

High pressure reactions between metals and silicates: implications for the light element in the core and core-mantle interactions

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Two long standing problems in the origin and evolution of the Earth's core are the identity of the light alloying element(s) and the origin and nature of the seismically anomalous D" layer directly overlying it. It is possible that the key to both these problems lies in high pressure and temperature chemistry. Ringwood and colleagues (1990a and b) showed that high pressure increased the solubility of O and other oxides in Fe-metal. Thus, at high pressures elements O and Si may become soluble enough in Fe-metal for them to contribute significantly to the light element budget in the core. In addition, one proposed origin of the D" layer is a chemical reaction between the liquid metal outer core and the solid silicate mantle overlying it (Knittle and Jeanloz 1989, 1991). In order to investigate the nature and extent of these possible chemical interactions, we have begun a diamond anvil cell study of the high pressure and temperature reactions between metal and silicate.

Experimental procedures

Our basic sample consisted of a metallic plate in contact with a silicate which was covered with a mineral plate to insulate the sample from the highly conductive diamond anvil. In the majority of runs the sample consisted of San Carlos olivine in contact with Fe-metal with an Al₂O₃ cover plate. However, we have also conducted runs with San Carlos enstatite for both the silicate and the cover plate with Fe-metal, and an Fe-free enstatite with an MgSiO₃ glass cover plate and Fe-metal. Also, in order to study very reducing conditions and evaluate the proposal that Si is the major light element in the core, we have performed runs with iron silicides consisting of 17 and 9 wt.% silicon and San Carlos olivine with MgSiO₃ glass cover plates. We have also successfully completed a run with a small amount of FeS added along with the Fe-metal and San Carlos olivine. After loading the sample into the

diamond cell, the diamond cell was placed in 100 °C vacuum oven over night. The oven was repressurized with Ar, and the cell was sealed. The flushing with Ar and immediate sealing ensures that there is no water or O from the atmosphere present so that the oxygen fugacity prevailing during the experiment is set by the sample assemblage. The interface between the metal and silicate was heated with an YLF laser with a hot spot size ranging from 20 to 50 µm. There is an average temperature gradient across the hot spot of 15 to 25 K/µm. However this is not indicative of the true temperature distribution across the hot spot as the temperature gradient is very flat across the central part but increases dramatically as the edges are approached. The metallic portion of the sample was melted during heating, and the initially clear San Carlos olivine and San Carlos enstatite darkened due to the transformation to the high pressure phases of perovskite and magnesiowüstite. The Fe-free enstatite remained clear. The run pressure was determined through the position of fluorescence peaks of rubies distributed throughout the sample. The samples were recovered after the runs and polished down to the heated surface.

Results and conclusions

The metal and silicate portions of the samples were analysed by electron microprobe. Figures 1 and 2 show the O and Si contents of the metal in typical runs with San Carlos olivine and Fe-Metal versus pressure. The number next to each point indicates the number of degrees above the melting point of Fe the temperature was. When measuring small amounts of O and Si in the metal on such small samples false amounts can be detected though the secondary fluorescence of X-rays from the silicate and the formation of an oxide coating on the Fe-metal. In order to check how much false O and Si we might detect in the metal we simply analysed an unheated sample of San Carlos olivine and Fe-metal. The false

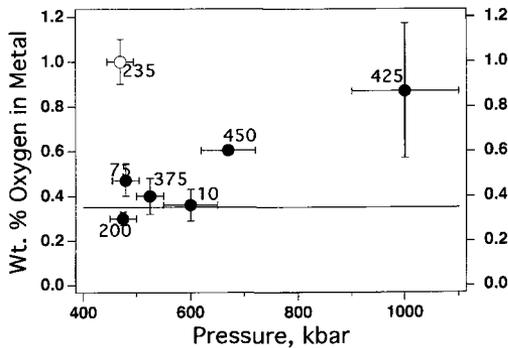


FIG. 1.

levels are indicated by the solid horizontal lines in the figures. The general trend observed in these figures is that the solubilities of both O and Si increase with increasing pressure and temperature. However, even at 1 Megabar the amounts of O and Si in the metal are still very low (less than 1 and 0.2 wt.% respectively) indicating that neither element on its own is likely to comprise a significant portion of the light element in the core.

We also see evidence for the effect of oxygen fugacity on the solubilities. The run labeled 75 in the two figures has a higher Fe content in the silicate than the run labeled 200 indicating that it was at a higher oxygen fugacity than the run labeled 200. The run at the higher oxygen fugacity shows more O in the metal and less Si in the metal than the more reducing run. Hence, as would be expected, Si is favoured in the metal at lower oxygen fugacities, and O is favoured at higher oxygen fugacities.

The open symbol in each figure represents a run that contained approximately 4 wt.% S in the metal. Compared to a run at similar temperature and pressure, the S-bearing run has much higher O and lower Si in the metal. This is in agreement with recent work at low pressure (Kilburn and Wood, 1997), and suggests that possibly a combination of O and S could make up the light element in the core.

Preliminary analysis of the runs with San Carlos enstatite and Fe-metal ($P = 650$ kbar, $T = 2900$ K) and the Fe-free enstatite and metal ($P = 625$ kbar, $T = 2700$ K) indicate that Fe-metal is essentially chemically inert in contact with enstatite: neither O nor Si were detected above the false levels.

To date one run with an Fe-silicide ($P = 560$ kbar, $T = 2800$ K) has been analysed. The Fe-silicide initially contained 17 wt.% Si which was reduced to 11 wt.% after heating. The Fe in the adjacent silicate

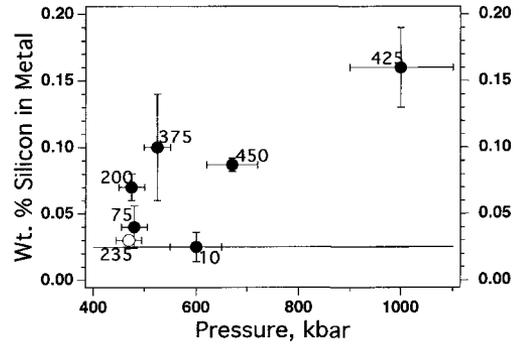


FIG. 2.

was reduced to 4 wt.% from 8 wt.%. Thus in order to have large amounts of Si in the core, the Fe content of the mantle would have to be reduced to below that observed. If later an oxidized component is added to bring the Fe content up to that observed, then the core and mantle would be out of equilibrium. This could result in a chemical reaction as the two try to re-equilibrate and thus form a D" layer enriched in Si and depleted in Fe.

In conclusion, we find that if Fe-metal equilibrated with typical mantle minerals during core formation, then neither O nor Si is very soluble in metal and neither is likely on its own to be the major light element in the core. However, we also find that S enhances the solubility of O, and thus a combination of these two elements could be responsible for the density deficit in the core. Furthermore, our results indicate that Fe-metal is essentially in equilibrium with a pervovskite plus magnesiowüstite assemblage and therefore a chemical reaction between the mantle and the core is unlikely to be responsible for forming D". The only way to form D" though a chemical reaction is if the core and mantle are out of equilibrium with one another as would be the case in a heterogeneous accretion scenario with Si comprising the light element in the core.

References

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