Crystallochemistry of Pyroxenes in Komatiites and in Lunar Basalts

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The talk

(1) Introduction

(2) Scientific goals

(3) Presentation of the rocks : komatiites and lunar basalts

(4) Methods

(5) Discussion

(6) Conclusions and future research

Komatiites ?

→ ultramafic volcanic rocks [MgO>18%]

→ *spinifex-textured* rocks

→ mainly Archean (also Proterozoic and Cretaceous)

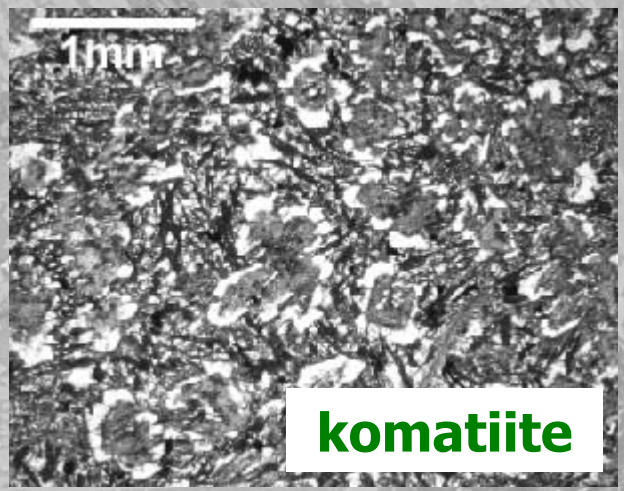
→ mainly extrusive rocks (lava flows)

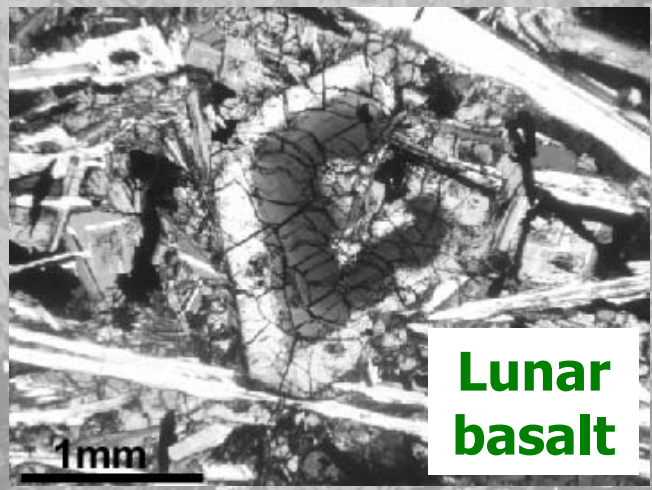
Lunar Mare Basalts ?

>> well-preserved minerals in fresh rocks!

>> crystallization sequence and pyroxene morphology comparable in komatiites and lunar basalts

>> anhydrous reference



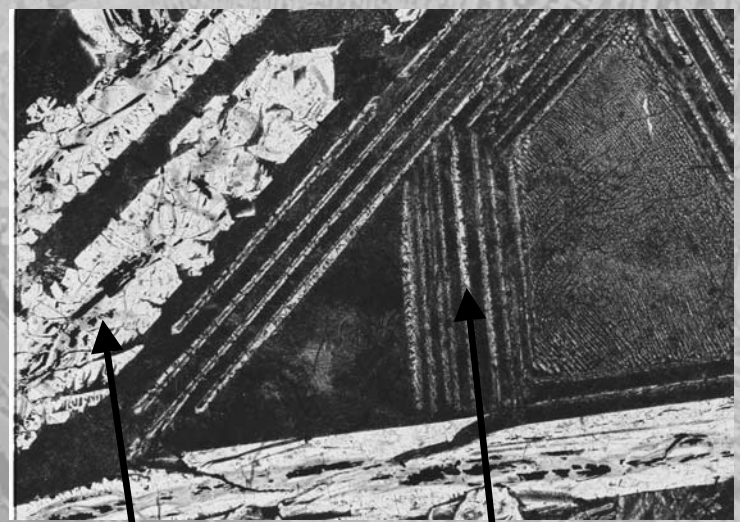


Introduction

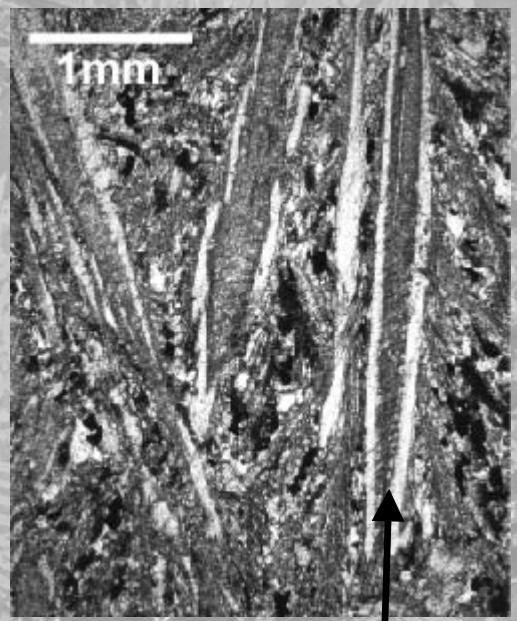
→ Texture characterized by large, skeletal or dendritic, platy, bladed or acicular grains of **olivine** or **pyroxene**

spinifex ?

olivine



olivine pyroxene



pyroxene

Scientific goals

To use pyroxene compositions to gain a better understanding of

- the **chemical and physical processes** that occurred during komatiite genesis
- the thermal and compositional state of the Earth's mantle in the Archean

→ **models** of crystallization of komatiite flows

→ **models** of early Earth's mantle dynamics

Scientific goals

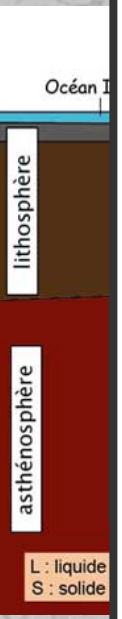
Two models try to explain the formation of komatiites:

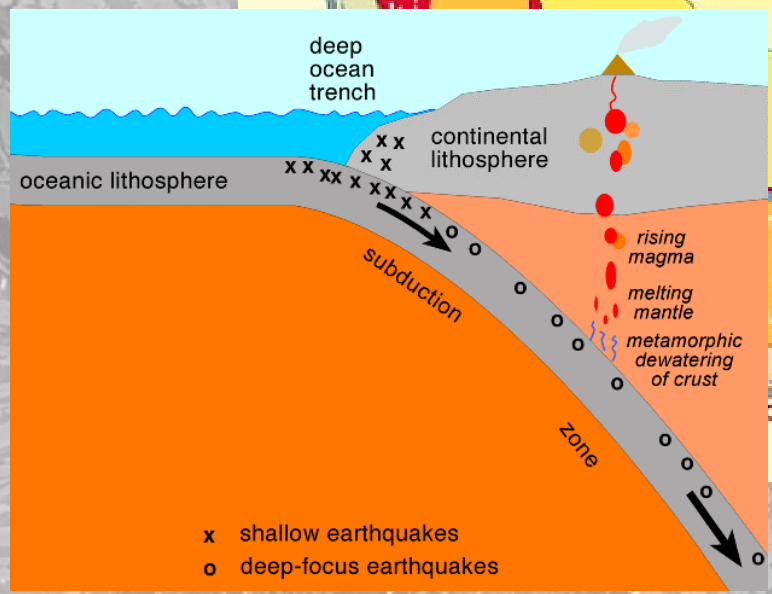
(1) hot and dry source (*plume*)

(2)relatively cold and wet source (*subduction zone*)

>> origin of spinifex texture

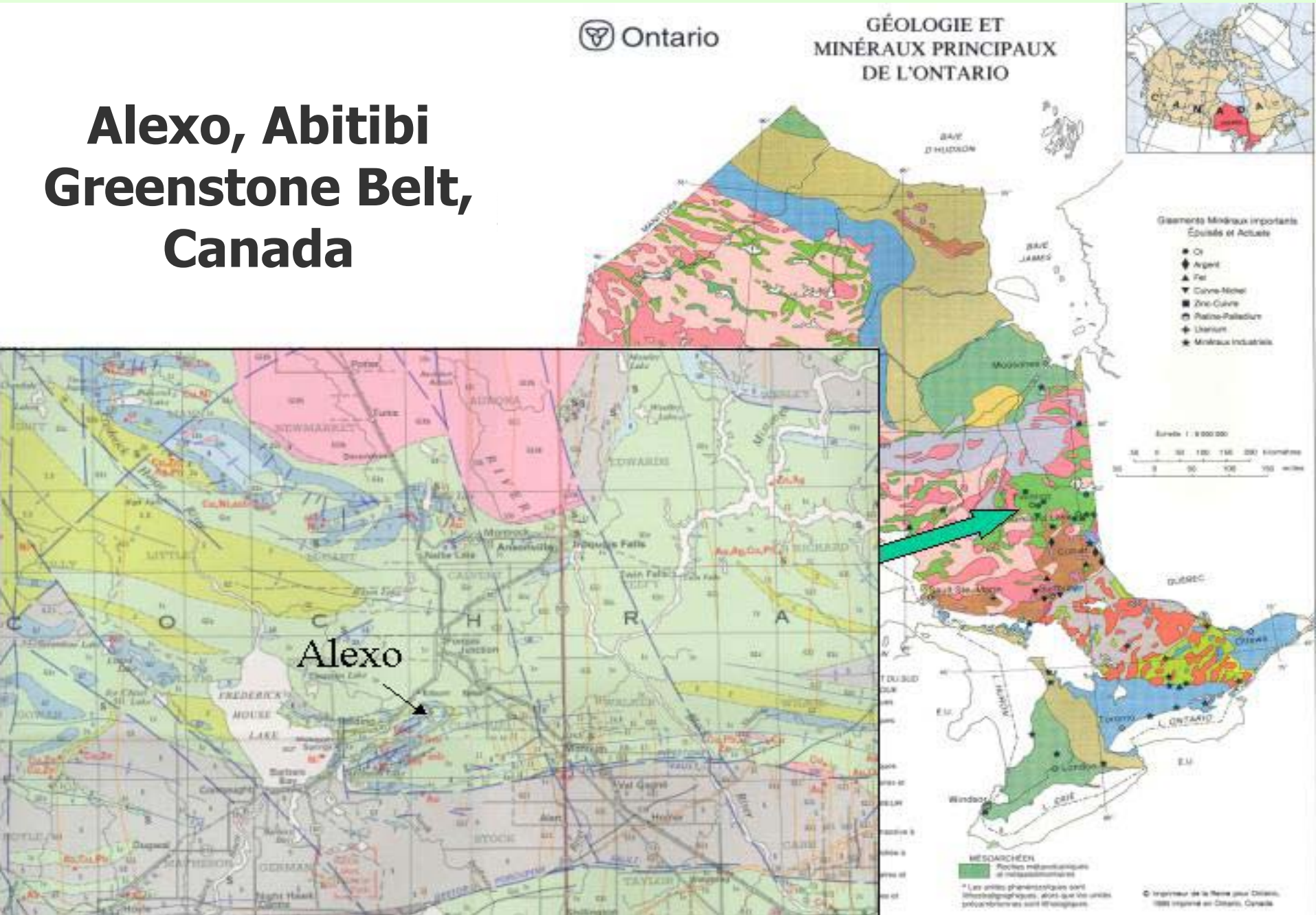
>> augite composition in Barberton komatiites (South Africa)





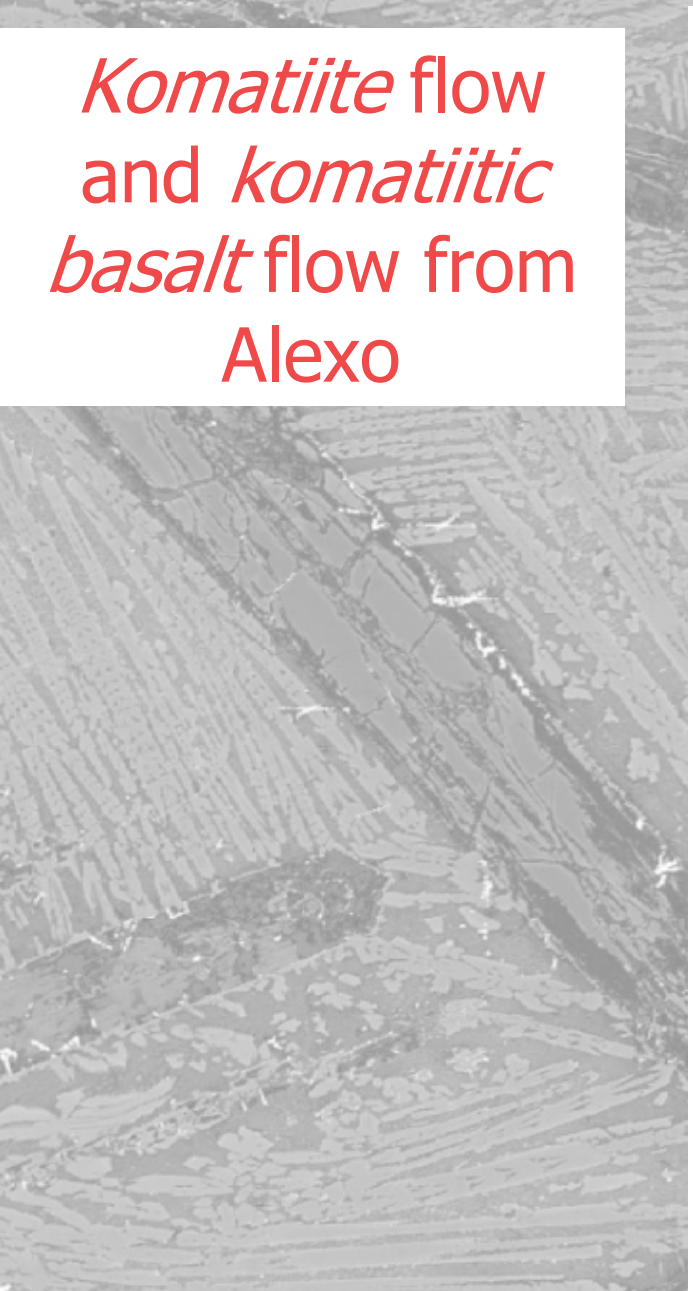
Presentation of the rocks : komatiites and lunar basalts

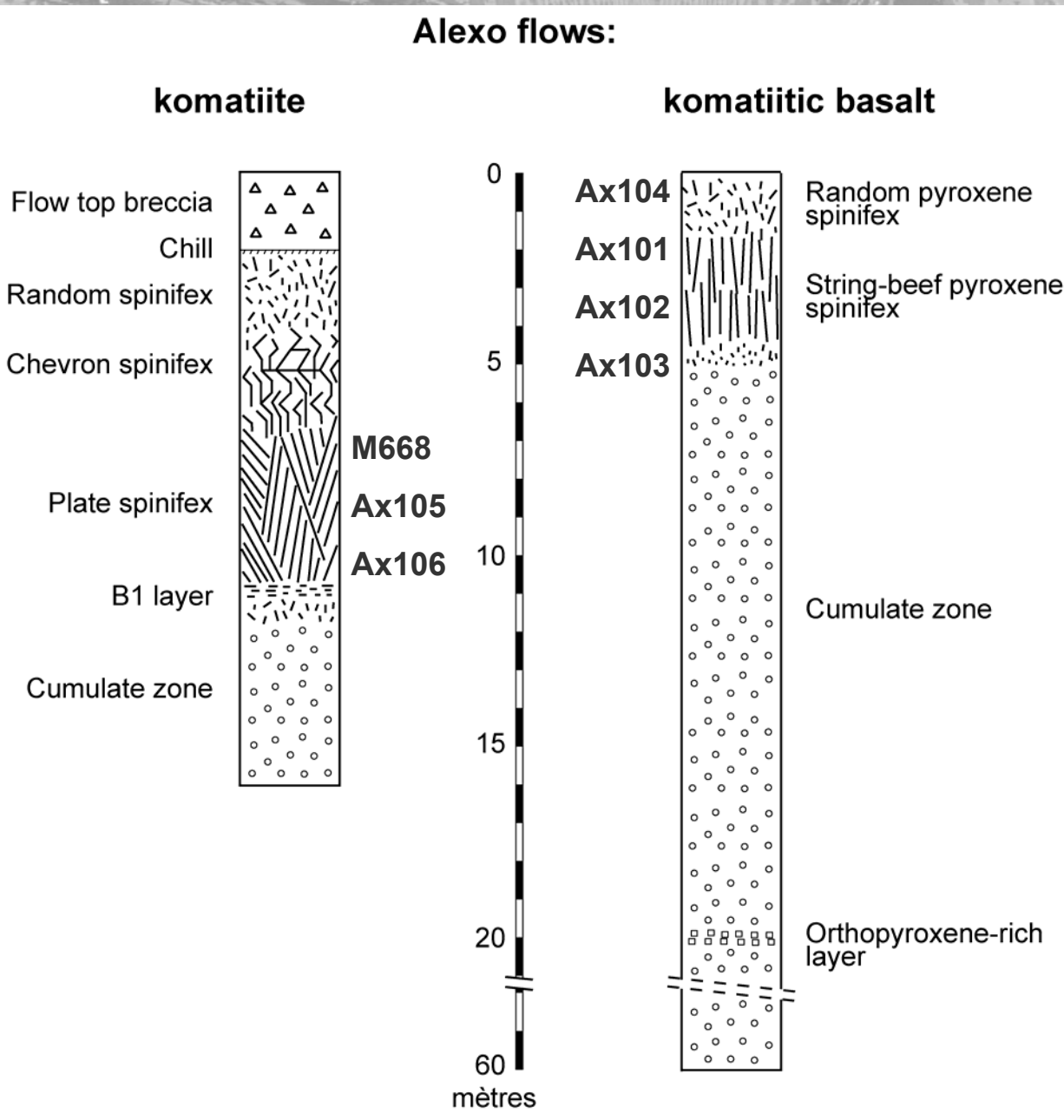
Alexo, Abitibi Greenstone Belt, Canada



Presentation of the rocks : komatiites and lunar basalts

Komatiite flow and *komatiitic basalt* flow from Alexo

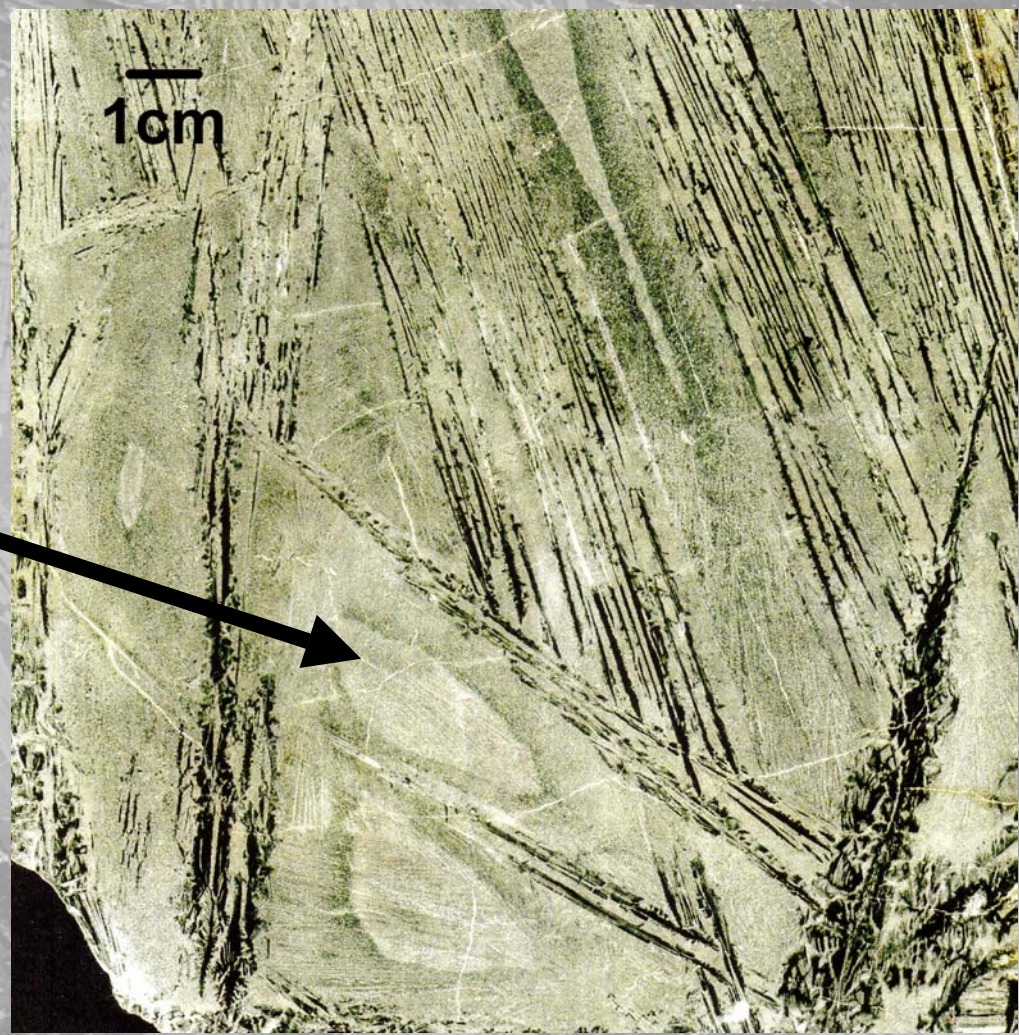




Presentation of the rocks : komatiites and lunar basalts

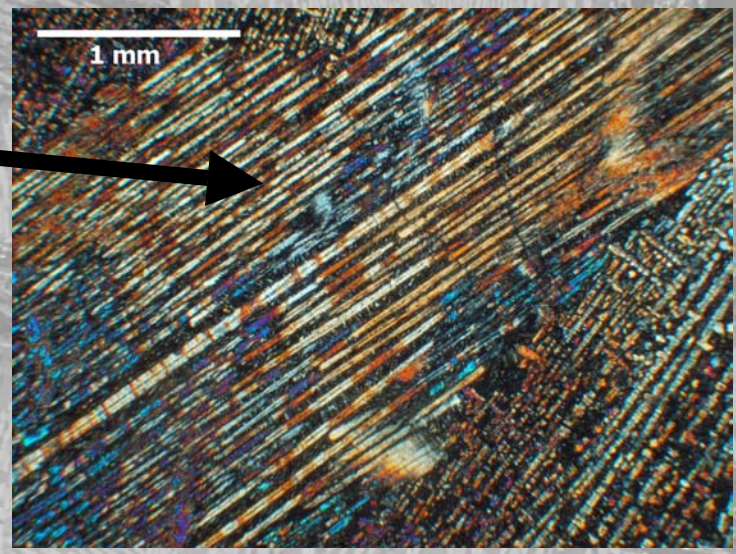
Komatiite flow and *komatiitic basalt* flow from Alexo

pyroxenes in volumes between platy olivines



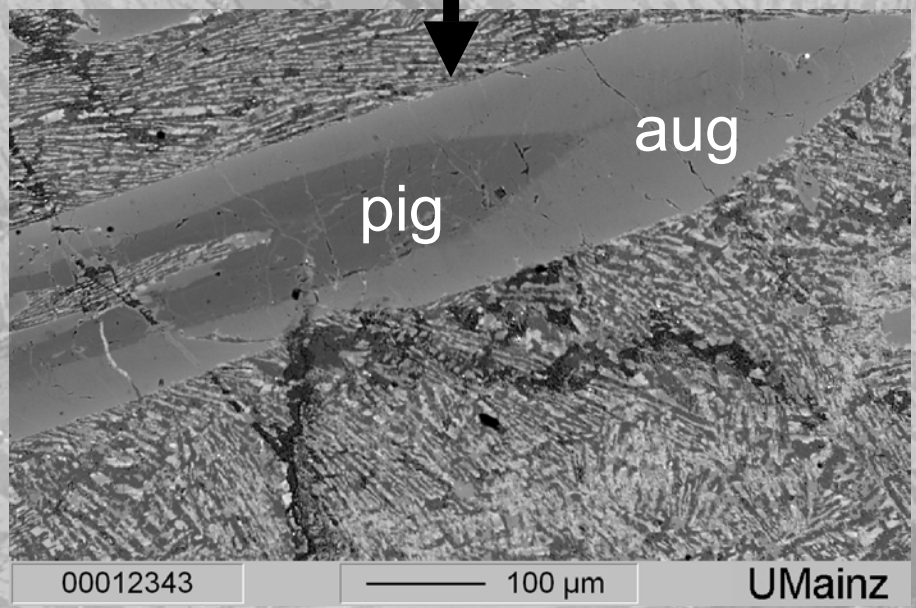
Presentation of the rocks : komatiites and lunar basalts

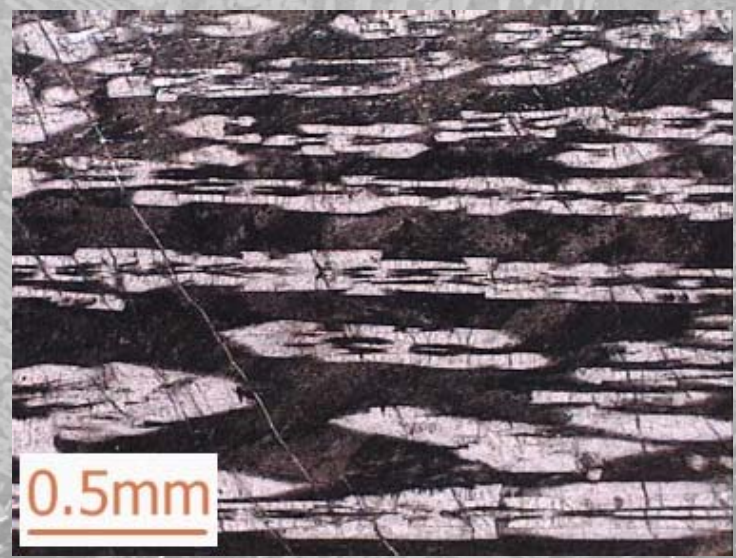
pyroxene needles



zoned crystals:

pigeonite core and augite rim





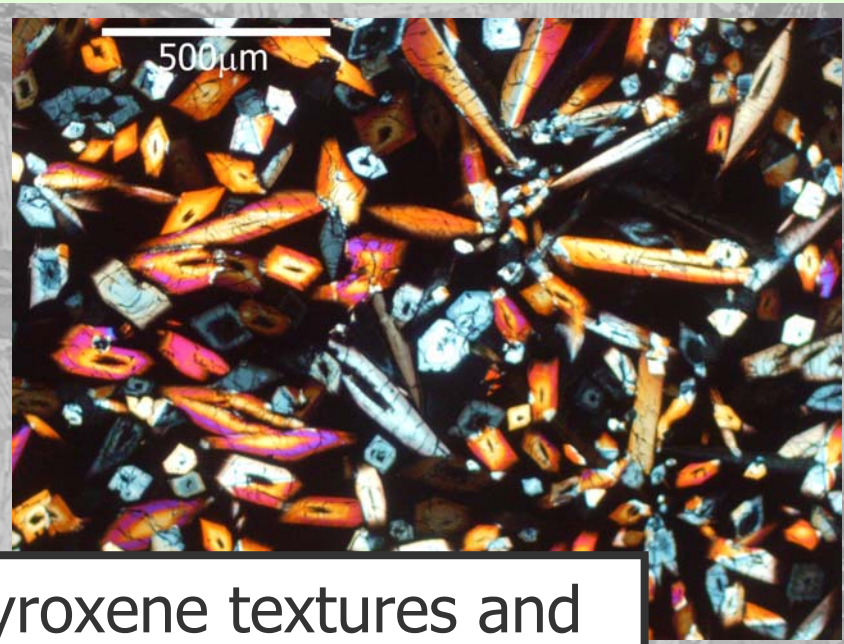
skeletal crystals

Presentation of the rocks : komatiites and lunar basalts

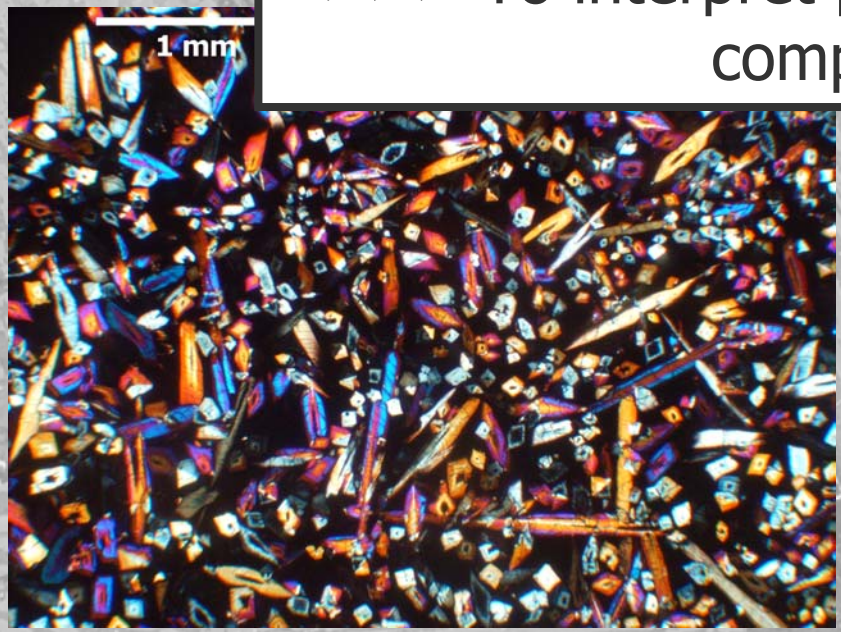
Lunar Mare Basalts :

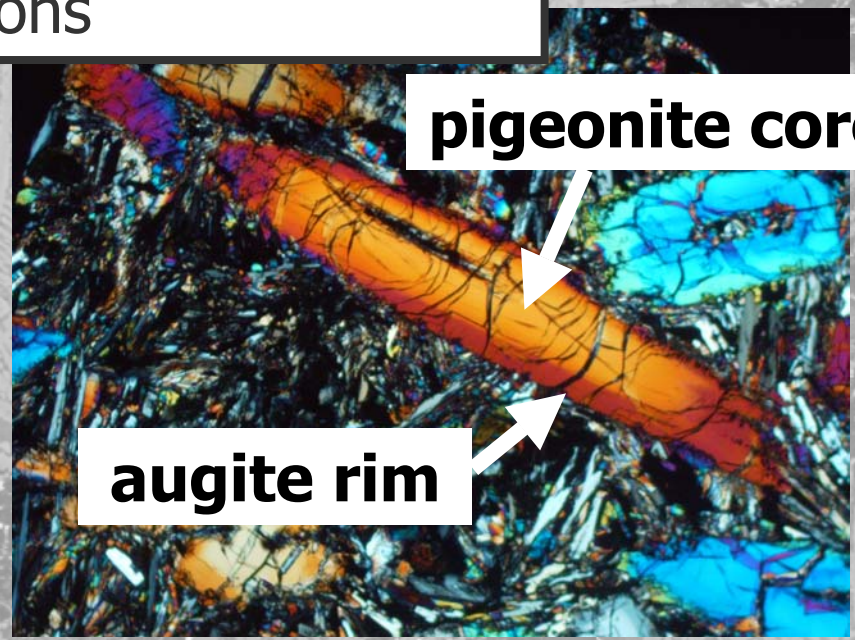
Apollo 12 *pigeonite basalt*

Apollo 15 *pigeonite basalt*



>>> To interpret pyroxene textures and compositions





Methods

1) Analytical approach

- Detailed study of the mineralogy and geochemistry of pyroxene in komatiites and in lunar mare basalts
- Use of SIMS (ion microprobe), electron microprobe, SEM

  >> Mainz (Institute of Petrology & Max Planck Institute)

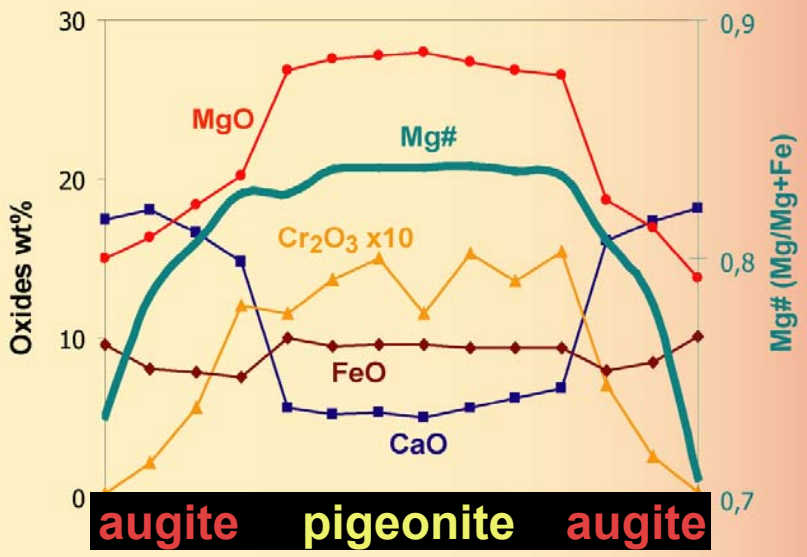
  >> Nancy (CRPG)

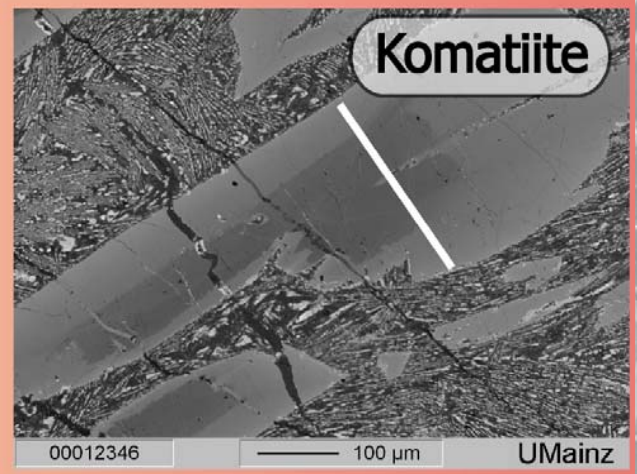
2) Experimental work

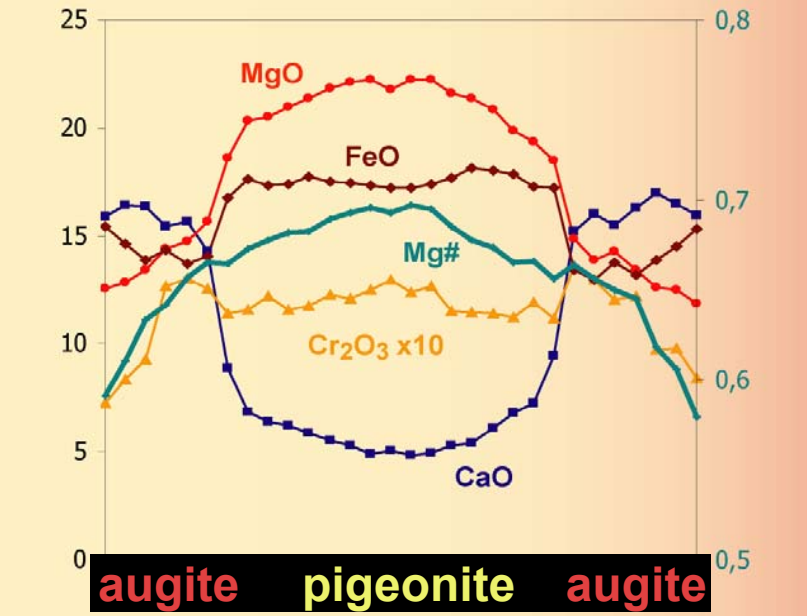
- Attempts to reproduce the spinifex texture, using pyroxene field composition
- Studies on simplified materials representing the parental magma of komatiites (Ca-Mg-Al-Si system)

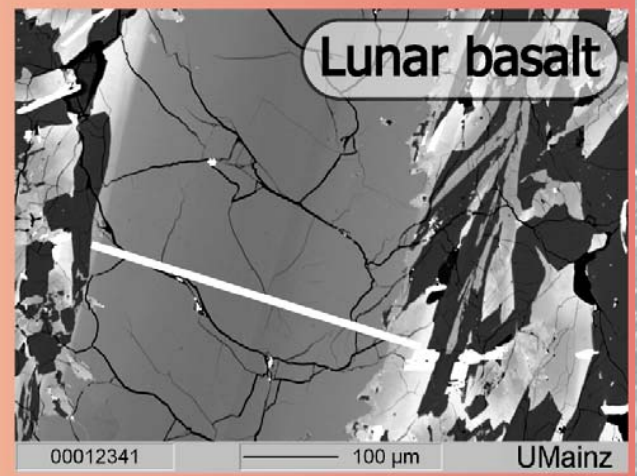
  >> Nancy (CRPG)

Analytical study





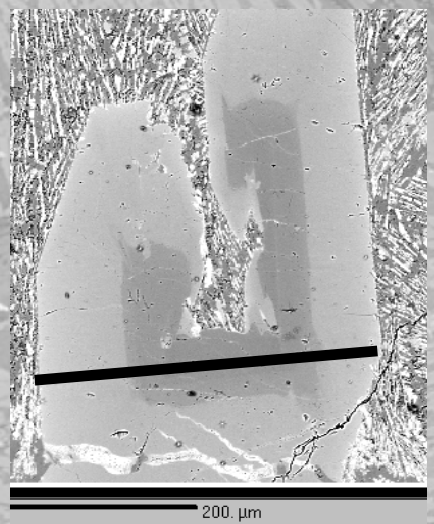


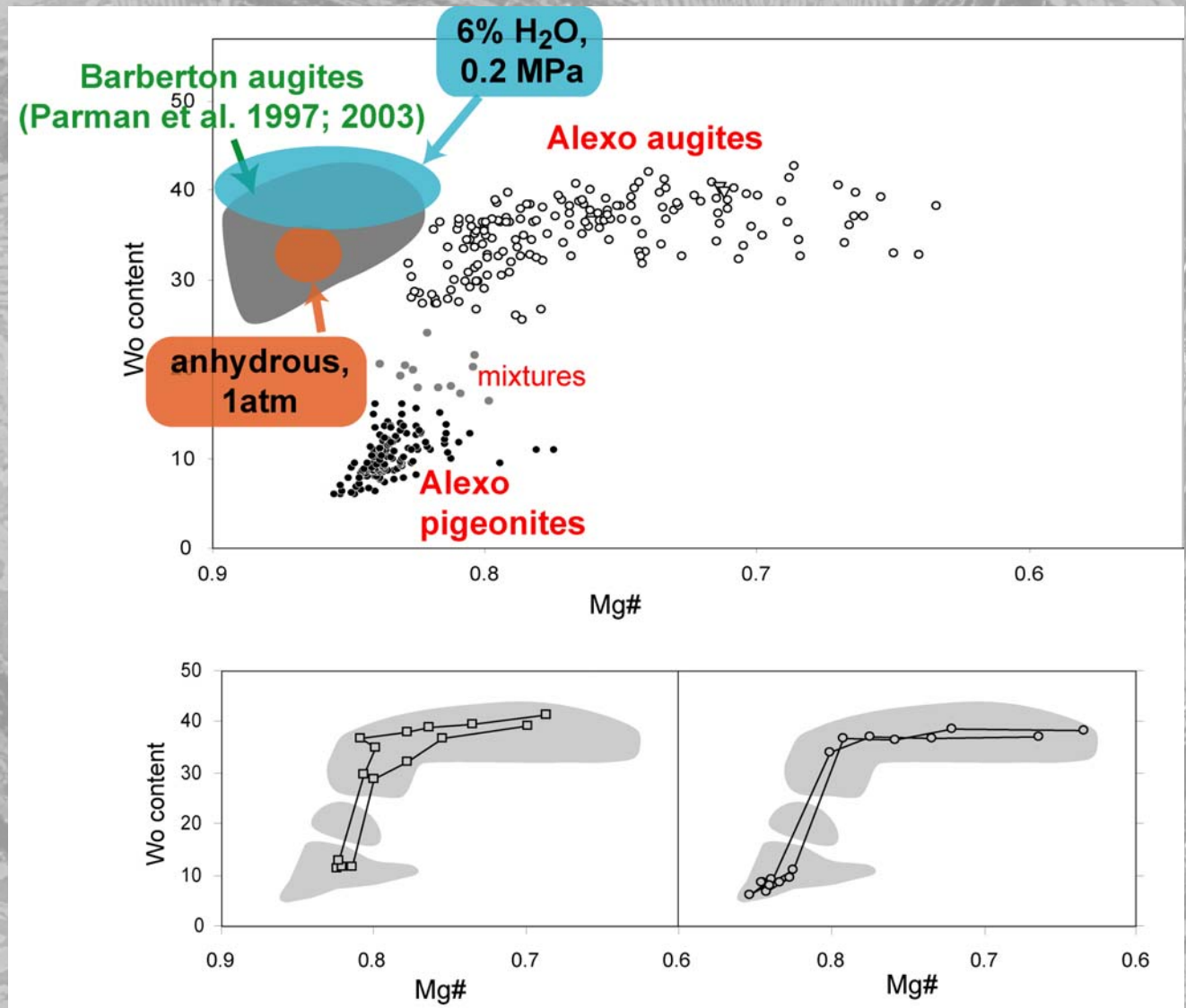


Zoning in pyroxene crystals in komatiites and lunar basalts is similar.
The crystallization sequence is the same in both lavas.

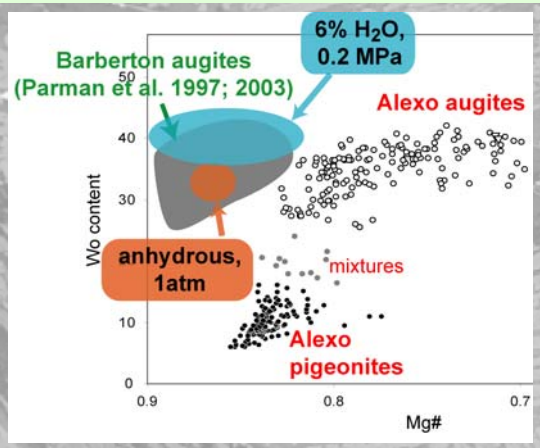
Analytical study

Alexo komatiite - Barberton komatiite





Analytical study



Barberton augites:
Barberton komatiites have high CaO/Al_2O_3

- altered grains
- all (but one) analyzed pyroxenes were in olivine cumulates

The unusual compositions of Barberton augites is due to the high CaO/Al_2O_3 of Barberton komatiites.

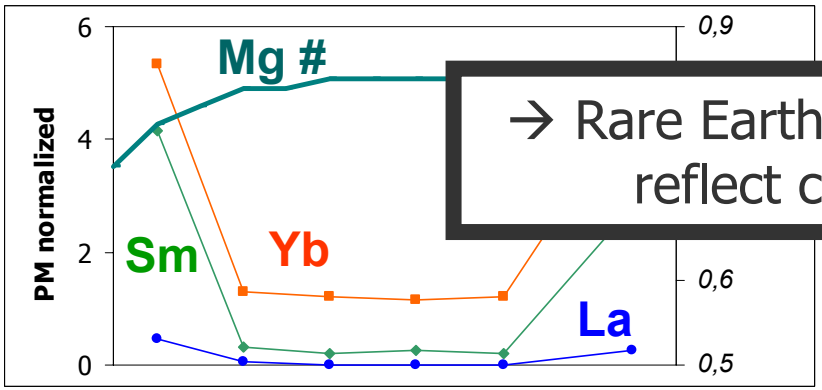
>>> water is not necessary to form Barberton pyroxenes

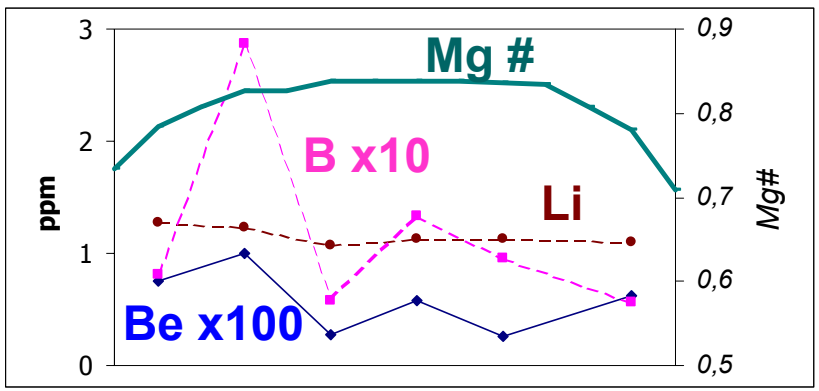
Clinopyroxene crystallizes at higher temperatures in compositions with high CaO/Al_2O_3 than in compositions with low CaO/Al_2O_3.

Augite that crystallizes a high temperature from liquids with high CaO/Al_2O_3 has high Mg#.

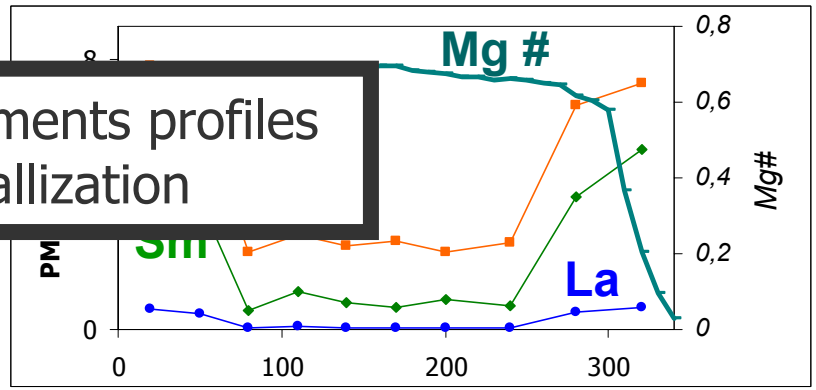
Analytical study

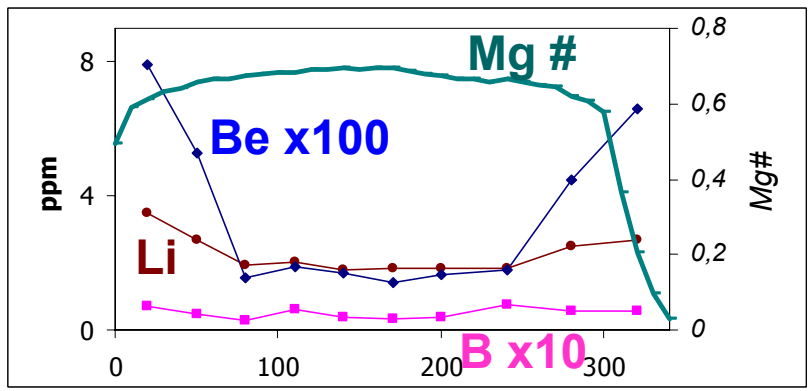
Komatiites





Lunar basalts



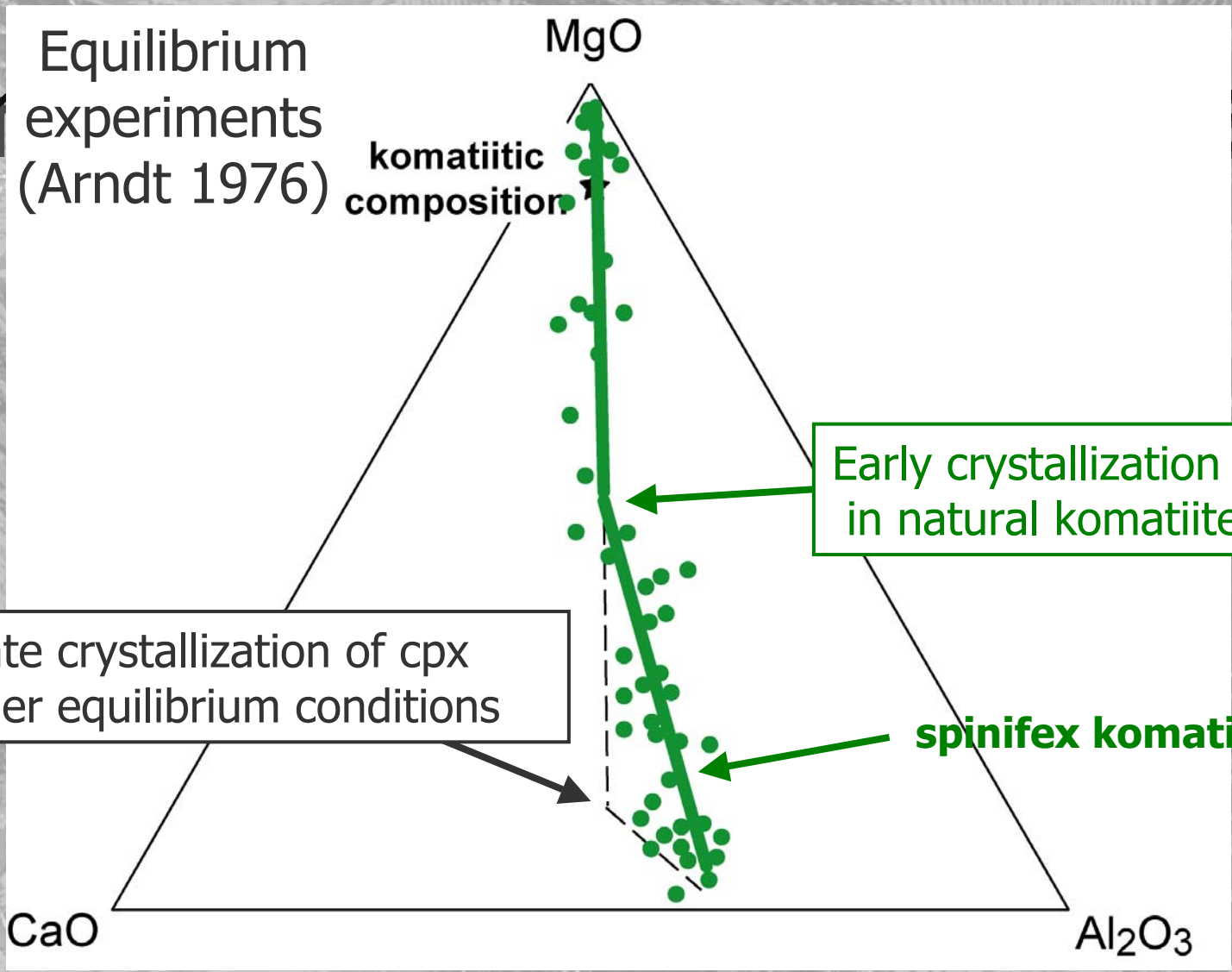


→ Rare Earth Elements profiles reflect crystallization

→ Be and Li profiles reflect alteration in komatiites

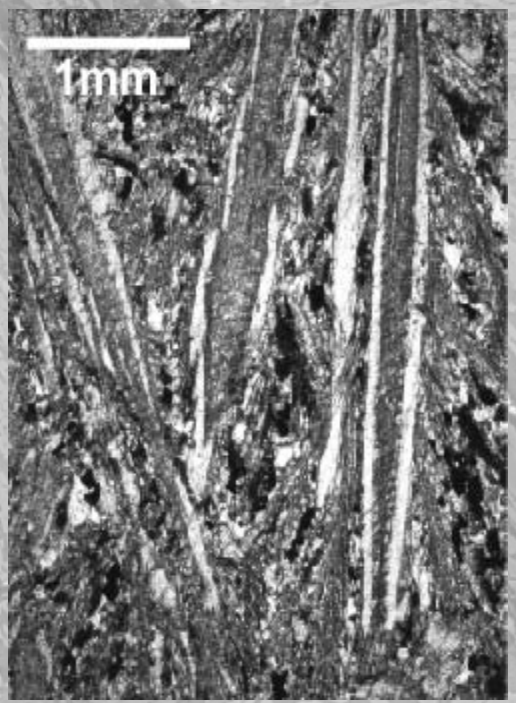
→ Be and Li profiles indicate geochemical behavior like REE

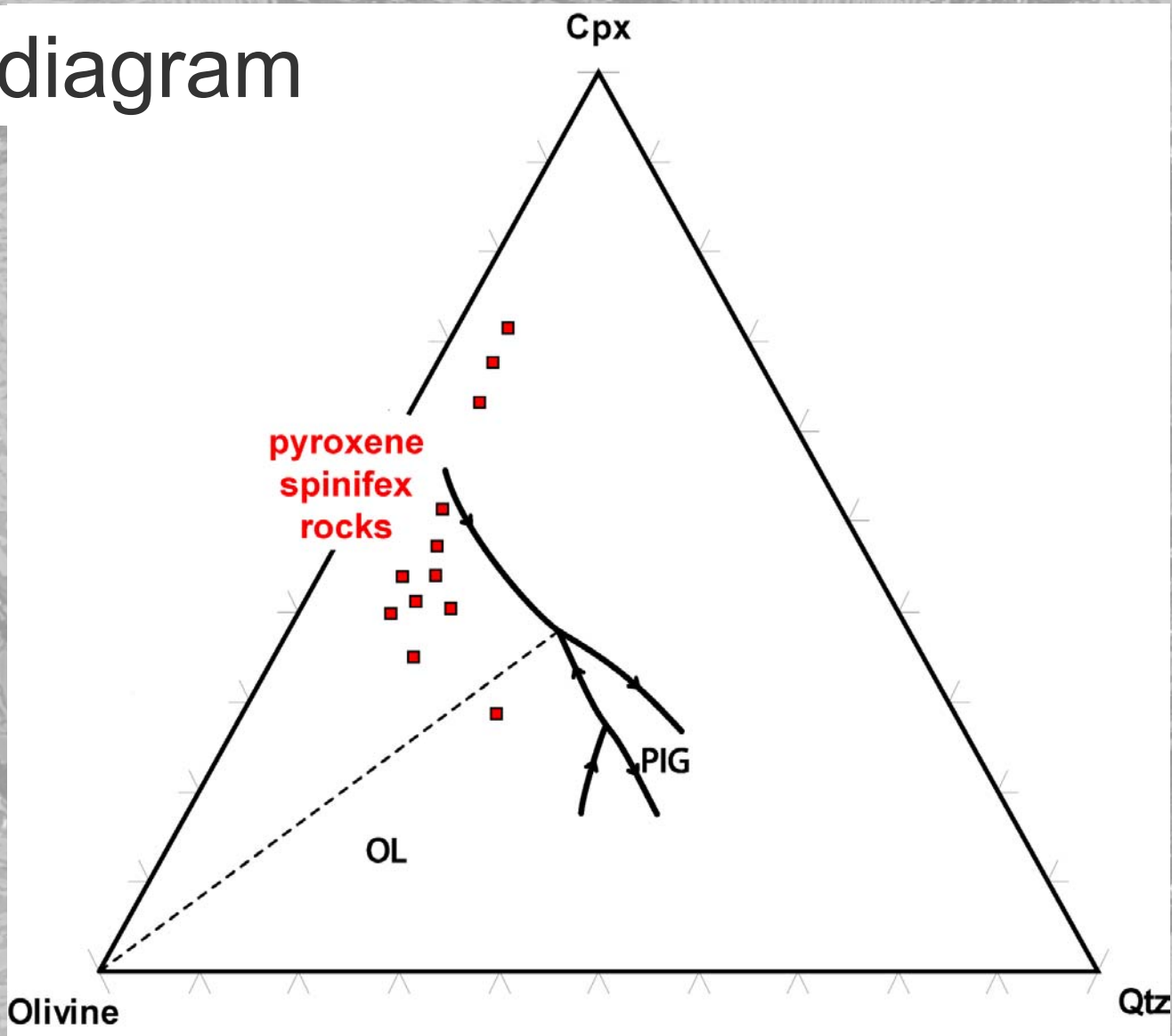
Analytical study



Analytical study

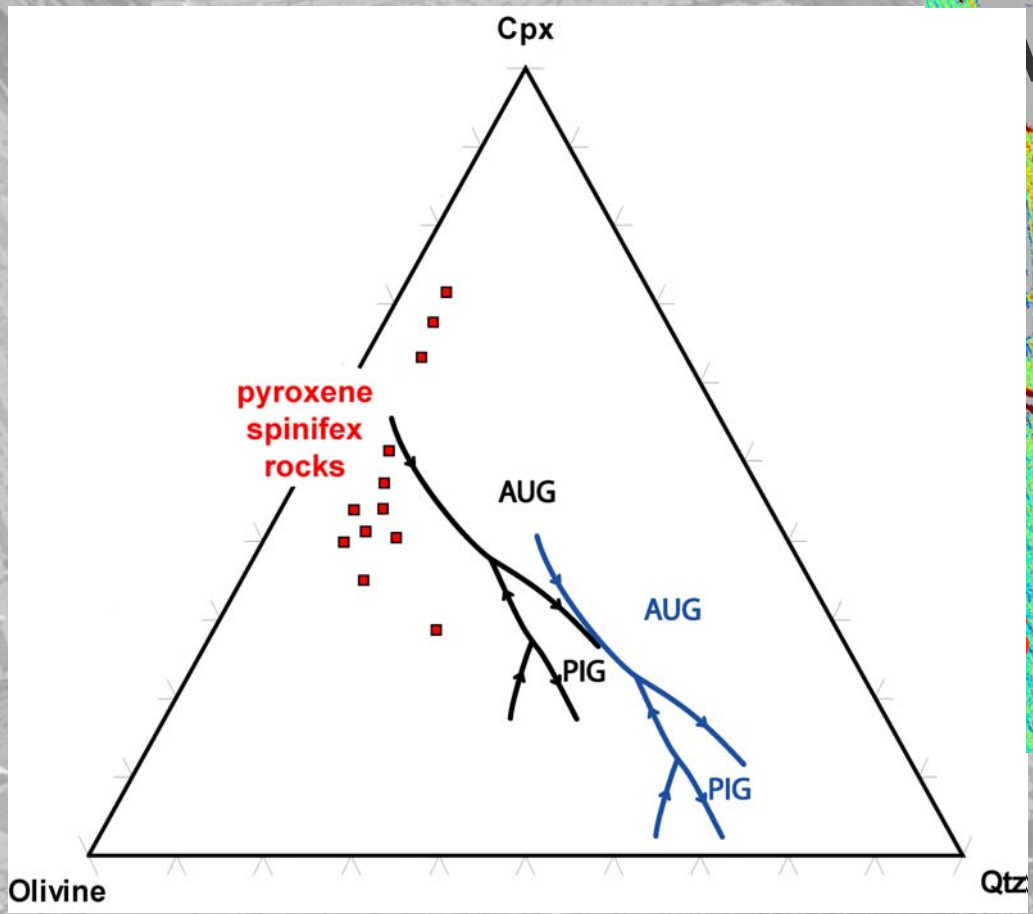
Phase diagram

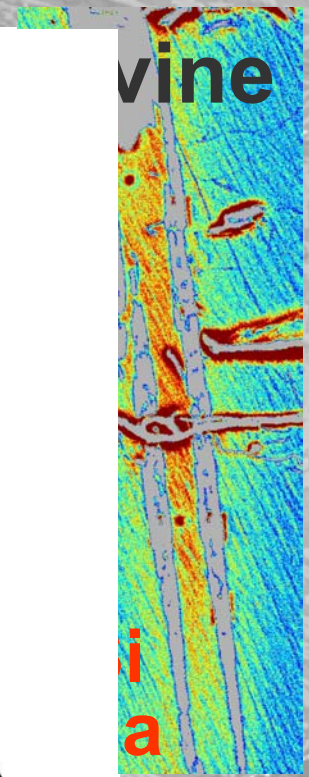




Analytical study

Early crystallization of pigeonite in komatiites: what are the solutions?





~~Alteration ?~~

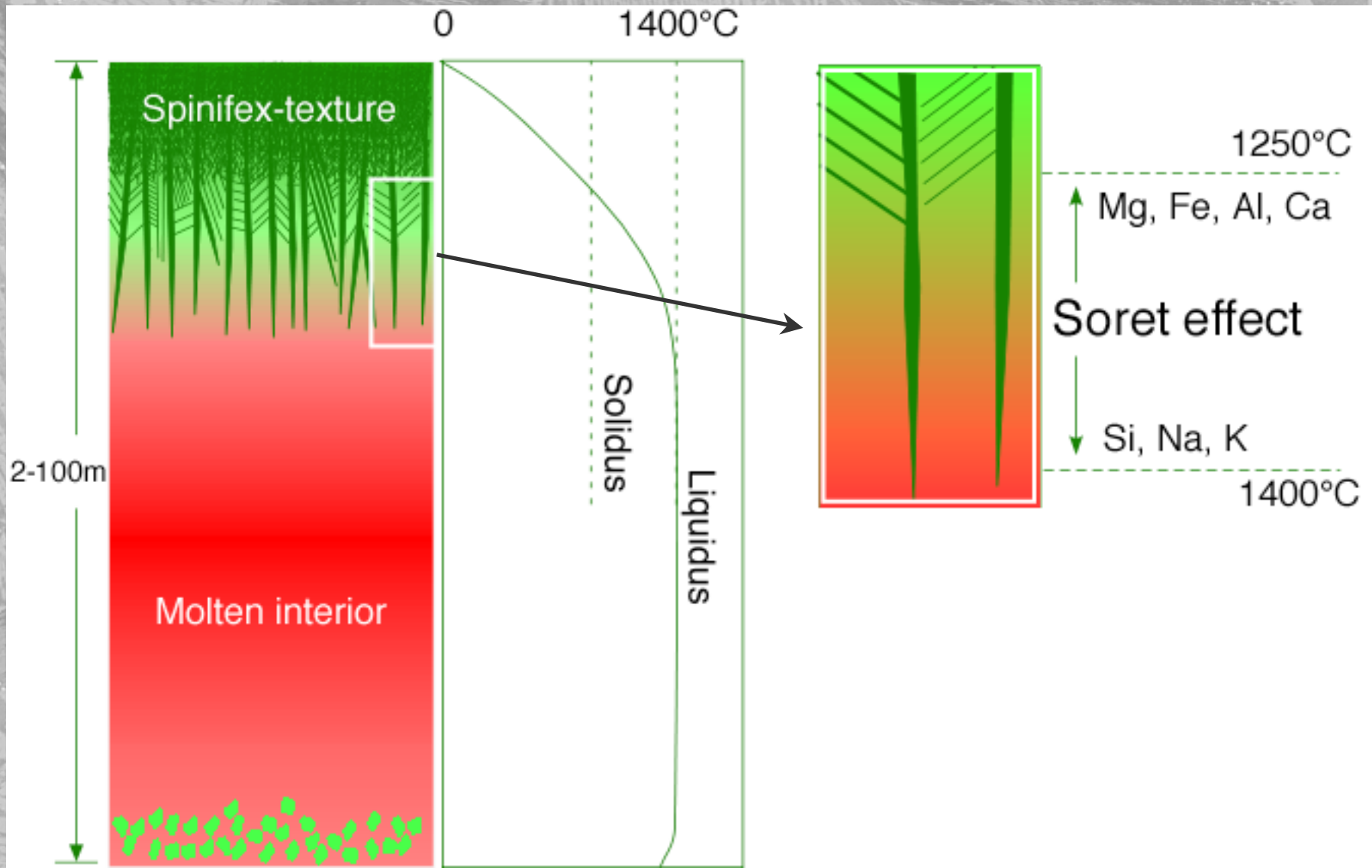
~~Pyroxene accumulation ? (Campbell & Arndt 1982)~~

~~Wrong phase relations ?~~

~~Chemical boundary layer ? (Faure & Schiano 2005)~~

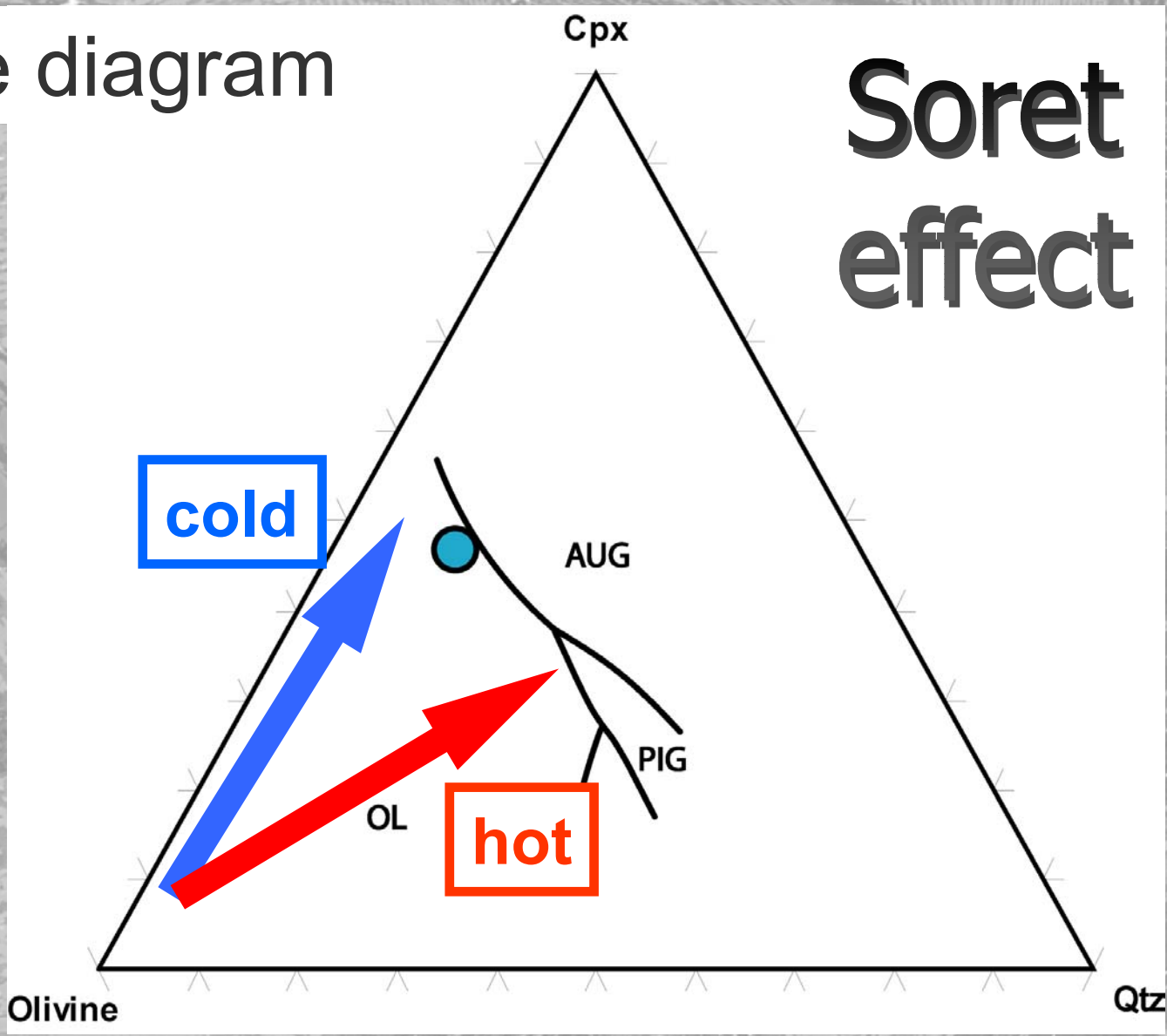
~~Water ? (Parman et al. 1997)~~

Soret effect



Analytical study

Phase diagram



Soret differentiation: how robust is it?

(1) Diffusion coefficients

Latypov (2006): 10^{-4}-10^{-5} cm^2/s for H_2O-saturated melts

LaTourrette et al. (1996): 10^{-7} cm^2/s for anhydrous liquids

→ Our estimate : 5.10^{-5} cm^2/s

(2) A **small** amount of water (0.2-0.5 wt%) is necessary

→ Water in melt inclusions (McDonough & Danyushevsky 1995; Shimizu et al. 2001)

→ Degassing kinetics (Moune et al. 2007)

(3) Moderate thermal gradient is sufficient

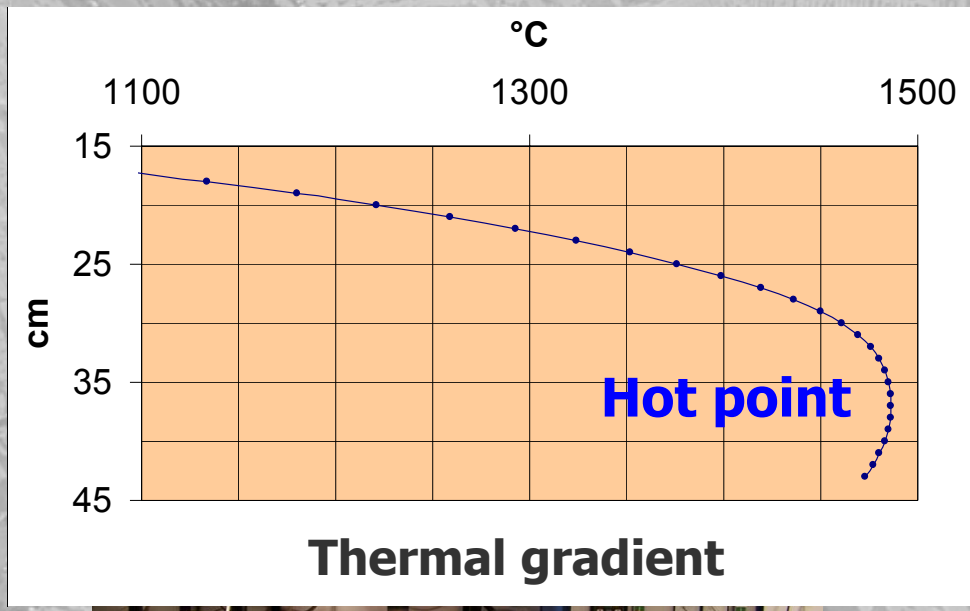
>>> Soret differentiation allows pigeonite to crystallize from a liquid that would have normally crystallized augite

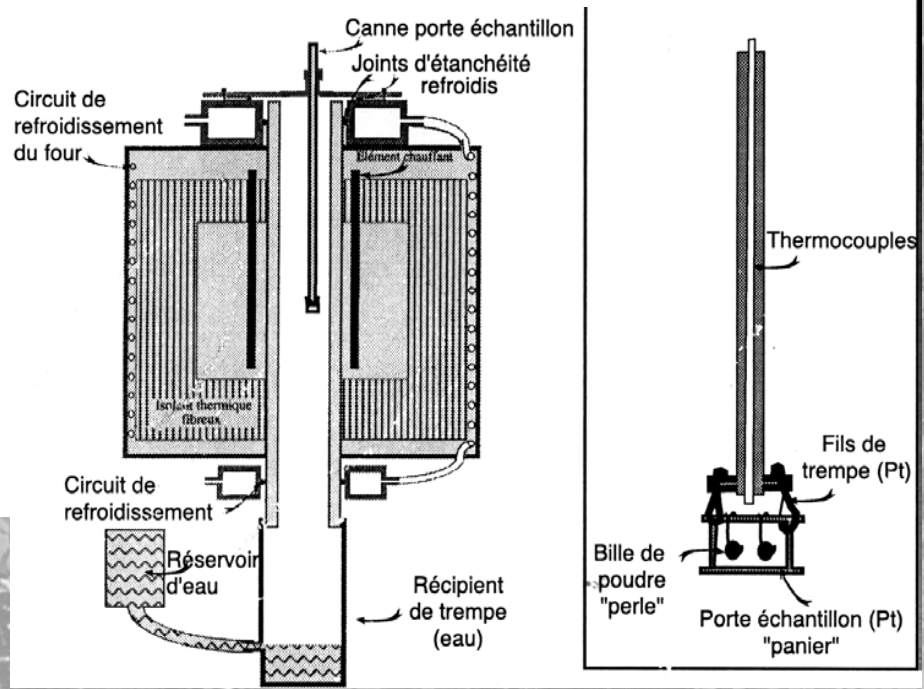
Experimental investigation

→ we used a vertical high-temperature, gas-mixing furnace

→ inert atmosphere is maintained by a flow of Ar

→ presence of a variable thermal gradient in the furnace, depending of the exact location of the graphite crucible

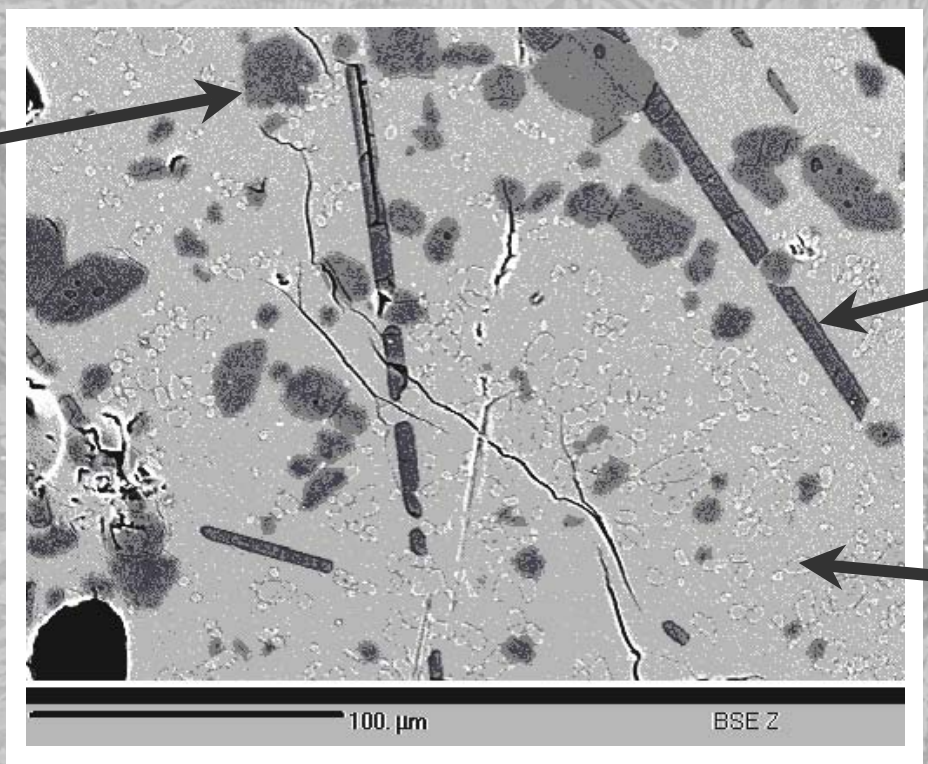




Experimental investigation

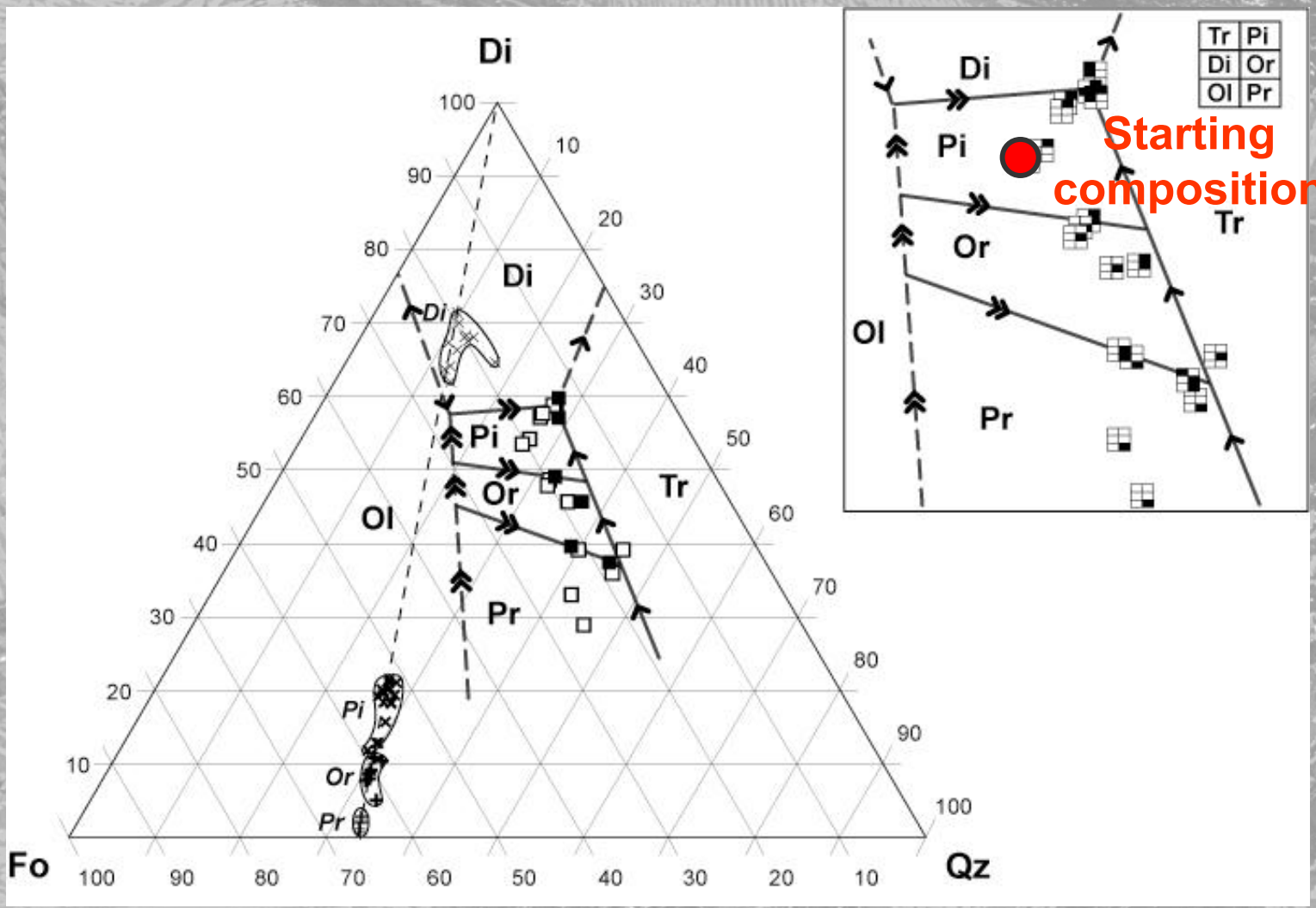
We performed two series of experiments:

- Isothermal crystallization experiments
- Dynamic crystallization experiments



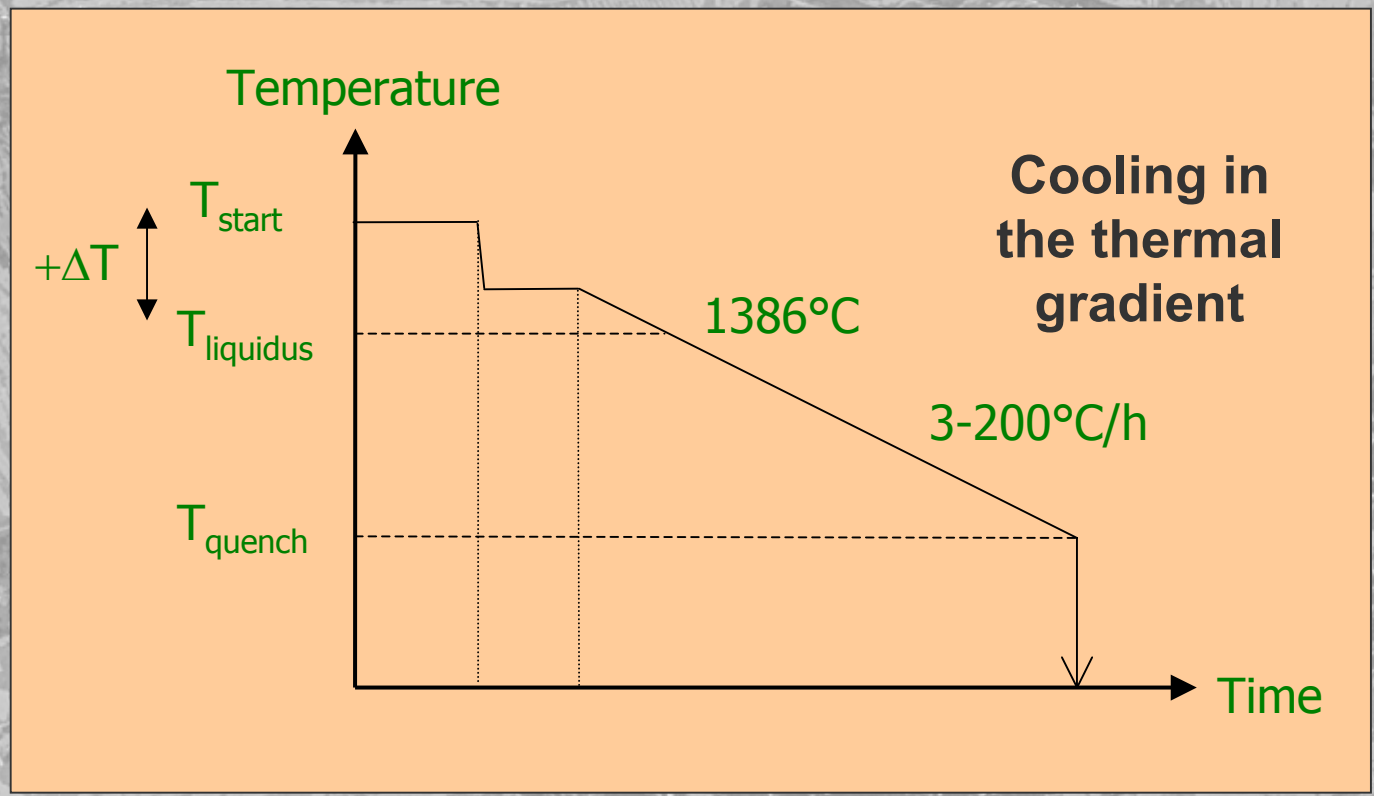
Experimental investigation

Liquidus boundaries / Pyroxene composition field



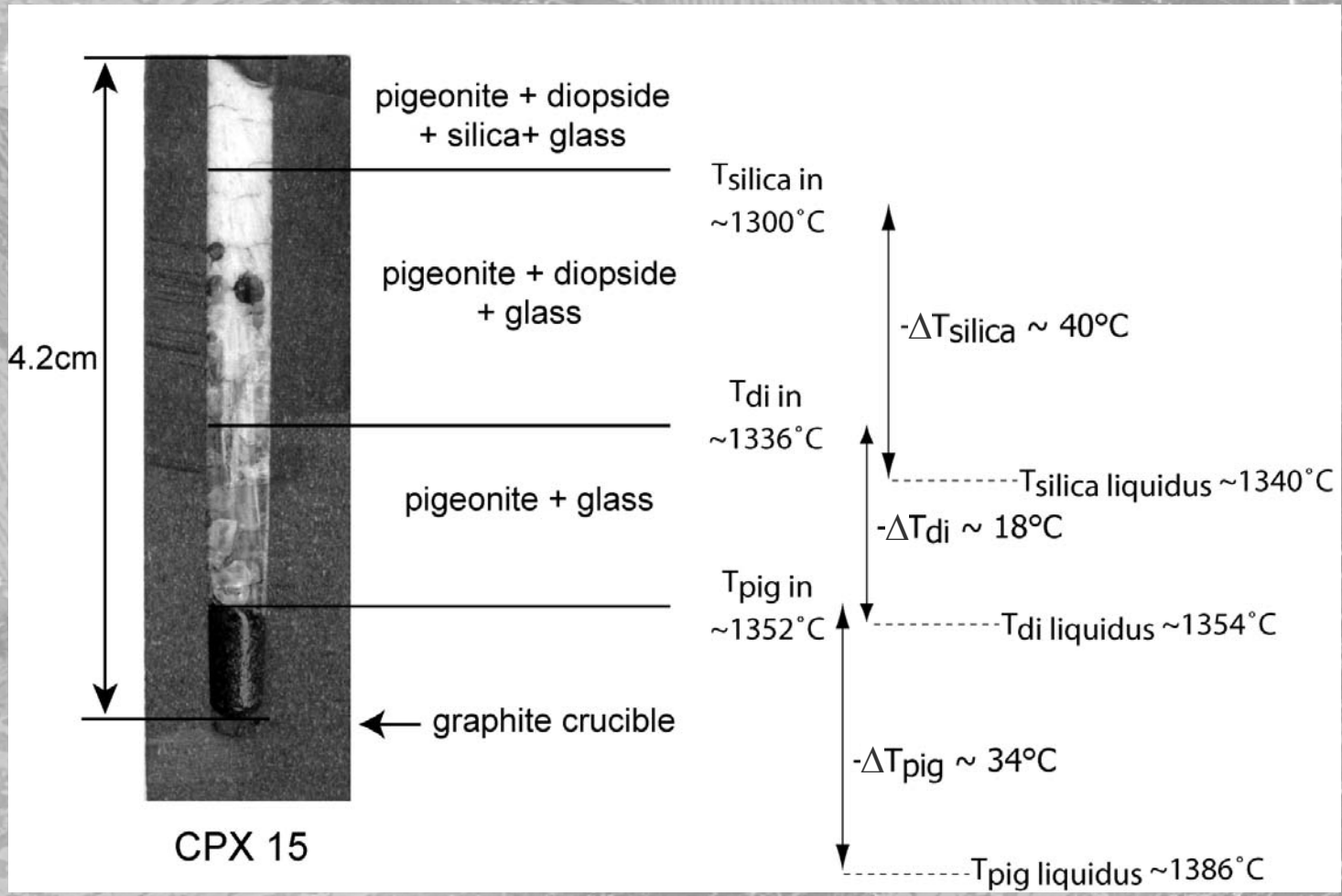
Experimental investigation

Typical procedure of cooling

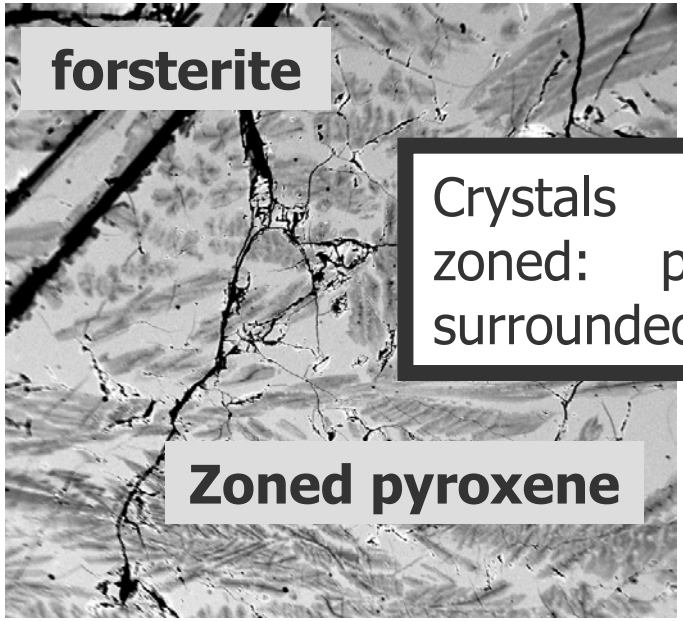


Experimental investigation

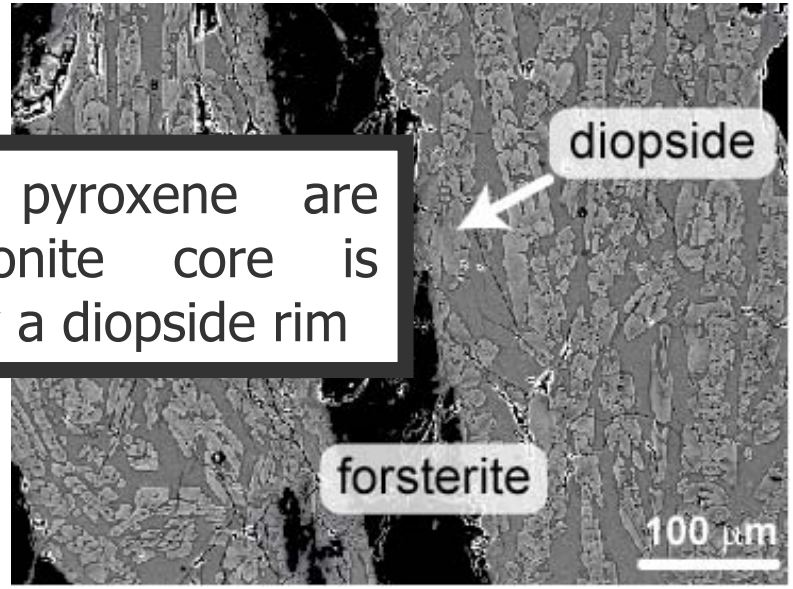
Example of a typical run



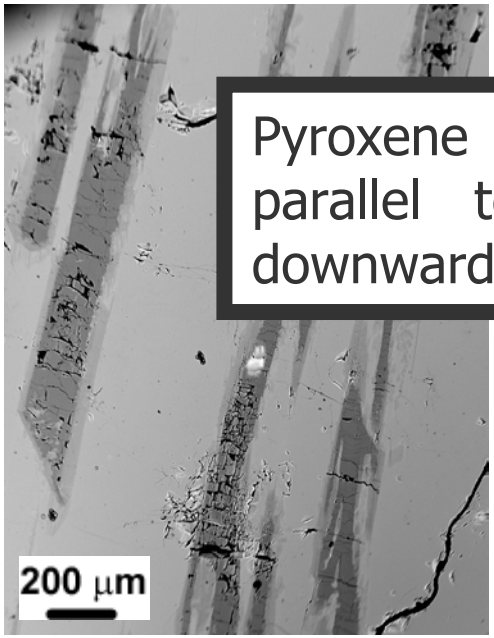
Experimental investigation

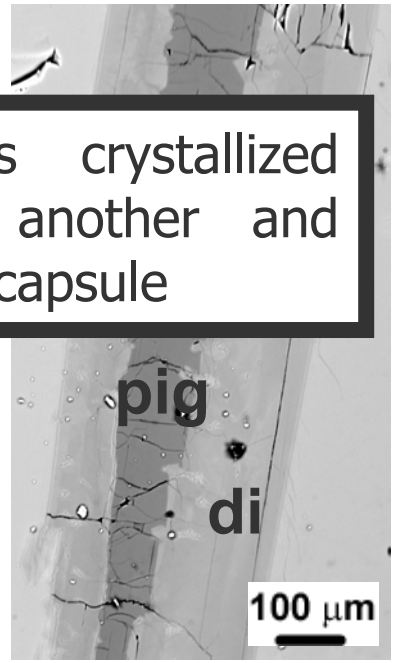


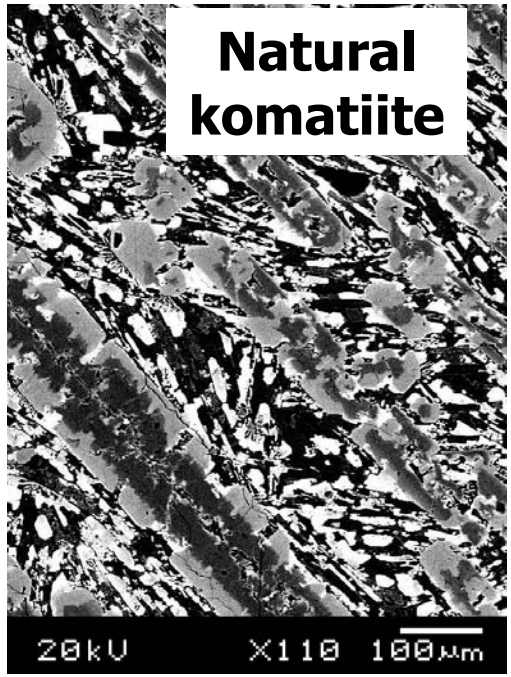
Crystals of pyroxene are zoned: pigeonite core is surrounded by a diopside rim



Pyroxene needles crystallized parallel to one another and downwards in the capsule

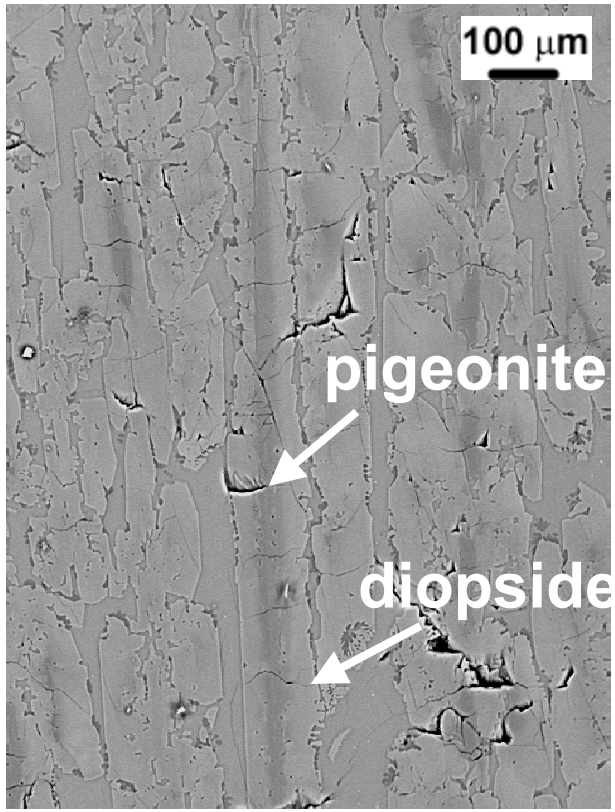






Experimental investigation

High cooling rate experiments



Pigeonite crystallizes in the thermal gradient even at high cooling rates (100°C/h)

Experimental investigation

(1) We were able to crystallize zoned crystals of pyroxene that perfectly mimic those in komatiites.

(2) Pyroxene crystals growth is constrained by the thermal gradient.

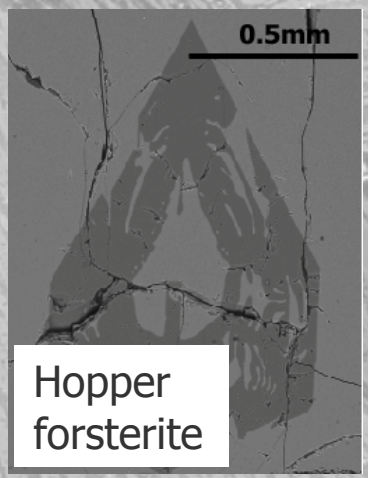
(3) Pigeonite formed at high cooling rates (100°C/h)

>>> what about olivine ?

Experimental investigation

Forsterite crystallization:

(1) various morphologies



Hopper forsterite

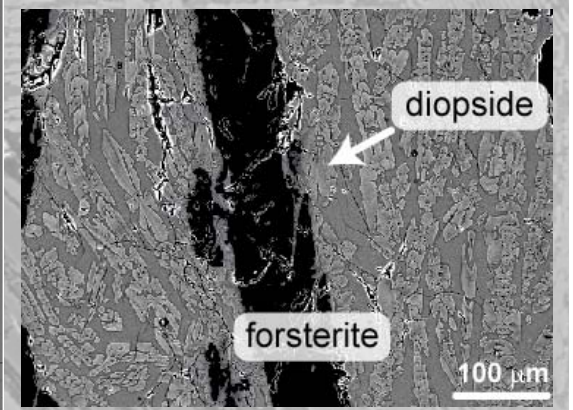
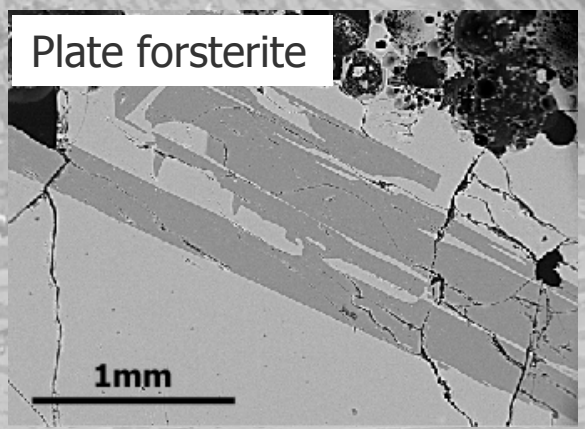
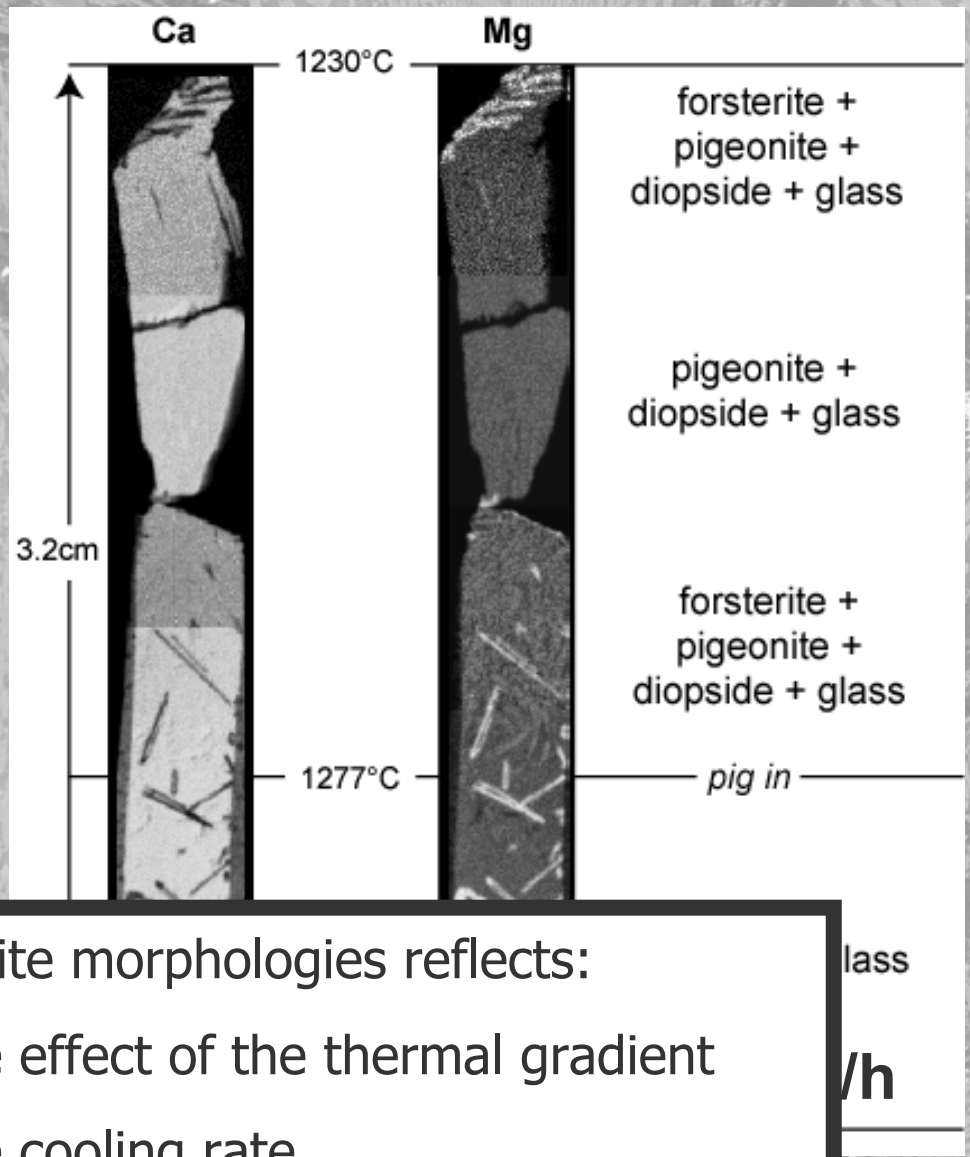


Plate forsterite





Forsterite morphologies reflects:

(1) the effect of the thermal gradient

(2) the cooling rate

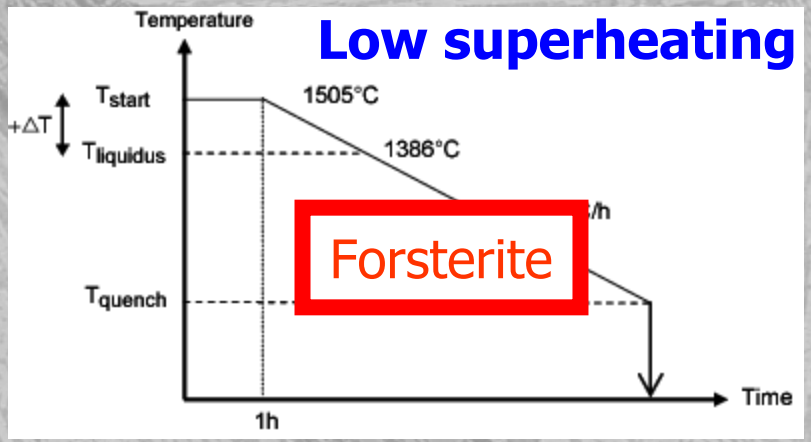
Experimental investigation

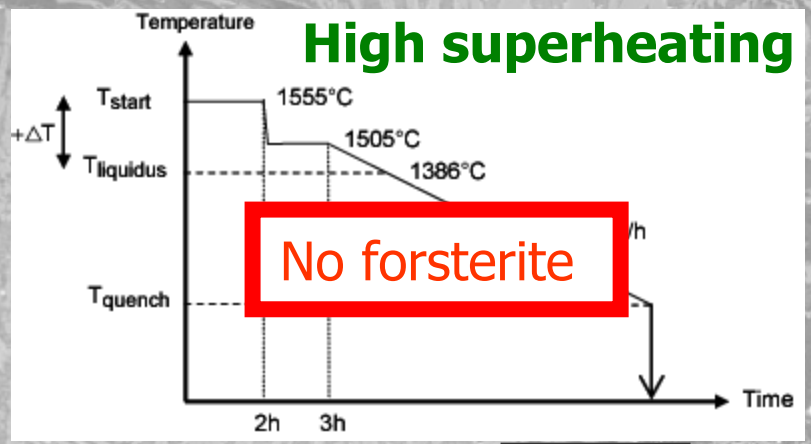
Forsterite crystallization:

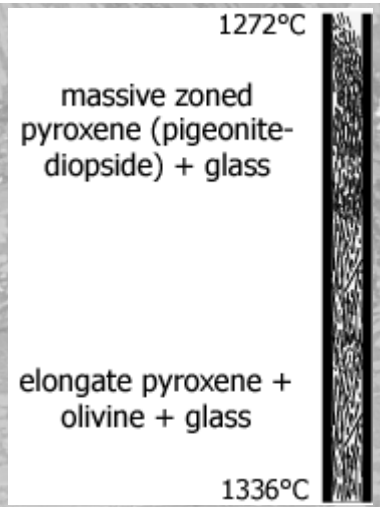
(1) various morphologies

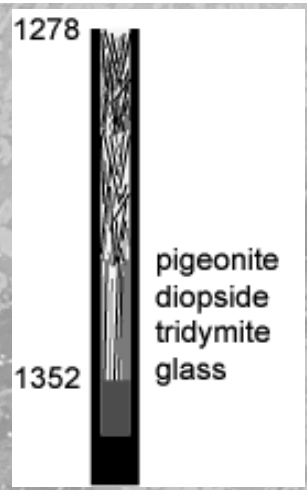
(2) metastable

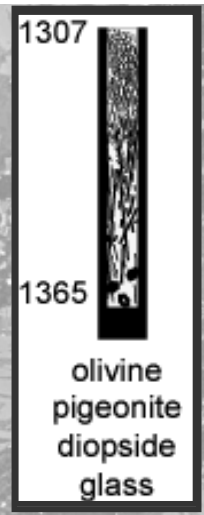
Metastable forsterite: a superheating consequence?



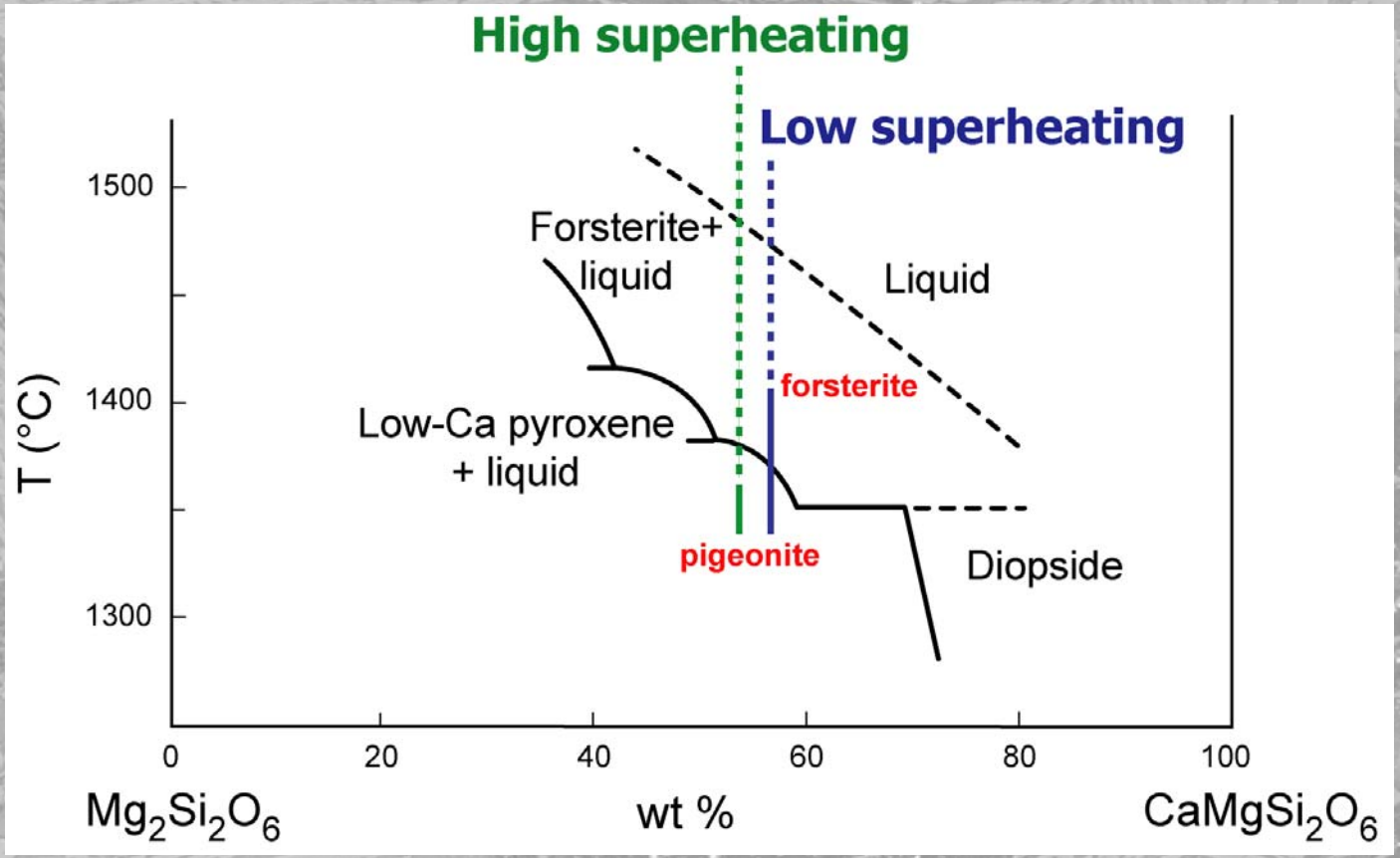








Metastable forsterite: a superheating consequence?



Conclusions

(1) Zoned pyroxene crystallizes in natural komatiites and in lunar basalts.

(2) For a given composition of komatiitic liquid, the type of pyroxene and the crystallization sequence depends on the conditions of crystallization.

(3) Constrained growth in a thermal gradient causes pigeonite to crystallize earlier than at equilibrium conditions. Soret differentiation is an efficient mechanism in pyroxene spinifex-textured lavas.

(4) There is no evidence for the presence of a significant amount of water in komatiites. Most komatiites are dry and hot

Future research

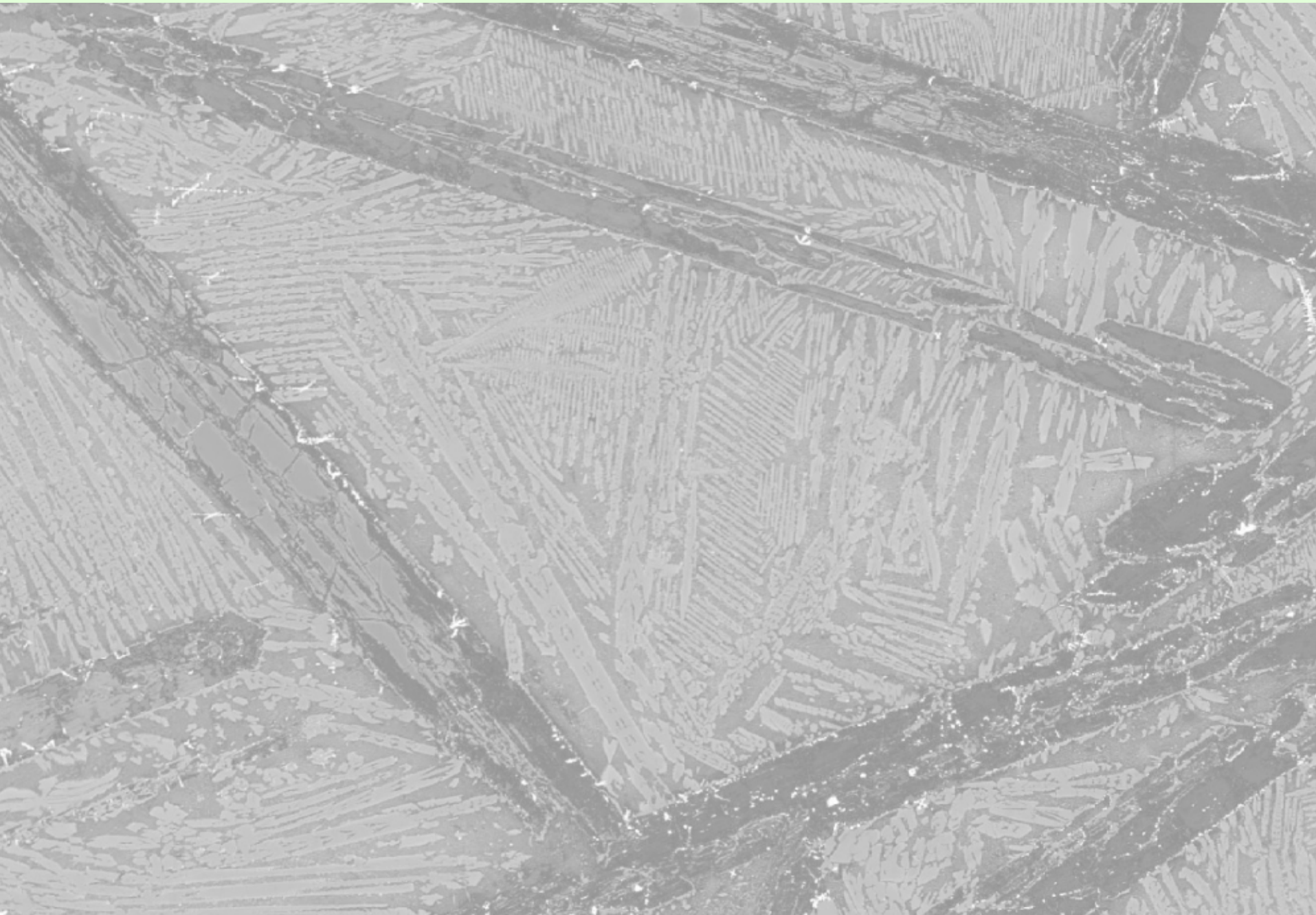
(1) To better understand the cooling mechanisms of komatiite flows – to have better contraints on Soret effect

(2) To better understand the crystallization of pigeonite:

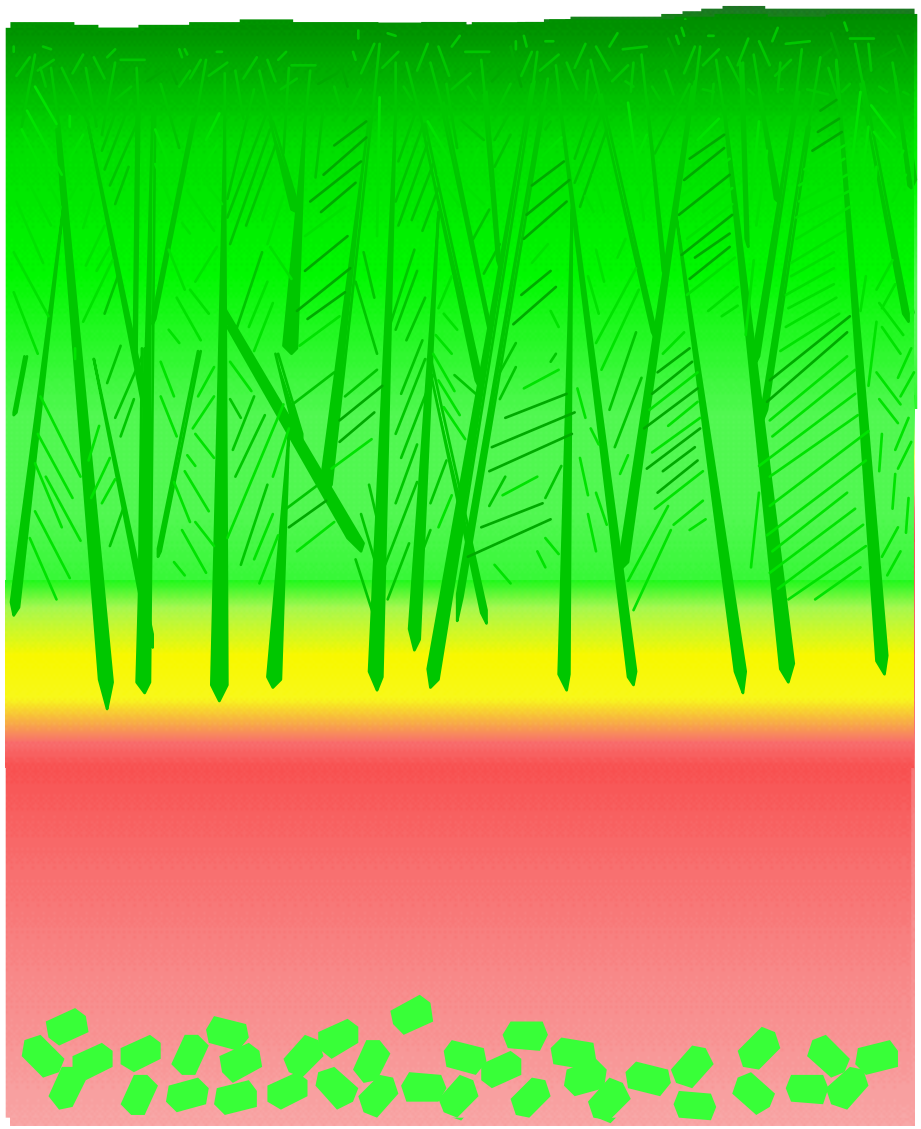
→ Experiments with olivine at the liquidus and pigeonite as the second mineral

→ Introduction of tracers such as Cr or REE, in order to follow the crystallization of pigeonite

Thank you



Model of a komatiite flow



Solidification of the crust and growth of skeletal olivine crystals

Settling of olivine phenocrysts to form cumulate layer