

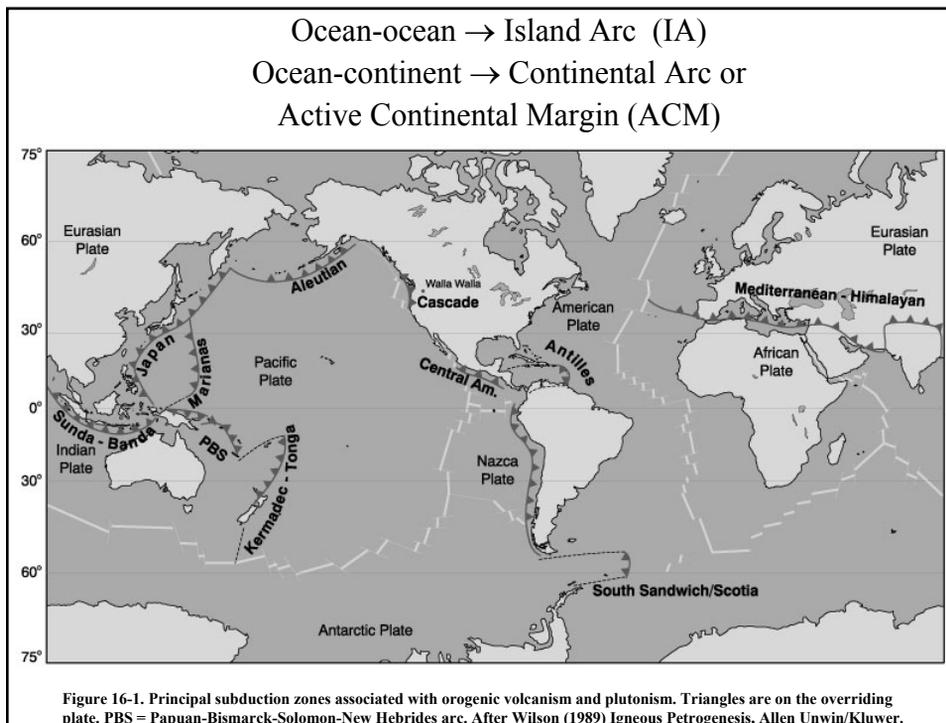
# Lecture 25 – Subduction Related Magmatism

Monday, May 2<sup>nd</sup> 2005

## Subduction Related Magmatism

- Activity along arcuate volcanic chains along subduction zones
- Distinctly different from the mainly basaltic provinces studied thus far:-
  - ☞ Composition more diverse and silicic
  - ☞ Basalt generally occurs in subordinate quantities
  - ☞ Also 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

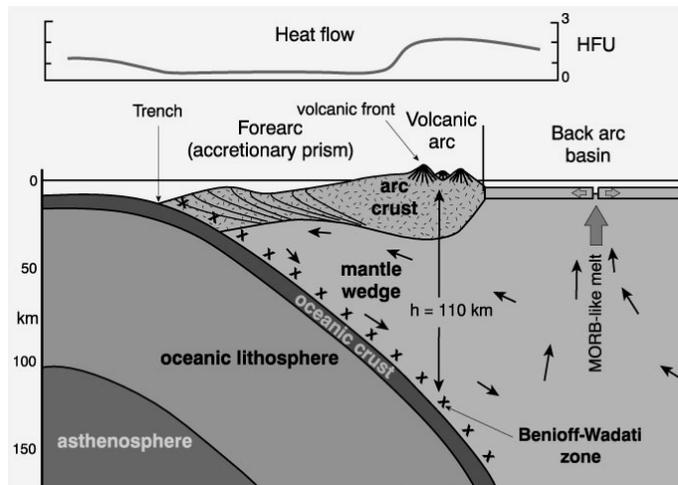


# Subduction Products

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

For simplicities sake we will focus on Island Arcs. This is because Continental Volcanic Arcs are further complicated by crustal melting and contamination

## Structure of an Island Arc



Dip of subduction =  $30 - 90^{\circ}$  with avg.  $\sim 45^{\circ}$

Vertical depth (h) = 100 – 200 km, avg.  $\sim 110$  km

Distance from trench to volcanic arc varies with dip of subduction zone

## 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

**Table 16-1.** Relative Proportions of Quaternary Volcanic Island Arc Rock Types

Locality	B	B-A	A	D	R
Talasea, Papua	9	23	55	9	4
Little Sitkin, Aleutians	0	78	4	18	0
Mt. Misery, Antilles (lavas)	17	22	49	12	0
Ave. Antilles	17	42		39	2
Ave. Japan (lava, ash falls)	14	85		2	0

After Gill (1981, Table 4.4) B = basalt B-A = basaltic andesite  
 A = andesite, D = dacite, R = rhyolite

## Major Elements and Magma Series

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

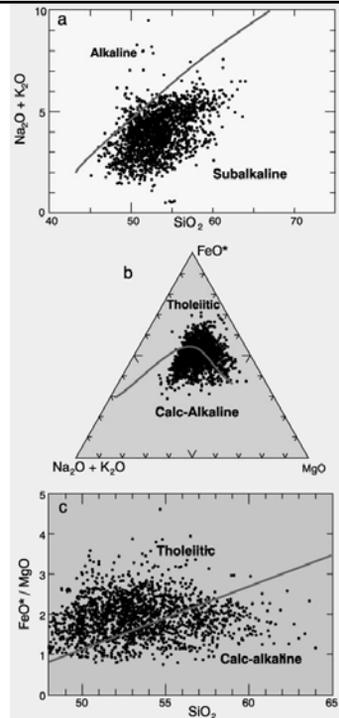
# Major Elements and Magma Series

- a. Alkali vs. silica
  - b. AFM
  - c.  $\text{FeO}^*/\text{MgO}$  vs. silica
- diagrams for 1946 analyses from ~ 30 island and continental arcs with emphasis on the more primitive volcanics.

## Conclusions:

1. Alkaline magmas are rare
2. Both tholeiitic and calc-alkaline magmas are present in volcanic arcs.

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



# Sub-series of Calc-Alkaline

- $\text{K}_2\text{O}$  is an important discriminator → 3 sub-series

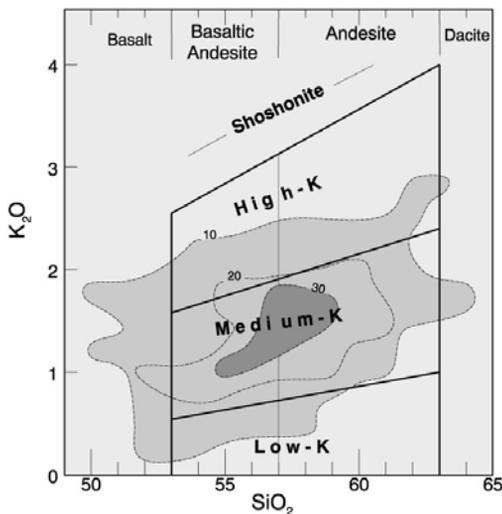
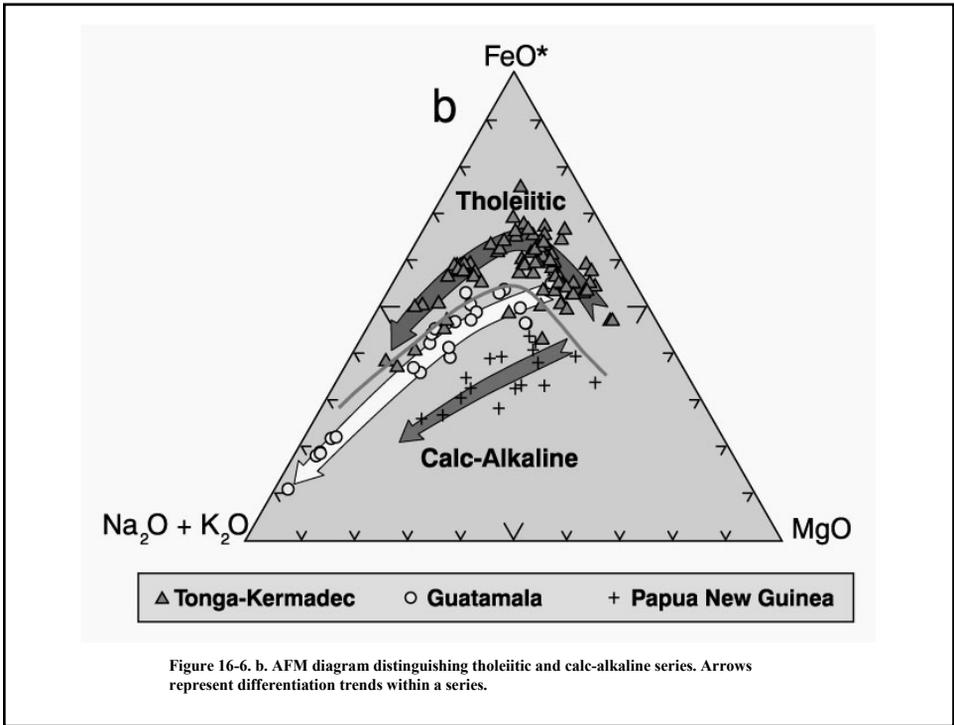
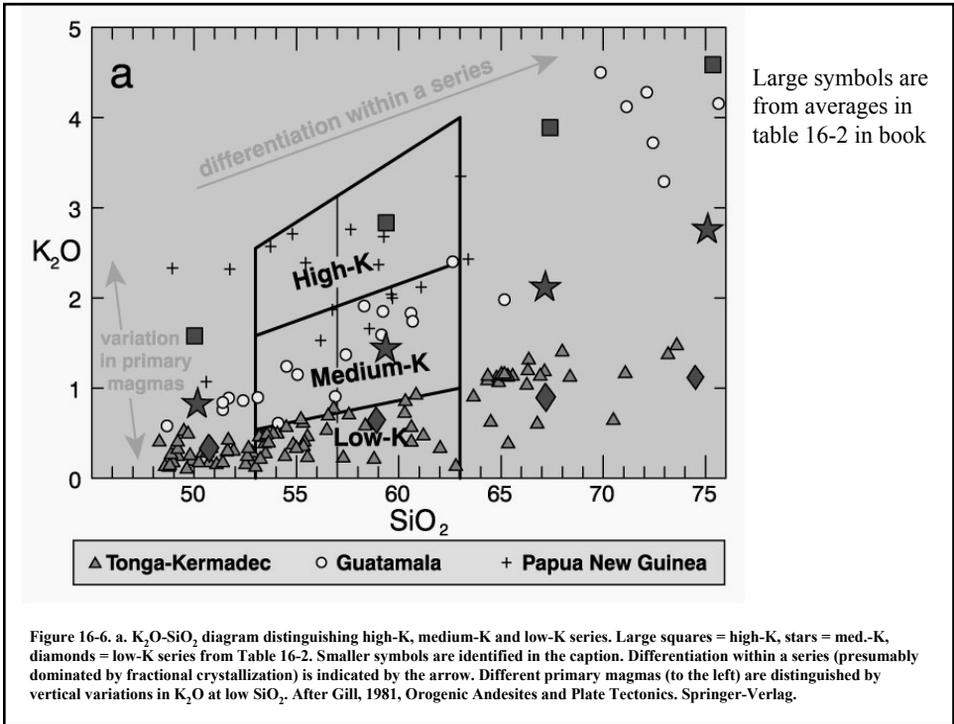


Figure 16-4. The three andesite series of Gill (1981) *Orogenic Andesites and Plate Tectonics*. Springer-Verlag. Contours represent the concentration of 2500 analyses of andesites stored in the large data file RKOC76 (Carnegie Institute of Washington).

Low-K are mostly tholeiites. Others are both tholeiites and calc-alkaline!



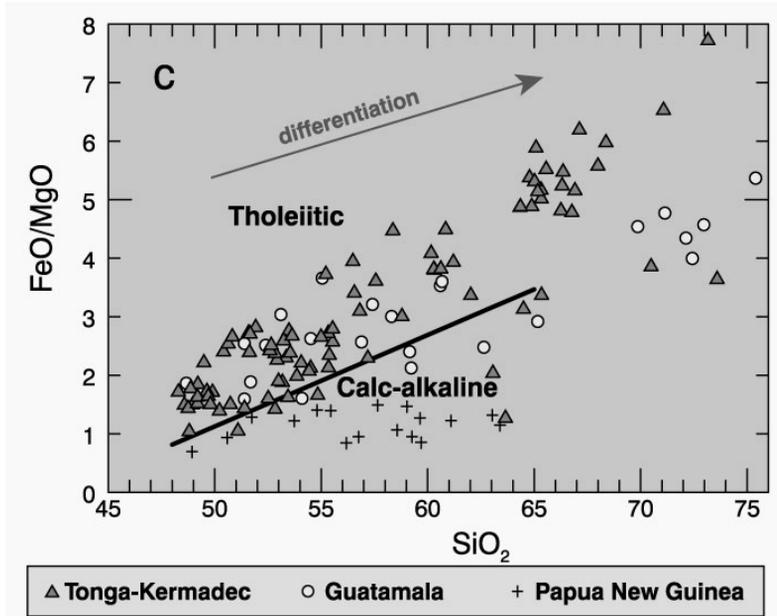


Figure 16-6. c.  $\text{FeO}^*/\text{MgO}$  vs.  $\text{SiO}_2$  diagram distinguishing tholeiitic and calc-alkaline series.

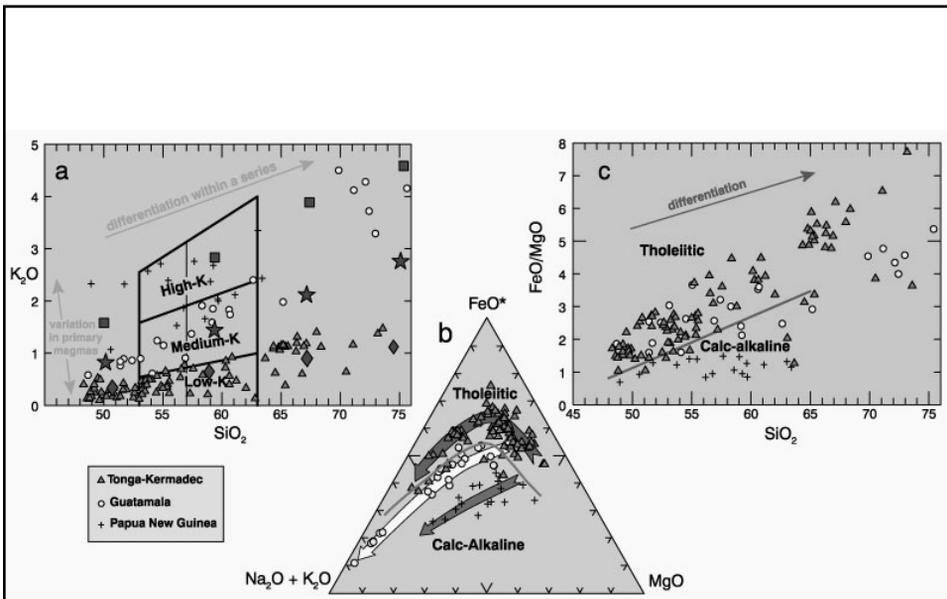
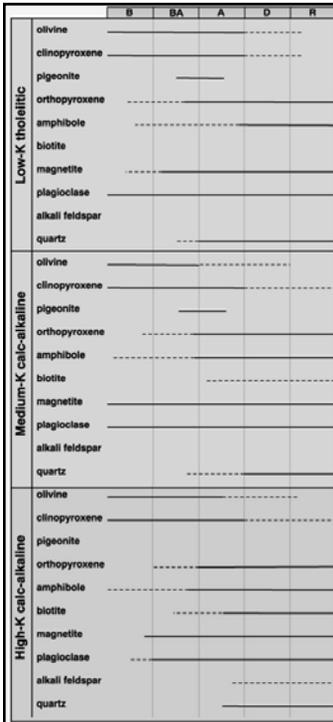


Figure 16-6. From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.



Island arc lavas are generally phyrlic (>20% phenocrysts)

Characteristic phenocryst mineralogy for the three main series

Typical crystallization sequence is:-  
 Ol + Cpx + Plag  
 Plag + Cpx + Opx  
 Plag + Cpx + Hbl  
 Plag + Hbl + Bio + Qtz  
 (magnetite can appear anywhere depending on oxygen fugacity)

Plag is typically more anorthitic ( $An_{50-70}$ ) than MORB or OIB (sometimes  $An_{90}$ )

## Tholeiitic vs. Calc-alkaline differentiation

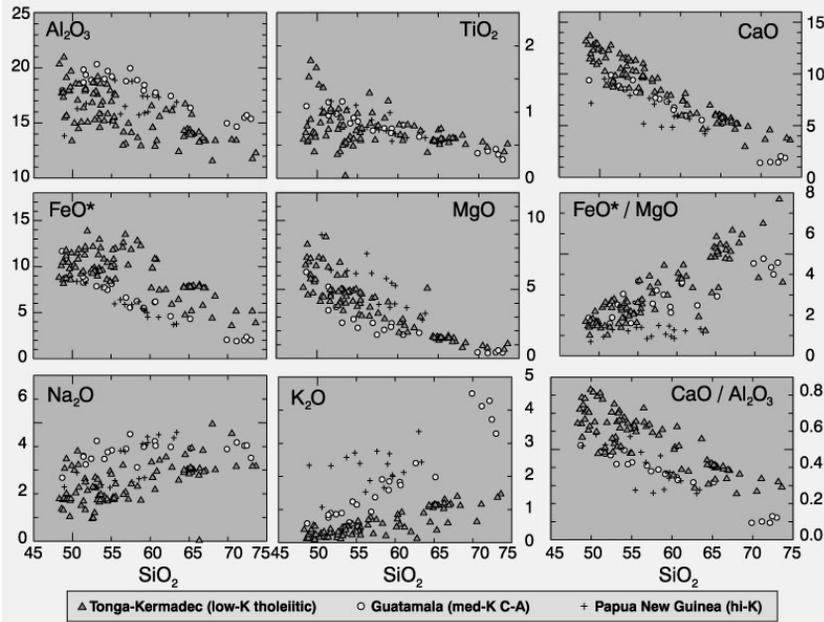
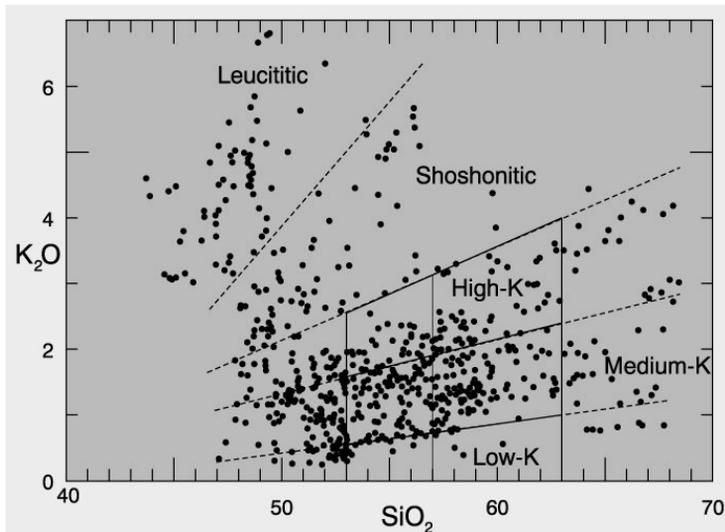


Figure 16-6. From Winter (2001) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

## 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  $\rightarrow$  high  $f_{O_2}$
- High water pressure also depresses the plagioclase liquidus and  $\rightarrow$  more An-rich
- As hydrous magma rises,  $\Delta P \rightarrow$  plagioclase liquidus moves to higher T  $\rightarrow$  crystallization of considerable An-rich-SiO<sub>2</sub>-poor plagioclase
- The crystallization of anorthitic plagioclase and low-silica, high-Fe hornblende is an alternative mechanism for the observed calc-alkaline differentiation trend



Variations in K<sub>2</sub>O – SiO<sub>2</sub> for the Sunda Arc, Indonesia  
In general K<sub>2</sub>O is related to the depth (h) to the Benioff Zone

Figure 16-8. K<sub>2</sub>O-SiO<sub>2</sub> diagram of nearly 700 analyses for Quaternary island arc volcanics from the Sunda-Banda arc. From Wheller et al. (1987) *J. Volcan. Geotherm. Res.*, 32, 137-160.

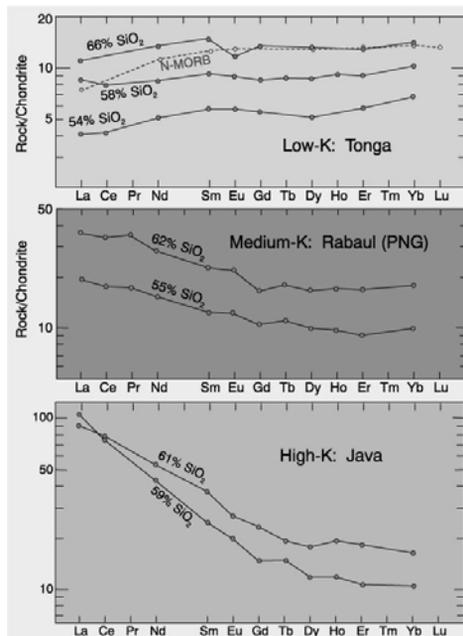
## Other Trends

- Spatial
  - ☞ “K-h”: low-K tholeiite near trench → C-A → alkaline as depth to seismic zone increases
  - ☞ Some along-arc as well
    - Antilles → more alkaline N → S
    - Aleutians is segmented with C-A prevalent in segments and tholeiite prevalent at ends
- Temporal
  - ☞ Early tholeiitic → later C-A and often latest alkaline is common

## What can we learn from the REE?

Within each of the 3 series, the patterns are similar but show increasing REE abundances with increasing  $\text{SiO}_2$

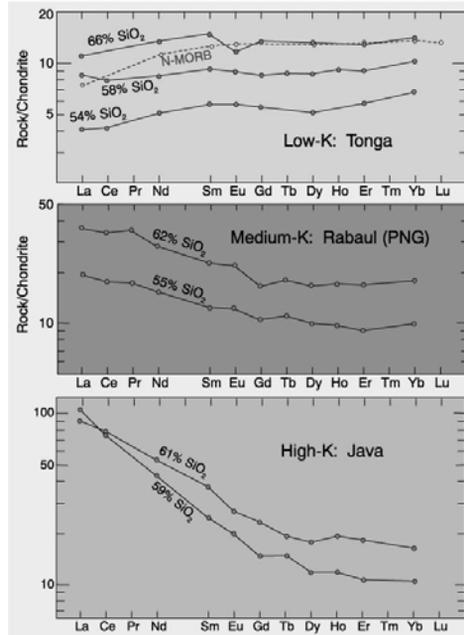
This is consistent with crystal fractionation involving Plag, Cpx, Olivine and possibly Magnetite



Note that the REE patterns of the three series are quite different, becoming steeper in LREE with increasing  $K_2O$ .

This implies different source compositions for the three series

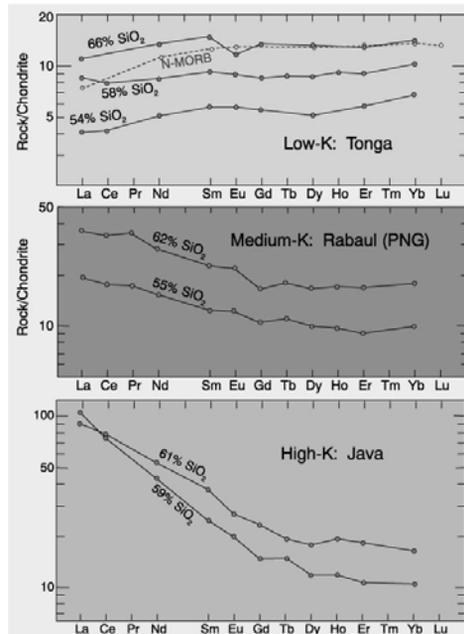
The Low-K series have patterns similar to N-MORB. However, the low  $SiO_2$  lavas have even lower concentrations than typical MORB (but not more depleted in LREE).



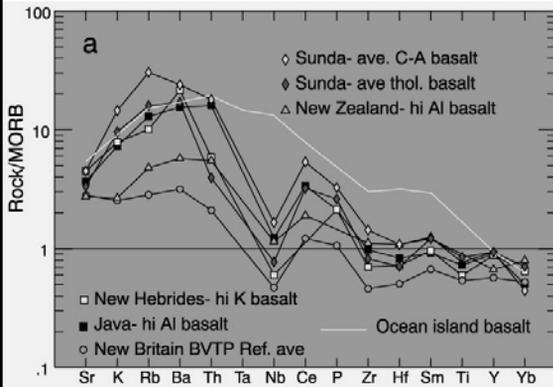
Note that the HREE are flat – ruling out the role of garnet in the source. Therefore shallow.

This also negates the idea that Island Arc magmas are simply produced by melting of oceanic basaltic crust (eclogite at > 100 km)

Eclogite = High P basalt (garnet plus pyroxene)



## MORB – Normalized Spider Diagram for Island Arc Basalts



(Why only basalts?)

Note that LIL elements (Sr, K, Rb, Ba) are decoupled from and higher than HFS elements (incl. REE)

OIB (yellow line) shown for comparison

LIL elements are hydrophilic (partition into hydrous fluids)

Note also characteristic negative Nb anomaly

Figure 16-11a. MORB-normalized spider diagrams for selected island arc basalts. Using the normalization and ordering scheme of Pearce (1983) with LIL on the left and HFS on the right and compatibility increasing outward from Ba-Th. Data from BVTP. Composite OIB from Fig 14-3 in yellow.

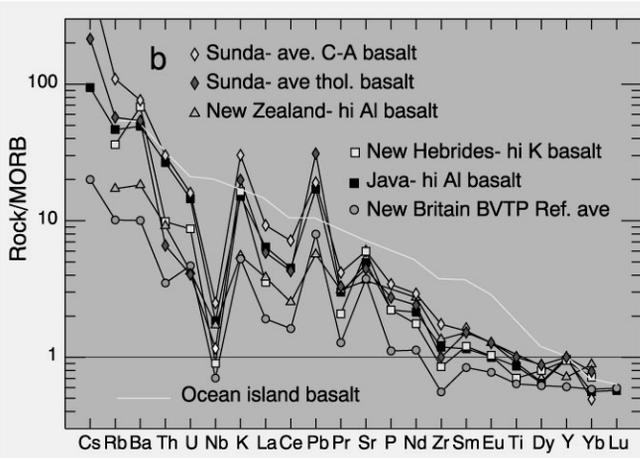


Figure 16-11b. MORB-normalized spider diagrams for selected island arc basalts. Using the normalization and ordering scheme of Sun and McDonough (1989) with increasing compatibility to the right. Data from BVTP. OIB data from Sun and McDonough (1989) In A. D. Saunders and M. J. Norry (eds.), *Magmatism in the Ocean Basins*. Geol. Soc. London Spec. Publ., 42, pp. 313-345.

Different scheme - same story! LIL elements (including Pb) form highs relative to adjacent HFS elements. Again confirming the importance of the role of fluids in subduction related magmatism.

## The Story So Far!

- Simple model of melting subducted oceanic crust appears untenable. Basalts are quite common, and HREE do not indicate role for garnet in melting eclogite (basalt crust).
- Flat HREE (similar to MORB) suggests involvement of shallow MORB mantle (peridotite).
- Elevated LIL (relative to HFS) implies involvement of fluids (water) in formation of arc magmas.