

Carbon solubility in metallic phases at high pressure and high temperature: preliminary results and application to planetary cores.

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Introduction. Metal-silicate segregation took place in many planetary bodies early in our solar system (e.g., [1, 2]). The metallic phases, which formed the planetary cores, are still changing today if the central metallic cores of planets solidify. The core of the Earth, Mars and Mercury are likely enriched in light elements (e.g. [3, 4]). Despite the importance of this question for the thermodynamic state of terrestrial planets, the dynamic of their cores and their early geology, these light elements are still not identified. The most probable candidates for the Earth, Mars and Mercury are: Si, O, S, H and C depending on the planet and formation model envisioned [5]. C is the fourth most abundant element in the solar system. C is also known for its high solubility in Fe-Ni alloys at High Pressure (HP) and High Temperature (HT). Cohenite and graphite have been found in differentiated meteorites and some ordinary chondrites [6]. These observations show that C is present during the formation of these materials. Several HP-HT studies tried to constrain the influence of C on elemental partitioning behavior [7, 8, 9 and references therein], on metal-carbonate reactions [10] with Si or S, or the solubility of C in metallic alloys [11]. None of these studies have benefited from direct C measurements. Direct analysis with classical techniques (like electron or ion microprobes) are complicated because of (i) the deposition of C on the sample by the beam, resulting in an artificial increase of its concentration [9], (ii) lack of reliable and homogeneous C standards.

The present study attempts to evaluate the solubility of carbon in metallic phases at HP-HT thanks to a less classical technique: the nuclear microprobe of the Laboratoire Pierre Süe, CEA Saclay (France) [12]. This microprobe has the major advantages not to be affected by C deposition (because its beam probes deeper in the sample) and the choice of the standards is less critical than with electron or ion probes.

Experimental and analytical procedures. Piston cylinder (PC) experiments were carried out using the Lunar and Planetary Institute QuickPress at the NASA Johnson Space Center (Houston, Texas, USA). Multi anvil (MA) experiments were carried out in the presses of the Bayerisches Geoinstitut, Bayreuth (Germany). Details of the experimental procedures are given by [13,14]. The starting material were either a simplified CI glass mixed with different

metallic phases (Fe-S, Fe-Si or Fe-S-Si) [14] or a natural meteorite (Indarch, an EH4) [13]. The oxygen fugacities of the samples were calculated relative to the iron/wüstite (IW) buffer as in [14]. A 1.8 MeV proton or deuteron beams of 600-1000 pA intensity with a focused beam was scanned over the samples with a spatial resolution of 5x5 µm (scanning rate ranging from 500 to 1000 Hz). Deposited charge ranged from 0.4 to 1 µC, depending on the analysis and the nature of the beam (proton or deuteron). Typically, 30 minutes of acquisition were needed to obtain good analytical data.

Results and discussion. The silicate phases of our samples consist of pyroxene (at 1 GPa) or majorite (at 20 GPa) and/or melt depending on the temperature. All the starting materials are molten at 1700°C at 1 GPa and 2400°C at 20 GPa. The PC experiments and the MA experiments are described in [13, 14]. The fO₂'s of the samples range from 1 log unit below the IW buffer to 7 log units below IW. No iron carbides were found in any of our samples. The C solubility in Fe-Si and Fe-S alloys are reported in the Fig. 1 as a function of P, T and redox conditions. Our first results suggest that: (i) the solubility of C in Fe-S phases shows no obvious correlation with P, T or fO₂. Its limit is very low, well below 1 wt%. (ii) the solubility of C in Fe-Si alloys shows a weak correlation with P, T compared to the Fe-S phases. Its limit is high at 1 GPa (between 3 and 1.5 wt%) and decreases at 20 GPa down to ~0.3wt%. These preliminary results confirm that the association of Si and C as light elements in a planetary core is likely contrarily to the association of S and C. Moreover, as the solubility of C in Fe-Si alloys seems to decrease with P and T, this association would be less favorable in bigger planetary bodies than in the smaller ones. Finally, these results strengthen the hypothesis that the diamonds collected at the surface of the Earth, which contain reducing metal inclusions (with Fe or FeSi), could have formed during early interactions at 10-25 GPa with reducing Si-rich metal [10].

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Acknowledgements. The MA experiments were performed at the Bayerisches Geoinstitut under the EU “Research Infrastructures: Transnational access” Programme (Contract N°505320 RITA High Pressure). The nuclear microprobe analyses were performed at laboratoire Pierre Sûe (France), a the French INSU facility, with the precious help of all the team.

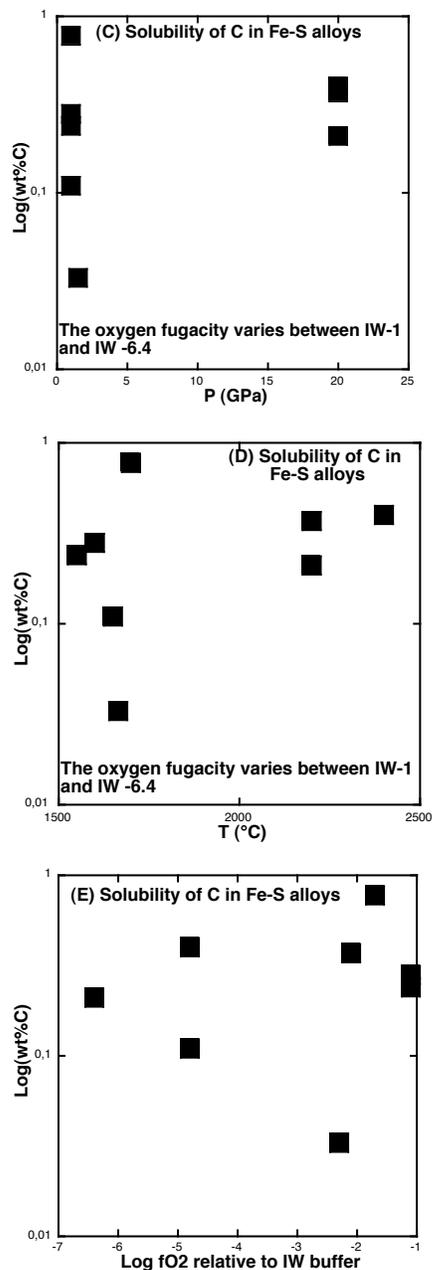
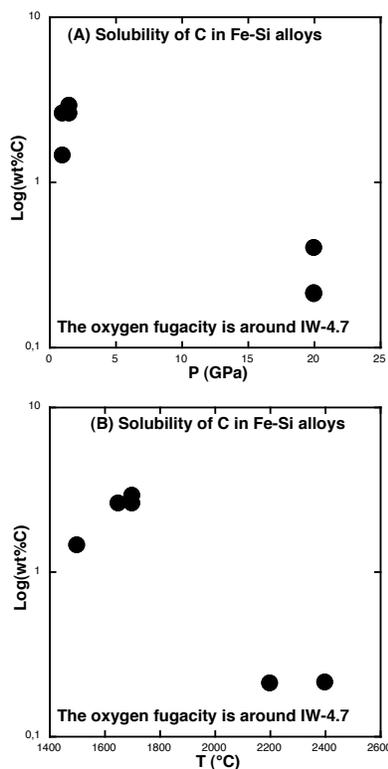


Fig. 1: C solubility : in Fe-Si alloys (A), (B) as a function of P and T, in Fe-S phases as a function of P (C), T (D) and redox conditions (E).