



SC 2- Dal mantello alle camere magmatiche

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Mineral chemistry as a petrological fingerprint of magma chamber processes

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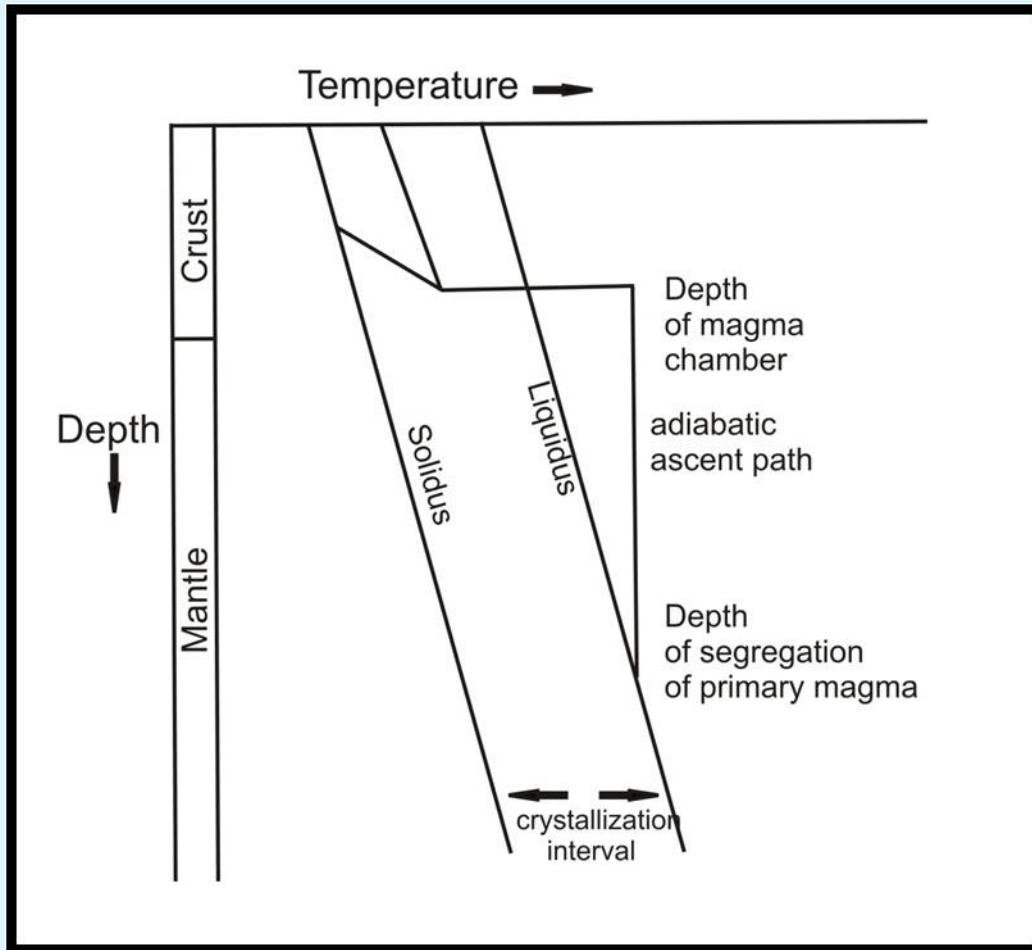
Summary

- **Magmatic processes**

- **Use of bulk rock analysis to study magmatic processes**

- **Usefulness of mineral chemistry in investigating magmatic processes**

Magmatic processes



Eruption

Magma ascent

Magma differentiation

Partial melting

Magmatic Differentiation

Any process by which a magma is able to diversify and produce a magma or rock of different composition

- Fractional Crystallization (FC)

- Assimilation ± Fractional Crystallization (AFC)

 - crystallization releases latent heat needed to melt rocks

 - surrounding the magma

- Magma mixing

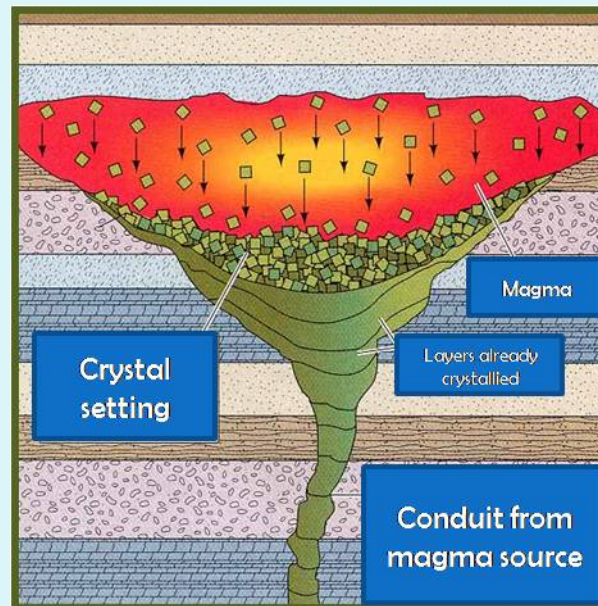
 - *In-situ* crystallization, convective crystallization

 - Filter pressing (Compaction)

Fractional Crystallization

Crystal Fractionation

The dominant mechanism by which most magmas, once formed, differentiate

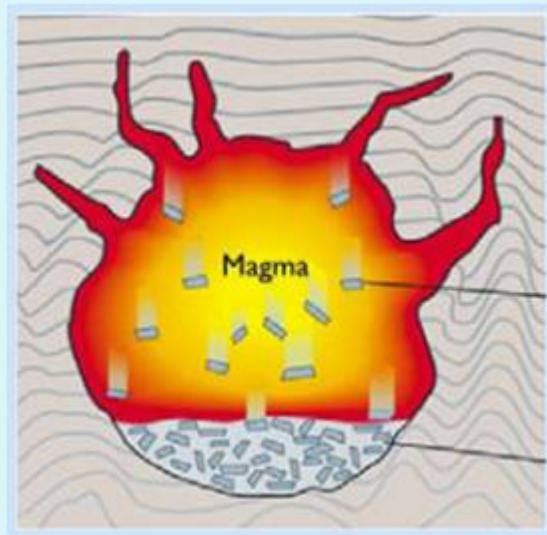


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Fractional Crystallization

- **Fractional Crystallization**

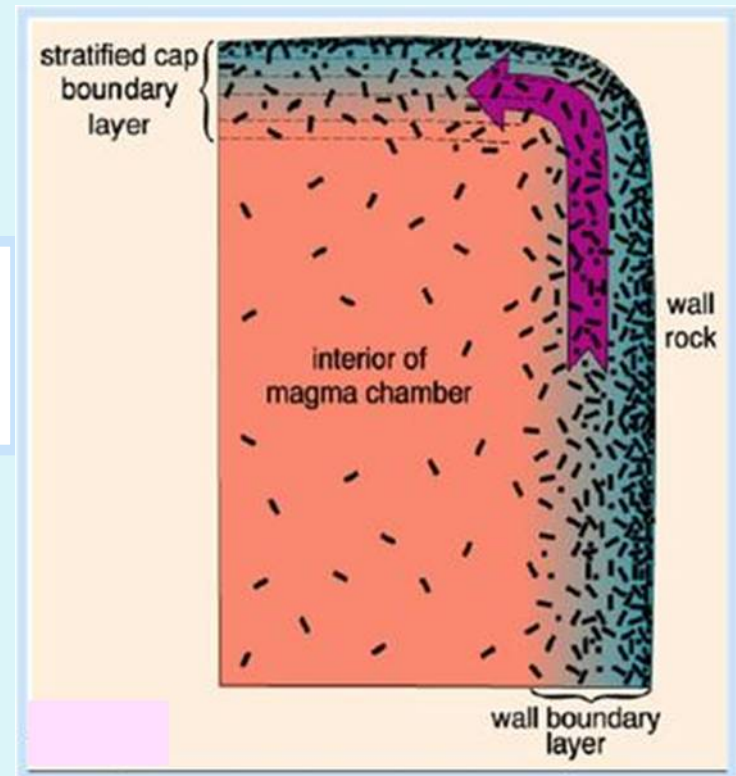
- separation of crystals from liquid
- gravitative settling or flotation may play significant role
- boundary layer crystallization may be most significant process



Crystals form from magma cooling and settle to floor of chamber

Crystals from early cooling accumulate

Wiley and Sons Ltd.

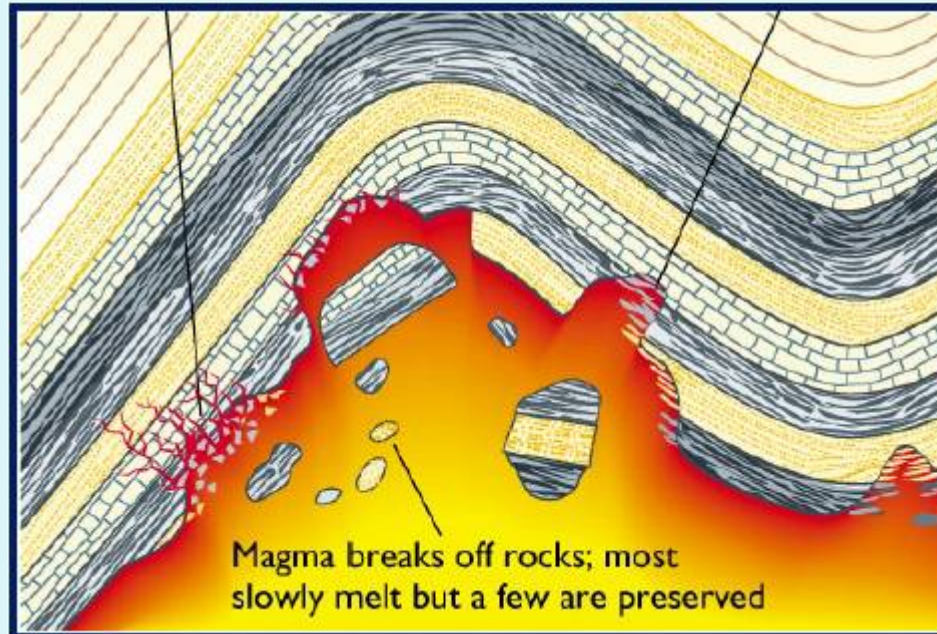


Winter, 2001

Fractional Crystallization \pm Assimilation

- **Assimilation \pm Fractional Crystallization**

- reaction/dissolution of wallrock
- crystallization provides heat for reaction
- can strongly modify trace element and isotopic concentration in magma

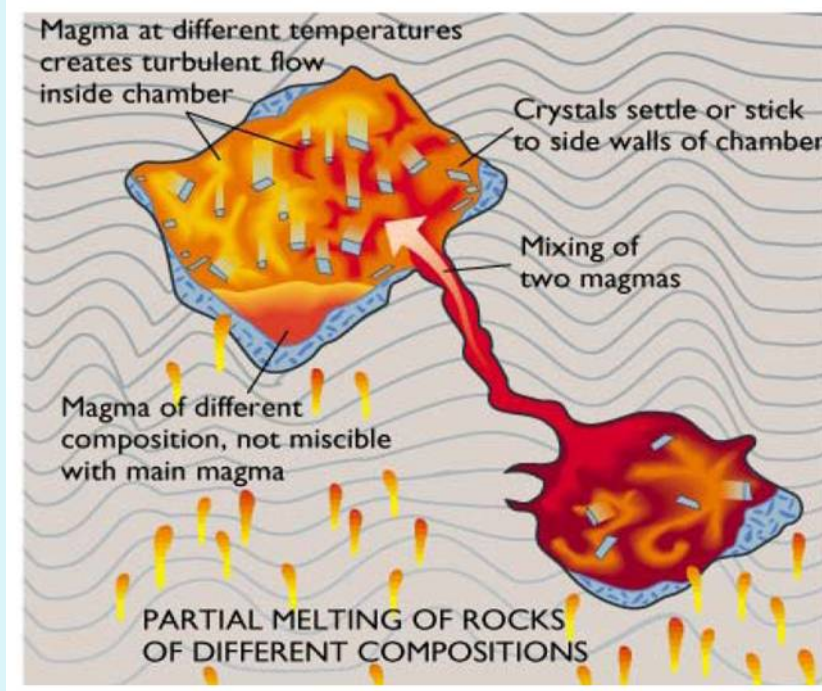


Magma Mixing

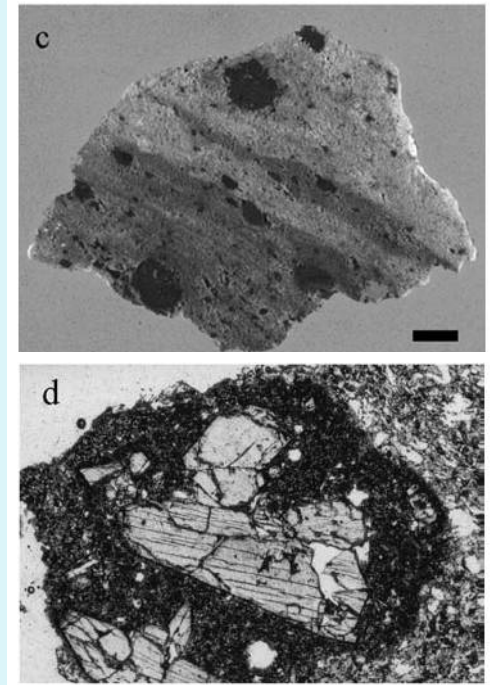
- **Magma mixing**

- mixing in *strictu sensu* → *banded and hybrid products*

- mingling → *physically distinct products*



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De Rosa et al., Bull Volcanol, no. 65, 2003

Approach

How do we display magmatic processes in a meaningful way?

Variation diagrams, REE patterns, etc.

Traditional petrology uses bulk rock analysis
Mineral chemistry is always more employed

Approach

- **Major elements:**
 - Concentration > 1 wt%
- **Minor elements:**
 - Concentration 0.1 wt% - 1 wt%
- **Trace elements:**
 - Concentration < 0.1 wt %

Typical major, minor and trace elements are:

- Si
- Al
- Fe
- Mg
- Ca
- Na
- K

- Ti
- Mn
- P
- Ni
- Cr

Major elements concentrations are expressed as wt % **oxydes** (SiO_2 , Al_2O_3 , etc.) while trace elements in ppm weight

Conceptually, some elements could be major in some systems, traces in other (e.g. K in the mantle or Zr in crustal magmas)

Harker type diagrams

The most commonly used

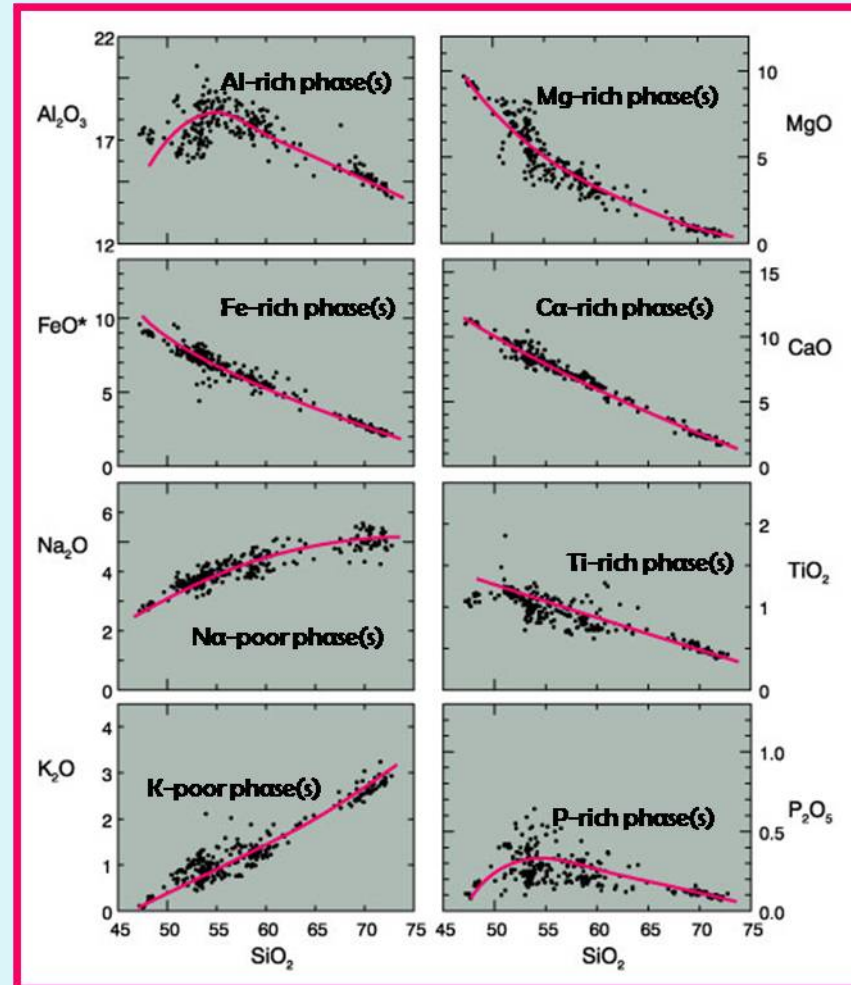
- X: something related to **differentiation** (SiO_2 or MgO or Zr)
- Y: any other element or ratio of elements

Harker type diagrams

(Bulk rock_Major elements)

Fractional crystallization

- Non-linear arrays



Winter, 2001

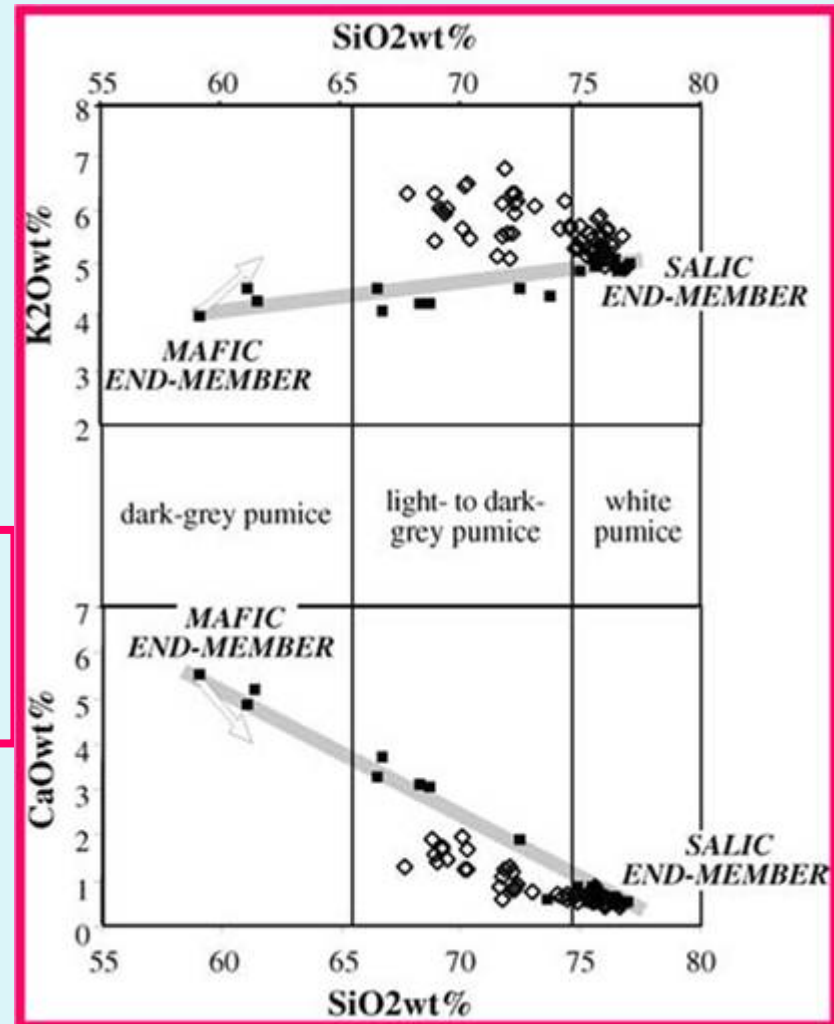
Harker type diagrams

(Bulk rock_Major elements)

Magma mixing

- linear arrays

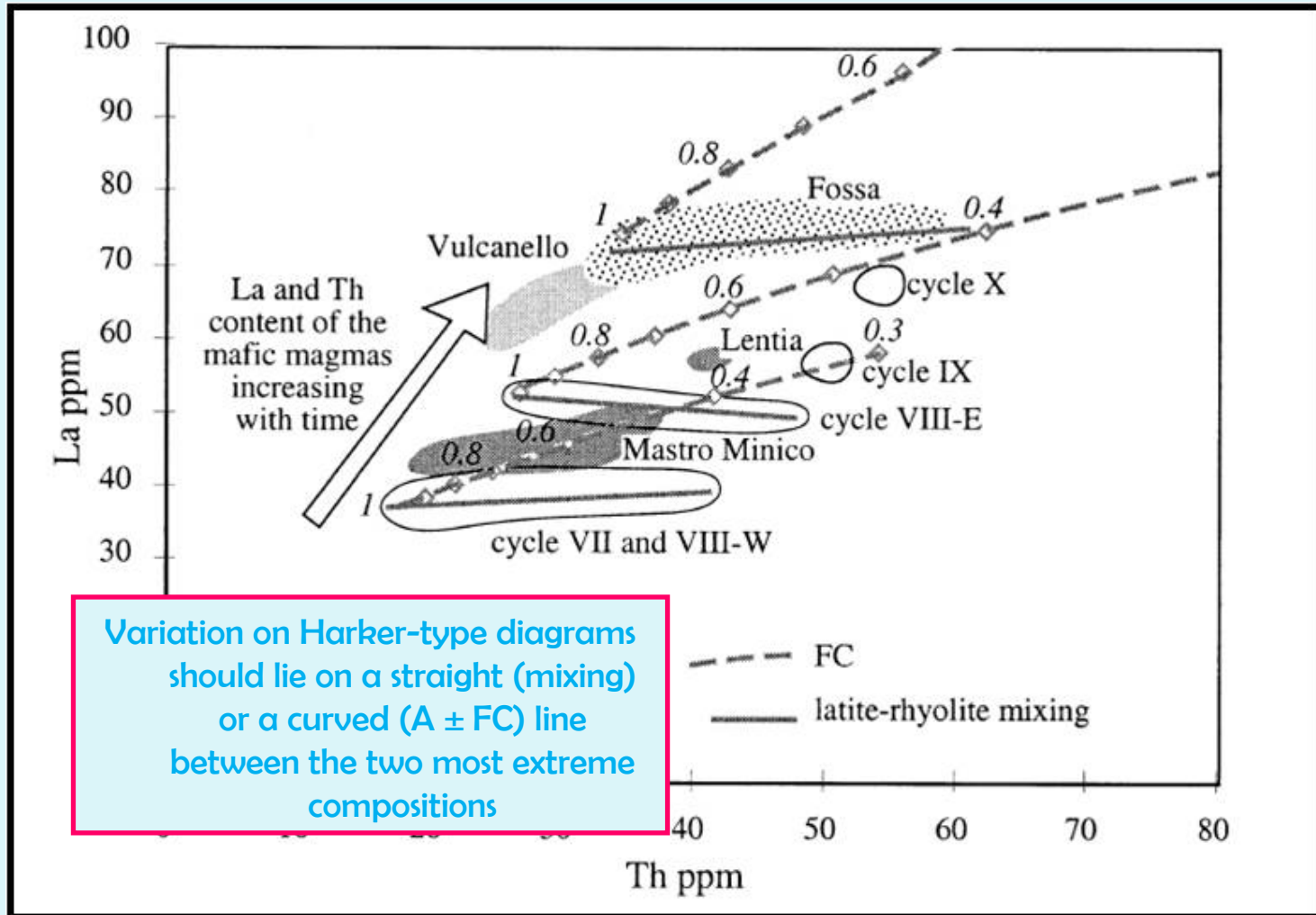
The open arrows suggest the liquid line of descent of the mafic end-member liquid



De Rosa et al., Bull Volcanol, no. 65, 2003

Harker type diagrams

(Bulk rock_Trace elements)



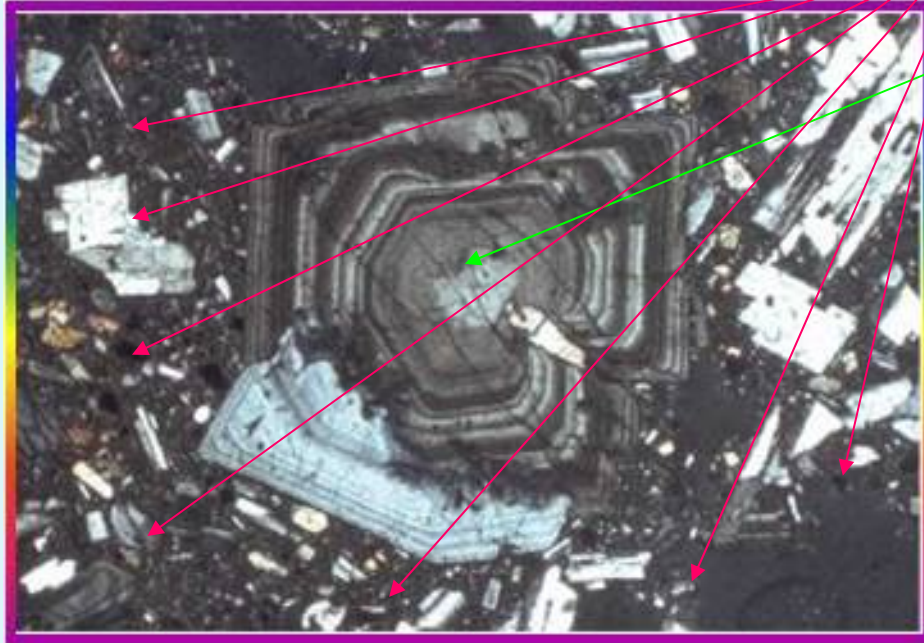
Gioncada et al., JVGR, no. 145, 2003

Minerals

Minerals composition and textures reflect the processes of crystallization and differentiation, once the magmas have left the sites of melt generation.

● Groundmass

● Crystals



Hawkesworth et al., 2004

Groundmass (previously the melt) is best for determining the eruption conditions.

The larger and hence older crystals often display chemical zonings and thus recording conditions of crystallization and growth history.

Mineral chemistry

The use of mineral chemistry, especially trace composition and isotopic values, in studying magmatic processes is relatively recent.

Main (modern) devices

- SEM-EDS (Scanning Electron Microscopy with X-ray microanalysis)
- SIMS (Secondary Ion Mass Spectrometry)
- EPM (Electron Probe Micro)
- The ICP family (Inductively Coupled Plasma):
 - ICP-AES (Atomic Emission Spectrophotometry)
 - ICP-MS and LA-ICP-MS
- TIMS (Thermo-Ionization Mass Spectrometry)
- SHRIMP (High Resolution Ion Microprobe)

	In situ	Major	Traces	Isotopes	Volatiles	
SEM-EDS	X	X				
SIMS	X		X		X	
Microprobe	X	X	X			<i>Cheap</i>
ICP-AES		(difficult)	X			<i>Replaced by ICP-MS</i>
ICP-MS		(difficult)	X			<i>De facto standard</i>
LA-ICP-MS	X	(difficult)	X	(possible)		<i>Increasingly popular; expensive, robust once set up. Lot of potential for isotopes</i>
ID-TIMS			(possible)	X		<i>Basic tool for geochronology. Complicated to use (clean chemistry)</i>
SHRIMP	X			X		<i>Regarded as standard for geochrono, but extremely expensive and difficult to use. Will probably be replaced by LA ICP MS</i>

Rollinson, 1993

Mineral chemistry

Magmatic processes are often investigated by:

Major element

(the example of Vulcanello)

Trace element

(the example from Lipari and Vulcano)

Isotopes

(examples from literature)

of rock-forming minerals

Mineral chemistry

Major elements

Major element composition of minerals strongly depends on several factors.

For example:

Clinopyroxene → oxygen fugacity-Mg#;
melt composition (Al_{cpx} – silica; Mg_{cpx} – $P_{\text{H}_2\text{O}}$)

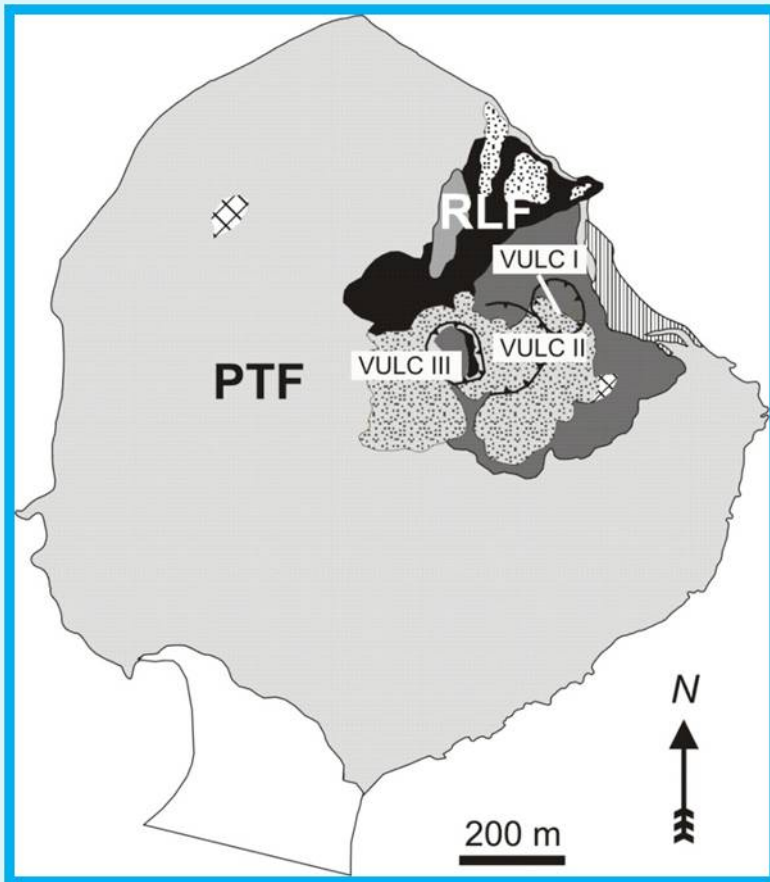
Plagioclase → water – An

Mineral chemistry

Major elements

The example of Vulcanello

Davì et al., Eur J Min, in press



1000 – 1200 AD → SHOSHONITE

1650 AD → LATITE

Mineral chemistry

Major elements

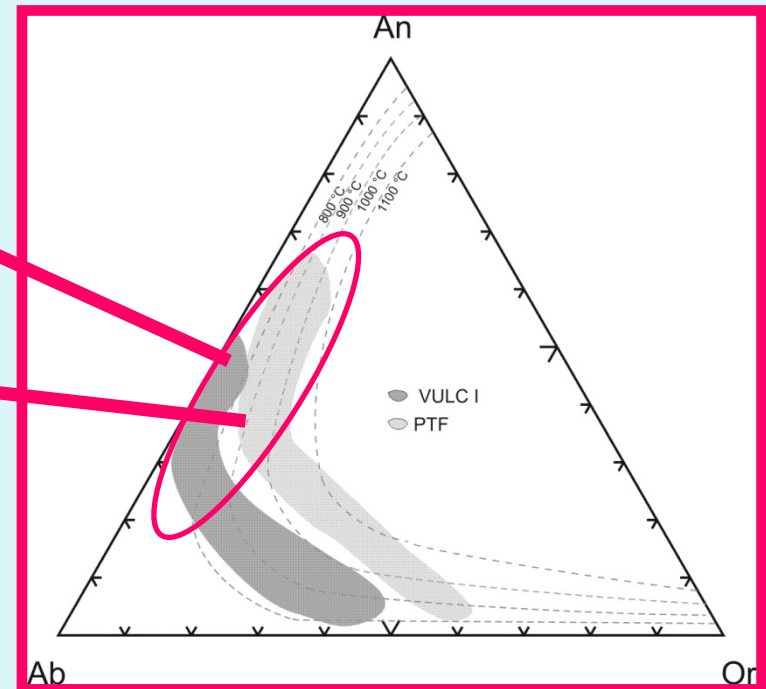
The example of Vulcanello

Davì et al., Eur J Min, in press

I cycle SHOSHONITE

II cycle SHOSHONITE

Degassing rises T_L of plagioclase



Mineral chemistry

Trace elements

T.E. of minerals of a volcanic rock depend on:

- 1) the composition of the magma they crystallized from
 - *solid/liquid partition coefficient in the silica-rich systems tend to be higher than those in the silica-poor systems*
 - *Na content of the magma is a strong determinant on the trace element abundances of clinopyroxene*

Mineral chemistry

Trace elements

- 2) **crystal-chemical control (i.e. major element composition of mineral dominates incorporation of T.E.)**
 - *The abundance of trace elements in plagioclase is highly dependant on their anorthite content*
 - *REE and trace element patterns are very different in clinopyroxene with augitic and aegirinic composition as well as in amphiboles with different major element composition*

- 3) **Pressure, temperature, water content and oxygen fugacity of the magma at the moment of crystallization**
 - *Oxygen fugacity concentrates Eu in plagioclase*

Mineral chemistry

Trace elements

T.E. in melt may depend on:

➤ **The order of crystallization and fractionation of the minerals**

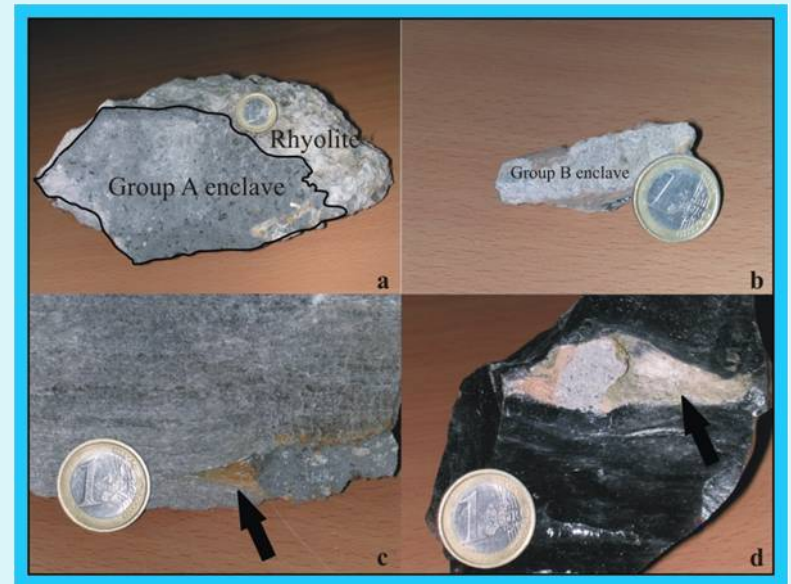
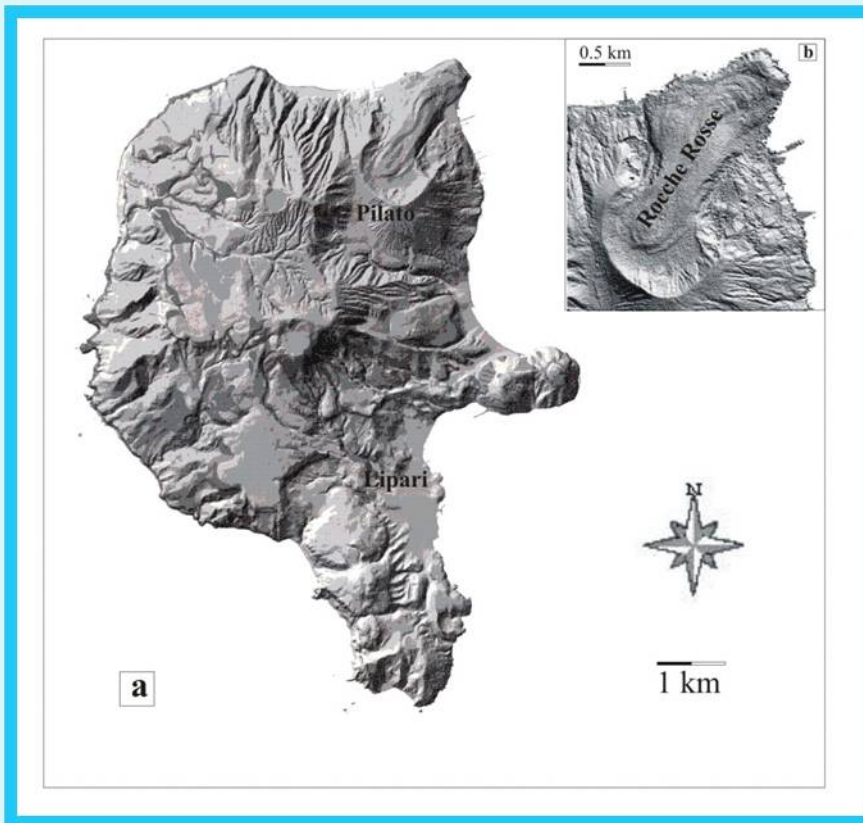
➤ **the rate of crustal assimilation**

Mineral chemistry

Trace elements

The Rocche Rosse (Lipari) example

Davì et al. , JVGR, no. 182, 2009

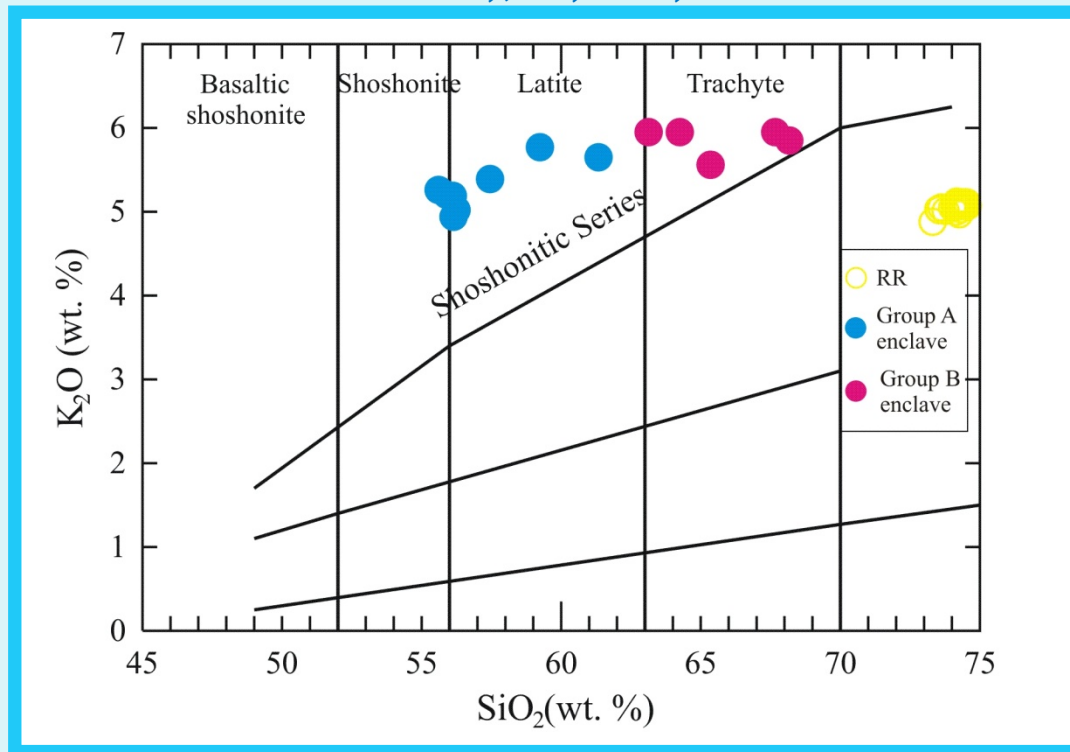


Mineral chemistry

Trace elements

The Rocche Rosse (Lipari) example

Davì et al., JVGR, no. 182, 2009



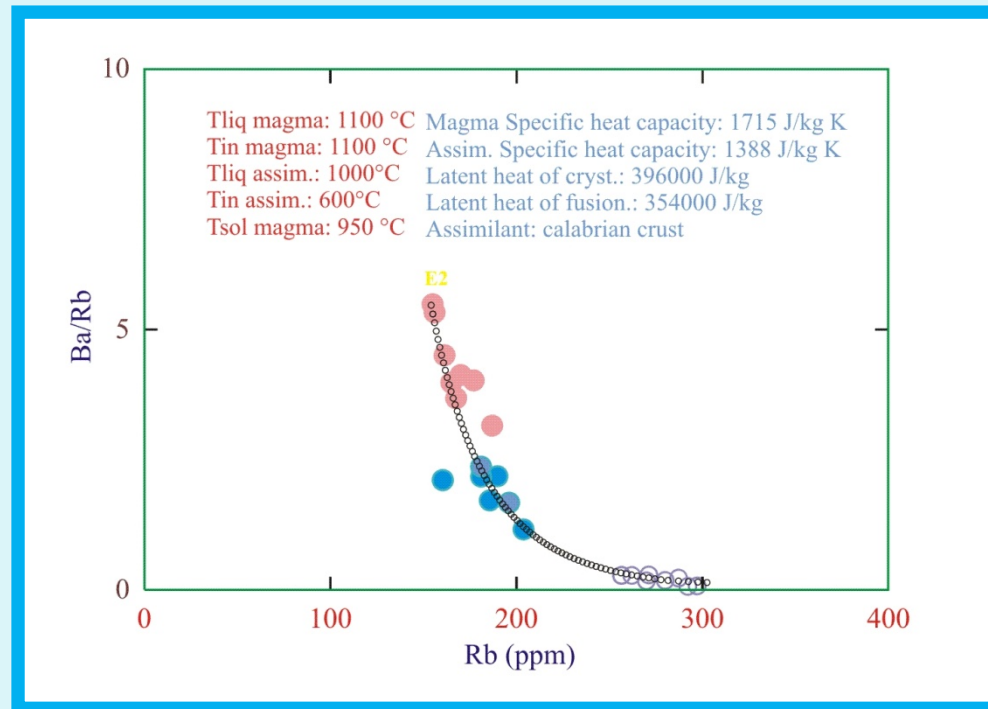
Mineral chemistry

Trace elements

The Rocche Rosse (Lipari)
example

Davì et al. , JVGR, no. 182, 2009

EC-RAFCE models

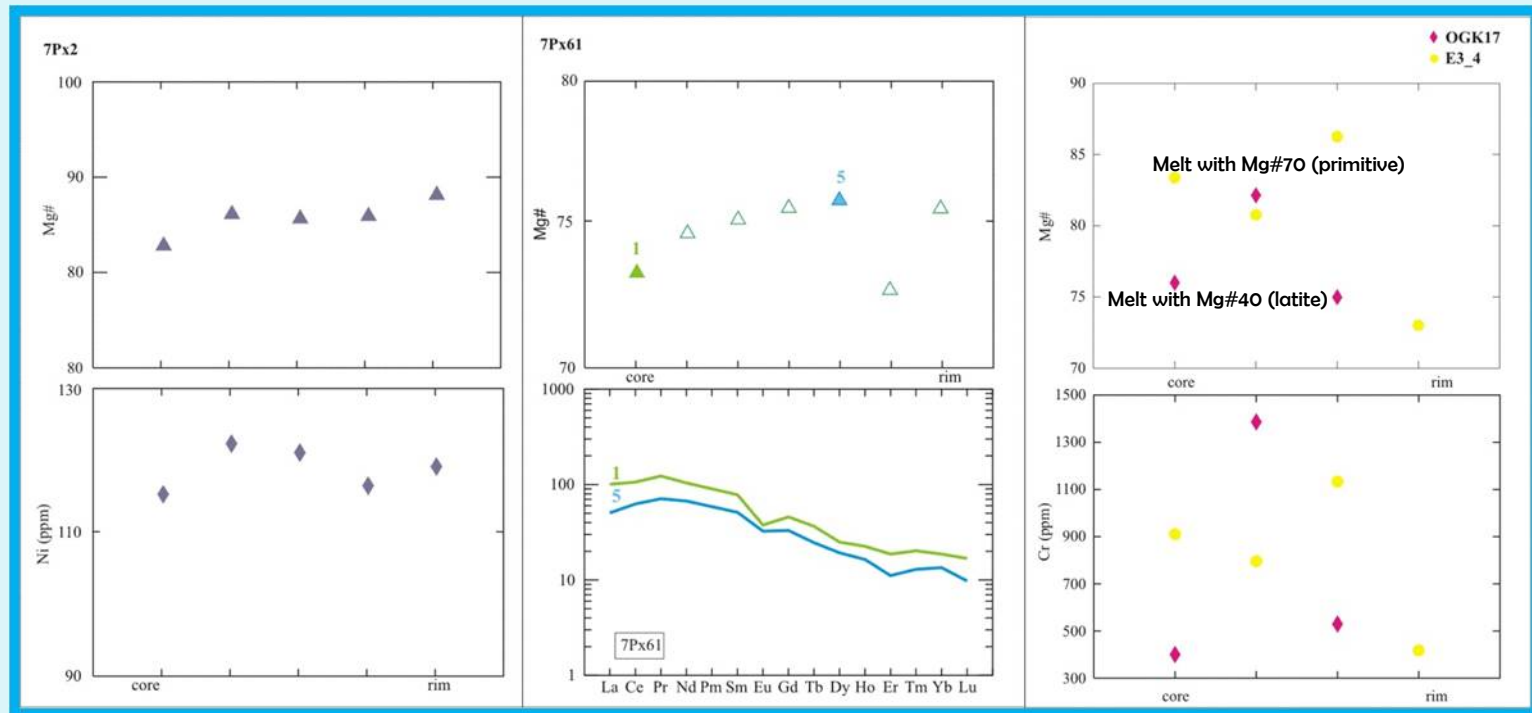


Mineral chemistry

Trace elements

The Rocche Rosse (Lipari) example

Davì et al., JVGR, no. 182, 2009



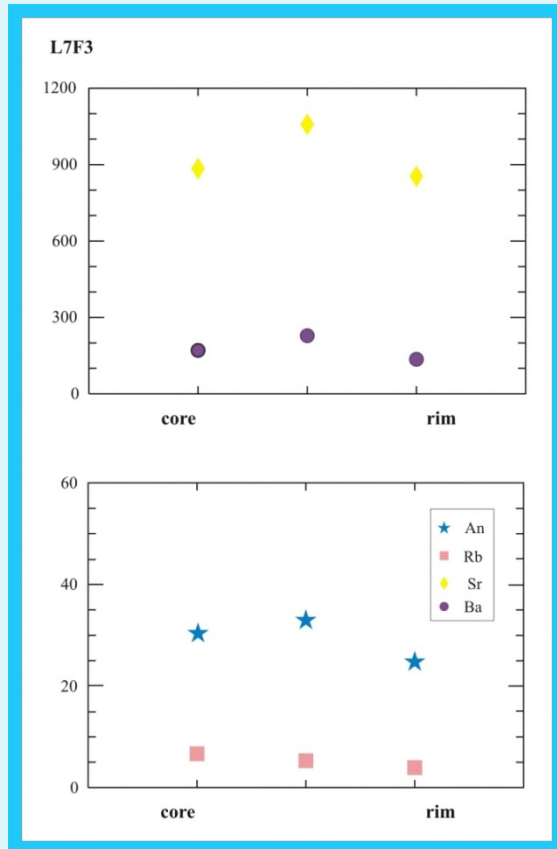
Clinopyroxene

Mineral chemistry

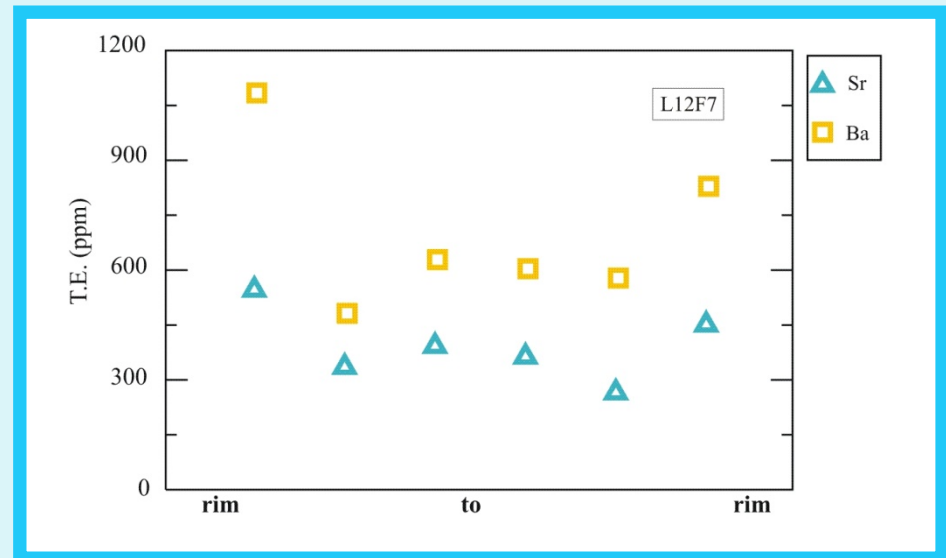
Trace elements

The Rocche Rosse (Lipari)
example

Davì et al. , JVGR, no. 182, 2009



Plagioclase



Alkali-feldspar

Mineral chemistry

Trace elements

The Rocche Rosse (Lipari)
example

Davì et al. , JVGR, no. 182, 2009

PHASE CHEMISTRY

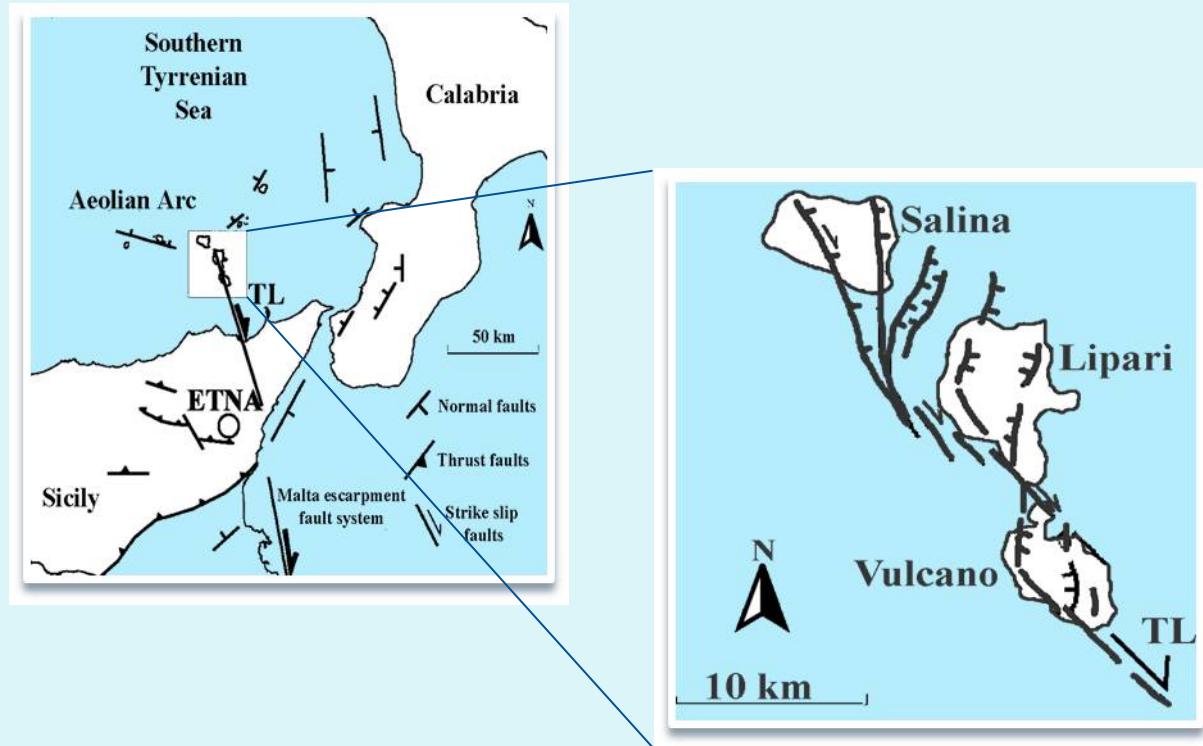


MAGMA MIXING

Mineral chemistry

Trace elements

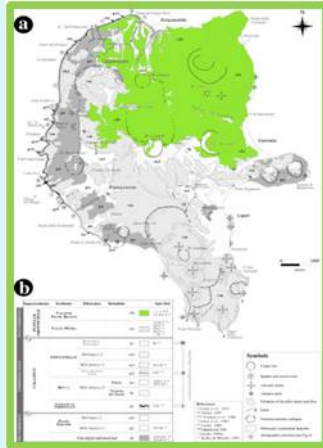
The L_{ipari} V_{ulcano} V_{olcanic} C_{omplex} example



Mineral chemistry

Trace elements

The L_{inari} V_{ulcano} V_{olcanic} C_{omplex} example

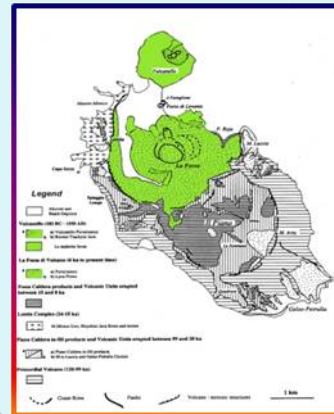


ROCCE ROSSE



VULCANELLO

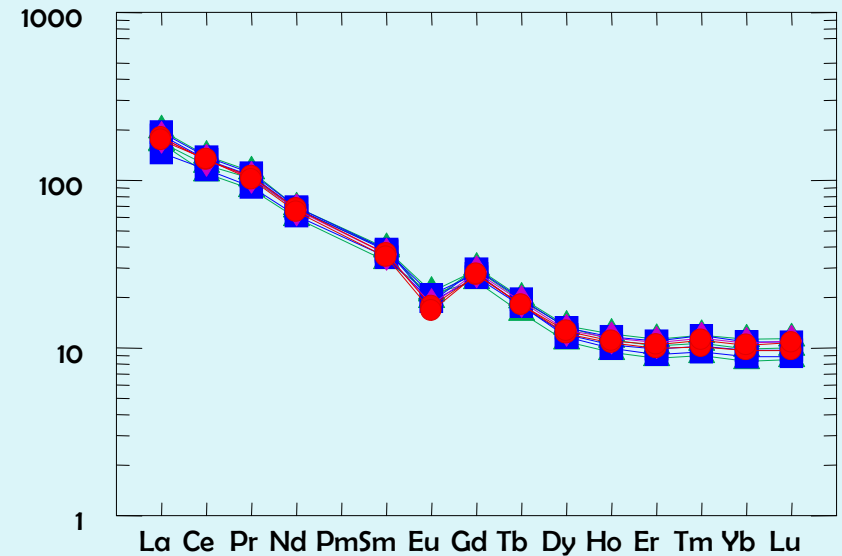
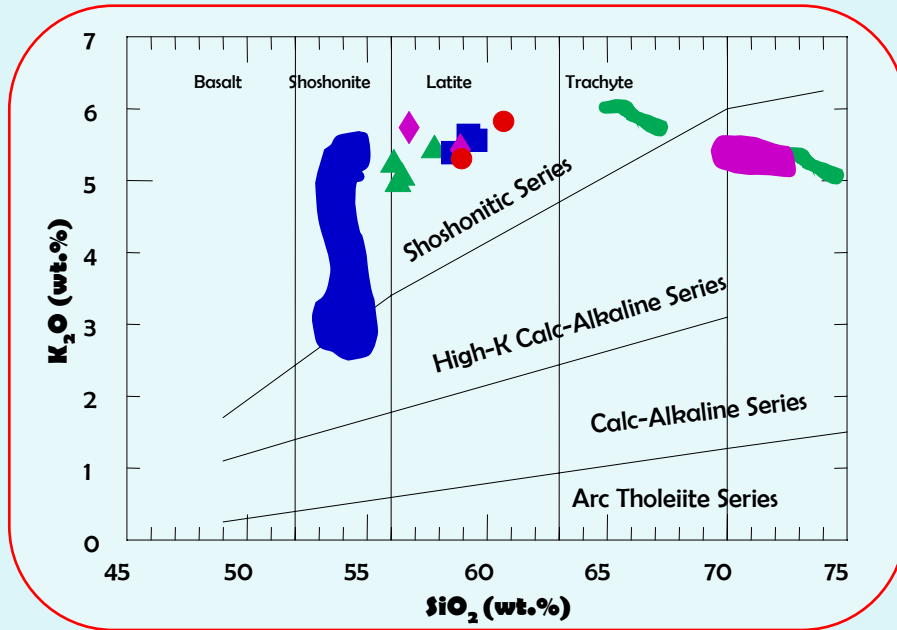
COMMENDA-PALIZZI



Mineral chemistry

Trace elements

The L_{ipari} V_{ulcano} $V_{olcanic}$ C_{omplex} example



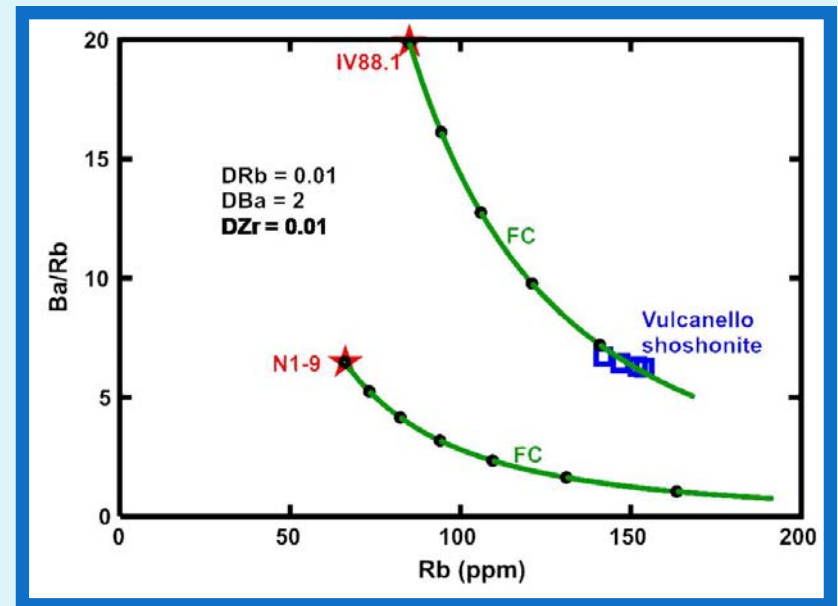
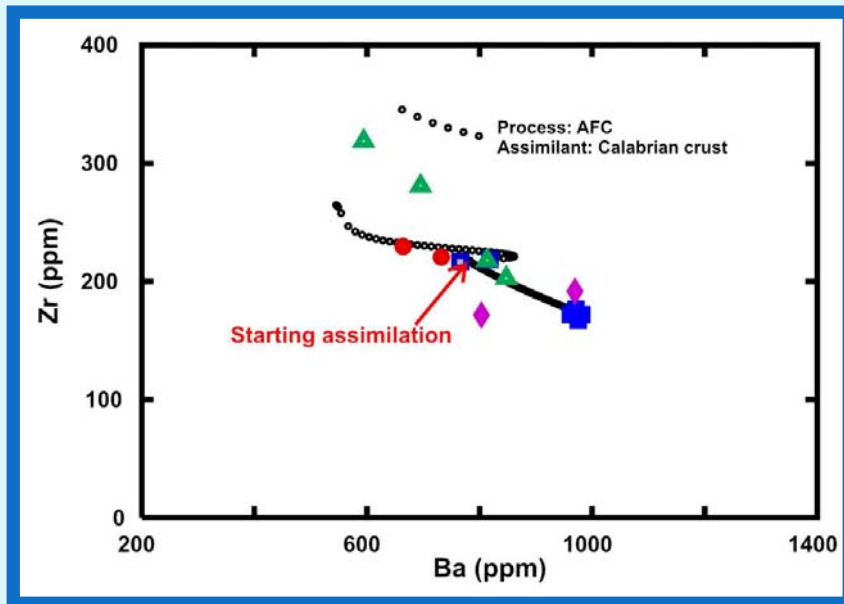
	Rocche Rosse	Vulcanello	Commenda	Palizzi
latites	cpx+ol+plg+K-feld	cpx+plg+ol± K-feld	cpx+plg+K-feld +ol	cpx+plg+K-feld±ol

Mineral chemistry

Trace elements

The Lipari Volcanic Complex example

EC-RAFCE models



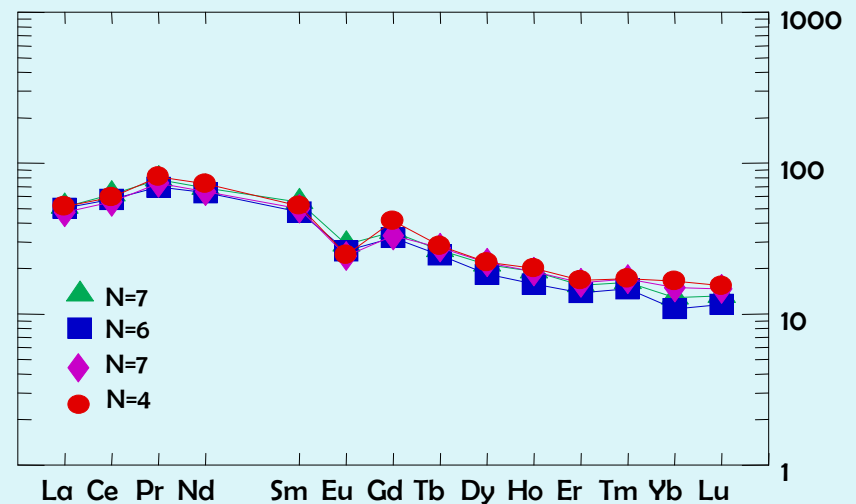
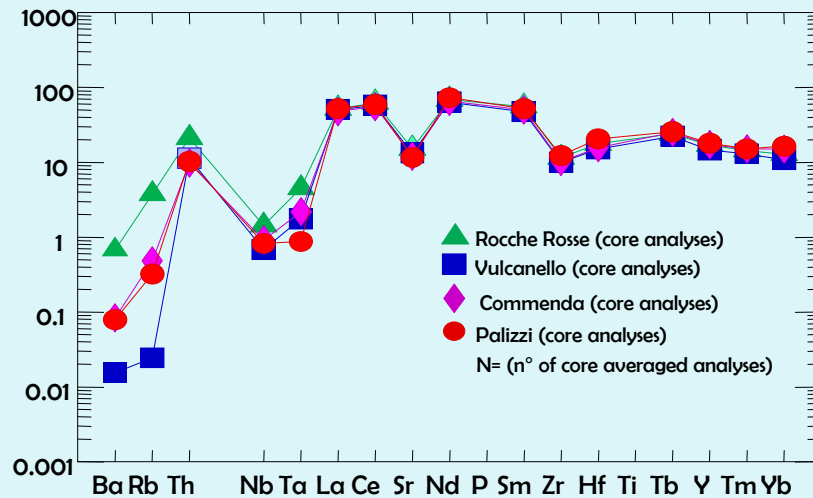
The N-E portion of Lipari belongs to the LVVC

Mineral chemistry

Trace elements

The Lipari V_{ulcano} $V_{olcanic}$ C_{omplex} example

Clinopyroxene ($En_{\approx 40}Fe_{\approx 13}$)

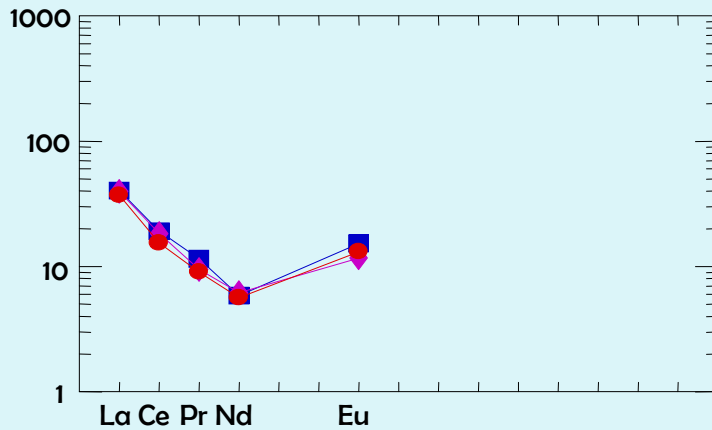


Mineral chemistry

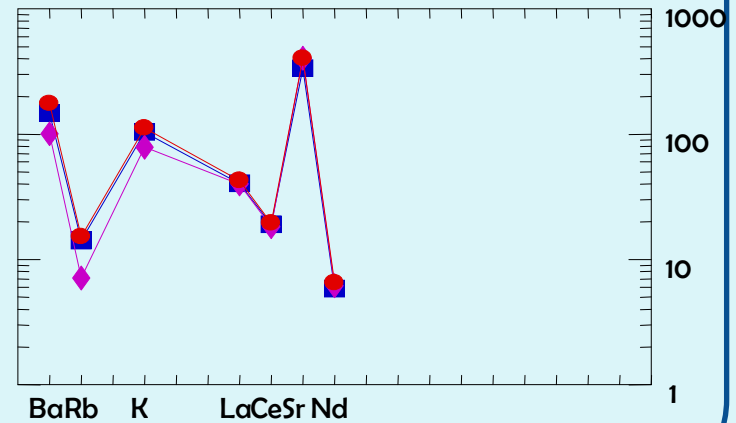
Trace elements

The Lipari Volcanic Complex example

Plagioclase ($An_{\approx 50}Or_{\approx 10}$)



■ N=10
◆ N=14
● N=9

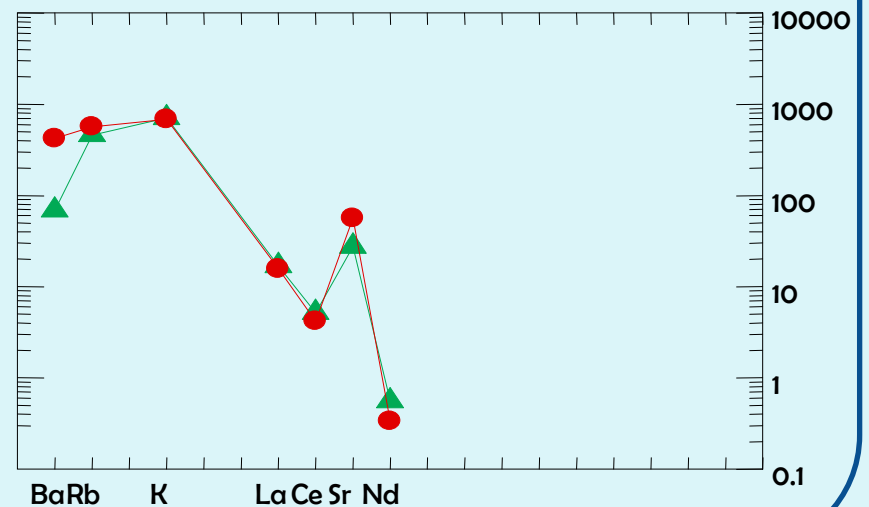
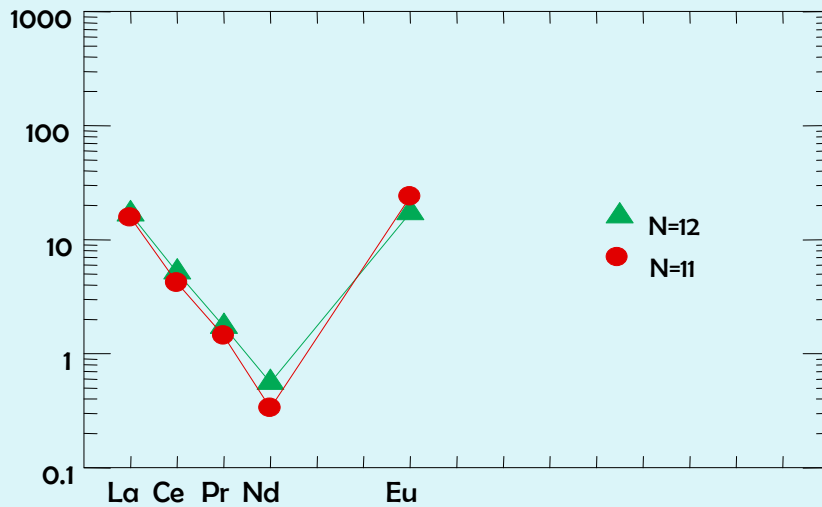


Mineral chemistry

Trace elements

The Lipari Volcanic Complex example

Alkali-feldspar ($An_{\approx 2}Or_{\approx 80}$)



Mineral chemistry

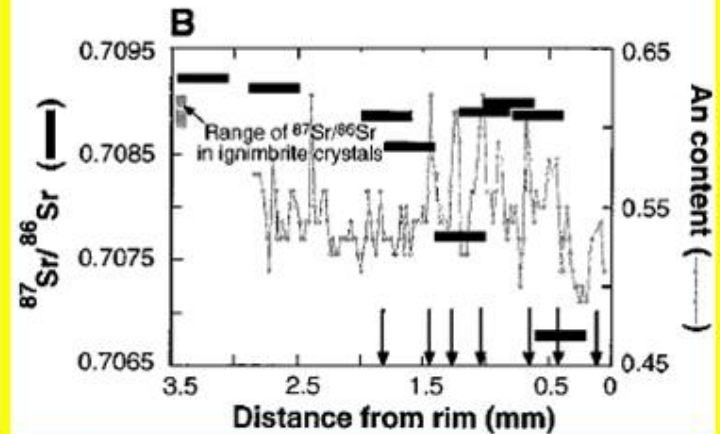
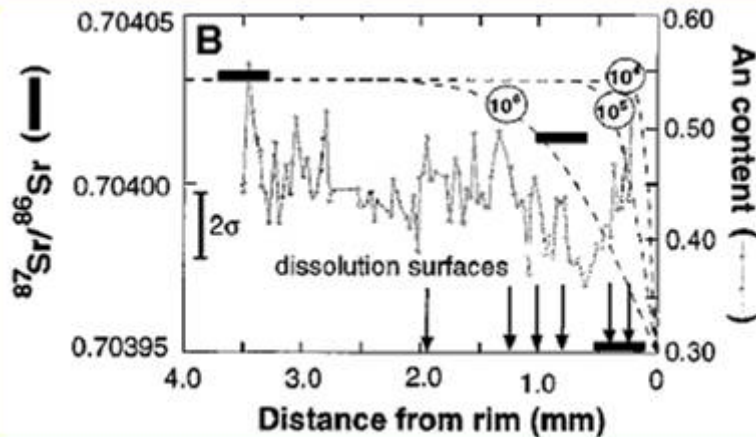
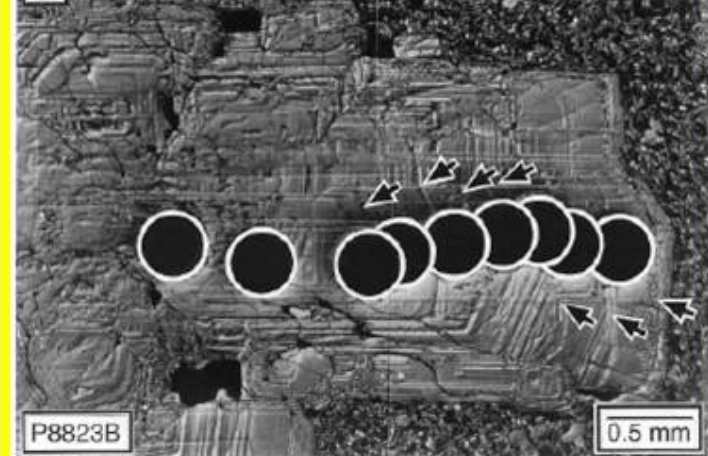
Isotopes

Examples from literature

Chaos Crags, Lassen National Park, California



Purico-Chascon

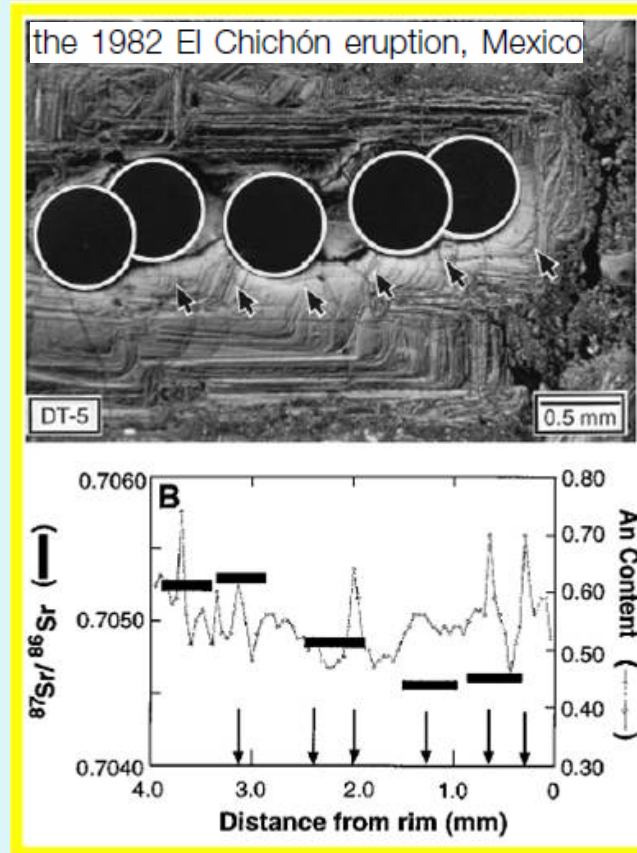


Davidson and Tepley, Science, no. 275, 1997

Mineral chemistry

Isotopes

Examples from literature



Davidson and Tepley, Science, no. 275, 1997