Metal–oxide equilibria at high pressure and temperature: Are Si and O the light elements in the core?

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Two important problems relating to the early history of the Earth and the formation of its iron rich core are currently being addressed in various experimental studies: (1) The abundances of the siderophile elements in the Earth's mantle have been the object of a number of experimental studies and have been explained by contrasting models for Earth accretion. (2) The density deficit of the core, as deduced from differences between geophysical measurements and experimental results on the density of Fe in high pressure experiments, may be accounted for by the addition of a light component to the Fe-Ni metal of the Earth's core. A number of possible candidates for such a light component such as C, Si, O, S and other elements have been proposed (for review see Poirier, 1994). Experimental data on the solubility of these elements in liquid metal alloys at pressures and temperatures relevant to the formation of the Earth's core are scarce. Therefore, high-pressure, high-temperature experiments on the solubilities of Si and O in Fe-Ni metal were performed to address the question of whether or not these elements may account for the density deficit in the core.

Experimental

In order to determine the solubilities of Si, Ti and O in liquid metal and liquid metal-magnesiowüstite partition coefficients for various elements, experiments were performed in a multi-anvil apparatus over the P-T range of 5 to 23 GPa and 1800 to 2400°C. An Fe-Ni-powder doped with Co, Ti, Si, O and other trace-elements was used as a starting material and held in MgO capsules. At run conditions the metal was always a liquid. During the experiments, the liquid metal reacts with the MgO capsule to produce magnesiowüstite enriched in Fe and the siderophile elements. A range of 3.5 log units of oxygen fugacity (below the IW buffer) was systematically imposed by varying the Si- and O-contents of the starting material. The quenched liquid metal and magnesiowüstite compositions were analysed by electron microprobe. Oxygen fugacities were calculated relative to the iron-wüstite buffer from the Fe contents of liquid metal and FeO content of magnesiowüstite, assuming ideal Fe-Ni and Fe-Mg mixing behavior in the metal alloy and in the oxide solid solutions, respectively.

Solubilities of Si, Ti and O in liquid metal

Si and O both dissolve in the liquid metal, while the concentration of Ti in the quenched liquid metal is always close to or below the microprobe detection limit. The solubilities of both Si and O in Fe-Ni-metal liquid are greater than expected, even at pressures as low as 5–9 GPa (Geβmann and Rubie, 1998). The low solubility of Ti in liquid metal weakens the main objection against the simultaneous presence of Si and O in the core (Ringwood and Hibberson, 1991).

Figure 1 shows the solubilities of Si and O in liquid metal at high pressure and temperature as a function of oxygen fugacity. The highest concentrations of Si in liquid metal are present in the most reducing experiments (~4 log bar units below the iron-wüstite (IW) buffer), while those of oxygen show the opposite trend: O contents of around 1 wt% are present under relatively oxidising conditions (slightly below the IW buffer).

Influence of pressure and temperature

The solubility of Si in liquid metal increases considerable with decreasing oxygen fugacity (at constant P,T) reaching values around 4–6 wt.% at IW-3 (Fig. 1). In addition, the solubility of Si also increases with increasing pressure (at constant f_{O_2}, T) and with increasing temperature (at constant P, f_{O_2}) as shown in Fig. 2. This result is further supported by the data of Kilburn and Wood (1997) obtained at 2.5 GPa and 1750°C which are shown in Fig. 2 for comparison. The trend suggests that considerable amounts of Si may be dissolved in liquid metal even at f_{O_2} levels close to the IW buffer curve at P,T conditions which are higher than those covered in the

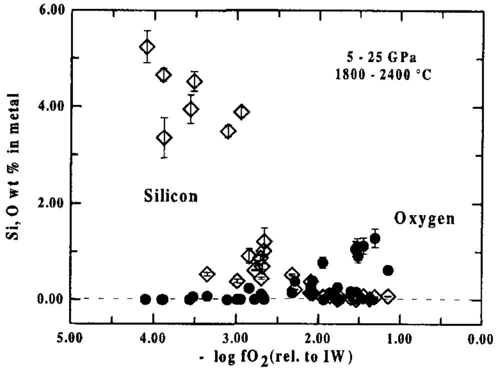

FIG. 1. Si and O contents of the quenched Fe-Ni-liquid metal as a function of oxygen fugacity. The data have been obtained from experiments covering a P,T range of 5–23 GPa and 1800–2400°C. The solubilities of Si and O in the metal vary inversely as a function of redox conditions. Up to 6 wt.% of Si have been determined in quenched Fe-Ni alloys. The maximum O-content is 1 wt.%.

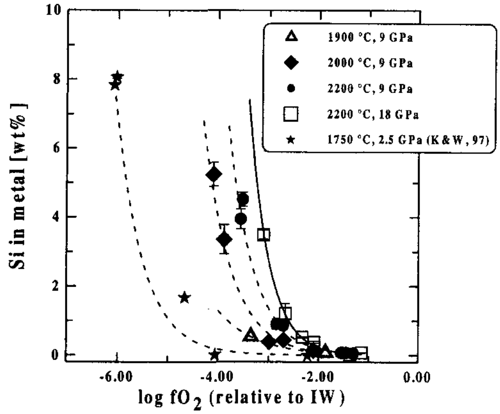

FIG. 2. Si contents in quenched Fe-Ni liquid metal as a function of oxygen fugacity. Regression lines are shown for sets of experiments performed at constant pressure and temperature. For a given f_{O_2} value, an increase in P (at constant T) and also increasing T (at constant P) both increase Si solubility. The data of Kilburn and Wood (1997) are shown for comparison.

present study. However, the solubilty of O as a function of f_{O_2} and pressure varies inversely with that of Si. The highest oxygen contents in liquid metal (around 1 wt.%) have been observed at oxygen fugacities slightly below the IW-buffer curve (Fig. 1). In contrast to Si, the O solubility decreases with increasing pressure. Increasing temperature appears to increase the solubility of O in liquid metal.

Conclusion

Because of the inverse solubility behavior of Si and O as a function of oxygen fugacity and pressure, it is concluded that it is unlikely that a combination of Si and O accounts for the density deficit in the Earh's core. Although the data indicate the possibility of high Si solubility at 'moderate' oxygen fugacities and very high pressures and temperatures, it still remains debatable whether Si is the dominant light element in the core.

References

Geβmann, C.K. and Rubie, D.C. (1998) *Geochim. Cosmochim. Acta*, **62**, in press.

Kilburn, M.R. and Wood, B.J. (1997) *Earth Planet. Sci. Lett.*, **152**, 139–48.

Poirier, J-P. (1994) *Phys. Earth Planet. Int.*, **85**, 319–37.

Ringwood, A.E. and Hibberson, W. (1991) *Earth Planet. Sci. Let.*, **102**, 235–51.