

High temperature reduction of San Carlos olivines and role of kinetics on metal/silicate interactions

G. Libourel

Centre de Recherches Pétrographiques et Géochimiques, CRPG-CNRS, BP 20, 54501 Vandoeuvre les Nancy, France

F. Guyot

Laboratoire de Minéralogie-Cristallographie and Institut de Physique du Globe, Université Paris-Jussieu, 4 place Jussieu, 75252 Paris, France

H. Leroux

Laboratoire de Structure et Propriétés de l'Etat, Université Sciences et Technologies de Lille, 59655 Villeneuve d'Ascq, France

Whether or not chondritic metal results from equilibrium condensation in the nebula (Grossman and Olsen, 1974) or reflects reduction during chondrule formation (Scott and Taylor, 1983) is still a matter of debate. Indeed, tiny metal globules are widespread not only in the matrix of primitive meteorites but also in olivine-pyroxene bearing chondrules, suggesting that reduction reactions could have been established either before or during chondrule formation. The causes of reduction processes are also controversial, either controlled by the reduced protosolar atmosphere or due to the presence of reduced carbon in the chondrule precursors (Connolly *et al.*, 1994). These issues and the role of kinetics are of fundamental importance in understanding chondrule formation processes and conditions, as well as pre-terrestrial metal-silicate differentiation. In addition, chondrules being the raw material for the Earth accretion, the understanding of the processes controlling the formation of metal and its compositions might also have strong implications on the segregation of metal phases during the early stages of the accretion and, in turn, on the composition and formation of the Earth's core.

Experimental techniques

In order to shed light on metal formation by reduction processes, a serie of experiments were carried out to establish i) the timing of the reduction and ii) the compositional effects of reduction. San Carlos olivines, Fa16 with trace amounts of Ni, Co, P, Mn, were used as starting material. Two starting compositions were experimented: an almost pure Fa16 powder, ground at a 50-100 μm size (NSC), and a mixture of ~85% of Fa16 and ~15% of San Carlos pyroxenes and spinels, also ground at a similar size

(NSC mix). They were run at one bar in a GERO vertical furnace, in the temperature range 1500 to 1610° C and under different reduced oxygen fugacities (IW-1 to C-CO buffer). These reduced atmospheres were imposed by a flux of different proportions of gases (CO-CO₂) or by using graphite capsules with a flux of pur CO gas. For a fixed temperature and oxygen fugacity, kinetics of reduction were examined by performing experiments with time scales of 5 min to 24 hours. Experiments were terminated by quenching the run products in the imposed atmosphere in dry conditions at ~500°C/sec.

Results

Whatever the starting material, each experiments produced an assemblage of olivines (Fo-rich), silicate glass and metal globules (Fe-Ni) either as tiny blebs (< 1 μm) included in olivine or as globules (1 to 50 μm) located in the silicate melt at the olivine grain boundaries. In the same run, olivines can show or not a dusty appearance, with or without preferential alignment of metal blebs mimicking 'dusty olivines' described in unequilibrated ordinary chondrules. Within such reacted olivines, TEM analyses reveals that tiny metal blebs are very often associated with a silicate melt strongly enriched in silica. It is also noticed that as the time of the reduction increases, for a fixed temperature and oxygen fugacity, the size of the metal globules located in the melt increases up to 50-100 μm suggesting the existence of coalescence phenomena.

With this set of experiments, it is possible to specify unambiguously the mechanism for the reduction reaction: Olivine (Fa 16) \rightarrow Olivine (< Fa16) + Si-glass + Fe metal + O₂, and to confirm that carbon is the most efficient agent of reduction. In

term of composition, olivine, Fe metal and glass are drastically dependent on the imposed oxygen fugacity, run duration and temperature. As the run duration increases for fixed oxygen fugacity and temperature, olivine becomes more forsteritic, Ni and Co contents of the metal phases decrease while Cr and Si increase. The melt, progressively impoverished in iron as reduction proceeds, evolved towards silica-rich compositions, and eventually, in strongly reduced conditions, towards Ca-Al-Ti rich compositions, due to incorporation of Si in the metal phase and/or volatilisation of SiO species from the melt.

In addition to these textural and compositional data, kinetics of metal/silicate interactions and rate constants of transfer reaction between olivine,

silicate melt and metal phase will be presented, and compared to thermodynamic affinities. In the light of these relations, we will evaluate to which extent the role of kinetic may affect metal and silicate compositions during pre-terrestrial and terrestrial metal-silicate differentiation.

References

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