Core formation in planetesimals: the importance and geochemical legacy of immiscibility in metallic liquids.

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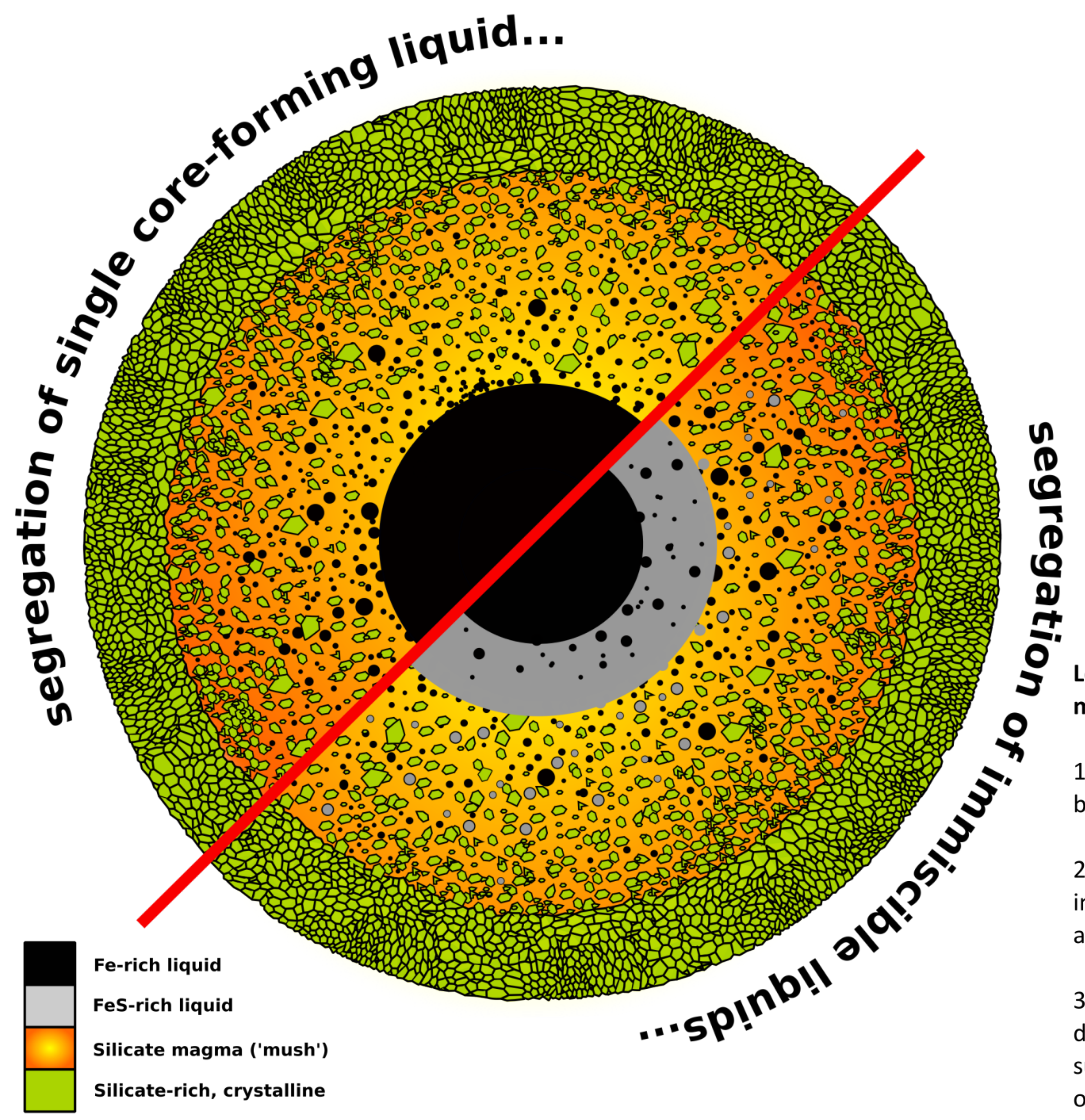


Segregation of Fe-rich liquids and formation of metallic cores was a key differentiation process in rocky bodies in the early solar system. Mechanisms for segregation in planetesimals (100-1000km bodies), and the proportion of these bodies which differentiated, remain unclear. Here we explore the important role of immiscibility of S-rich and S-poor liquids in core formation models.

-The dominant process of core formation was probably **segregation of Fe-rich liquid from a crystal-rich magma ocean** (left).

-In S- and P-rich systems[1] and at C saturation[2,3] immiscibility results in separation of S-rich and S-poor core-forming liquids.

-Various 'low-temperature' models of core-formation have also been proposed (below right) which typically involve percolation of FeS-rich liquids through crystalline silicate, either before or just after the onset of low-degree silicate melting.

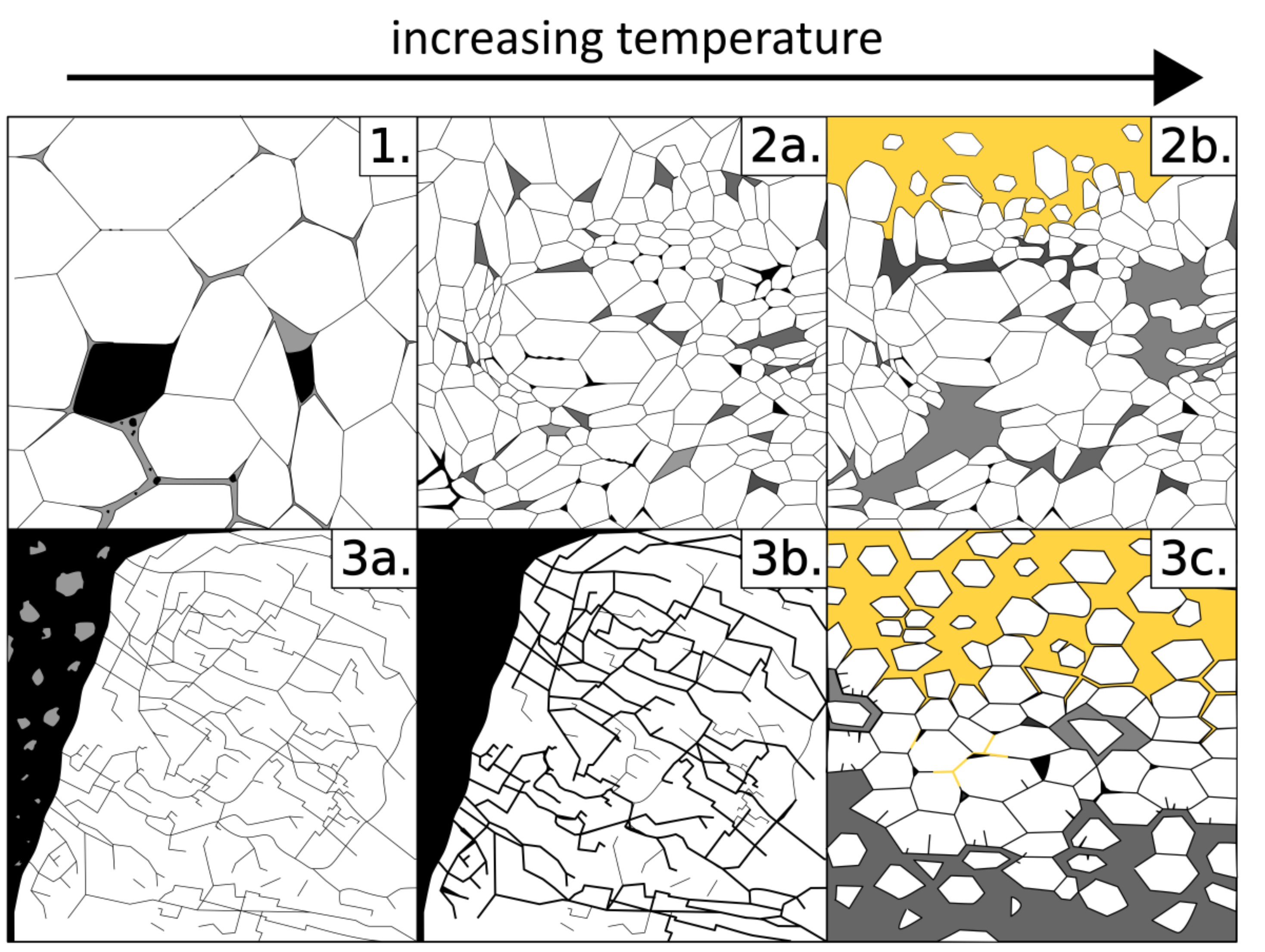
-Mechanisms and conditions of segregation will have strong influence on core composition; e.g. early-formed (low T) metallic liquids are assumed to be S-rich (near eutectic in the Fe-FeS system), with a decrease in S content at higher T. However, immiscibility can also result in segregation of S-rich liquids.

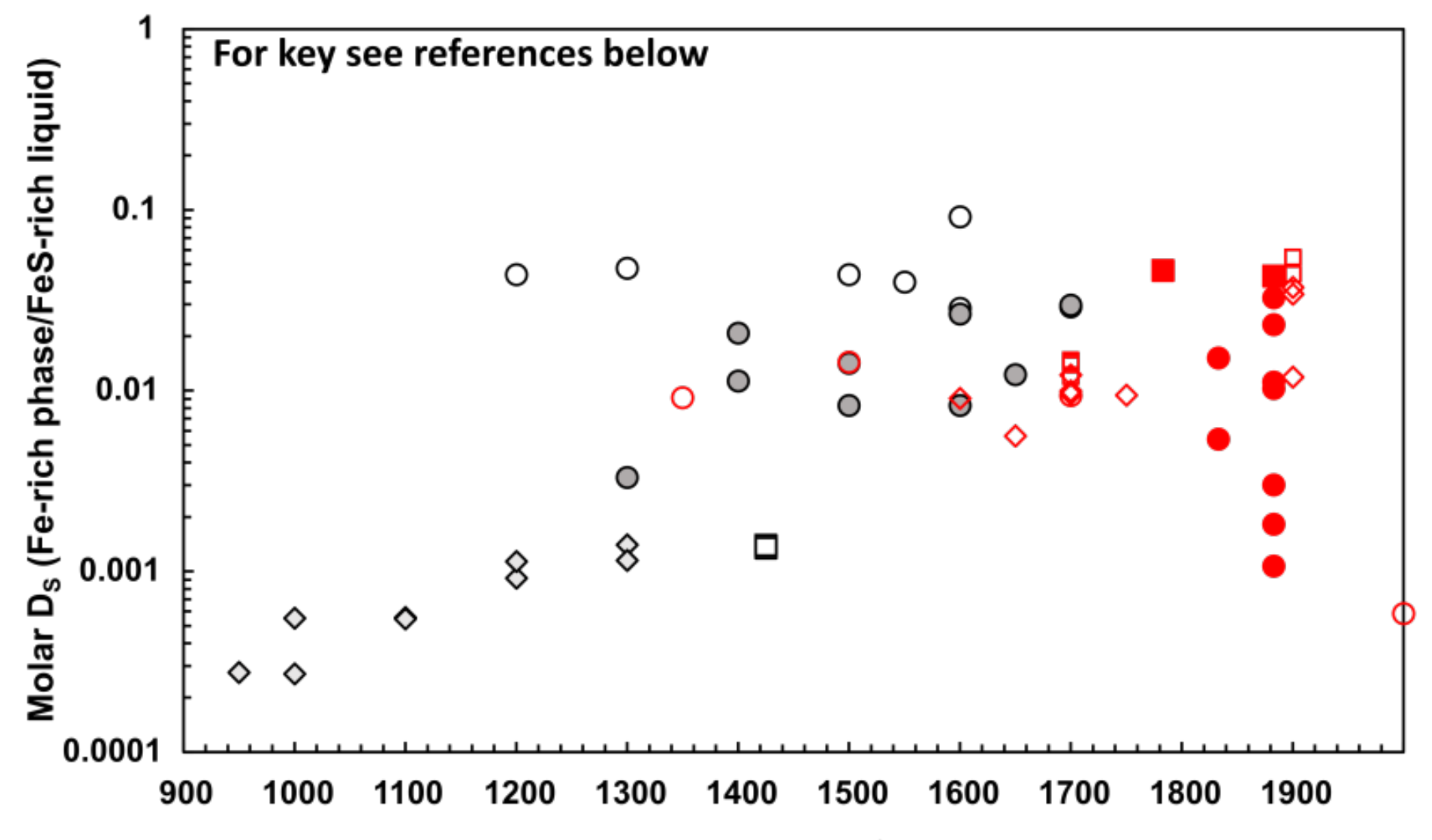
Low-temperature core-formation models:

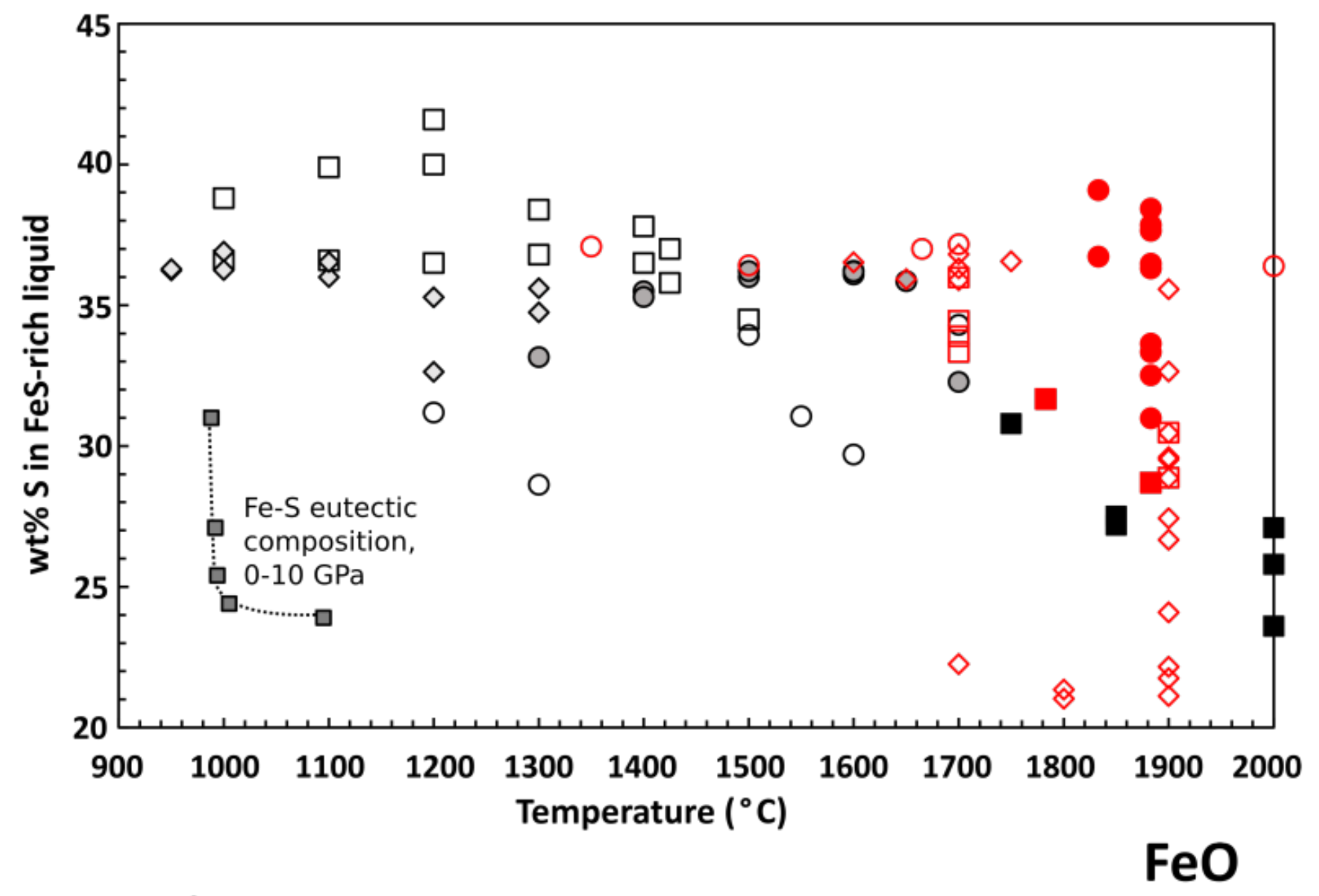
1. Percolation of S-rich liquids, aided by deformation, porosity etc.

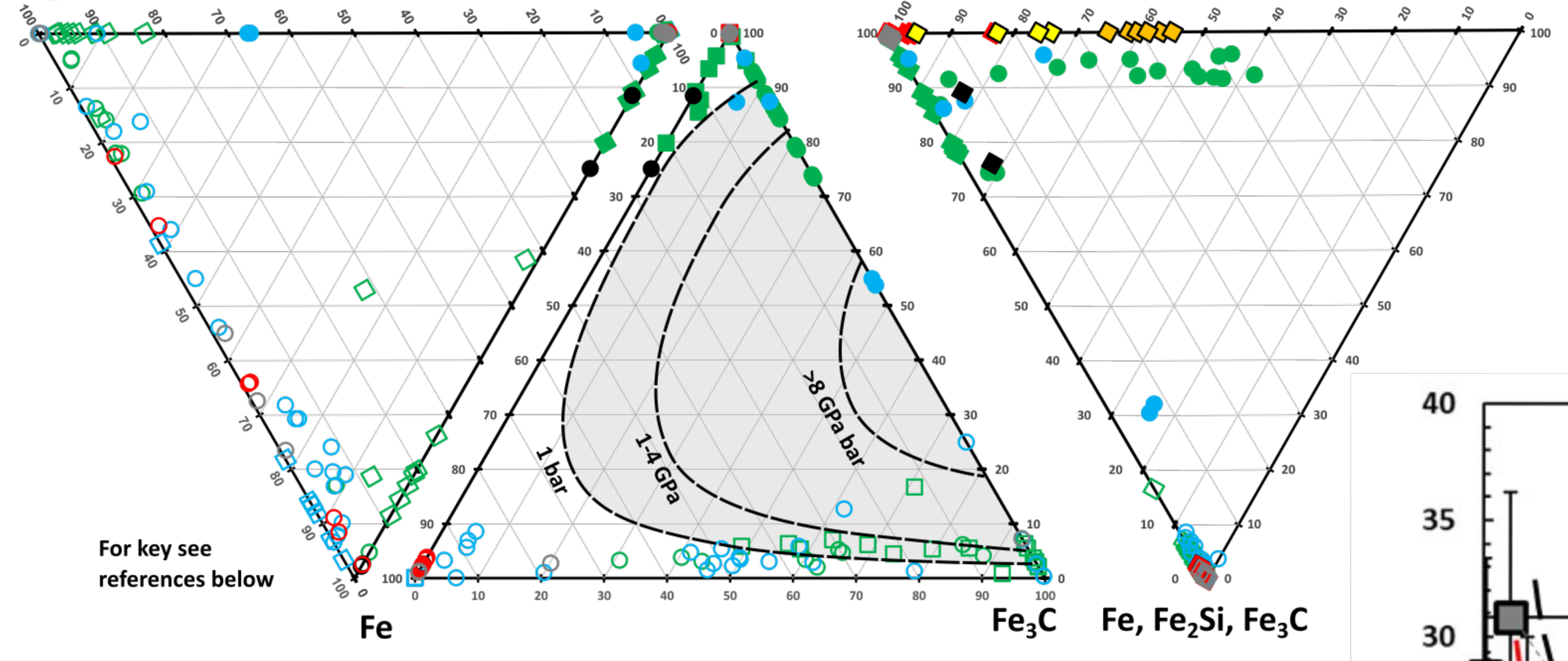
2. Low-degree silicate melting increases metallic melt fraction and aids phase segregation.

3. Tomkins et al.[4] model of impact driven FeS liquid mobilisation and subsequent segregation at the onset of silicate melting.









A review of published data from partial melting experiments in chondritic systems (left) provides insight into the composition of metallic liquids formed under various conditions:

(1) as expected, initial liquids are S-rich, with a large T range over which metallic components melt before the onset of silicate melting (left, top). However,

(2) FeS-rich liquids have S contents exceeding Fe-FeS eutectic compositions, with little change in composition with increasing T, and

(3) There is immiscibility/separation of Fe-rich (S-poor, P-rich, C-rich, O-poor, Si-bearing) and FeS-rich (P-poor, C-poor, O-bearing) solids/liquids (left, bottom) over a wide P-T-fO_2 range.

Partial melting experiments are likely C-saturated due to experimental design, meaning that metallic liquid compositions and melt relations are dominated by the effects of immiscibility.

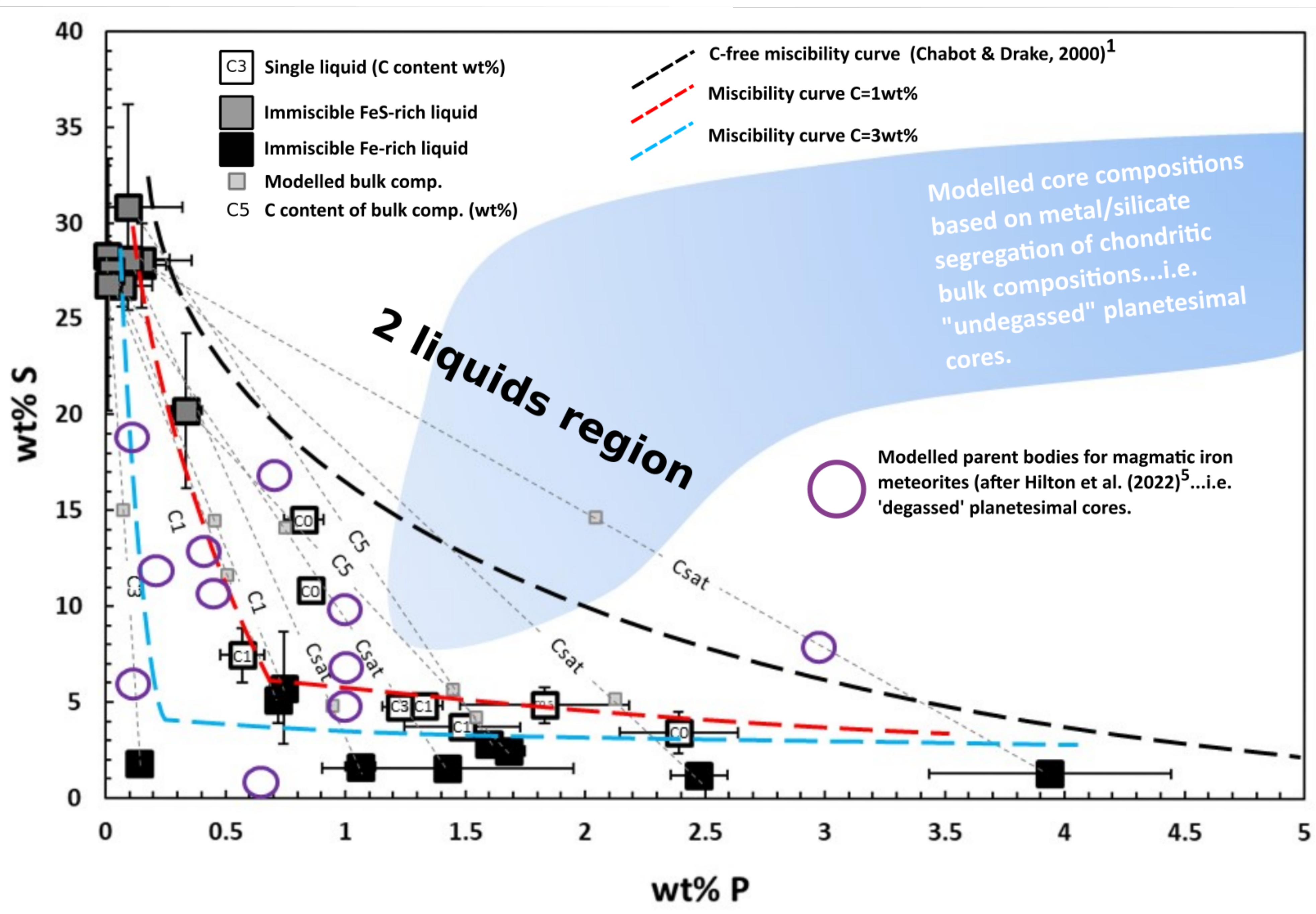
-**Our new superliquidus experiments** (0.5 GPa/1673K) in the system Fe-Ni-P-S-O-C **constrain the role of C in driving immiscibility (right).** Bulk C contents resulting in immiscibility mirror trends in C solubility in Fe-rich liquids[6], although immiscibility occurs at C contents considerably below saturation.

-Differentiation of planetesimals with chondritic compositions (assuming no degassing/loss of C, P, S) results in core immiscibility.

-In contrast, parent bodies to magmatic iron meteorites were single liquids due to substantial degassing[7] and low C, P, S contents.

-Bulk composition, size and growth rate, and degree of degassing, controlled the extent of immiscibility in planetesimal cores.

-Immiscibility can also occur during low-temperature core formation, and obfuscates results from partial melting experiments.



References: [1]Chabot NL & Drake (2000) Meteorit. & Planet. Sci. 35:807. [2]Corgne et al. (2008) GCA 72:2409. [3]Dasgupta et al. (2009) GCA 73:6678. [4]Tomkins et al. GCA 100:41. [5]Hilton et al. (2022) GCA 318:112. [6]Zhang et al. (2018). GCA 225:66. [7]Grewal DS & Asimow GCA 344, 146–159 (2023). **Black/grey =data from partial melting experiments.** Open squares: McCoy et al. (1999) Meteorit. & Planet. Sci. 34:735, circles: Berthet et al. (2009) GCA 73:6402, diamonds: Ford et al. (2008) Meteorit. & Planet. Sci. 43:1399, black squares: Corgne et al.[2]. **Red =data from FeS/silicate liquid partitioning experiments.** Red squares: Steenstra et al. (2020) GCA 286:248, unfilled squares: Boujibar et al. (2019) Am. Min. 104:1224, open circles: Malavergne et al. (2014), red circles: Steenstra et al. (2020) Icarus 335, open diamonds: Boujibar et al. (2020) GCA 269:622. **Ternary plots.** Blue squares: McCoy et al. (1999), green squares: Berthet et al. (2009), red squares: Ford et al. (2008), green circles: Boujibar et al. (2020), blue circles: Boujibar et al. (2019), black squares: Steenstra et al. (2020a), red circles: Steenstra et al. (2020b), grey circles: Malavergne et al. (2014) EPSL 394:186, yellow squares: FeS from percolation experiments of Terasaki et al. (2008) EPSL 273:132. Shaded region on FeS-Fe-Fe_3C ternary: immiscibilities from Corgne et al. (2008)[2].

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