Physicochemistry of evaporation of forterite, enstatite, and melt

September 10, 2003
Dust Workshop

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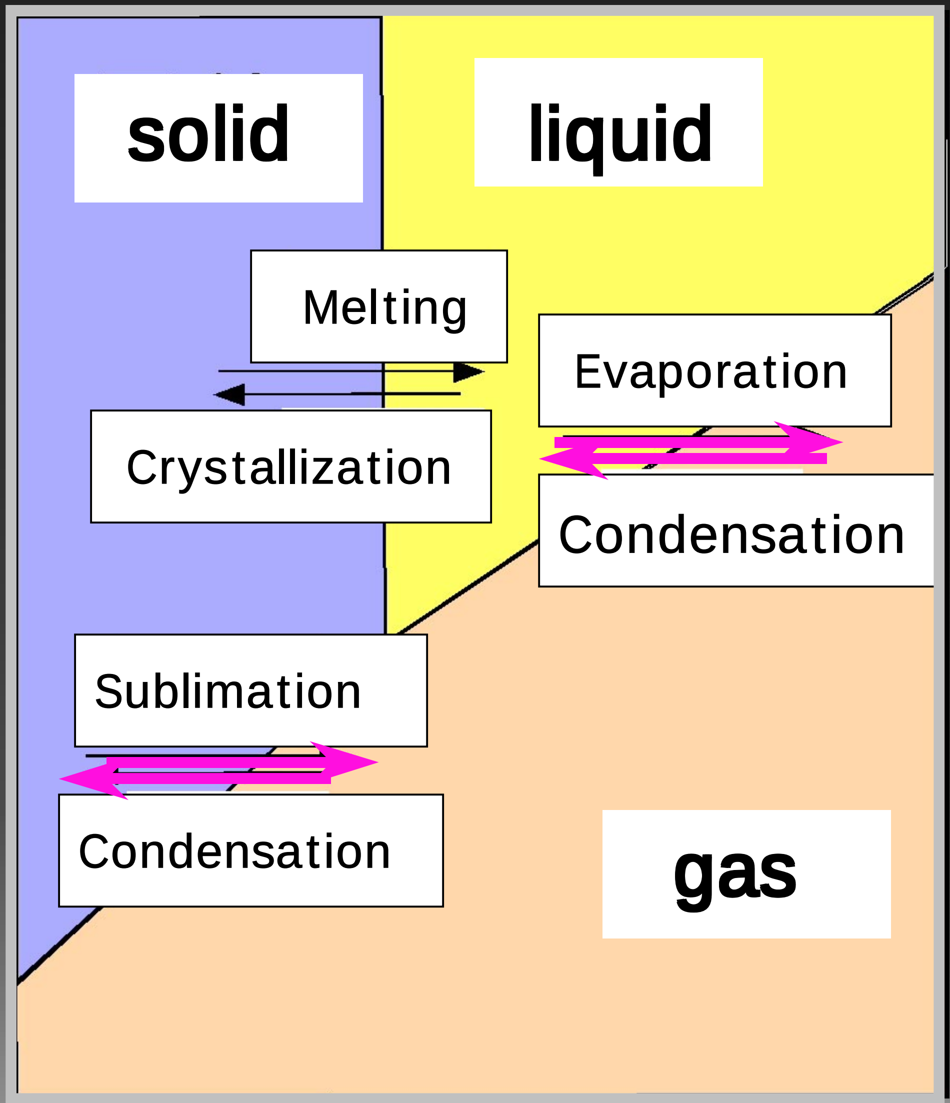
Evaporation, Condensation, and Melting



1. Thermodynamic equiibrium
   → stable phase, composition, condition, trend of reaction

   thermodynamic calculation

2. Kinetics of phase change
   → timescale of the reaction, size, kinetic parameter

   experiments

Kinetic theory of gas molecules : Hertz - Knudsen Equation

Evaporation rate of a substance

$$J_i = \frac{\alpha_e P_{eq,\,i} - \alpha_c P_i}{(2\pi mkT)^{1/2}}$$

J_i : evaporation rate of element I from the condensed phase

$P_{eq,\,i}$: equilibrium vapor pressure of element i

P_i : vapor pressure of elements i in the ambient gas

α_e : evaporation coefficient ($0 \le \alpha_e \le 1$)

α_c : condensation coefficient ($0 \le \alpha_c \le 1$)

Experimental determination of α_e and α_e is crucial

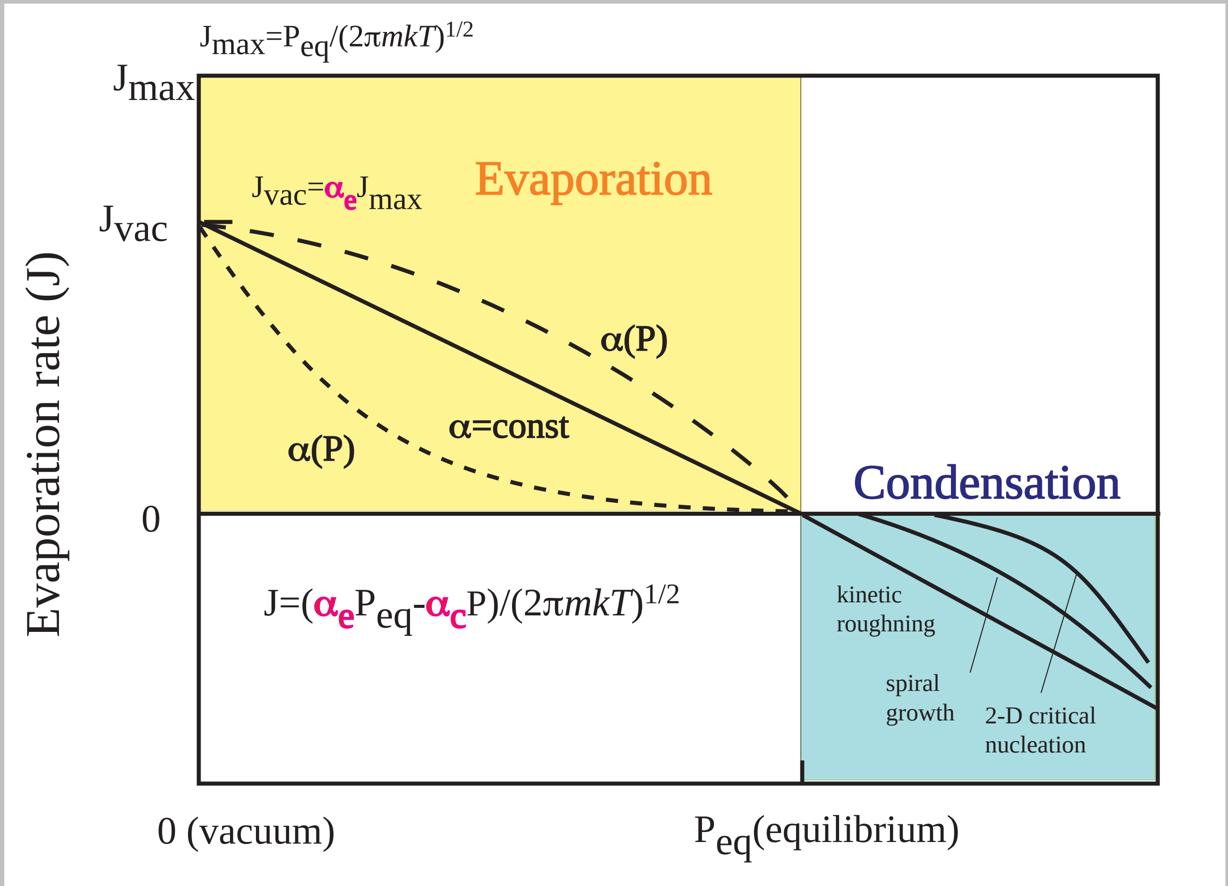
Evaporation Coefficient α_e and condensation coefficient α_c

$$P_i \longrightarrow 0$$

$$J_{i\,c} = \frac{\alpha_e P_{eq,\,i}}{(2\pi mkT)^{1/2}}$$

evaporation rate in vacuum

$P_{eq,\,i}$: thermochemically calculated
α_e: experimentally determined



$$P_i \longrightarrow P_{eq,\,i}$$

$$J_{i\,c} = 0$$

no evaporation
in equilibrium

Mode of evaporation

Congruent evaporation

A → A (gas) (Fo→Fo, SiO_2→SiO_2)

the same composition before and after partial evaporation

Simple evaporation

no chemical fractionation

mass-dependent isotopic fractionation

Incongruent evaporation

A → B (solid) + C (gas) (En→ Fo+Si-rich gas, almost all melt)

different residue after partial evaporation

complicated evaporation

fractionation

mass-dependent isotopic fractionation

Chemical and Isotopic Fractionations

Parameters governing the degree of chemical and isotopic fractionation

Intrinsic feature of condensed phase:

J_{evap} (evaporation flux) controlled by P_{eq} (equilibrium pressure) and α_e (evaporation coefficient)

D (diffusivity) in the condensed phase

K (isotopic fractionation factor)

Extrinsic or environmental factors :

J_{cond} (condensation flux) controlled by P_{gas} (ambient pressure) and α_c (condensation coefficient)

T evolution; τ (cooling rate of the system)

P evolution; η (dust enrichment factor)

What to do

<u>Determine the kinetic parameters by experiments</u>

Vacuum experiments:

J_{evap} (evaporation flux) → α_e (evaporation coefficient)

D (diffusivity)

K (isotopic fractionation factor)

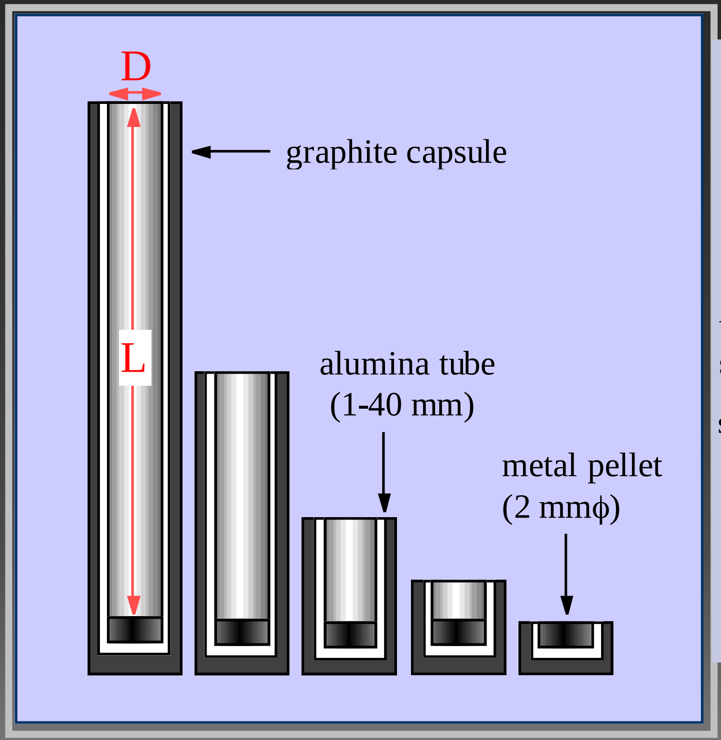
Evaporation experiments in the presence of ambient gas :

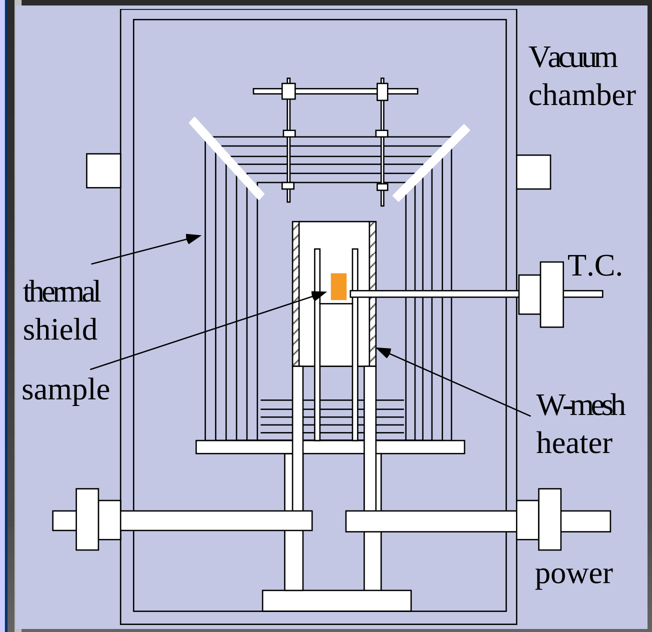
J → α_c (condensation coefficient)

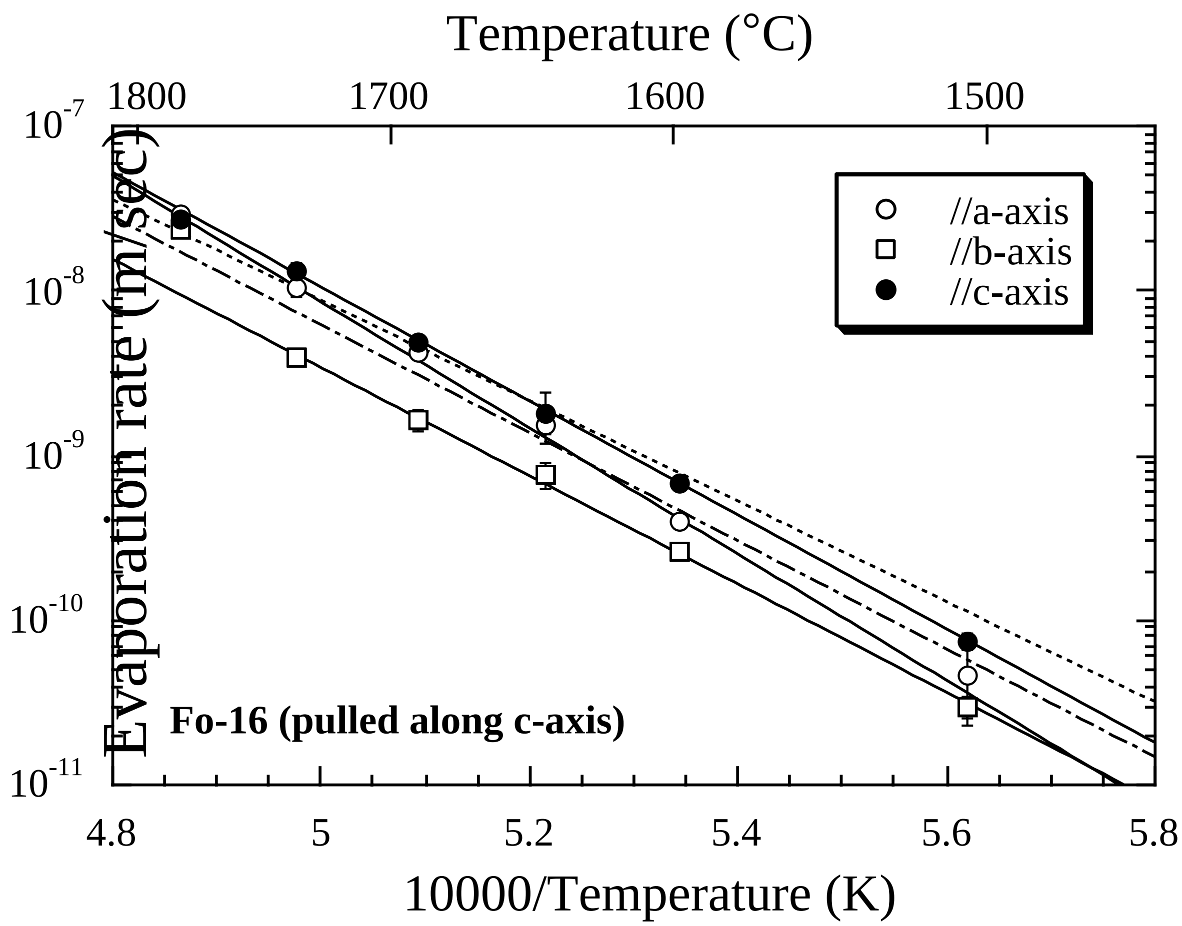
<u>Apply the results to model the evolution of solid materials heated at various P, T, and C conditions with various thermal trajeoctory</u>

Experiments : techinique

Ambient gas pressure control
by changing the capsule length

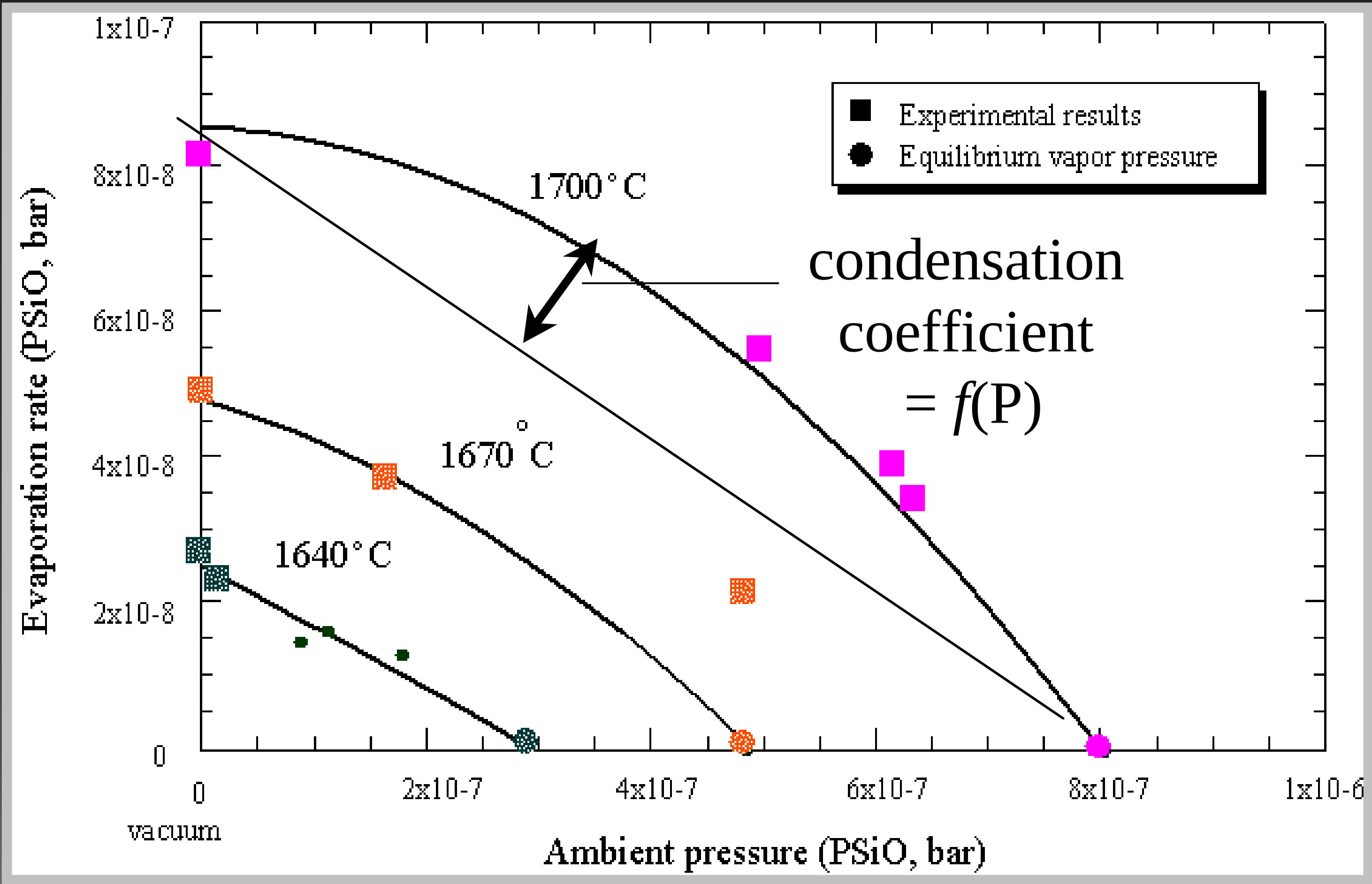






Temperature (°C)
1800
1700
1600
1500
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
Evaporation rate (m/sec)
//a-axis
//b-axis
//c-axis
Fo-16 (pulled along c-axis)
4.8
5
5.2
5.4
5.6
5.8
10000/Temperature (K)

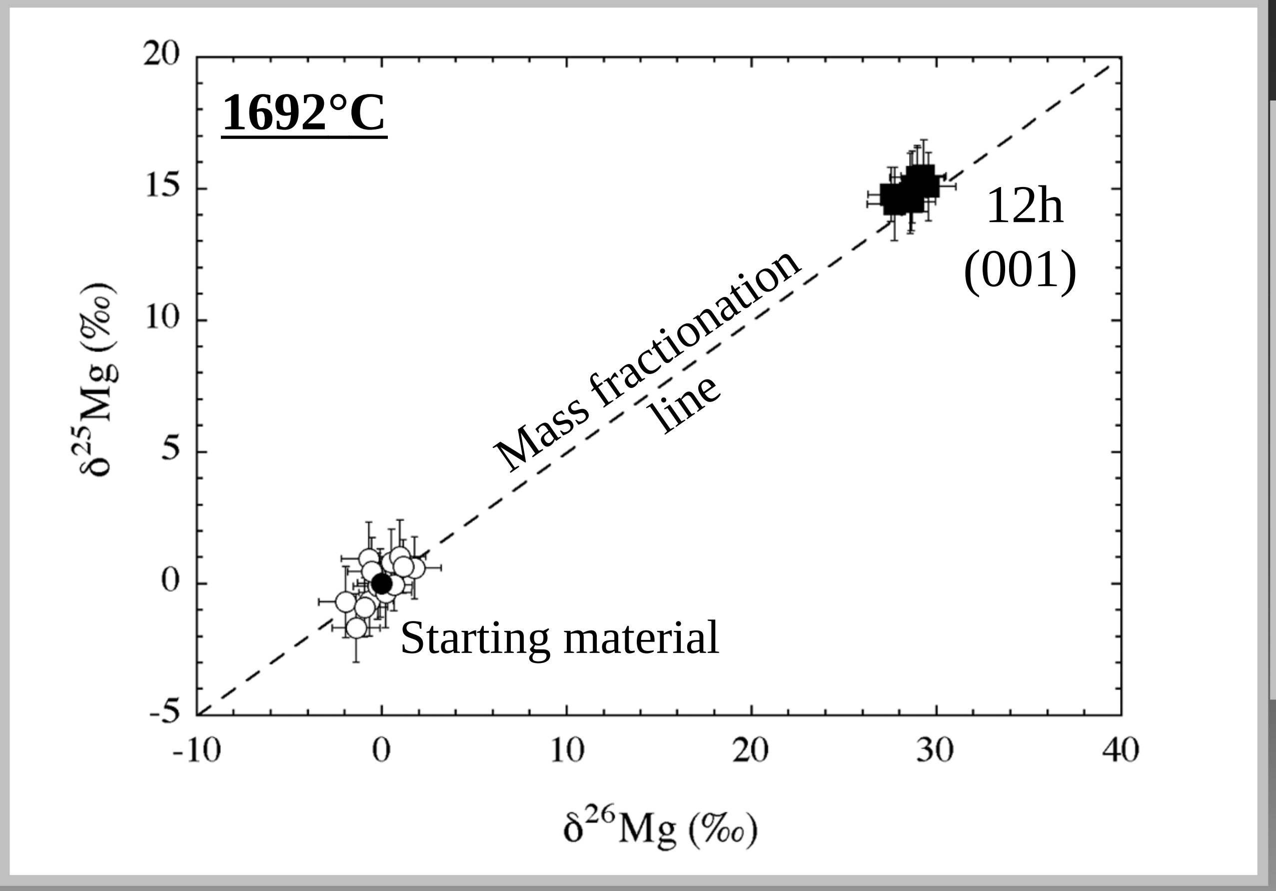
Evaporation of forsterite (2) condensation coefficient



condensation coeficient : pressure dependent

Evaporation of forsterite (3) isotopic fractionation -1

$$\delta^{i}Mg[‰] = \left(\frac{({}^{i}Mg/{}^{24}Mg)_{sample}}{({}^{i}Mg/{}^{24}Mg)_{std}} - 1 \right) \times 1000 (i = 25,26)$$

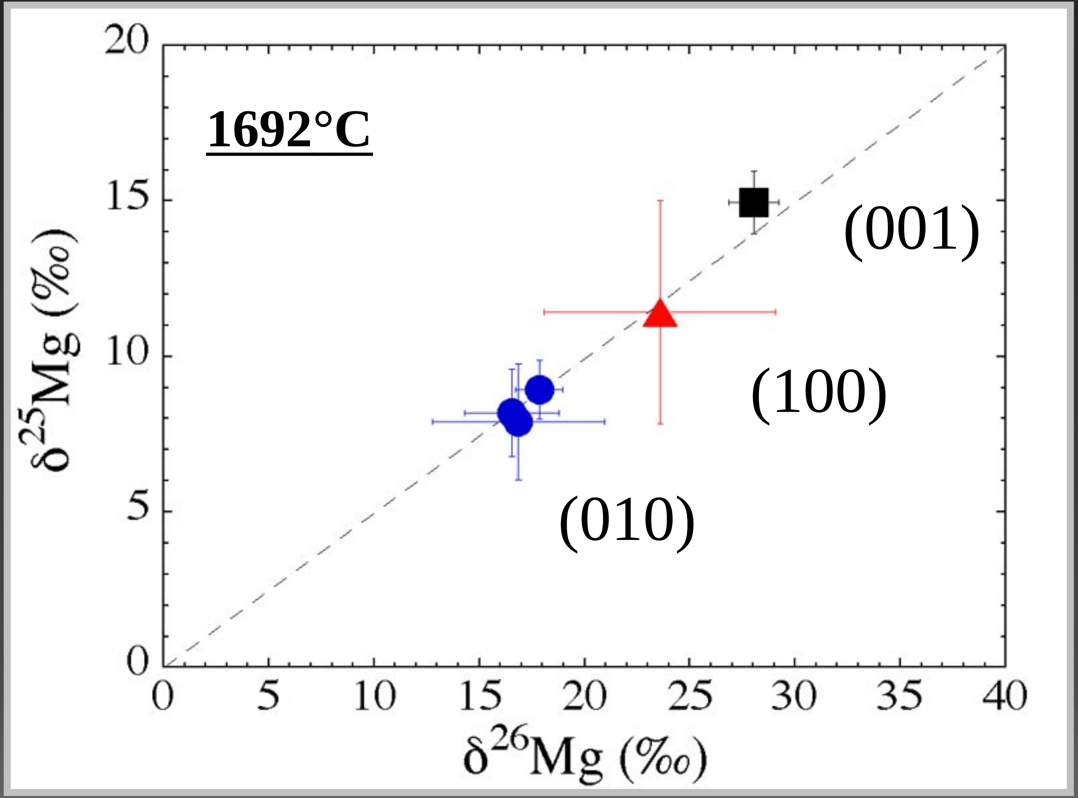


Evaporation residue

↓

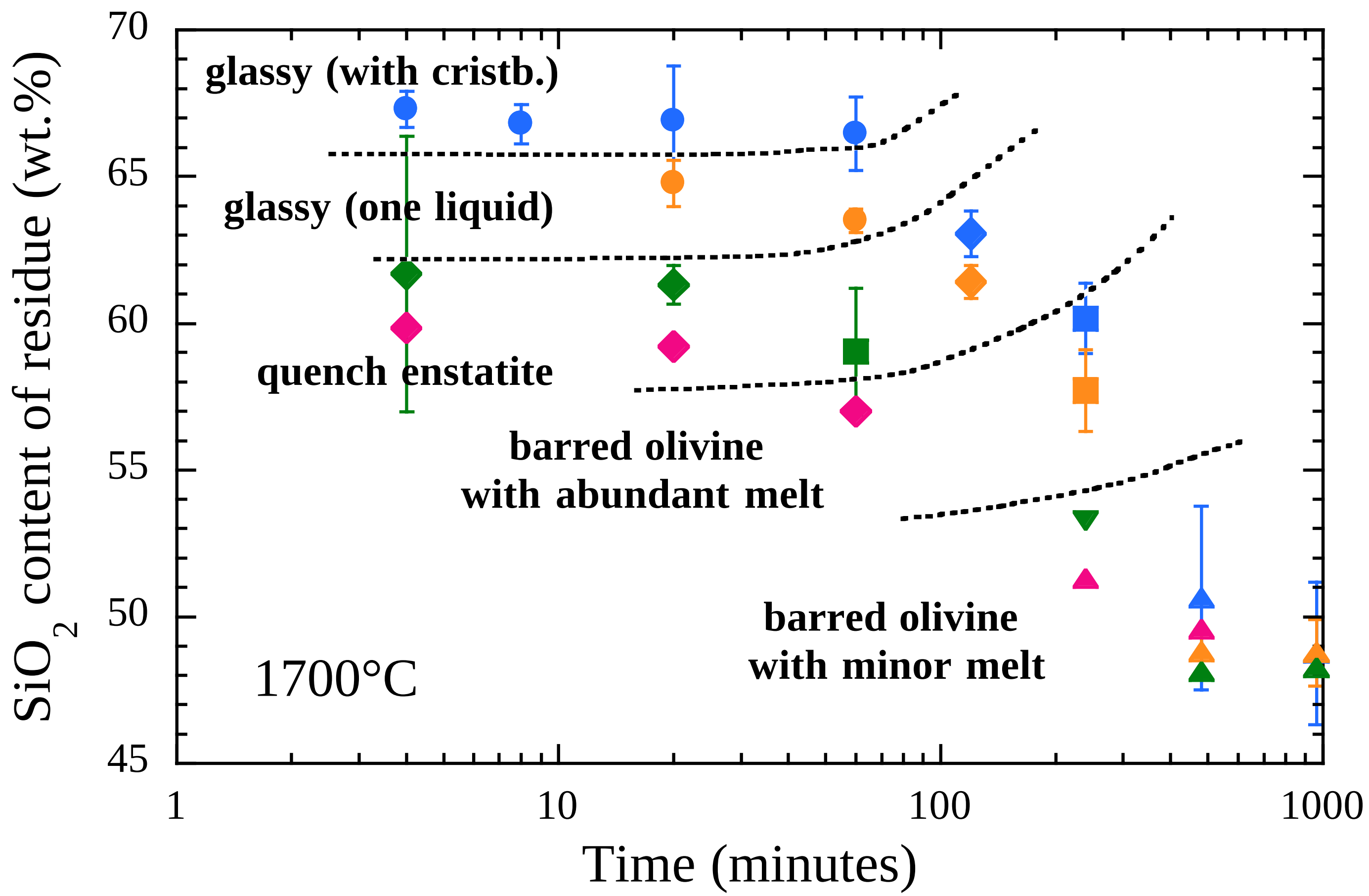
Isotopically heavier than before

Evaporation of forsterite (3) isotopic fractionation - 2



Isotopic fractionations: anisotropoic

Evaporation of silicate melt
(1) change residue composition in MgO-SiO2 system



continuous compositional change with evaporation
Residue → Mg-rich

Evaporation of silicate melt (2) evaporation coefficient