

Project A02-02

An appraisal on core–mantle interaction based on element partitioning

「元素分配から制約する核–マントルの相互
作用」の概要

M. Satish-Kumar

Faculty of Science, Niigata University

“Interaction and Coevolution of the Core and Mantle
~Toward Integrated Deep Earth Science~”
Kick-off symposium, Aug.7-8, 2015

Members

Principal Investigator

M. Satish-Kumar (Niigata University)

Co-investigators

Tetsu KOGISO (Kyoto University)

Shigehiko TATENO (ISEI, Okayama University)

Kenji MIBE (Tokyo University)

Seiji KAMADA (Tohoku University)

Introduction and background

- Element abundance and distribution in the Earth
- Partitioning of elements and isotopes during core formation and thereafter

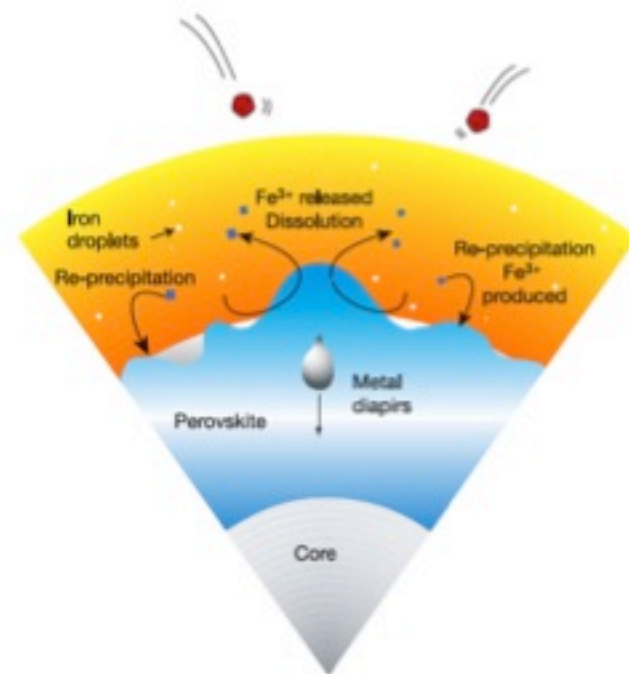
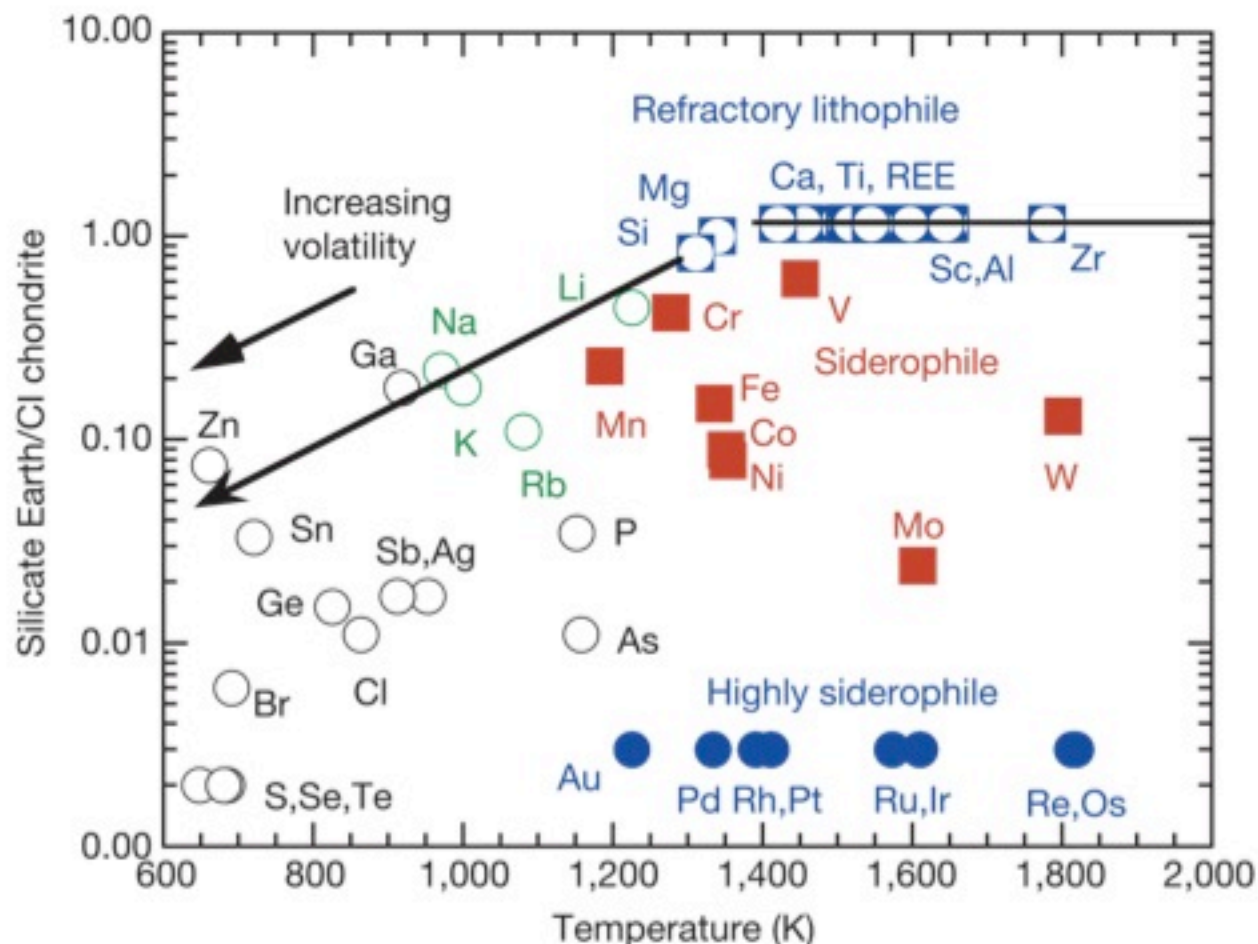


Figure 5 | Sketch of a possible mechanism by which the mantle may have self-oxidized via perovskite crystallization. Lower-mantle perovskite (Pv) generates Fe^{3+} and Fe^0 (metal) from disproportionation of Fe^{2+} . Fe metal is swept to the core by descending metal diapirs while the vigour of accretion and core segregation causes dissolution and recrystallization of perovskite with release of Fe^{3+} to the overlying magma ocean.

Wood et al, 2006



Elemental abundances in the silicate Earth are ratioed to those in CI carbonaceous chondrites and normalized to $D(\text{Earth})/D(\text{CI})$. *Wood et al, Nature 451, (2008)*

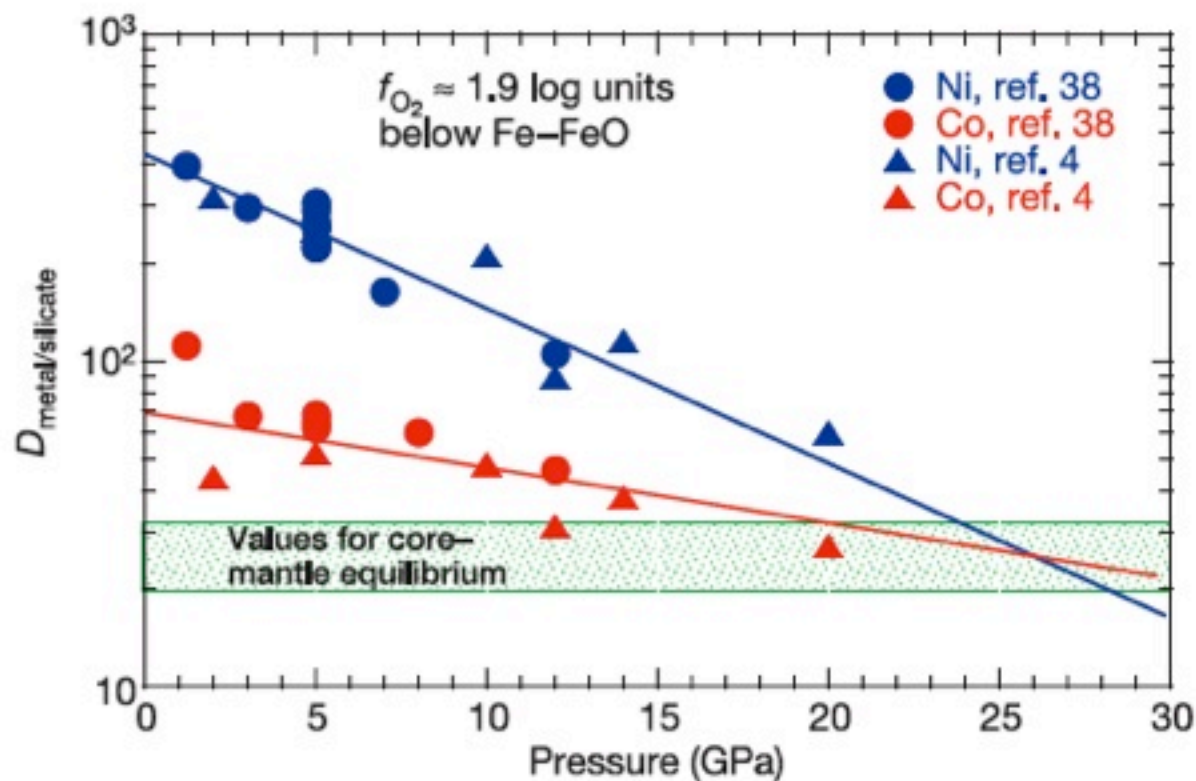
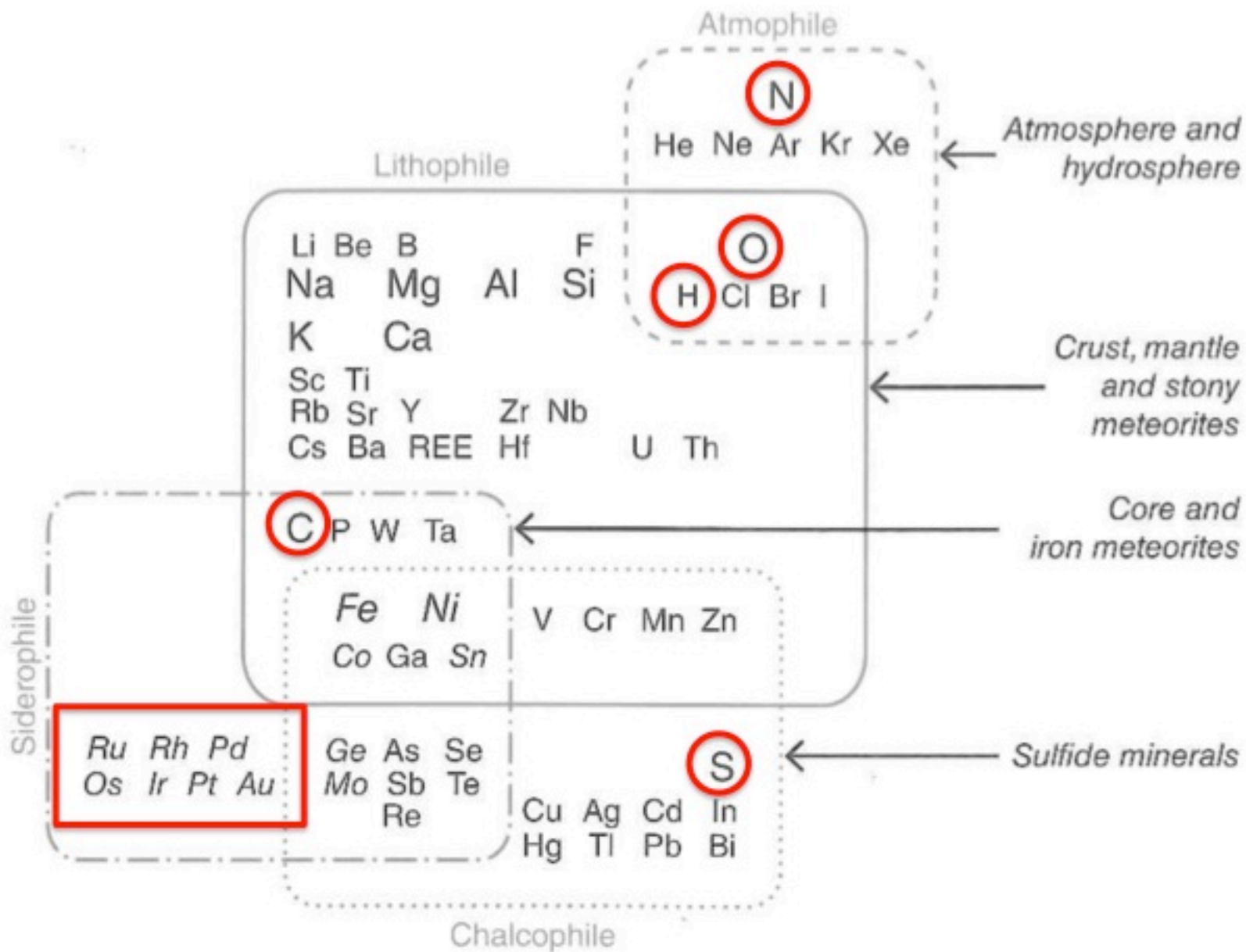


Figure 2 | The effect of pressure on Ni and Co partitioning. The liquid metal–liquid silicate partition coefficients ($D_i = \frac{[i]_{\text{metal}}}{[i]_{\text{silicate}}}$) for Ni and Co are those at 2,123–2,750 K and oxygen fugacity corresponding to current FeO content of the mantle. Data are from ref. 4 and ref. 38. Note that values approach those required for core–mantle equilibrium at the current FeO content of the mantle when pressure is ~ 28 GPa.

Wood et al, Nature 451, (2008)



Objectives

HPHT experiments

Microscale element/isotope analysis

- Light element distribution in the deep mantle and core
- Light element isotope fractionation between melt and solid phases (silicate and metals)
- Element partitioning between silicate, metallic and sulfide phases and melts

Obstacles

- Volume of samples
- Chemical equilibrium

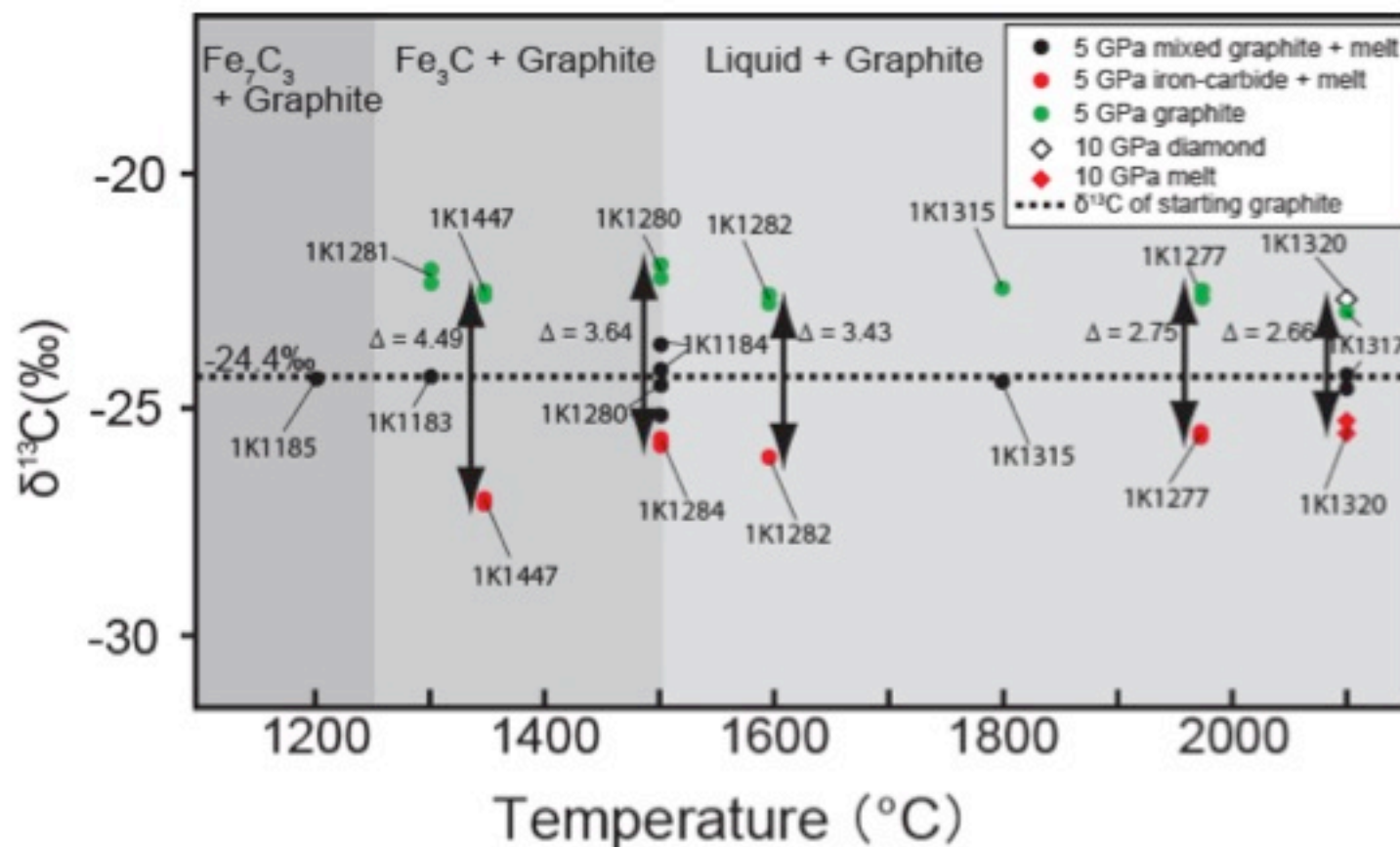
Methods

- ❖ Approach for light element partitioning and isotope fractionation experiments (Satish)
- ❖ Highly siderophile element partitioning experiments
(Detailed explanation by Kogiso)
- ❖ Element partitioning between Immiscible melts and fluids (Mibe)
- ❖ DAC experiments on element partitioning
(Tateno and Kamada)
(Detailed explanation by Tateno)

Research Plan

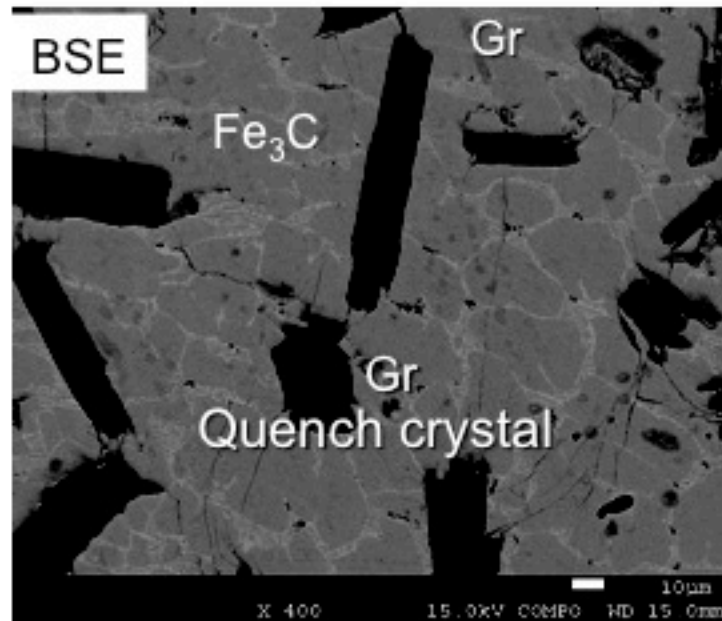
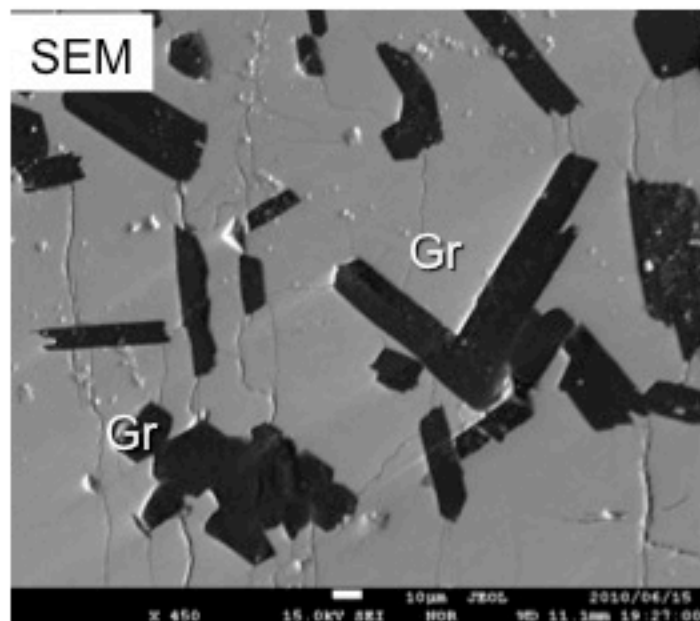
- 2015
 - Installation of gas source isotope ratio mass spectrometer (IRMS).
 - Standardization and set up of laser ablation microscale isotope preparation facility.
- 2016-2019
 - HPHT experiments on various chemical systems
 - Microscale analysis of element partitioning and isotope fractionation using FsLA-IRMS and SIMS

Carbon isotope fractionation between graphite/diamond and iron carbide melt



(Satish-Kumar et al., 2011, EPSL)

Isotope fractionation experiments in the Fe-C system @ 5GPa 1500°C 30min



Fe 93.39±0.29

C 6.61±0.19

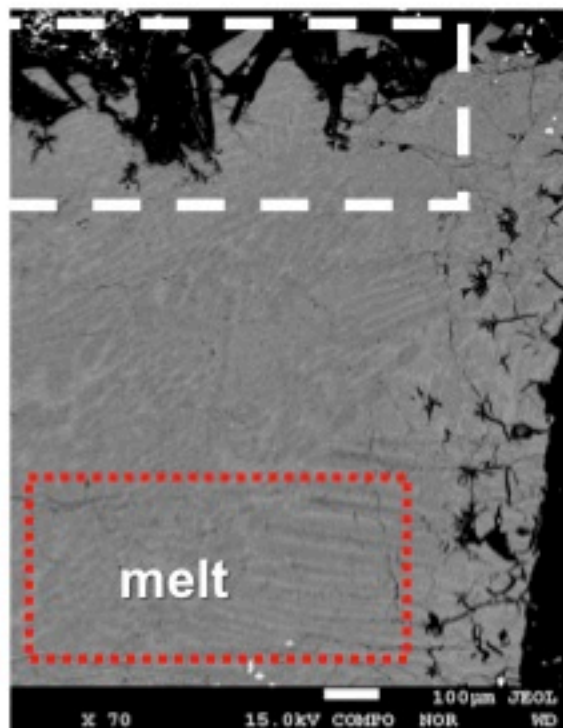
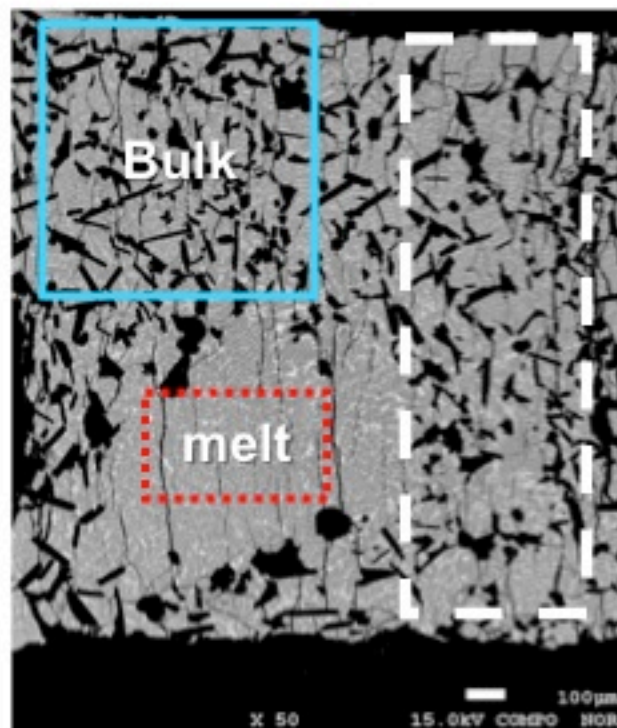
Total 100.01±0.32 (*n* = 8)

Ideal composition

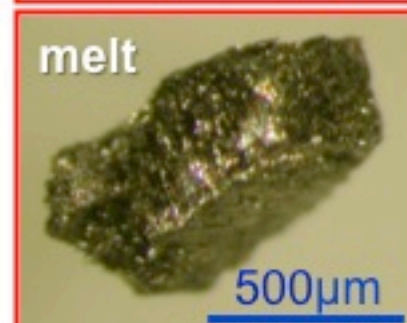
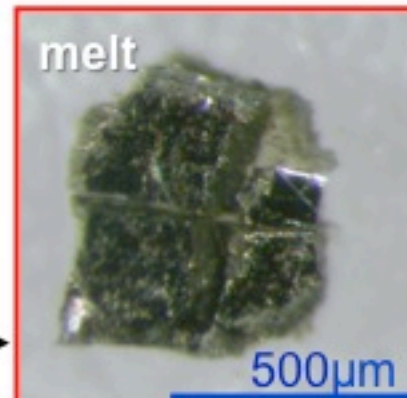
- Fe₃C ... 93.3wt.%Fe 6.7wt.%C

- Fe₇C₃ ... 91.6wt.%Fe 8.4wt.%C

Sampling and analytical strategy for microscale isotope measurements

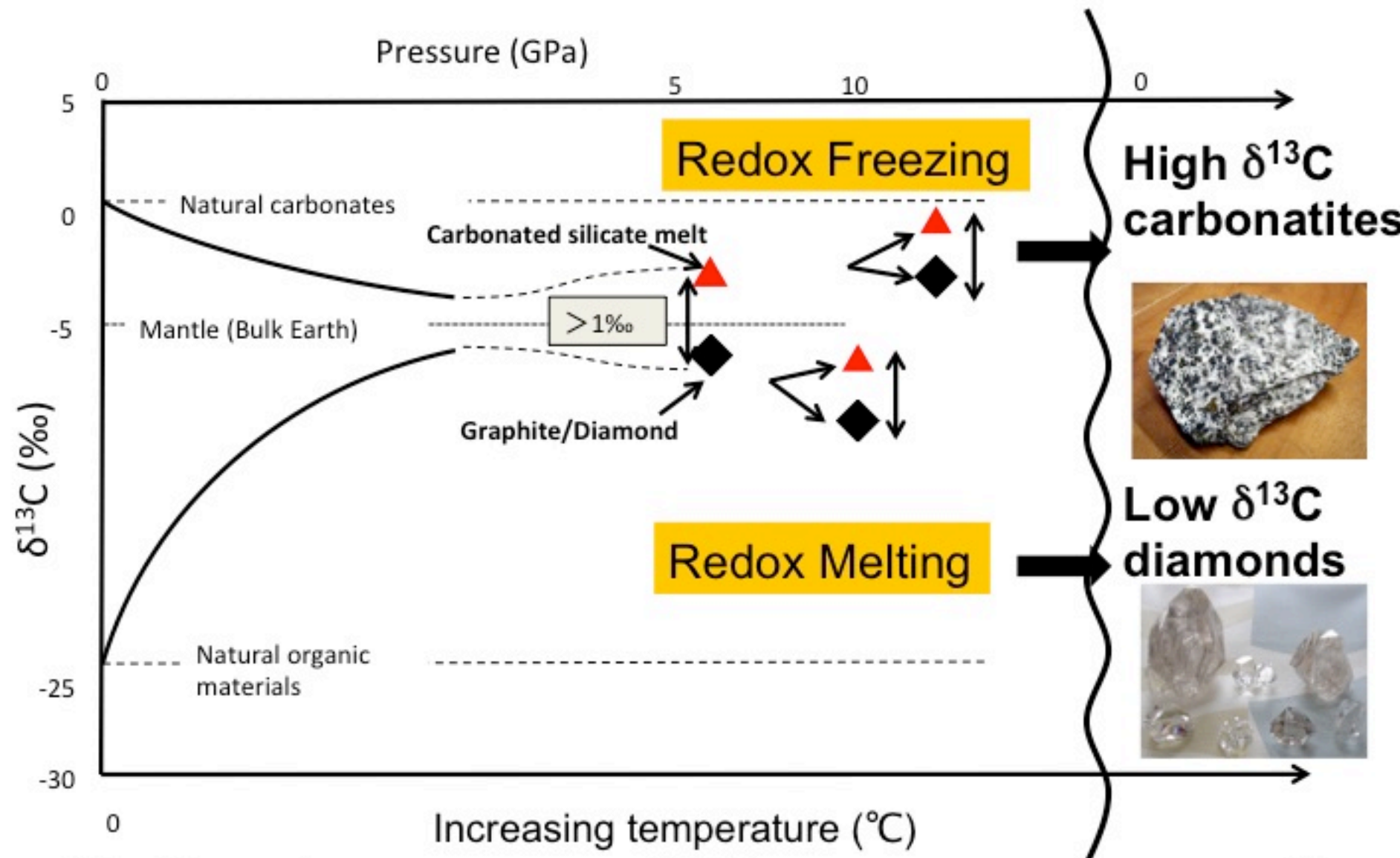


Cut

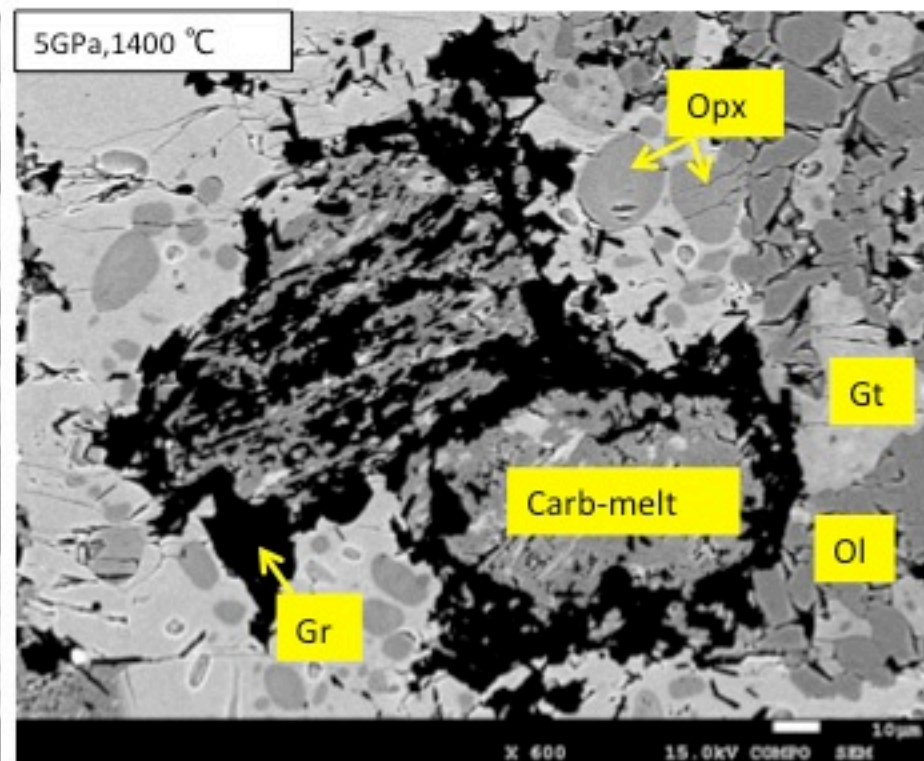
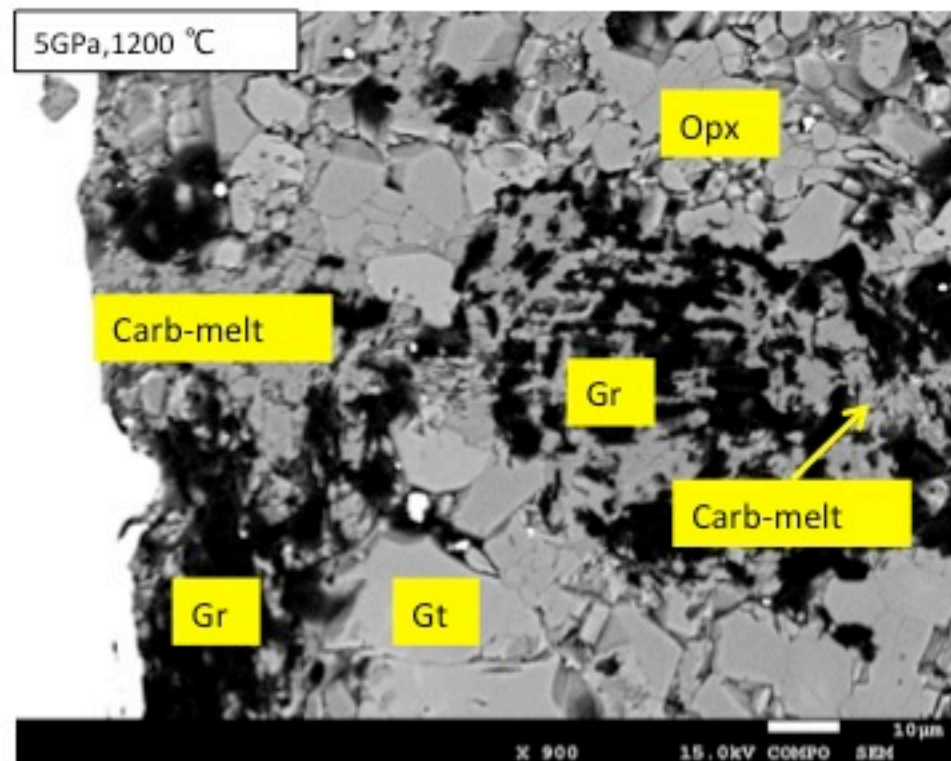


A model for carbon isotope evolution in the mantle

(Mizutani, Satish-Kumar & Yoshino., 2014, EPSL)

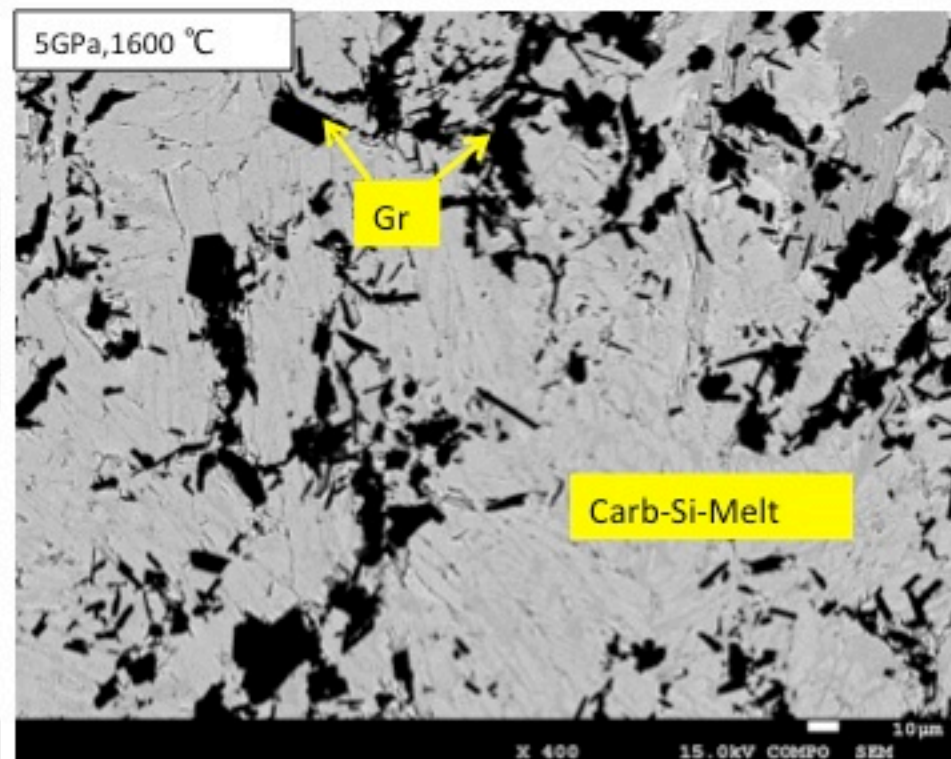
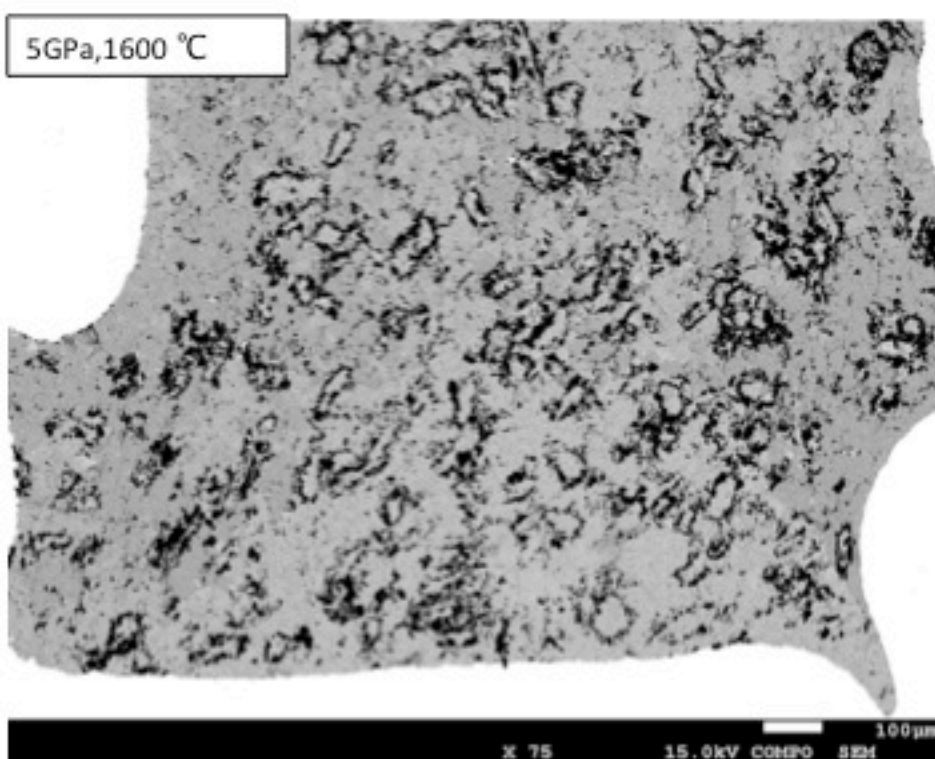


Run No.	<i>P</i> (GPa)	<i>T</i> (°C)	Time (min)	Phase relation						
1K1988	5	1200	1440	Gt	Ol	Opx	Cpx	Gr	Mgs/C-melt	-
1K1984	5	1400	1440	Gt	Ol	Opx	Cpx	Gr	C-melt	FeC
1K1986	5	1600	720	Gt	Ol	Opx		Gr	C-Si-melt	-

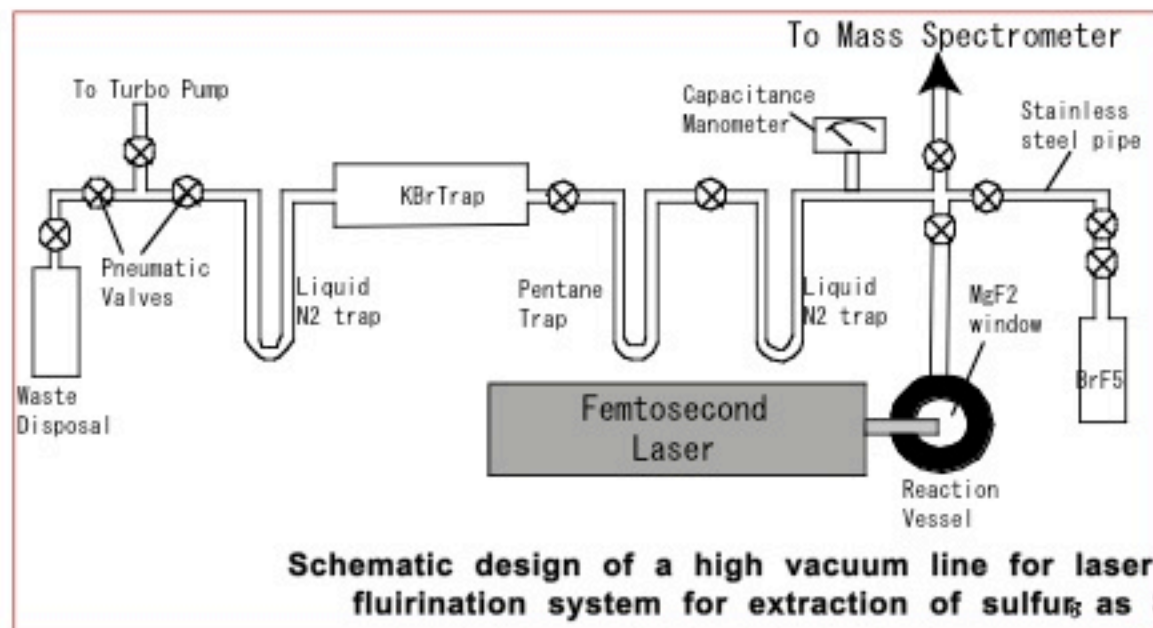


(CMASN + CO₂) 5GPa, 1600°C

Run No.	P (GPa)	T (°C)	Time (min)	Phase relation					
1K1986	5	1600	720	Gt	Ol	Opx	Gr	C-Si-melt	-

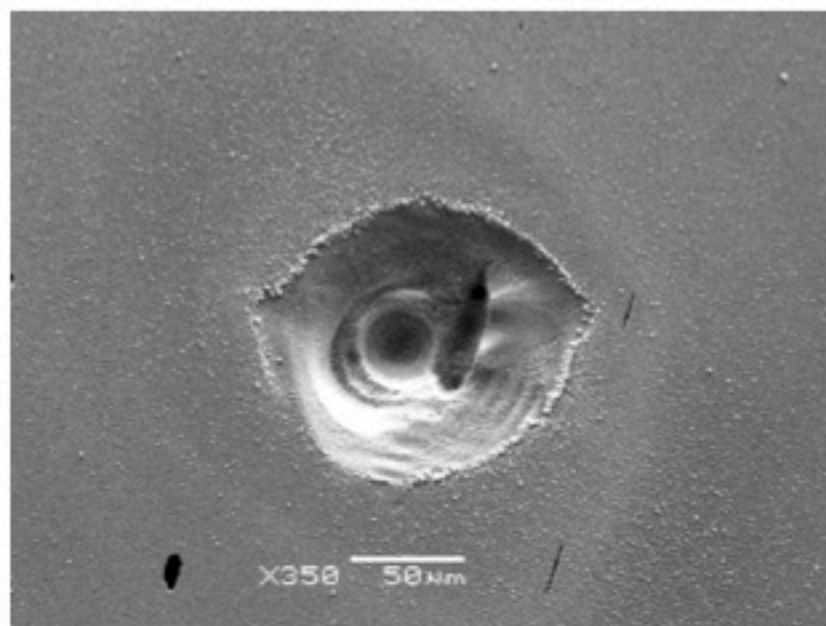


Method for light element partitioning and isotope fractionation studies



$^{13}\text{C}/^{12}\text{C}$, $^{15}\text{N}/^{14}\text{N}$, $^{18}\text{O}/^{16}\text{O}$, $^{34}\text{S}/^{32}\text{S}$, $^{33}\text{S}/^{32}\text{S}$, $^{36}\text{S}/^{32}\text{S}$
(from SO_2 and SF_6), $^{28}\text{Si}/^{29}\text{Si}$

Femtosecond laser ablation system for sulfur isotope analysis



Merits:

No temperature effect during ablation
Submicrom milling and easy to react

Demerits:

Transparent minerals need UV
Submicrom milling and easy to react

HPHT experiments

- Carbonated mantle melting and isotope fractionation
- Light element isotope fractionation experiments
 - Fe-C system
 - Fe-S system
 - Fe-Mg-Si-O-C-S (+H, N) system

Unsolved questions
Isotopic and elemental
Equilibrium
OR
Disequilibrium

Quench textures

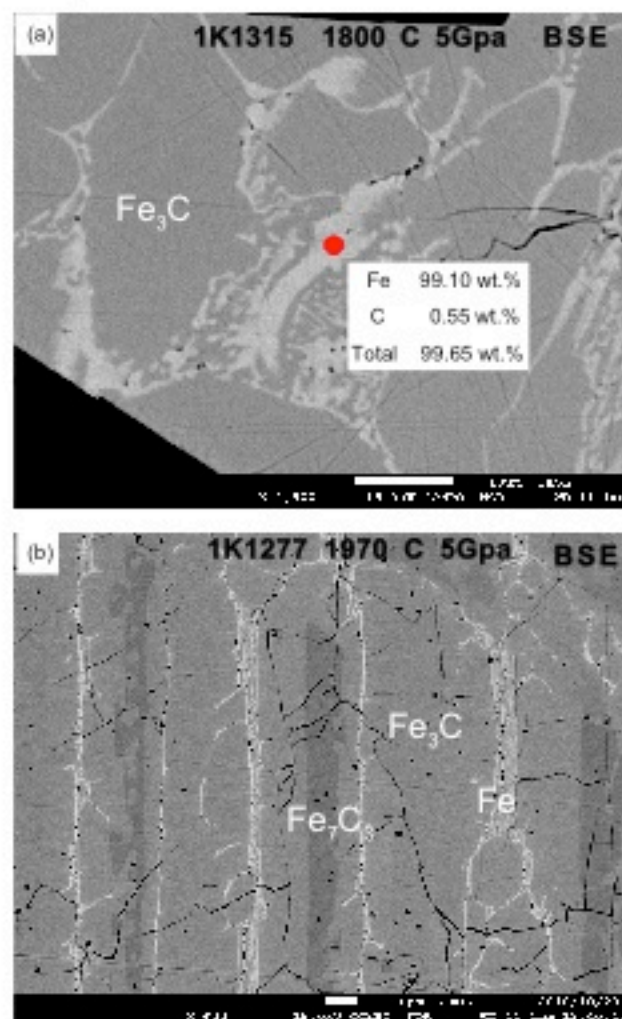
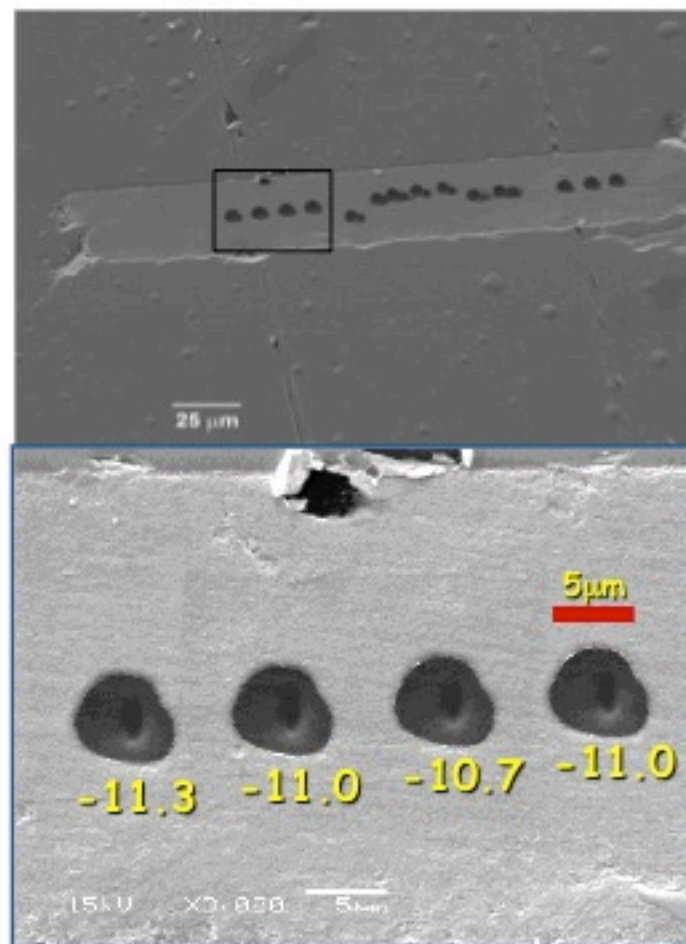


Figure 2

SIMS sample preparation

Results of Graphite standard

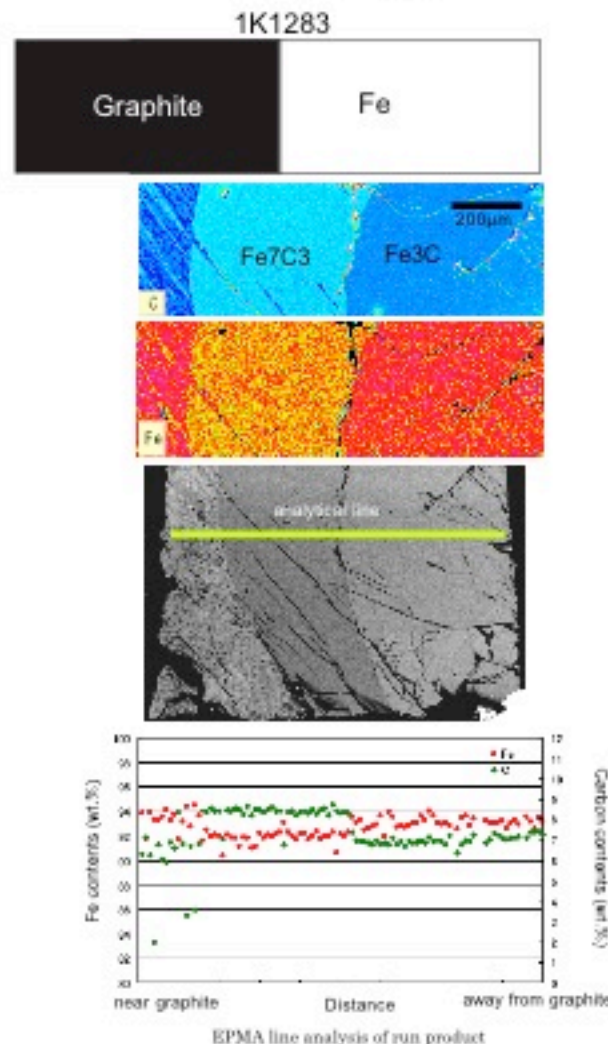
$$\delta^{13}\text{C}_{\text{VPDB}} = -11.19 \pm 0.33\text{‰} \quad (n=9)$$



(Satish-Kumar et al., 2011 CMP)

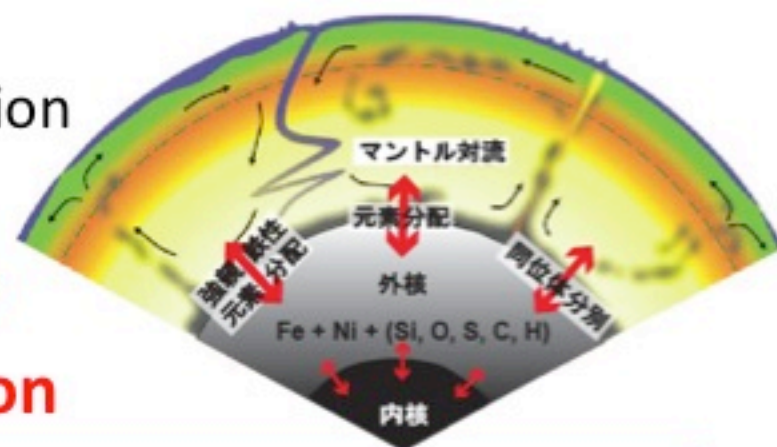
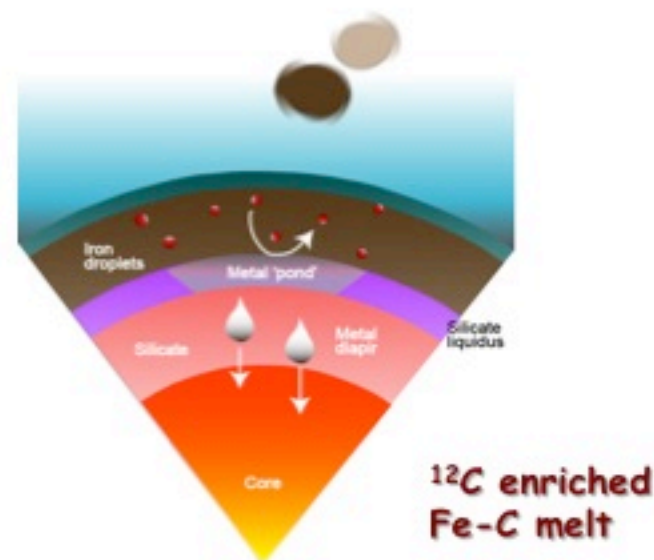
SIMS target

Elemental and isotopic Profiles



Expected outcome

- Determination of partition coefficients for light elements, trace elements and highly siderophile elements
- Estimation of isotope fractionation for light elements (H, C, N, O, S and Si)
- Partitioning of elements during core formation
- Element mobility at the CMB
- Toward a model on chemical evolution through time and depth



Dream!! Precise measurement of Elemental and isotopic composition at CMB conditions

$^{13}\text{C}/^{12}\text{C}$, $^{15}\text{N}/^{14}\text{N}$, $^{18}\text{O}/^{16}\text{O}$, $^{34}\text{S}/^{32}\text{S}$, $^{33}\text{S}/^{32}\text{S}$, $^{36}\text{S}/^{32}\text{S}$ (from SO_2 and SF_6), $^{28}\text{Si}/^{29}\text{Si}$