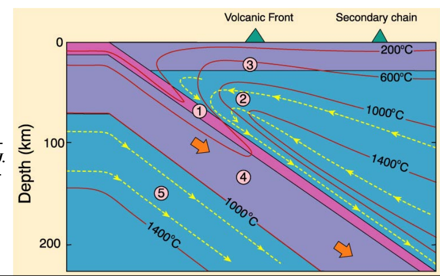
- Typical thermal model for a subduction zone
- Isotherms will be higher (i.e. the system will be hotter) if
  - a) the convergence rate is slower
  - b) the subducted slab is young and near the ridge (warmer)
  - c) the arc is young (<50-100 Ma according to Peacock, 1991)

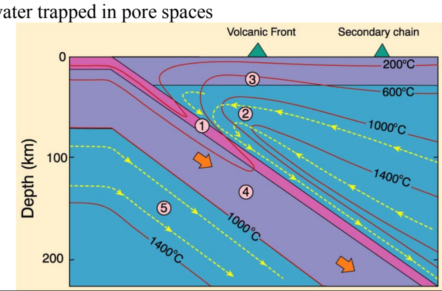
yellow curves = mantle flow



Cross section of a subduction zone showing isotherms (red- after Furukawa, 1993, *J. Geophys. Res.*, 98, 8309-8319) and mantle flow lines (yellow- after Tatsumi and Eggins, 1995, *Subduction Zone Magmatism*. Blackwell. Oxford).

The principal source components → IA magmas

1. The crustal portion of the subducted slab
   - 1a Altered oceanic crust (hydrated by circulating seawater, and metamorphosed in large part to greenschist facies)
   - 1b Subducted oceanic and forearc sediments
   - 1c Seawater trapped in pore spaces



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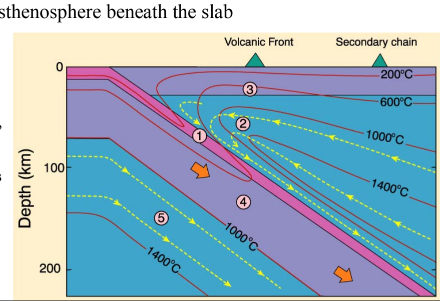
The principal source components → IA magmas

2. The mantle wedge between the slab and the arc crust
3. The arc crust
4. The lithospheric mantle of the subducting plate
5. The asthenosphere beneath the slab



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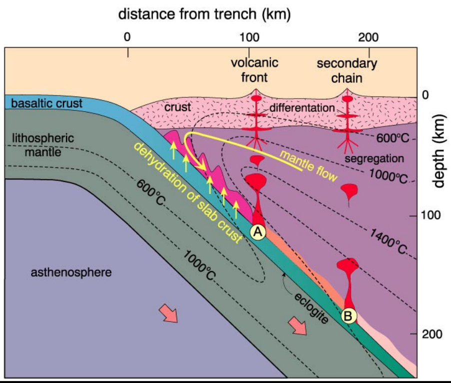
Island Arc Petrogenesis



A proposed model for subduction zone magmatism with particular reference to island arcs. Dehydration of slab crust causes hydration of the mantle (violet), which undergoes partial melting as amphibole (A) and phlogopite (B) dehydrate. From Tatsumi (1989), *J. Geophys. Res.*, 94, 4697-4707 and Tatsumi and Eggins (1995). *Subduction Zone Magmatism*. Blackwell. Oxford.

Multi-stage, Multi-source Process

- Dehydration of the slab provides the LIL enrichments + enriched Nd, Sr, and Pb isotopic signatures
  - These components, plus other dissolved silicate materials, are transferred to the wedge in a fluid phase (or melt?)
- The mantle wedge provides the HFS and other depleted and compatible element characteristics

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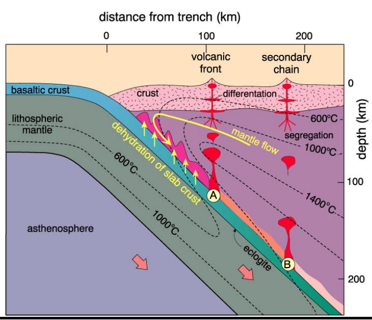
- Phlogopite is stable in ultramafic rocks beyond the conditions at which amphibole breaks down
- P-T-t paths for the wedge reach the phlogopite-2-pyroxene dehydration reaction at about 200 km depth



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