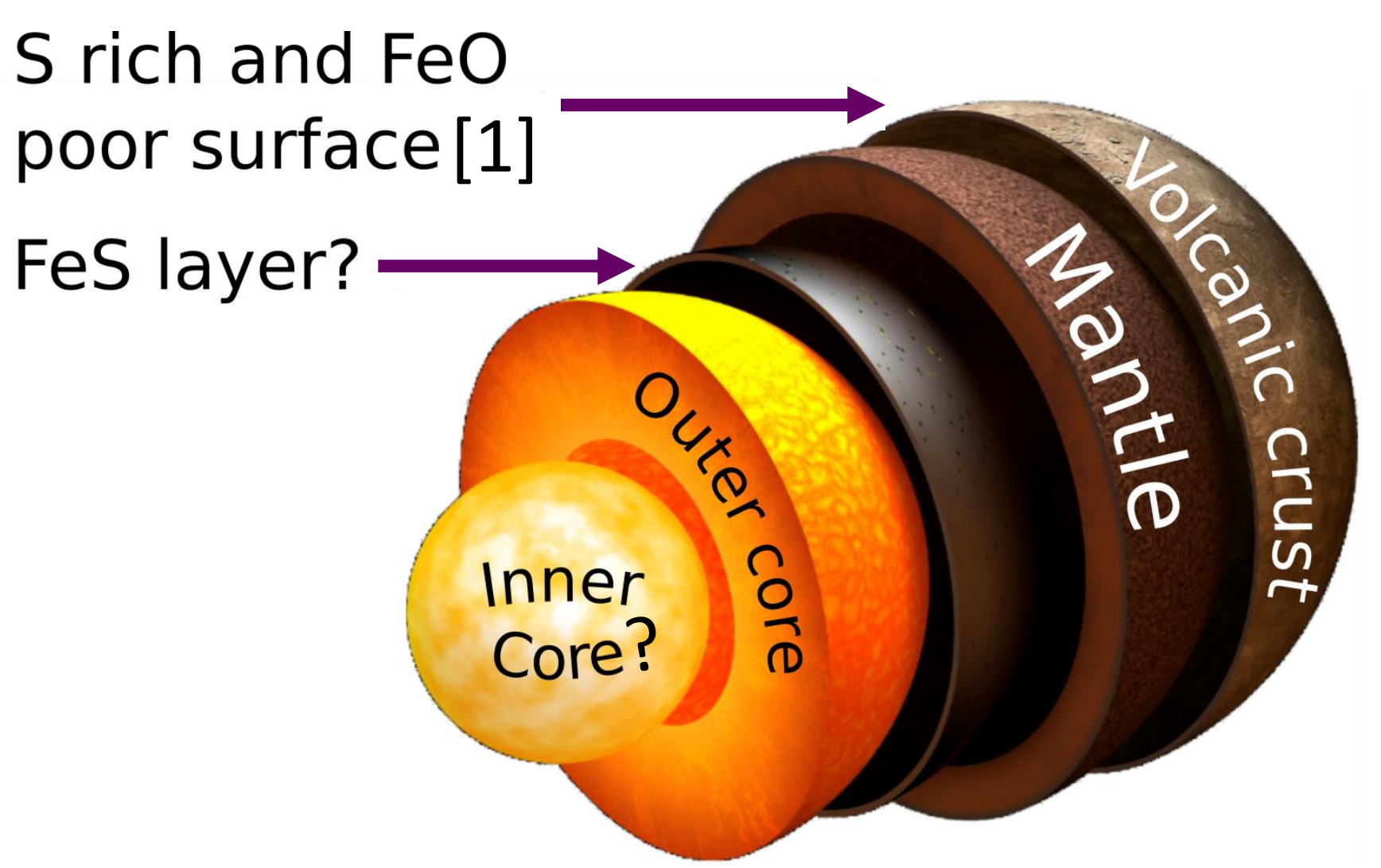
The Distribution of Heat-producing Elements during Mercury Evolution

Hadrien Pirotte[1,4*], Camille Cartier[2], Olivier Namur[3], Anne Pommier[4], Bernard Charlier[1]

[1]University of Liège, Belgium; [2]Centre de Recherches Pétrographiques et Géochimiques, France; [3]University of Leuven, Belgium; [4]University of California San Diego, Scripps Institution of Oceanography, USA
* Contact: hadrien.pirotte@doct.uliege.be or hpirotte@ucsd.edu

Motivation

To understand the distribution of U, Th and K in Mercury and link it with the planet's thermal evolution and its volatile budget.


S rich and FeO poor surface [1]

FeS layer?

The interior of Mercury. After Charlier & Namur, 2019 [2]

The major scientific questions are:

- ➢ Do sulfides in the mantle and crust of Mercury represent a reservoir for heat-producing elements?
- ➢ What is the core-mantle-crust distribution of heat-producing elements?

Experimental approach

Starting material: an analogue of Mercury's silicate mantle

Synthetic powder corresponding to the silicate part of an enstatite chondrite [3]
+ U, Th, K ; + Si metal; ± FeS, CaS, S
Different Si/SiO_2 ratio to control oxygen fugacity
Some experiments are iron-free

Starting composition

Oxides	wt%
SiO_2	61.26
TiO_2	0.10
Al_2O_3	2.76
Cr_2O_3	0.82
Fe_2O_3	0.00
FeO	0.00
MnO	0.43
MgO	31.37
CaO	1.65
Na_2O	1.55
K_2O	0.19
P_2O_5	0.90
Total	101.03

Experimental equipment and conditions

Phase equilibria experiments were performed at pressure, temperature, and oxygen fugacity conditions relevant to Mercury's magma ocean using

- Internally Heated Pressure Vessel: 0.1 GPa, 1520 – 1600°C
- Piston-cylinder apparatus: 1 – 3 GPa, 1400 – 1700°C
- Multi-anvil apparatus: 6 GPa, 1700°C

The piston-cylinder in the University of Liège

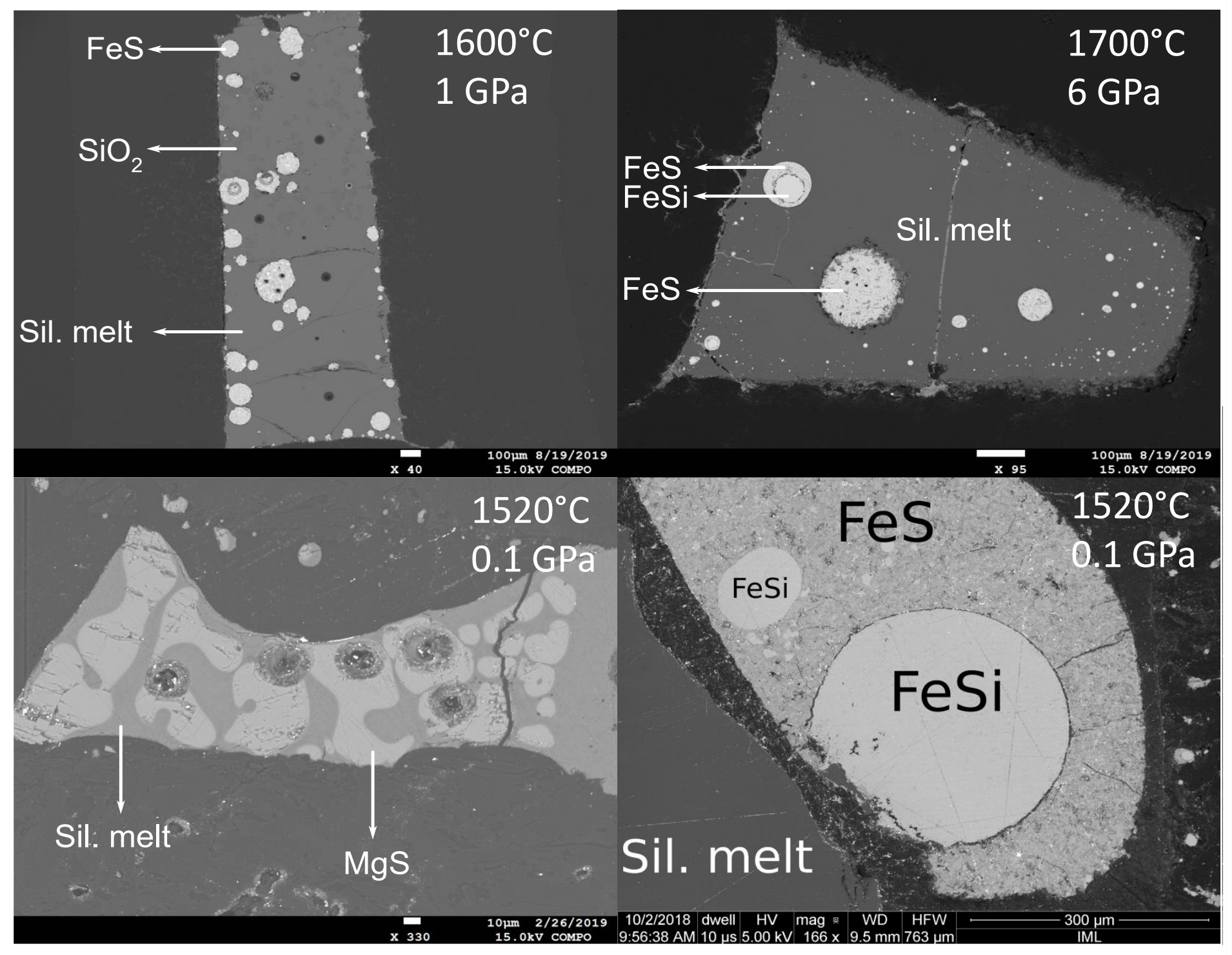
Analytical methods

Different methods were used to analyze the texture and chemistry of the samples recovered from experiments quenched at high temperature:

- Optical microscope, Scanning Electron Microscope (SEM) + Energy Dispersive Spectroscopy (EDS) for characterizing textures and phases
- Electron Probe Micro-Analyzer (EPMA) for quantifying the major and minor elements composition
- Laser Ablation – Inductively Coupled Plasma – Mass Spectrometry (LA-ICPMS) for quantifying minor and trace elements

Phases equilibria and textures

- The quenched samples present the following phases: silicate melts + FeS + Fe-Si (± SiO_2, ± Si and ± enstatite)
- FeS and Fe-Si phases are large enough for high quality and numerous LA-ICP-MS data to be collected
- Sulfides rich in Mg, Ca, Cr, Mn and Fe are present in some experiments



Examples of backscattered SEM images of recovered samples. Experimental conditions indicated on the top right of each image. Samples are contained in graphite capsules

- Other sulfides are more difficult to measure
- Immiscibility between FeS and Fe-Si. FeS surrounds Fe-Si as a result of wetting properties [4]
- In the Fe-free, CaS-dopped experiments, metallic phases composed of Si, Cr, Mn, P are observed
- In some experiments at low fO_2 conditions (~IW – 3), Fe-P is sometimes present

Oxygen fugacity (fO_2) determination

Oxygen fugacity has been estimated using the 2 following methods:

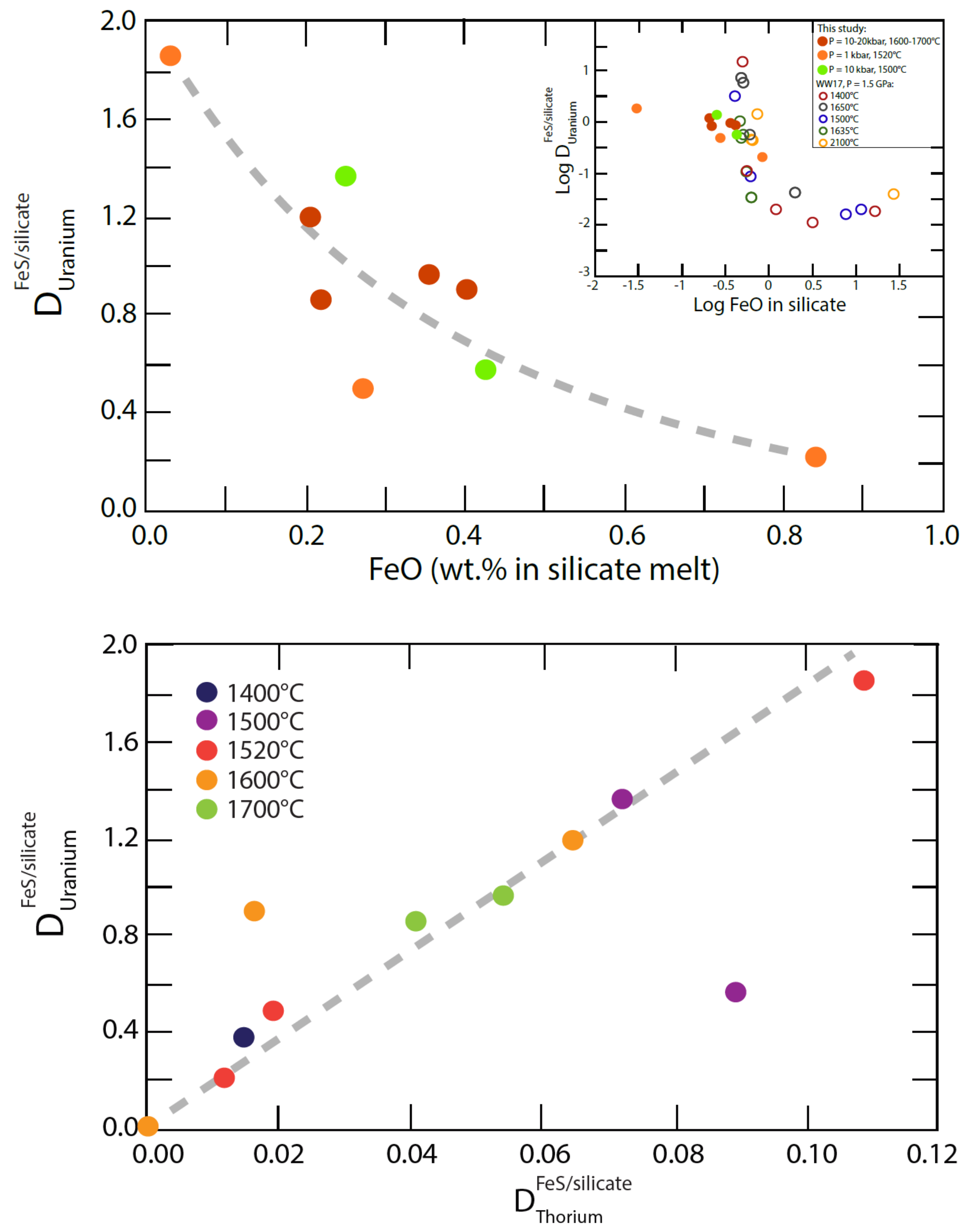
(1) $Fe_{Metal} + 1/2\ O_2 = FeO_{Silicate}$

(2) Sulfur Content at Sulfide Saturation (SCSS) [5]

Partition coefficients are expressed as a function of FeO in the silicate melt. fO_2 estimates obtained with (1) are similar to estimates provided by (2)

Partition coefficients

- $D_U^{FeS/sil}$ increases with decreasing fO_2. Future data over a range of pressure will help constrain the effect of P. No clear effect of T on partitioning is observed
- Contrastingly, literature data suggest exponential partitioning of U at very low fO_2 [6,7]
- The ratio between $D_U^{FeS/sil}$ and $D_{Th}^{FeS/sil}$ seems constant and independent of fO_2, T or P
- K partitions less in the sulfides than U for the same fO_2. New data at extremely low fO_2 are required to better constrain K partitioning
- Current dataset of partitioning data of CaMgS doesn't allow constraining partitioning data. However, $D_U^{sul/sil}$ and $D_{Th}^{sul/sil}$ are higher than their FeS counterparts



Heat-producing elements partitioning results. Top panel: $dU^{FeS/sil}$ as a function of FeO content in the silicate melt. Inset: comparison with data from Wohlers & Wood, 2017. Bottom panel: $dU^{FeS/sil}$ as a function of $dTh^{FeS/sil}$

- Heat-producing elements do not partition into Fe-Si. There is no clear trend between U and Th partitioning and fO_2
- Fe-P incorporates U and Th ($D_U^{FeP/sil}$ ~ 4). More experiments are needed to understand the partitioning behavior in the Fe-P phases

Take-home message

- ➢ U, Th and K display increasing chalcophile behavior at low fO_2
- ➢ FeS does not fractionate U and Th
- ➢ An FeS layer should incorporate large amounts of U, Th and K
- ➢ An Fe-Si core should be mainly depleted in heat-producing elements
- ➢ Accessory phases such as Fe-P could be a secondary reservoir for U, Th, K

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