

# Petrogénesis y evolución magmática

## Clase 2

### Motivación

### Origen de los magmas

*Magmatismo y geodinámica*

*Procesos: decompression vs. flux melting*

*Subduction factory*

*Migración y ascenso de magmas*

### Diferenciación magmática

*MASH y Hot Zone*

*Procesos AFC*

### Evolución magmática y estilo eruptivo

### Lecturas complementarias

# Petrogénesis y evolución magmática

## Motivación

¿Cuál es el origen de la diversidad de los magmas?

¿Cómo se explica tal diversidad en un mismo ambiente tectónico e incluso en un mismo volcán?

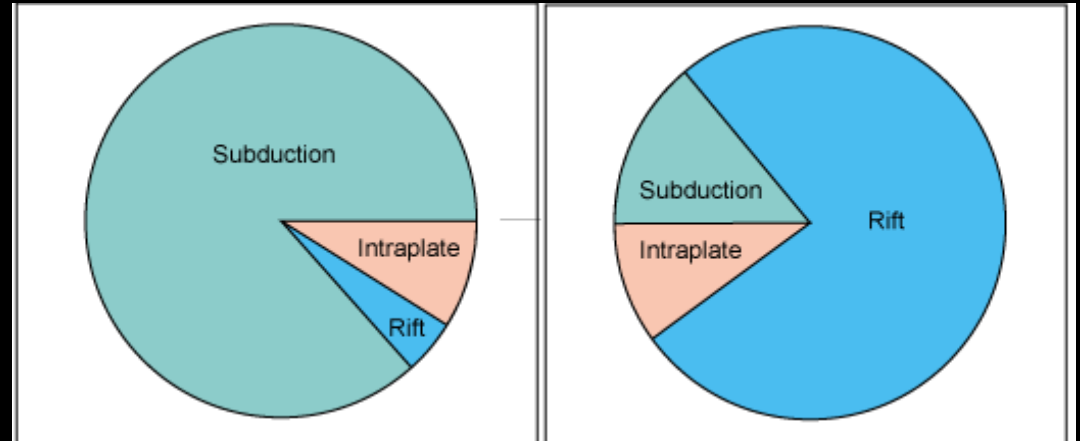
¿Cómo se relaciona la evolución magmática con el estilo eruptivo?

¿Es posible inferir las condiciones eruptivas a partir de las características geoquímicas?

# Petrogénesis y evolución magmática

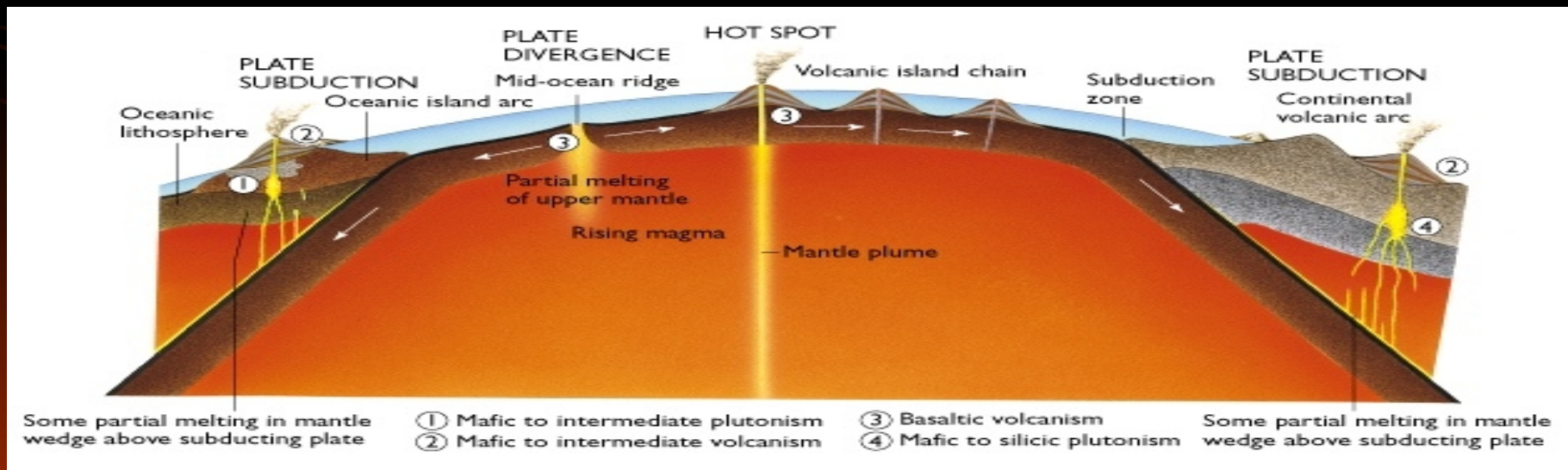
## Origen de los magmas

### Magmatismo y geodinámica



erupciones documentadas

volumen emitido



# Origen de los magmas

## Magmatismo y geodinámica: plumas y hot spots

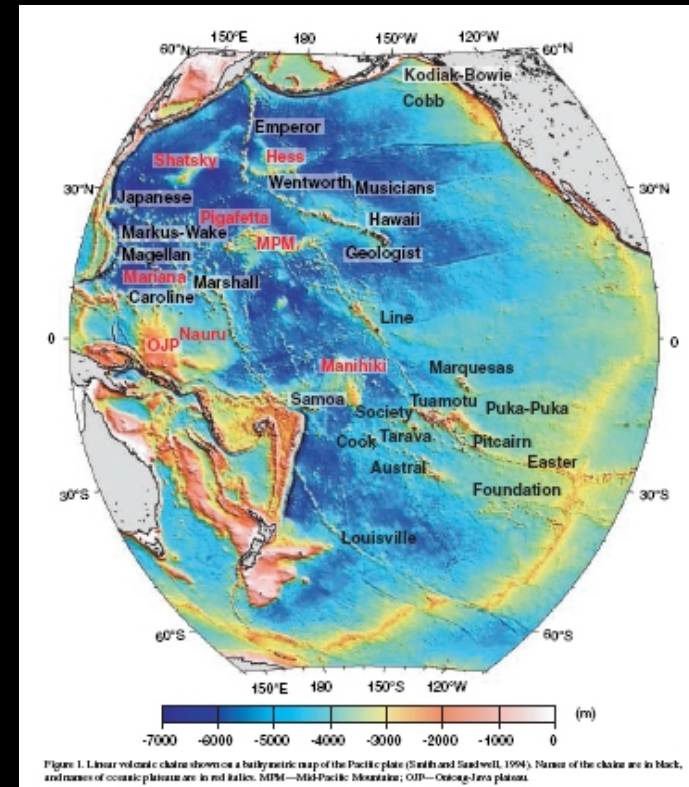
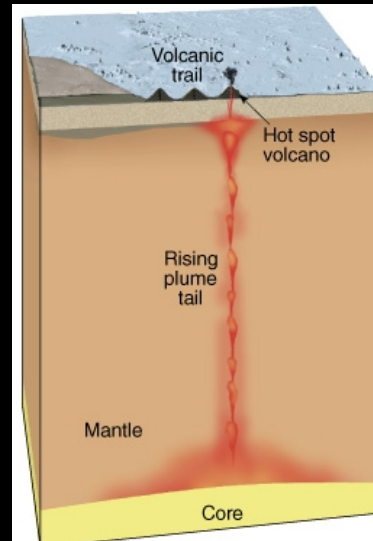
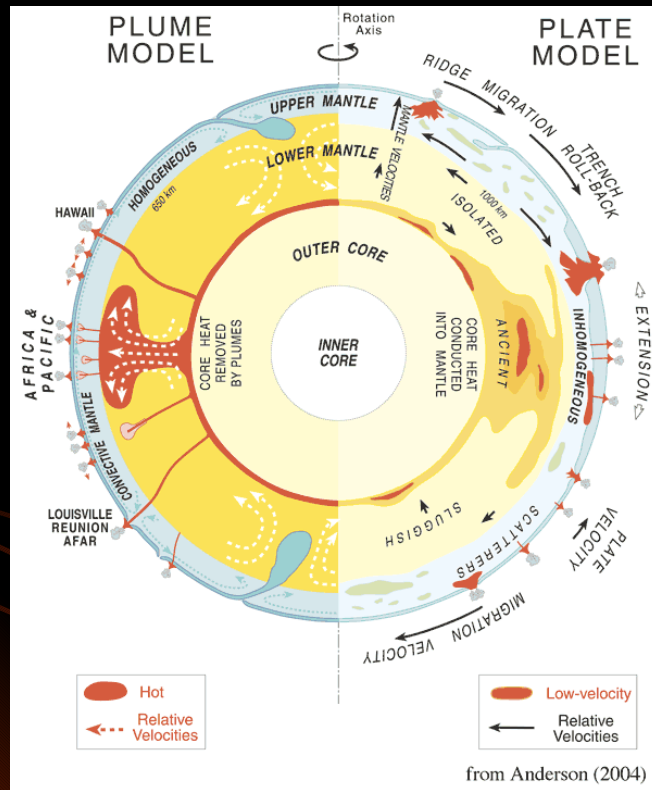
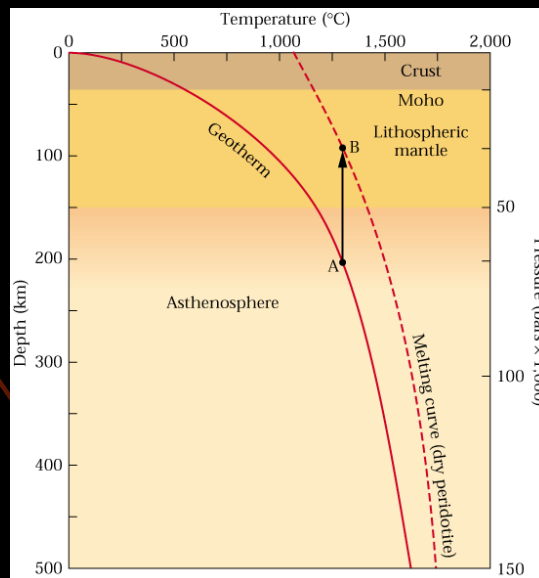
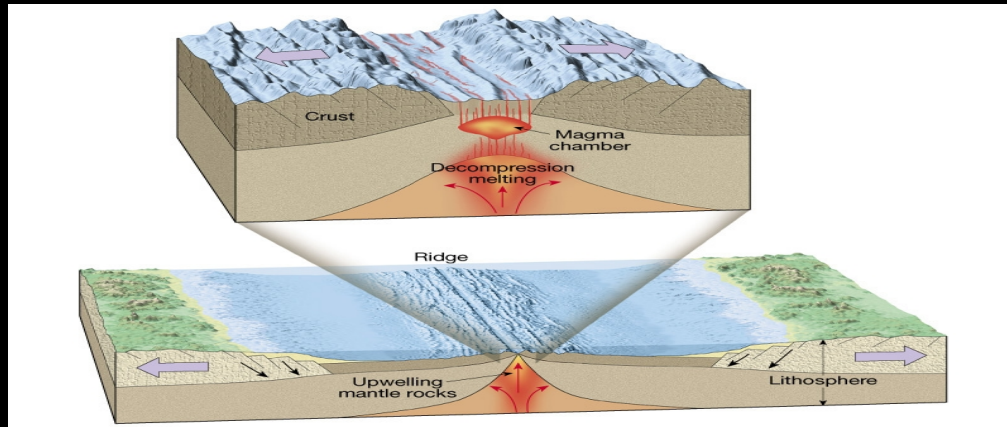


Figure 1. Linear volcanic chains shown on a bathymetric map of the Pacific plate (Smith and Sandwell, 1994). Names of the chains are in black, and names of oceanic plateaus are in red italics. MPM—Mid-Pacific Mountains; OJP—Oleau-Java plateau.

# Petrogénesis y evolución magmática

## Origen de los magmas

Procesos: decompression melting



Lithology	Estimated thickness m	Interpretation
Turbiditic graywacke and mudrocks	> 500	Deep-sea sediments
Tuff, schist, chert, carbonate rock	< 200	
Pillow breccia pillow basalt massive lava	> 300	Submarine eruptions
Locally no host rock, 100% mafic dikes, abundant interdikes gabbro and/or serpentinite	< 1000	Sheet dikes grading down into gabbro
Gabbro	> 100	
Serpentinite	> 1000	Meta-morphosed peridotite

Oceanic crust  
Upper mantle

(a)

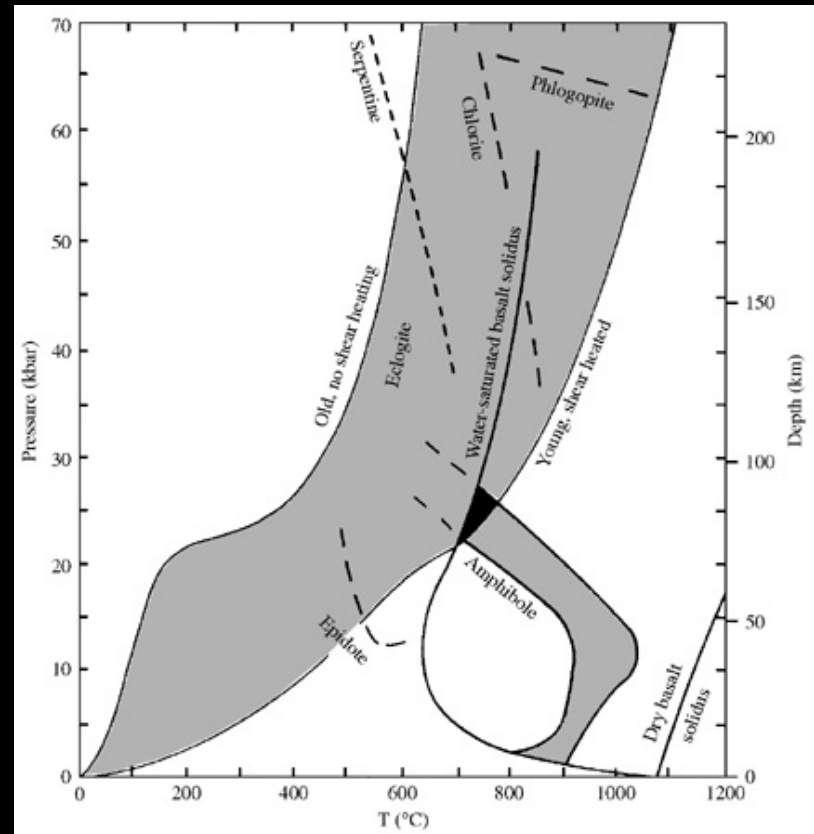
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# Petrogénesis y evolución magmática

## Origen de los magmas

Procesos: slab melting y 'adakitas'

- Fusión parcial de basaltos del slab
- Reducido campo P-T para fusión
- Solo slab 'jóvenes' (< 5 Ma)
- Magmas 'adakíticos' (alto Sr/Y; bajo Y, HREE)



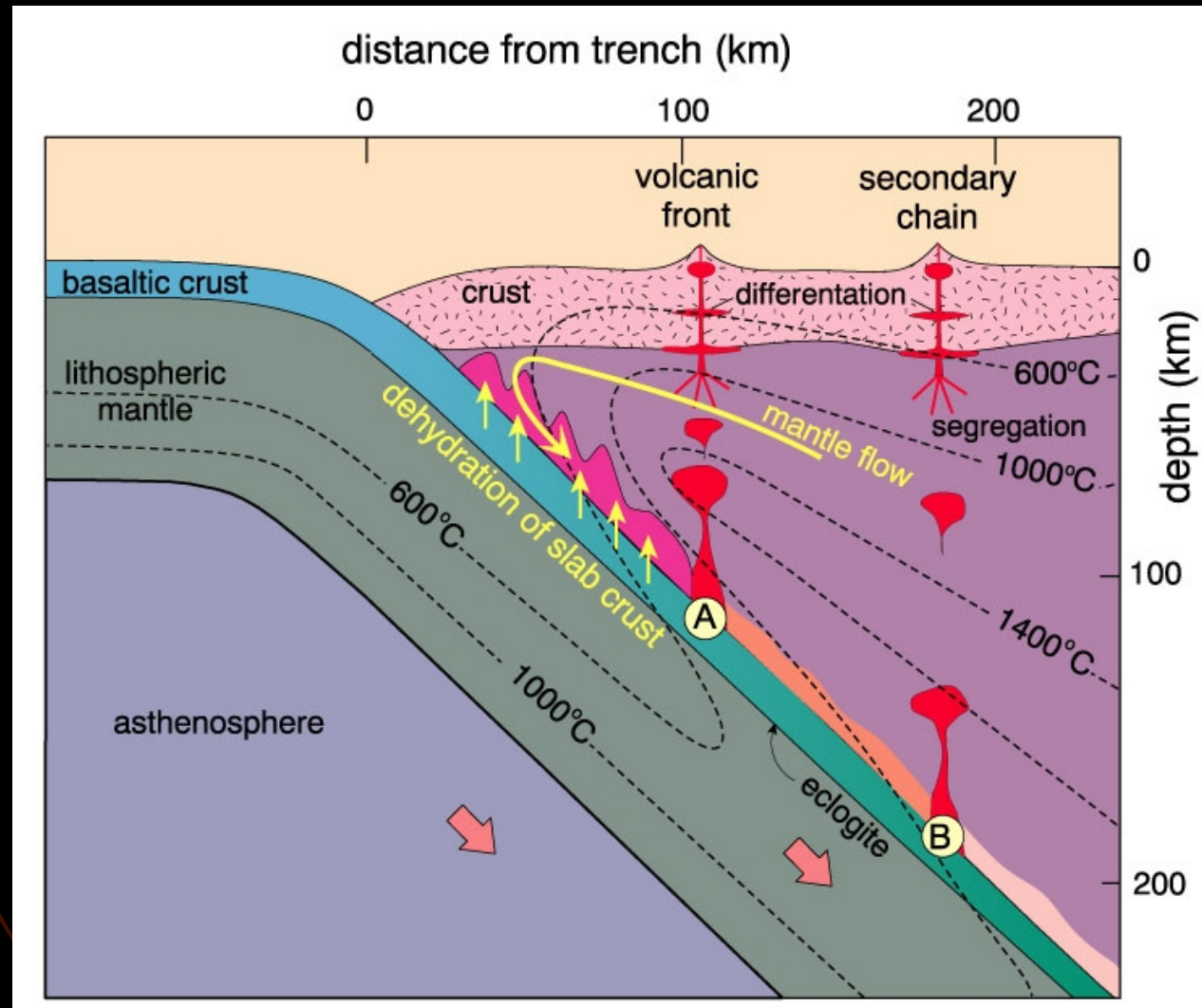
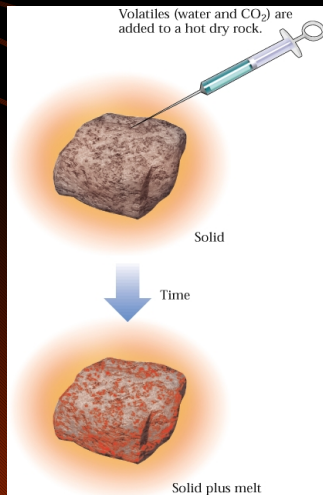


# Petrogénesis y evolución magmática

## Origen de los magmas

### Procesos: flux melting

Figure 16-11b. 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.



# Petrogénesis y evolución magmática

## Origen de los magmas

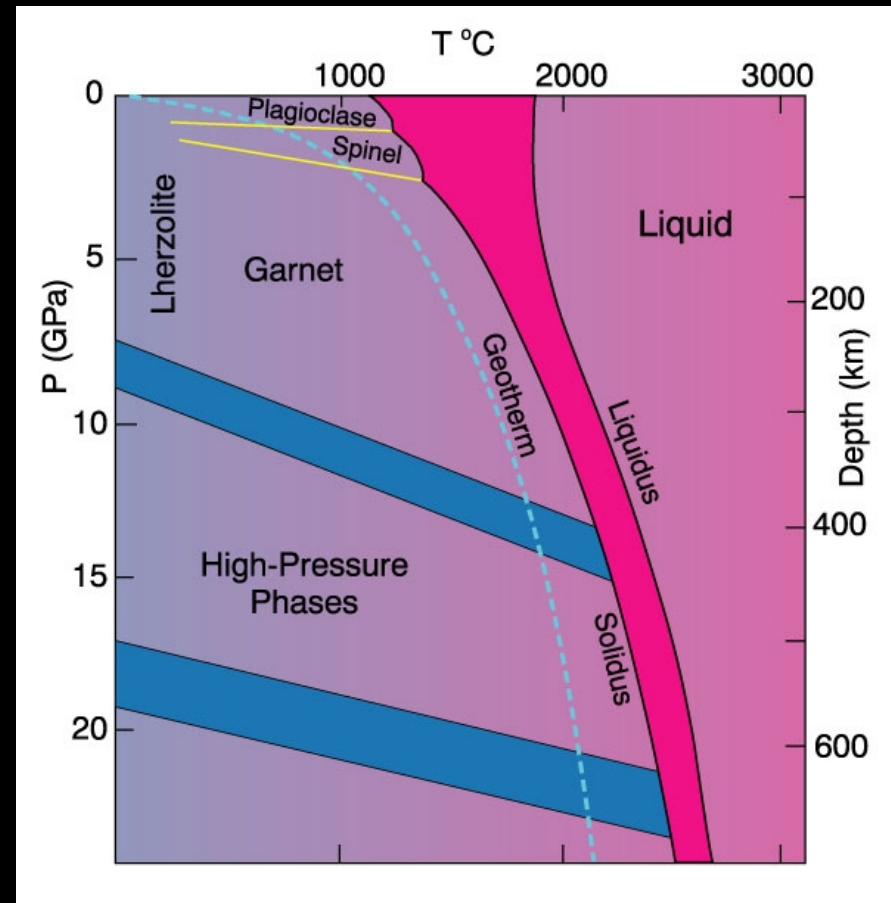
Procesos: fusión parcial del manto

## Manto fértil = lherzolita de 4 fases

(Ol + Opx + Cpx + Al-rich phase)

Al-phase is P sensitive

- Plagioclase
  - ♦ shallow (<30 km)
- Spinel
  - ♦ 30-70 km
- Garnet
  - ♦ >70 km





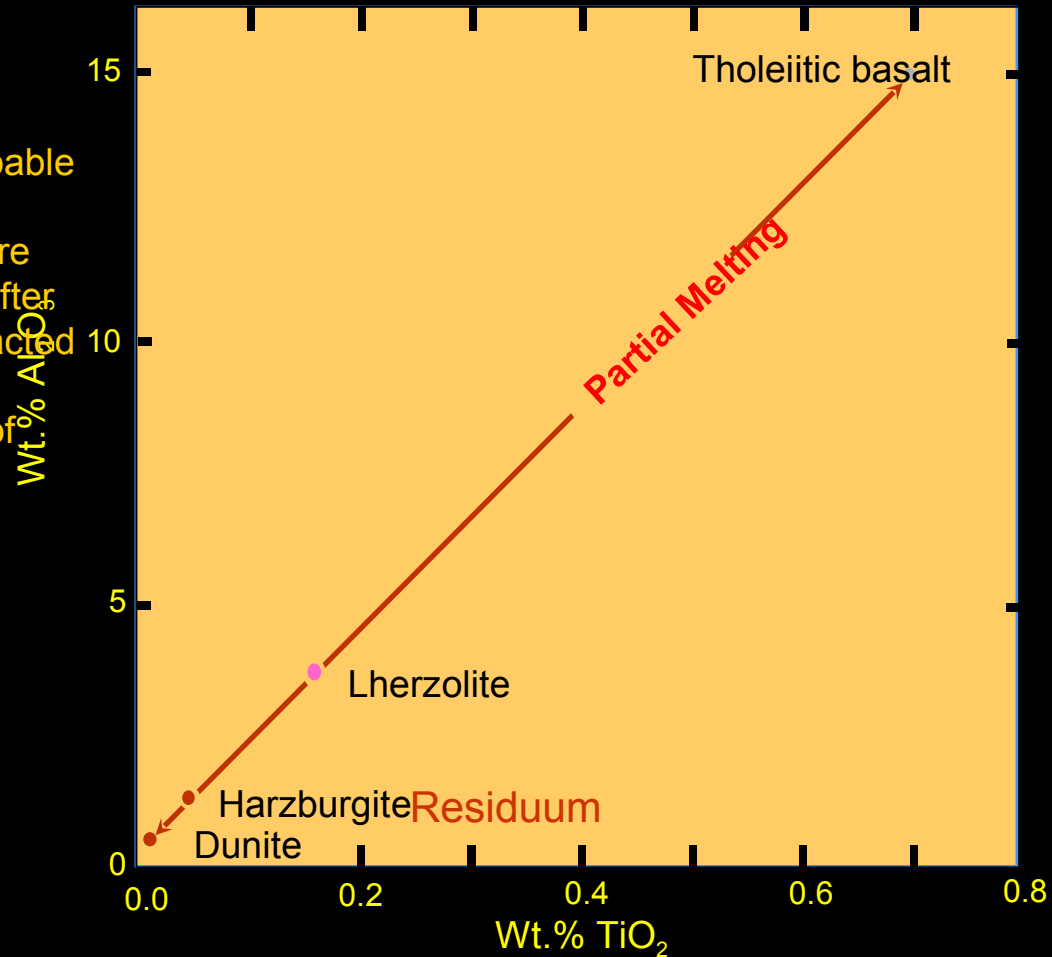
# Petrogénesis y evolución magmática

## Origen de los magmas

Procesos: fusión parcial del manto

Lherzolite is considered  
“fertile” mantle  $\Rightarrow$  capable  
of producing basalt

Dunite and harzburgite are  
refractory residuum after  
basalt has been extracted  
by partial melting  $\Rightarrow$   
“infertile”, incapable of  
producing basalt



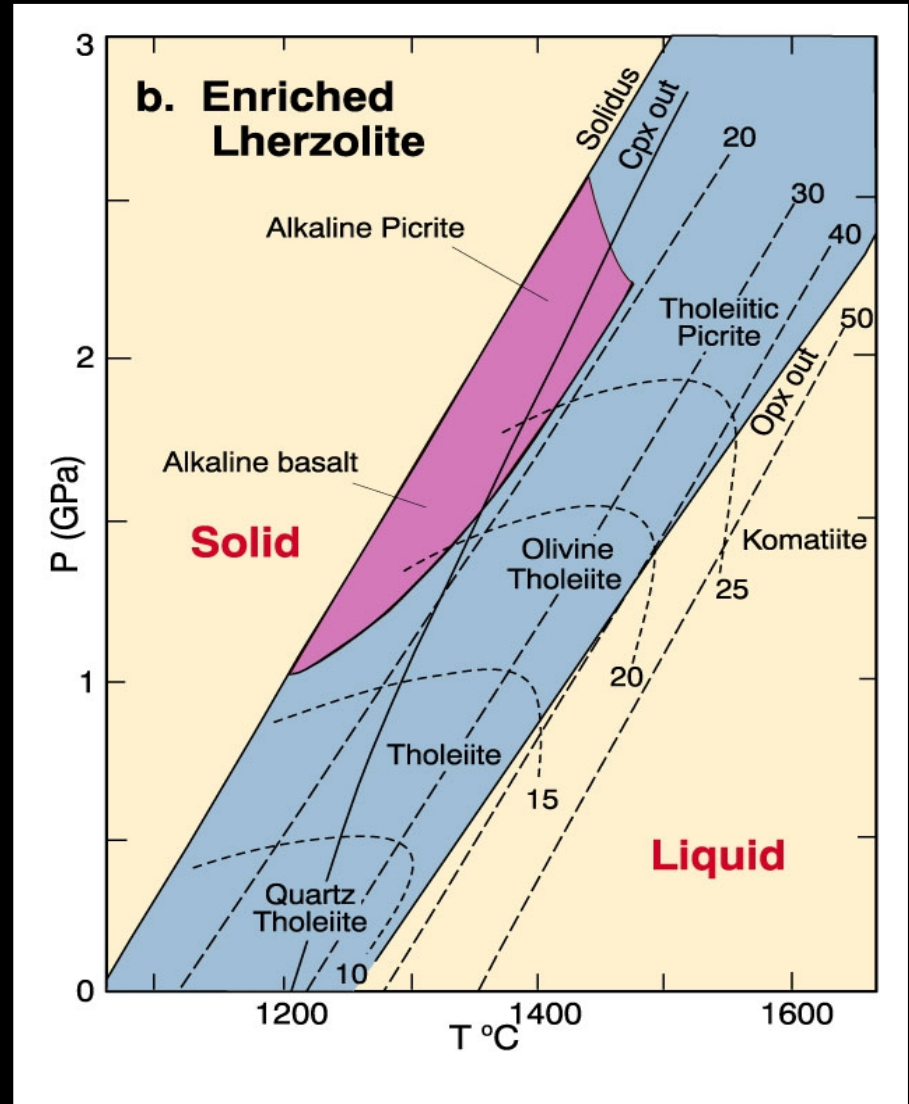
# Petrogénesis y evolución magmática

## Origen de los magmas

Procesos: fusión parcial del manto

- Tholeiites are lower pressure and larger % of partial melting
- Alkaline basalts are higher pressure and smaller % of partial melting

Figure 10-17b. Results of partial melting experiments on fertile lherzolites. Dashed lines are contours representing percent partial melt produced. Strongly curved lines are contours of the normative olivine content of the melt. "Opx out" and "Cpx out" represent the degree of melting at which these phases are completely consumed in the melt. The shaded area represents the conditions required for the generation of alkaline basaltic magmas. After Jaques and Green (1980). Contrib. Mineral. Petrol., 73, 287-310.

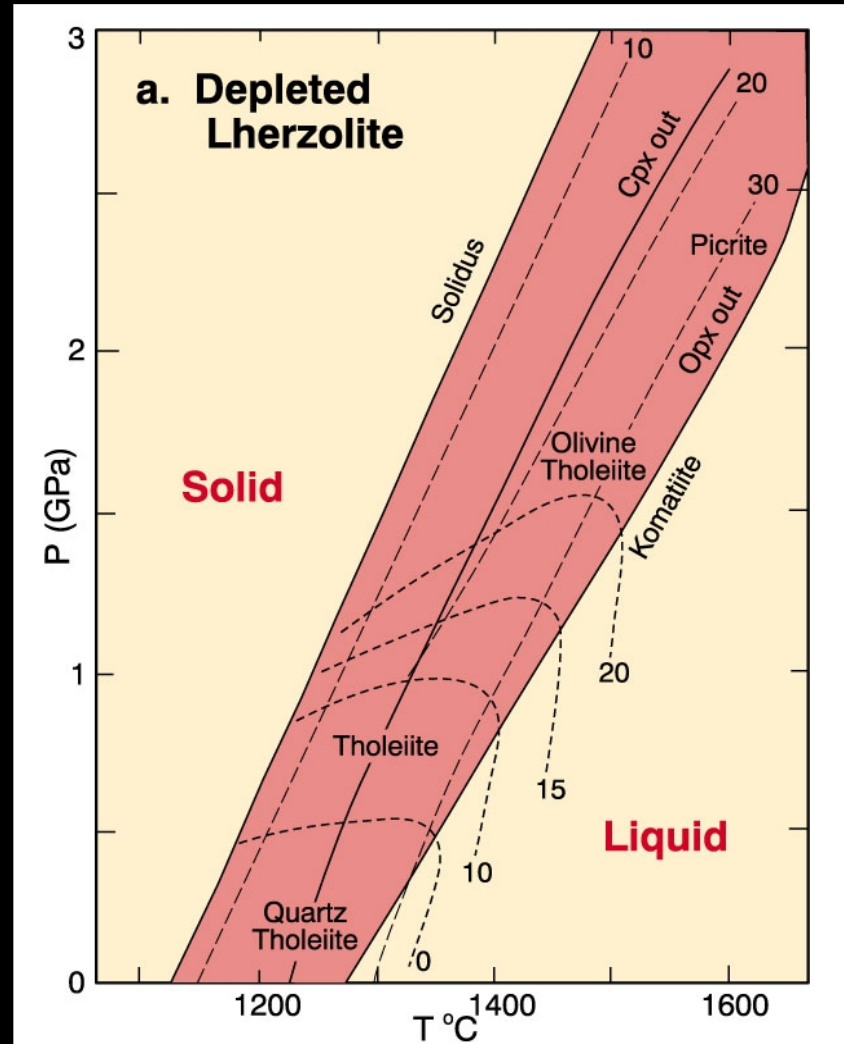


# Petrogénesis y evolución magmática

## Origen de los magmas

Procesos: fusión parcial del manto

Figure 10-17a. Results of partial melting experiments on depleted lherzolites. Dashed lines are contours representing percent partial melt produced. Strongly curved lines are contours of the normative olivine content of the melt. "Opx out" and "Cpx out" represent the degree of melting at which these phases are completely consumed in the melt. After Jaques and Green (1980). Contrib. Mineral. Petrol., 73, 287-310.

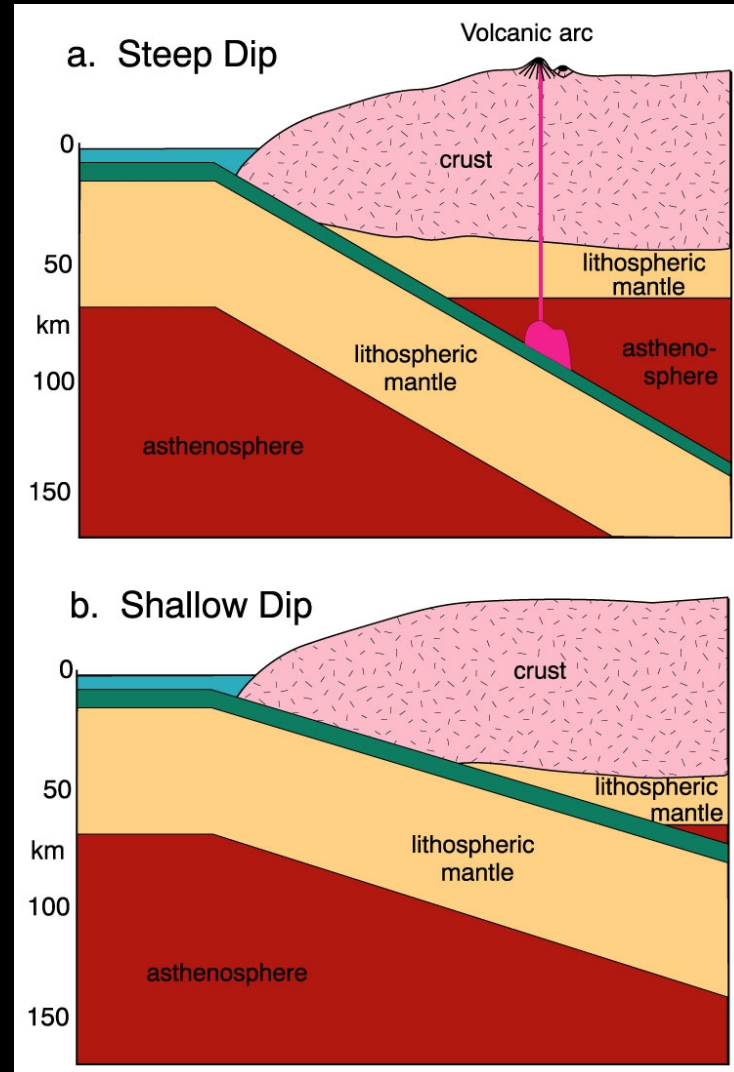


# Petrogénesis y evolución magmática

## Origen de los magmas

Procesos: subduction factory

**Figure 17-2.** Schematic diagram to illustrate how a shallow dip of the subducting slab can pinch out the asthenosphere from the overlying mantle wedge. Winter (2001) *An Introduction to Igneous and Metamorphic Petrology*. Prentice Hall.

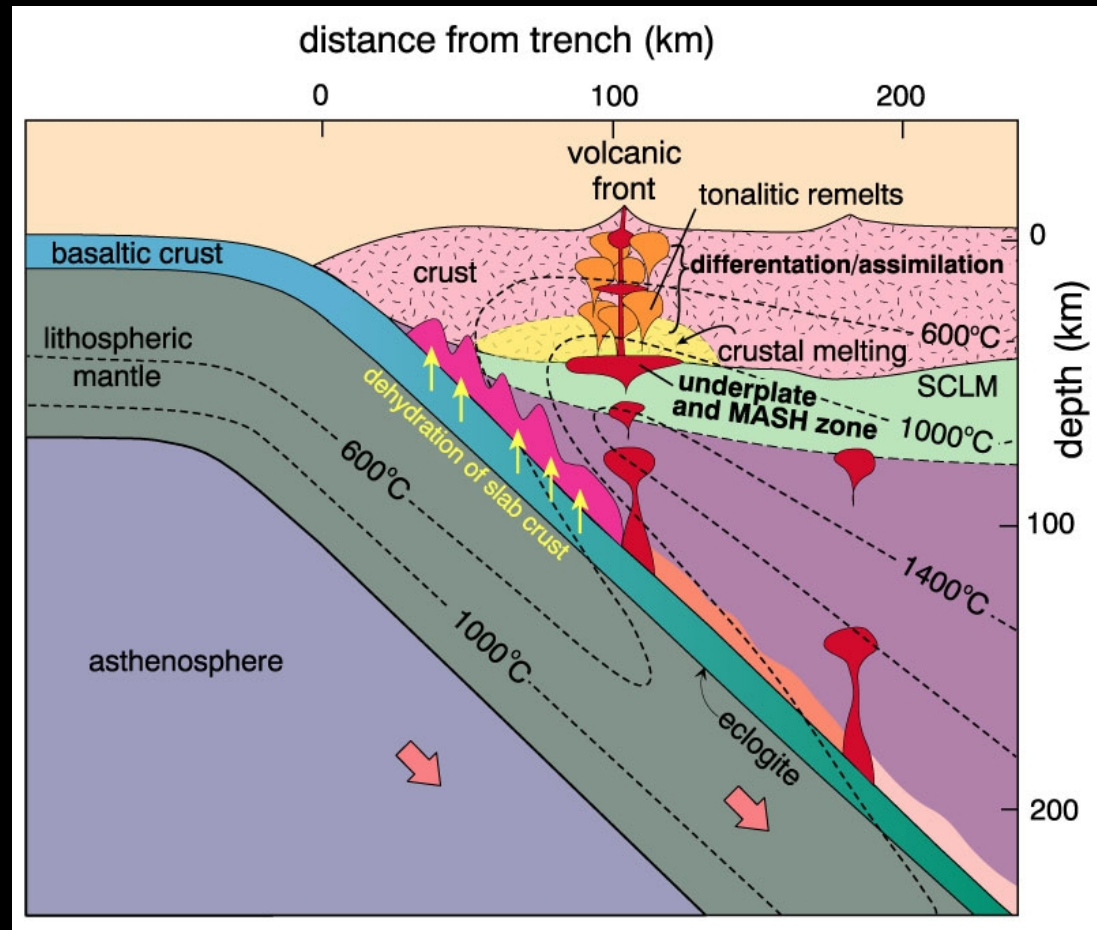


# Petrogénesis y evolución magmática

## Origen de los magmas

Procesos: subduction factory

**Figure 17-23.** Schematic cross section of an active continental margin subduction zone, showing the dehydration of the subducting slab, hydration and melting of a heterogeneous mantle wedge (including enriched sub-continental lithospheric mantle), crustal underplating of mantle-derived melts where MASH processes may occur, as well as crystallization of the underplates. Remelting of the underplate to produce tonalitic magmas and a possible zone of crustal anatexis is also shown. As magmas pass through the continental crust they may differentiate further and/or assimilate continental crust. Winter (2001) *An Introduction to Igneous and Metamorphic Petrology*. Prentice Hall.

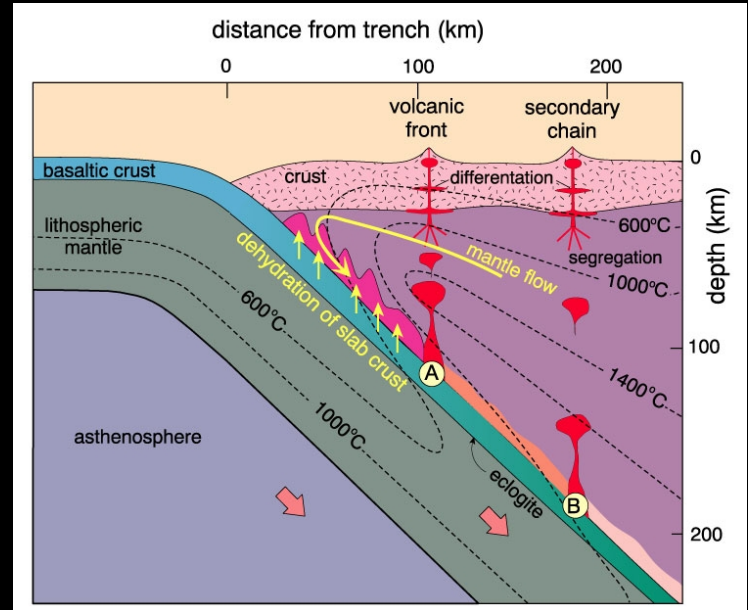
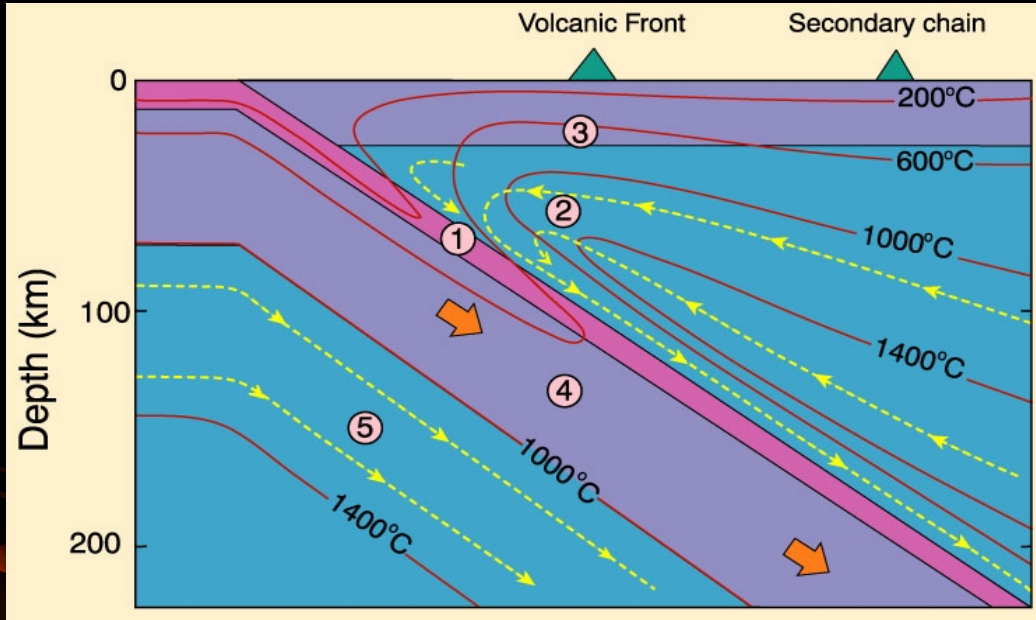




# Petrogénesis y evolución magmática

## Origen de los magmas

Procesos: subduction factory



## Lectura complementaria:

Hacker et al., 2004: Subduction factory 2: Are intermediate-depths earthquakes in subducting slabs linked to metamorphic dehydration reactions?. *Journal of Geophysical Research* 108, B1: 2030

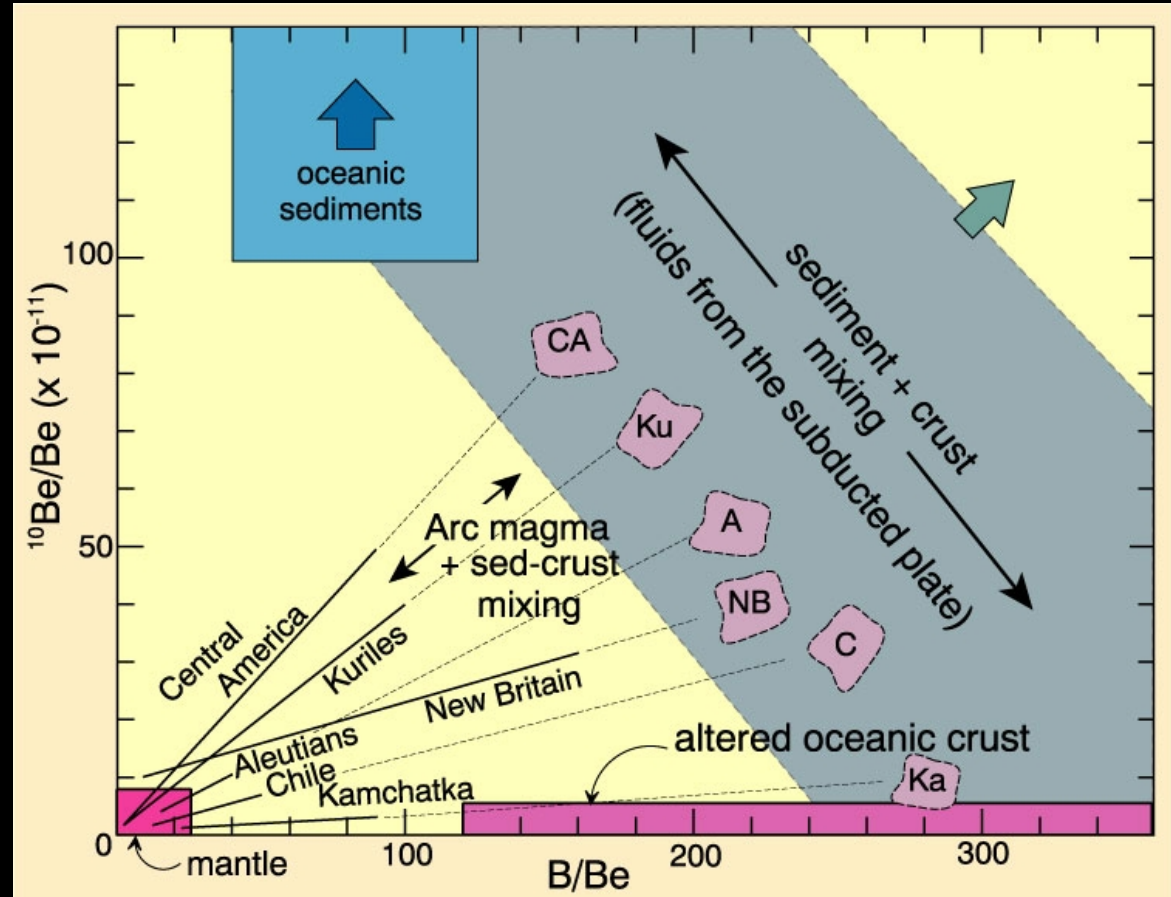
# Petrogénesis y evolución magmática

## Origen de los magmas

Procesos: subduction factory

**Figure 16-14.**

$^{10}\text{Be}/\text{Be}(\text{total})$  vs.  $\text{B}/\text{Be}$   
for six arcs. After  
Morris (1989) *Carnegie  
Inst. of Washington  
Yearb.*, 88, 111-123.



# Petrogénesis y evolución magmática

## Origen de los magmas

Procesos: migración y ascenso

....Flujo en medios porosos, microfracturas y diques...detalles más adelante

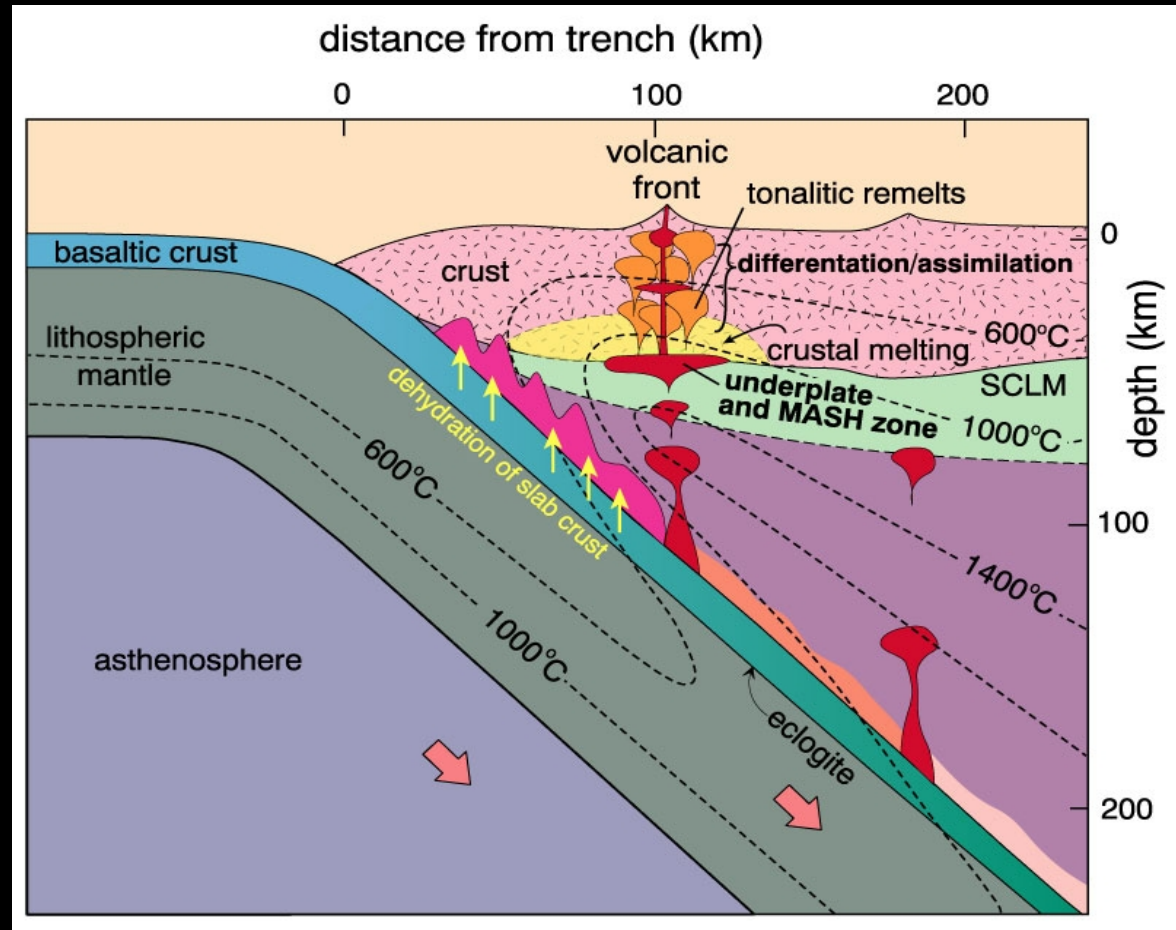
Lectura complementaria:

*Davies, J.H. 1999. The role of hydraulic fractures and intermediate-depth earthquakes in generating subduction-zone magmatism. Nature 398: 142-145*

# Petrogénesis y evolución magmática

## Diferenciación magmática

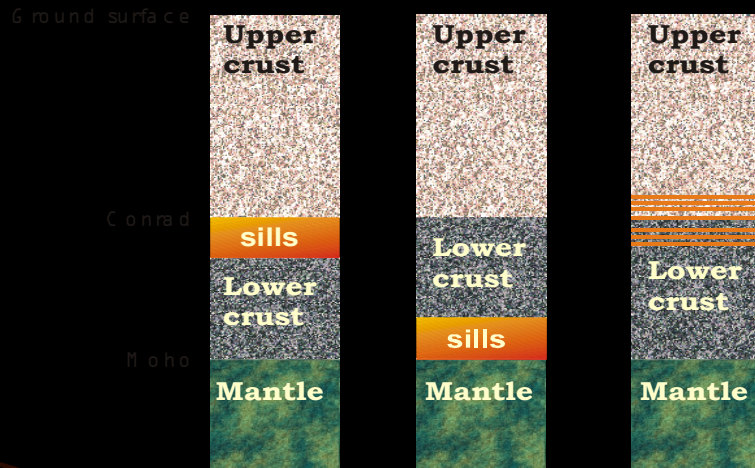
### MASH zone



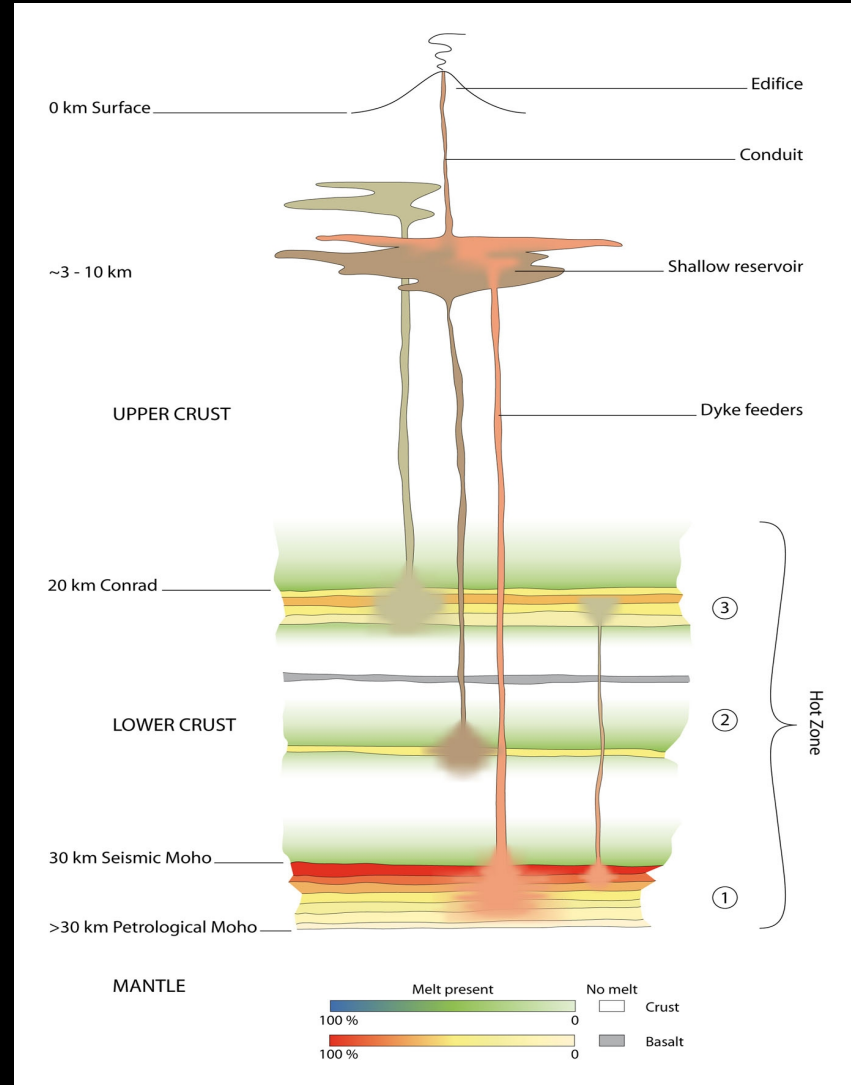
# Petrogénesis y evolución magmática

## Diferenciación magmática

### HOT zone



- Basalt sills intrude into crust and thermally equilibrate with geotherm
- At depths with temperatures above wet basalt solidus residual melts are formed
- Transfer of heat and volatiles from basalt to older crustal rocks causes partial melting
- Most magma differentiation occurs in deep crust where the geotherm exceeds solidus
- Residual melts and partial melts segregate and ascent into shallow crust to form ephemeral magma chambers, plutons or immediately erupt



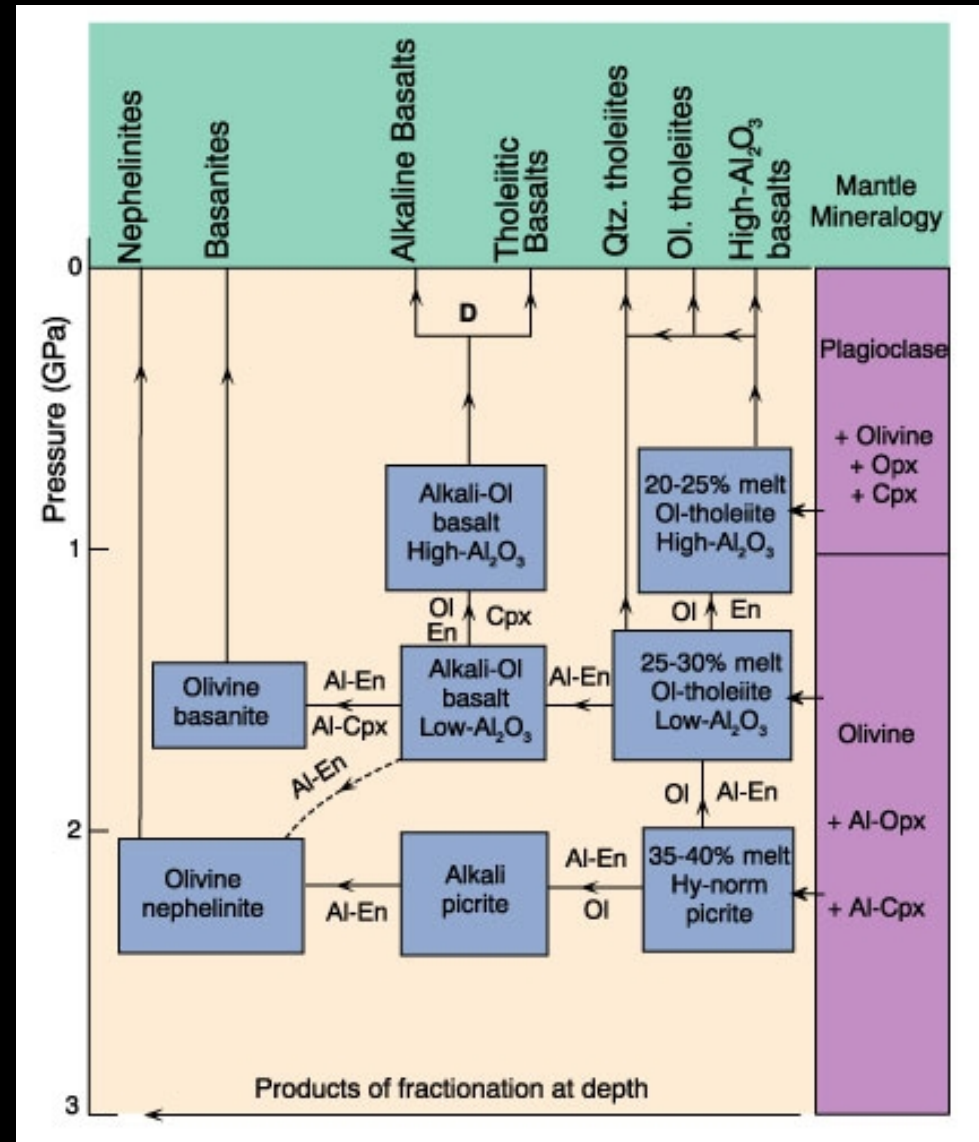


# Petrogénesis y evolución magmática

## Diferenciación magmática

### Cristalización fraccionada

- Tholeiite to alkaline  
by FX at med to high P
- Not at low P
  - ♦ Thermal divide
- Al in pyroxenes at Hi P
  - ♦ Low-P FX □ hi-Al shallow magmas ("hi-Al" basalt)

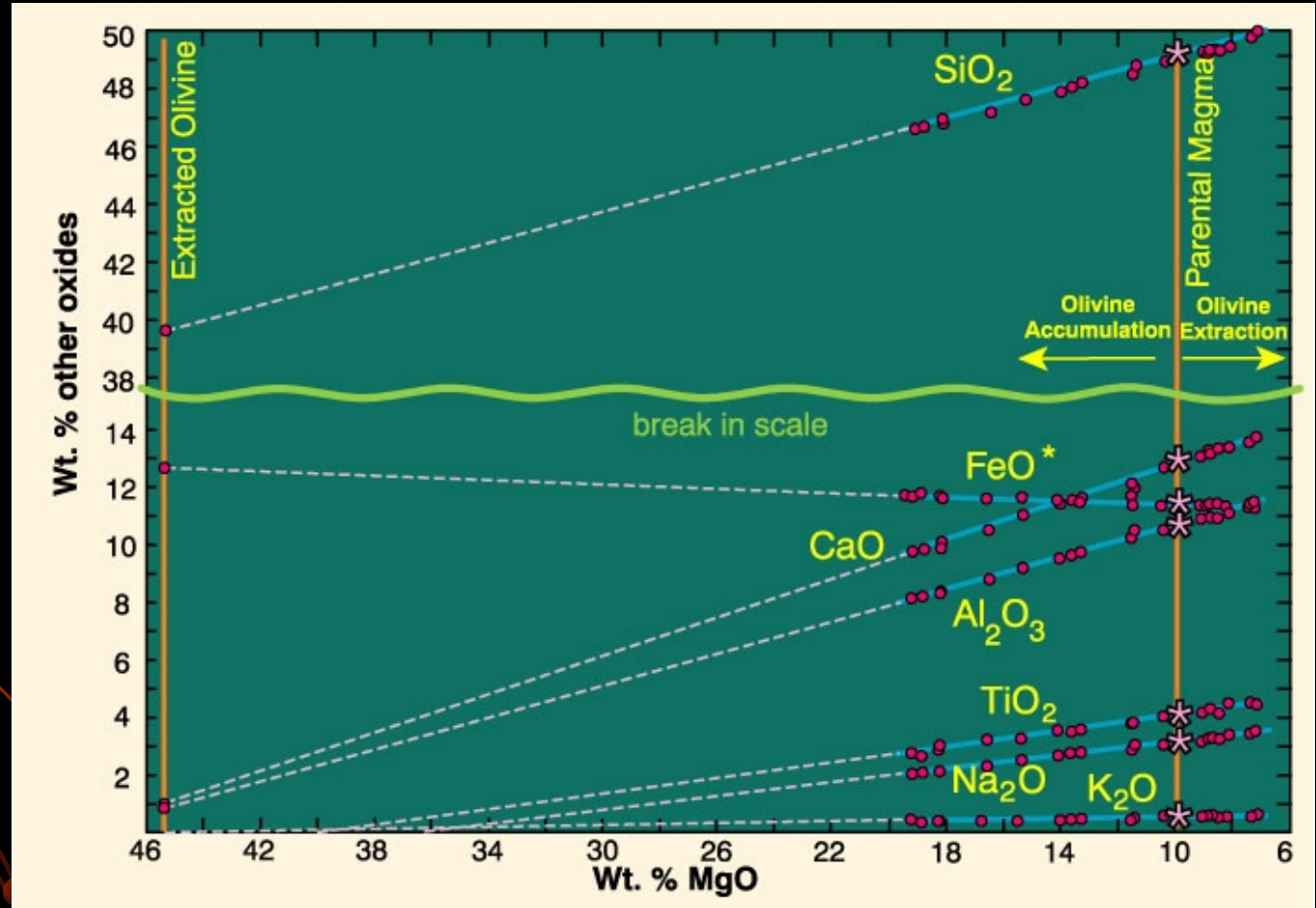


**Figure 10-10** Schematic representation of the fractional crystallization scheme of Green and Ringwood (1967) and Green (1969). After Wyllie (1971). *The Dynamic Earth: Textbook in Geosciences*. John Wiley & Sons.

# Petrogénesis y evolución magmática

## Diferenciación magmática

### Cristalización fraccionada



**Figure 11-2** Variation diagram using MgO as the abscissa for lavas associated with the 1959 Kilauea eruption in Hawaii. After Murata and Richter, 1966 (as modified by Best, 1982)

# Petrogénesis y evolución magmática

## Evolución magmática y estilo eruptivo

Soufriere Hills, Montserrat (tomado de R.S.J. Sparks)

### Some Observations:



SHV has erupted monotonous porphyritic hornblende andesite domes for >330 ka

Magma sits on U series equiline indicating long magma residence time(>10<sup>5</sup> yrs)

Volcanism highly episodic with short periods of dome extrusion (10<sup>2</sup>-10<sup>3</sup> yrs) alternating with large (>>10<sup>4</sup> yr gaps)

Crystal diffusion age and <sup>210</sup>Pb data indicate magma residence in upper crust very short (10<sup>1</sup> to <10<sup>3</sup> years)

Historic volcano-seismic crises suggest current magma chamber <<10<sup>3</sup> yrs





# Petrogénesis y evolución magmática

## Evolución magmática y estilo eruptivo

SHV Magma:

Plag-amph-opx-oxide

55-60% phenocrysts

Resorbed quartz

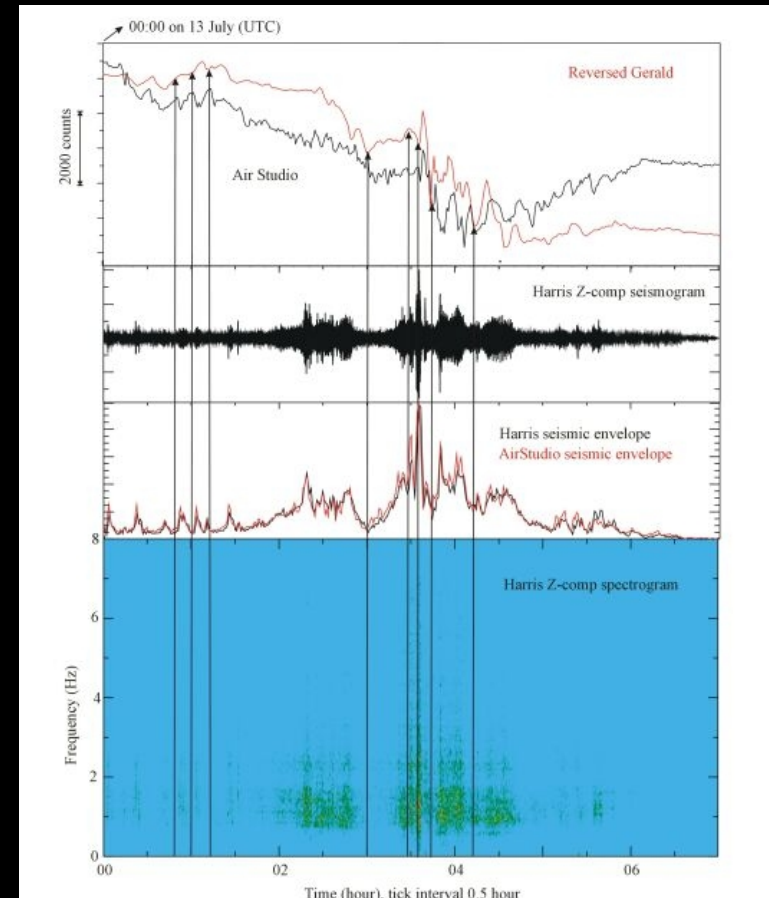
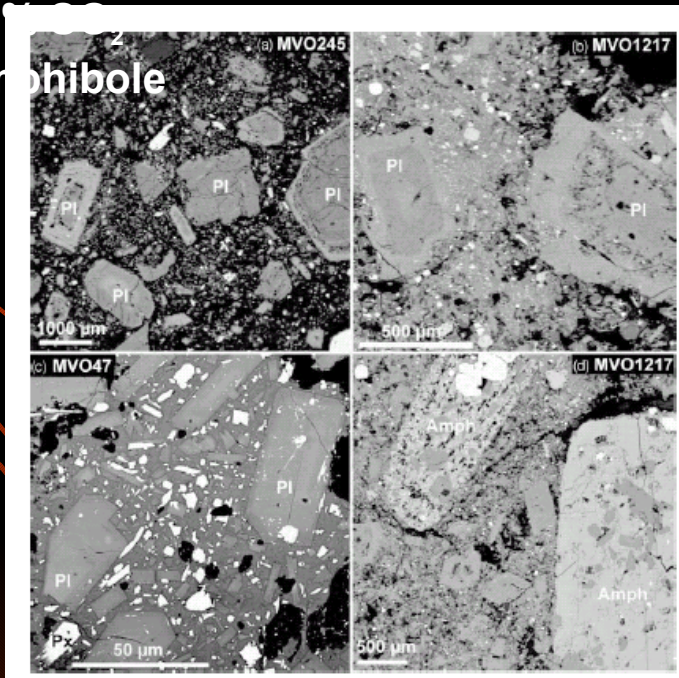
Rhyolite melt ( $\text{SiO}_2 > 73\%$ )

1-2% basaltic inclusions

830 to 870°C

>5% water; 5%

REE data: amphibole

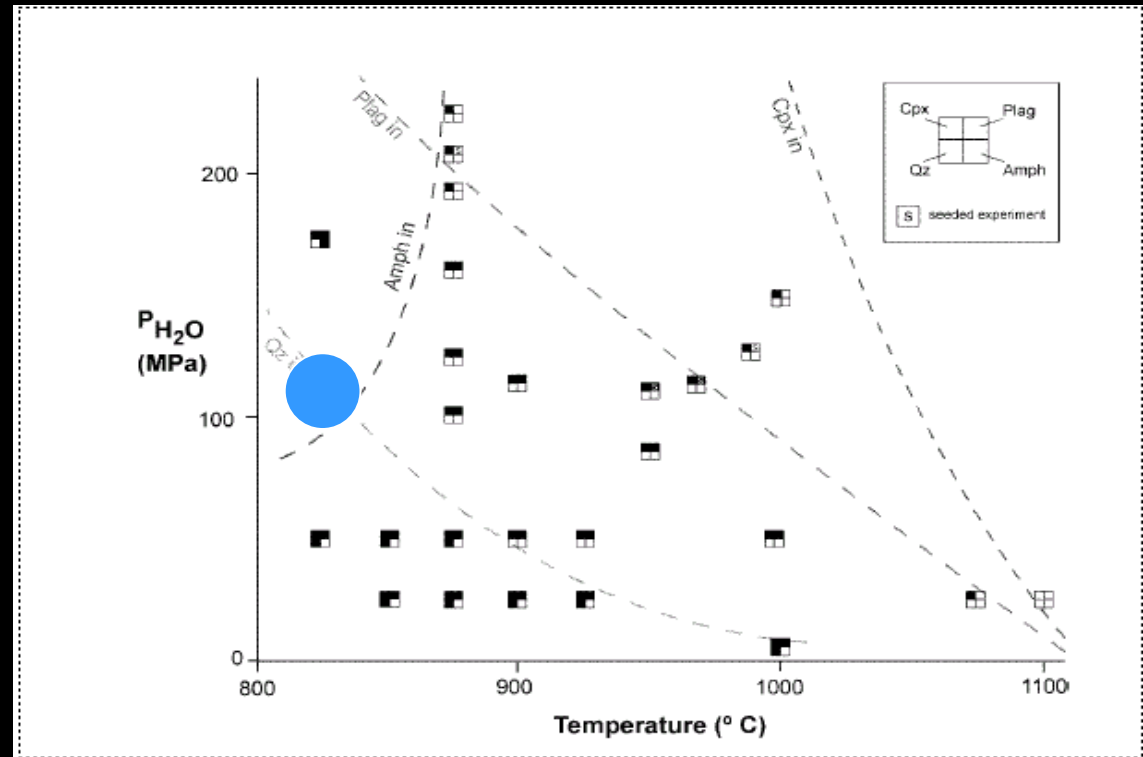


Chamber depth 5.5 km  
Chamber volume 4 km<sup>3</sup>  
Bubbles ~3%

# Petrogénesis y evolución magmática

## Evolución magmática y estilo eruptivo

Phase equilibria studies show difficulty of generating SHV andesite by low pressure fractionation of arc basalt



*andesite originates as from deep crust hot zone as residual melt from wet arc basalt*



# Petrogénesis y evolución magmática

## Evolución magmática y estilo eruptivo

Soufriere Hills, Montserrat (*tomado de R.S.J. Sparks*)

### Model for generation of andesite at SHV (parte I)

- Primitive wet arc basalt intrudes into deep crust at  $\sim 1050^{\circ}\text{C}$  on geotherm (Moho at 30 km?) and crystallises (ol + cpx) to generate evolved wet basalt (MgO $\sim 5\%$ ,  $>5\%$  water)

**CONSISTENT WITH MAFIC INCLUSIONS, BASALTIC LAVAS ON MONSERRAT**

- Evolved basalt intrudes into deep crust at  $\sim 900^{\circ}\text{C}$  depth on geotherm, cools and generates andesitic residual melt by crystallization of plag-amphibole

**CONSISTENT WITH REE DATA, HORNBLENDE GABBRO NODULES AND SEISMIC VELOCITIES OF ARC LOWER CRUST**

- Residual andesite melt has high water content ( $\sim 10\%$ ) and large excess  $\text{SO}_2$  originating from basalt parent.

**CONSISTENT WITH GEOPHYSICAL DATA ON STRAIN RESPONSE TO LARGE DOME COLLAPSE AND EXCESS  $\text{SO}_2$  EMISSIONS**

# Petrogénesis y evolución magmática

## Evolución magmática y estilo eruptivo

Soufriere Hills, Montserrat (*tomado de R.S.J. Sparks*)

### Melt residence times and segregation in hot zones

- U series data in arc magmas suggest that magma residence time increases in more evolved magmas: basalts ( $\ll 10^4$  years from  $^{226}\text{Ra}$  excesses) to andesites and dacites ( $>10^4$  to  $>10^5$  years from lack of  $^{226}\text{Ra}$  or even  $^{235}\text{U}$  excesses)
- Wet andesitic, dacitic and rhyolite melts generated in hot zone have viscosities of  $10^3$  to  $10^5$  Pa s range.
- Time scale of compaction and melt separation of order  $10^4$  to  $10^6$  years (MacKenzie, EPSL, 1984)

**CONSISTENT WITH AGE AND U SERIES DATA FROM SHV**

# Petrogénesis y evolución magmática

## Evolución magmática y estilo eruptivo

Soufriere Hills, Montserrat (*tomado de R.S.J. Sparks*)

### Model for generation of andesite at SHV (Parte 2)

- Residual andesite melt (possibly plus entrained crystals) ascends into upper crust in dykes

**CONSISTENT WITH EARLY DEEP SEISMICITY (>10 Km)**

- Magma first becomes superheated during ascent and then supersaturated in volatiles
- Liquidus is reached in upper crust in volatile saturated magmas triggering rapid crystallization of low pressure phenocryst assemblage

**CONSISTENT WITH SHORT CRYSTAL RESIDENCE TIME AND TEXTURES INDICATING RAPID GROWTH**

- Viscosity goes up and dykes slow down in cold brittle upper crust

**CONSISTENT WITH VOLCANOTECTONIC EARTHQUAKES**

- Repeated intrusions form ephemeral magma chamber at 5.5 km depth which is large enough to erupt in 1995

**CONSISTENT WITH HISTORIC AND GEOPHYSICAL DATA**

# Petrogénesis y evolución magmática

## Evolución magmática y estilo eruptivo

Soufriere Hills, Montserrat (*tomado de R.S.J. Sparks*)

### NOTE ON THE SHV UPPER CRUSTAL CHAMBER

- Long time-scale magma supply at SHV ( $\sim 0.02 \text{ m}^3/\text{s}$  or  $0.2 \text{ mm/year}$  focused below volcano) far too low to sustain permanent magma chamber in the upper crust
- Formation of ephemeral chamber requires episodic segregation of large volumes of andesitic melt from deep hot zone in short periods of time at supply rates  $\sim 10\text{-}100$  times the long-term average

### CONSISTENT WITH STRATIGRAPHY AT SHV

Lectura complementaria:

*Druitt, T.H.; Kokelaar, B.P. (editors). 2002. The eruption of Soufrière Hills Volcano, Monserrat, from 1995 to 1999. Geological Society of London, Memoirs 21.*

# Petrogénesis y evolución magmática

## Referencias y Lectura recomendada

### *Papers*

Annen, C.; Blundy, J.; Sparks, S. 2006. *The Genesis of Intermediate and Silicic Magmas in Deep Crustal Hot Zones*. *Journal of Petrology* 47 (3): 505-539.

Davies, J.H. 1999. *The role of hydraulic fractures and intermediate-depth earthquakes in generating subduction-zone magmatism*. *Nature* 398: 142-145.

Hacker et al., 2004: *Subduction factory 2: Are intermediate-depths earthquakes in subducting slabs linked to metamorphic dehydration reactions?*. *Journal of Geophysical Research* 108, B1: 2030

### *Libros*

Druitt, T.H.; Kokelaar, B.P. (editors). 2002. *The eruption of Soufrière Hills Volcano, Monserrat, from 1995 to 1999*. Geological Society of London, Memoirs 21.

*...y una lista adicional de artículos se entregará en el Laboratorio*