Deep-Earth Equilibration Between Molten Iron and Solid Silicates

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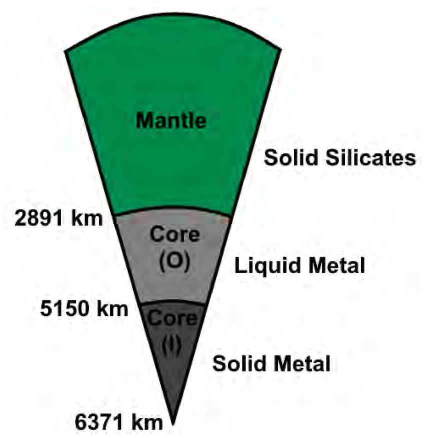
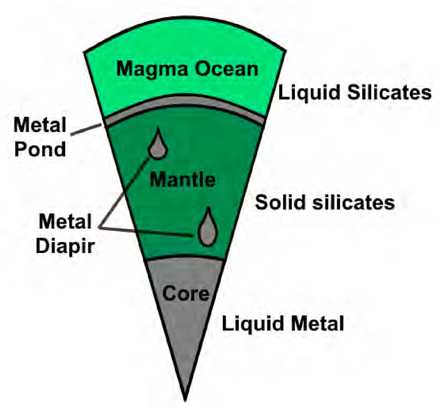
1. Background

Terrestrial bodies are composed primarily from iron-rich metals and silicate minerals, so interactions between these phases are important for the chemistry of planetary interiors.

On Earth, the core-mantle boundary (CMB) represents an interface between the two phases; importantly, the metallic (core) side of the CMB is molten, while the silicate (mantle) side is solid.



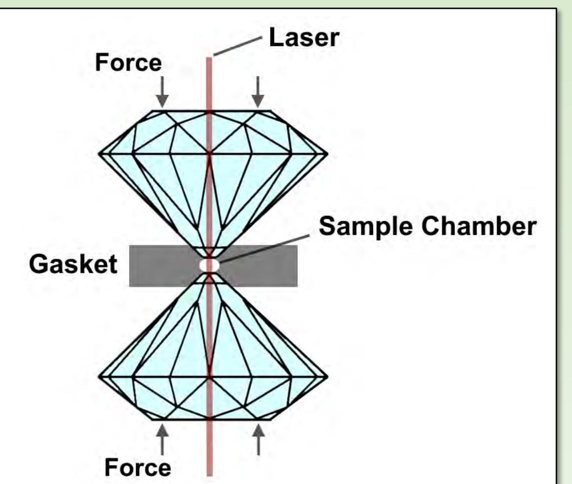


Early Earth likely experienced liquid metal from impactors descending through solid silicates [1]. This stage of differentiation may have influenced properties such as the redox state of the mantle.

2. Experimental Methods

We used a laser-heated diamond anvil cell to replicate pressure and temperature conditions of the lower mantle (~40 GPa, >2500 K).

The silicate phase was an olivine-rich xenolith from Kilbourne Hole, NM (the source of the KLB-1 geochemical standard) [2].

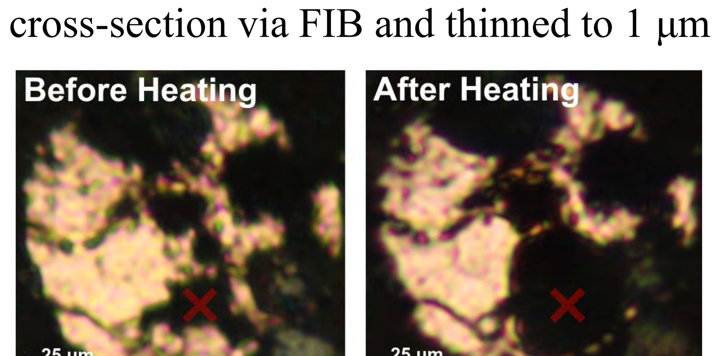


Schematic illustration of a laser-heated diamond anvil cell.

KLB-1	
Oxide	**Weight %**
SiO_2	44.84
MgO	39.52
FeO	8.20
Al_2O_3	3.51
CaO	3.07
Cr_2O_3	0.32
K_2O	0.30

A sample of KLB peridotite with grains of olivine (green) and pyroxene (black).

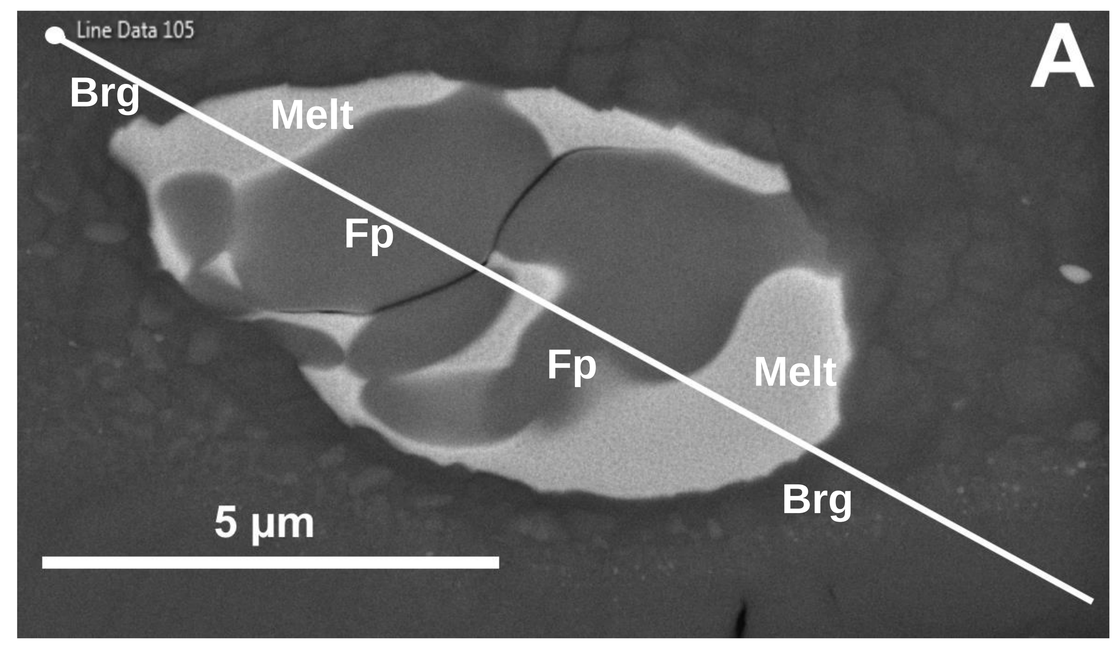
KLB was combined with two metallic compositions: pure Fe (Experiment A) and Fe-16Si, a candidate composition for the Earth's core (Experiment B) [3]. The materials were heated to above the metal's melting point (~2900 K for Fe and ~2600 K for Fe-16Si) but below the 40 GPa silicate solidus (~3000 K) [3,4,5]. Samples were recovered in cross-section via FIB and thinned to 1 µm for analysis.

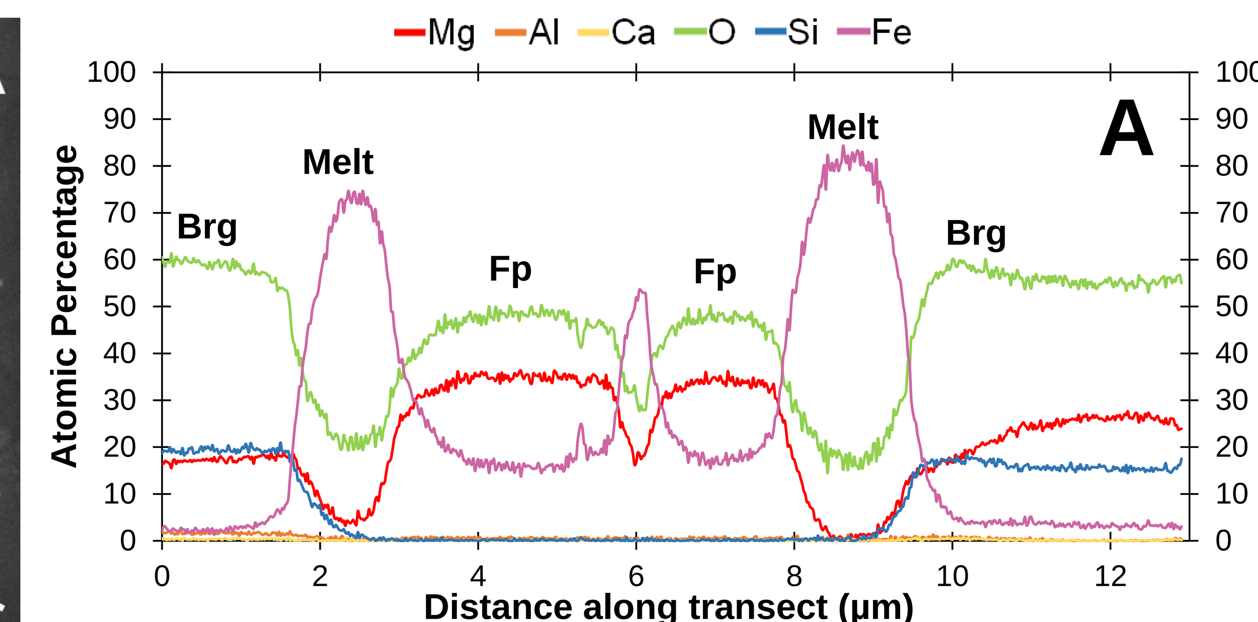


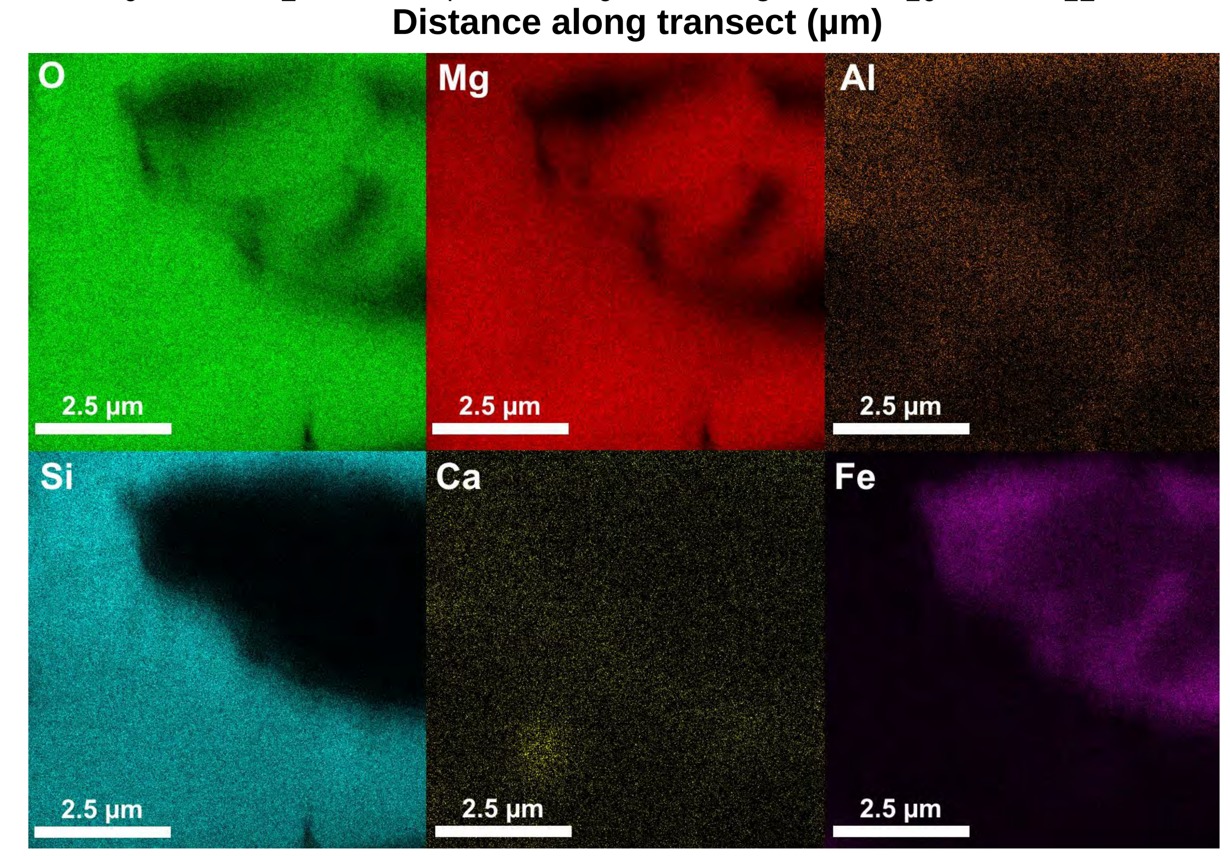
Above: The sample chamber of our diamond anvil cell. Dark regions contain metals, light regions contain silicates only. Expansion of the targeted spot (the red 'X') likely indicates melting of the metal.

3. Results

Experiment A: Peridotite + Fe





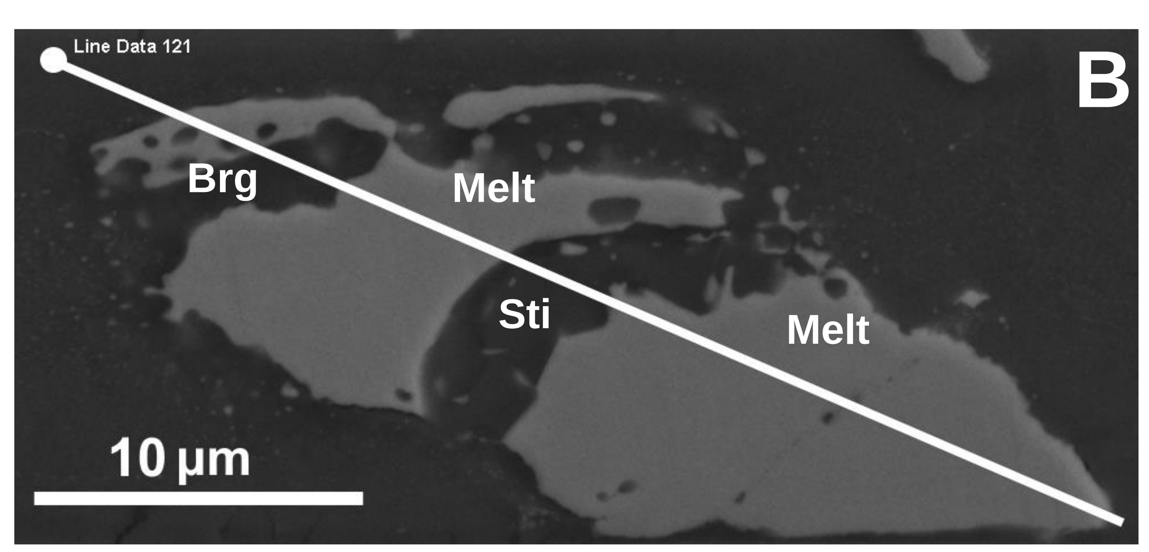


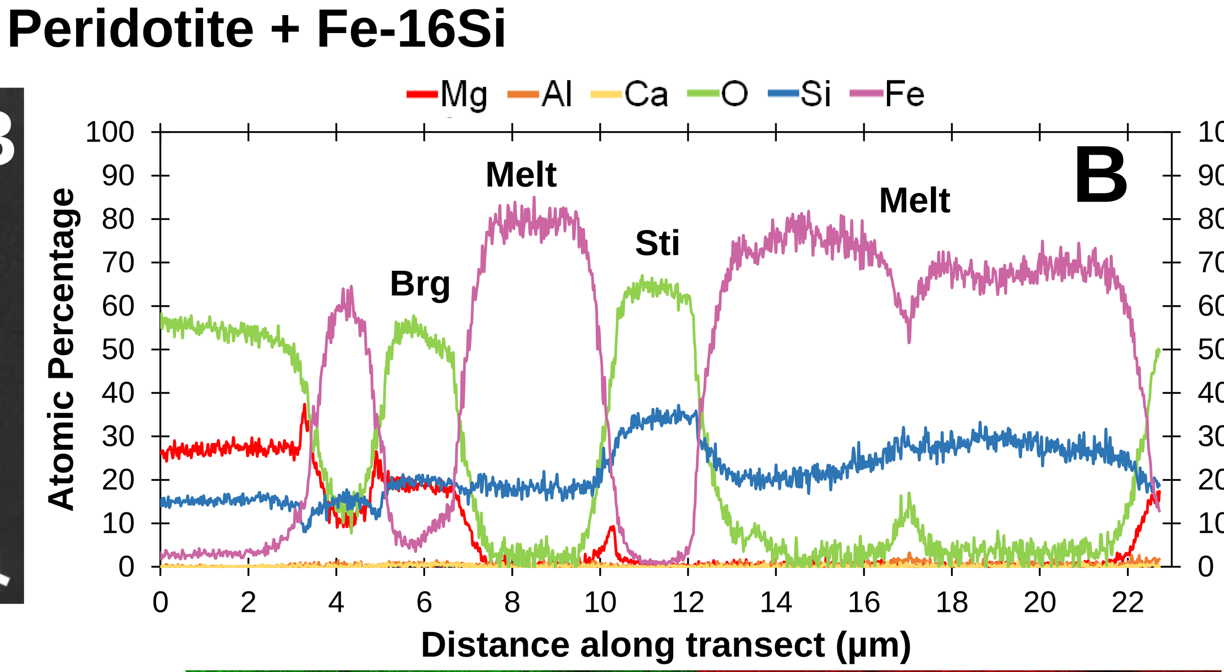
Above: Back Scattered Electron (BSE) image of the heated spot showing metallic melt (the bright regions) infiltrated by ellipsoidal oxide grains. 'Brg' is bridgmanite, 'Fp' is ferropericlase, 'Melt' is the quenched metallic liquid.

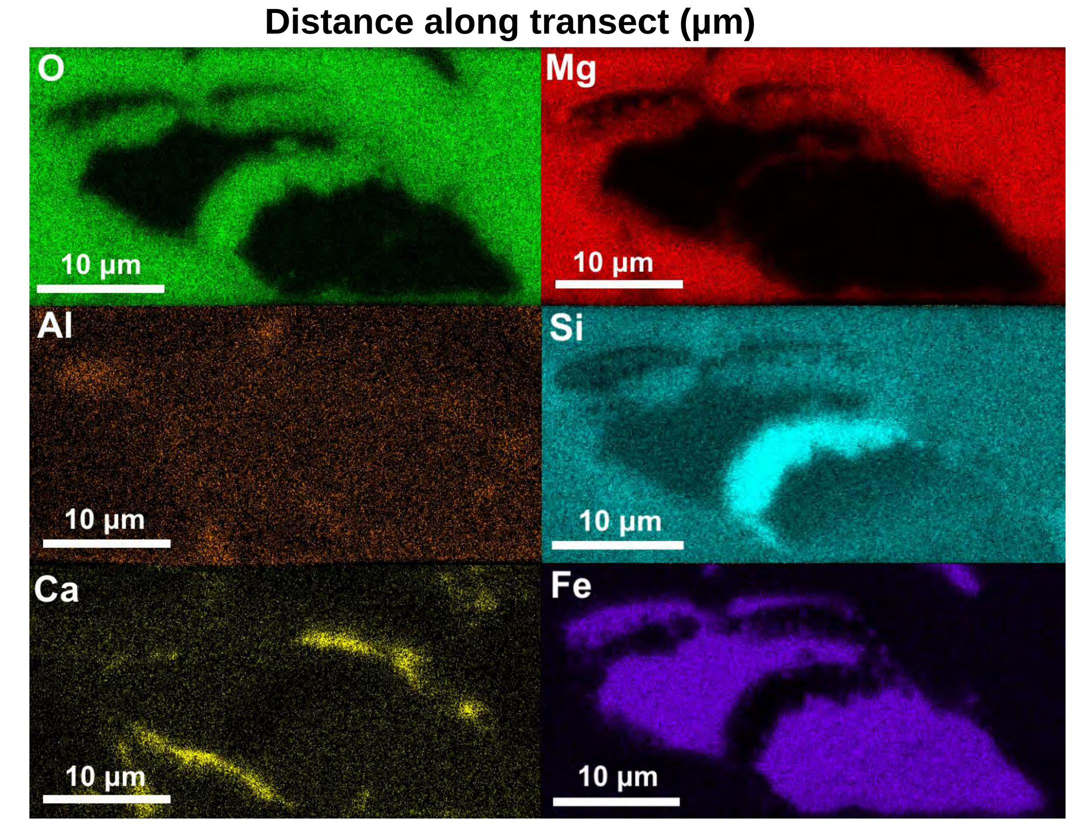
Top Right: Graph showing elemental abundances along the transect ('Line 105') visible in the BSE image. Melt regions are rich in O but poor in other light elements.

Bottom Right: Energy Dispersive Spectroscopy (EDS) elemental maps of a portion of the heated spot showing an Fe, and O-rich melt pocket has with almost no Si.

Experiment B: Peridotite + Fe-16Si







Above: BSE image of the heated spot. 'Sti' is stishovite. Notice the light colored spots embedded in the bands crossing the melt; these are metallic grains that have not been incorporated into the larger melt pockets.

Top Right: Graph showing elemental abundances along the transect ('Line 121') visible in the BSE image. Parts of these profiles (especially Brg) are compromised by insufficient spatial resolution to separate the metallic and non-metallic components.

Bottom Right: EDS elemental maps of the heated spot showing a Si-rich melt with almost no O. Notice the strong enrichment of Si in the central Sti band.

4. Discussion

Coexistence of Solid Silicates and Metallic Melt

There is a narrow temperature range in which solid KLB silicates can coexist with Fe-rich metallic melt.

The different metallic compositions lead to two divergent equilibrium systems: Brg-Fp-Melt in Experiment A, and Brg-Sti-Melt in Experiment B.

The Experiment A system was more oxidizing than typically assumed for deep-Earth equilibration, while Experiment B was much more reducing. Neither experiment had coexisting O and Si in the melt [6].

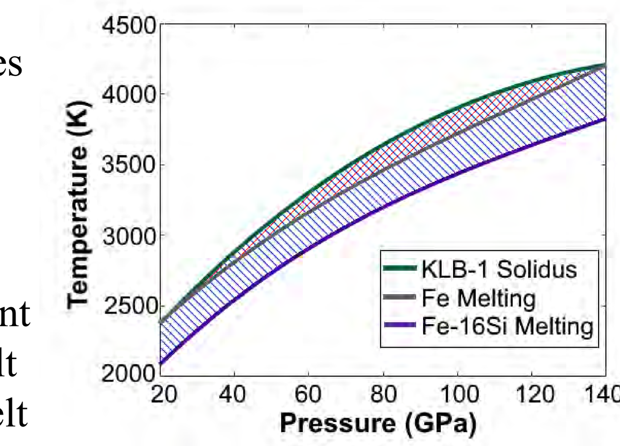


Diagram illustrating the KLB solidus and the melting curves of our metals at lower mantle pressures. Solid silicate coexists with pure Fe in the red hashed region, and with Fe-16Si in the blue hashed region. Data from: [3,4,5].

	A (KLB + Fe)	B (KLB + Fe-16Si)
Bridgmanite $(Mg,Fe)SiO_3$	$(Mg_{0.87}Fe_{0.13})(Si_{0.92}Al_{0.08})O_3$	$(Mg_{1.00})(Si_{0.99}Al_{0.03})O_3$
Ferropericlase $(Mg,Fe)O$	$(Mg_{0.69}Fe_{0.31})O$	----------------------------
Stishovite SiO_2	----------------------------	$Si_{1.00}O_2$
Melt (wt%)	94% Fe, 5.6% O, 0.4% Si	89% Fe, 0.8% O, 10% Si
fO_2	$\Delta IW = -0.8$	$\Delta IW < -2.5$

Comparison between the equilibrium systems of Experiments A & B. Experiment A contains an Fe-bearing oxide, while all the Fe in Experiment B has been reduced to native metal [7]. The exact oxidation state of Experiment B could not be determined due to the lack of Fe in the silicate phase.

5. Conclusions

Relatively modest variations in the metallic starting composition dramatically altered the composition of the equilibrium systems.

Elemental partitioning between silicates and metals in 'mixed-phase' (solid + liquid) systems is substantially different from partitioning in completely solid or completely liquid systems [8,9].

Redox conditions during core formation and at core-mantle boundaries may substantially alter the internal mineralogies of differentiated terrestrial bodies [10].

References & Acknowledgments

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