

THE SARATOV CHONDRITE COMPRESSED AT ULTRA-HIGH SHOCK PRESSURE; D. D. Badjukov¹, M. A. Nazarov¹, F. Brandstaetter², G. Kurat², E. A. Kozlov³, and Yu. N. Zhugin³, ¹Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow 117975, Russia, ²Naturhistorisches Museum, Postfach 417, A-1014 Vienna, Austria, ³Russian Federal Nuclear Center, Snezhinsk, 454070, Russia.

Experimental studies [1-3] and model calculations [4] have demonstrated that liquid iron can react chemically with silicates at pressures prevailing at the Earth's core-mantle boundary (140 GPa). The reactions are believed to be responsible for the development of chemical heterogeneities at the core-mantle boundary and for the incorporation of light elements into the Earth's core [1,3]. It has also been suggested that similar reactions may occur during the early accretion history of the Earth [2,4]. In this work we studied metal-silicate relations in two samples of the Saratov (L4 fall) chondrite loaded by a converging shock wave up to a pressure and a temperature prevailing in the Earth's inner core. The experiments show a progressive oxidation of Fe, Ni metal with increasing pressure. Above a certain pressure only a Fe-rich silicate melt and metal-sulfide liquids coexist. Such sulfide liquids probably govern the distribution of siderophile elements in the core-mantle system.

Experimental. Two spherical samples (3 cm in diameter) were prepared. One was made from a single piece and the other from crushed Saratov chondrite. These samples were compressed in a evacuated container by a converging shock wave according to a method described by [5]. Due to the geometry of the shock wave propagation the shock pressure rises from the surface of the sphere toward the center. The peak pressure and temperature reached in the center of the sphere can be estimated to be about 400 GPa and 4000 °C, respectively.

Results. Both recovered samples show a similar development of shock metamorphism from the surface toward the center. The innermost part (~0.5 cm radius) consists of a porous (12 vol.%) quenched melt that is composed of olivine crystals (59.5 vol.%) enclosed in a fine-grained mesostasis (12.1 vol.%) of low Ca pyroxene and glass.

Table 1. Composition of silicates (wt. %).

	1	2	3	4	5
SiO ₂	47.9	42.5	43.9	52.2	55.9
TiO ₂	0.15	0.14	0.12	0.34	0.56
Al ₂ O ₃	2.69	2.39	2.37	6.89	7.29
Cr ₂ O ₃	0.67	0.60	0.51	0.37	0.29
FeO	14.7	24.3	20.5	26.0	17.5
MnO	0.40	0.36	0.32	0.47	0.59
MgO	29.9	26.6	28.9	3.99	1.20
CaO	2.35	2.09	2.25	6.42	13.15
Na ₂ O	1.01	0.89	1.00	2.92	3.24
K ₂ O	0.12	0.10	0.12	0.36	0.24
Total	99.89	99.97	99.99	99.96	99.96

1. Silicate fraction of Saratov [8]
2. Sulfide-free fraction of Saratov [8]
3. Bulk composition of shock melt
4. Mesostasis of quenched shock melt
5. Glass in mesostasis

(Fig.) which consist of S-poor (0.8-7.5 wt.% S; 9-20 wt.% Ni.) and S-rich (22-32 wt.% S; 7-22 wt.% Ni) metal-sulfide liquids. The S-poor liquid is always surrounded by the S-rich liquid and avoids the contact with silicates. In the outer part of the partially melted zone there are metal and/or sulfide nuggets which have phase composition similar to those of L chondrites. Commonly, the marginal parts of the nuggets are decorated by metal-magnetite eutectic-like intergrowths. These nuggets are enveloped by a Ni-rich (1-4 wt.% Ni) magnetite. Olivine at the contact with the magnetite rim contains up to 2 wt.% NiO and is rich in Fe (Fo 65). The outermost part of the samples is a lithified zone that has a compact chondritic texture. Olivine and pyroxene are fractured, and show some mosaicism and undulatory extinction. There are rare shock veins and melt

Accessories in the mesostasis are thin needles of a Ca-Cr-rich silicate and small (<5 μm) globules of a Ni-rich (up to 12 wt.% Ni) sulfide liquid. No metal is present in the shock melt. The bulk silicate melt (total minus sulfides) is distinctly enriched in Fe relative to the silicate fraction of Saratov (Table 1). The composition of olivine ranges from Fo 86 (core) to Fo 60 (rim) and is rich in Cr (0.4-0.6 wt.% Cr₂O₃). The mesostasis glass is rich in Si, Fe, and Ca, has an unusually high Ca/Al ratio (Table 1), and contains about 1% S. The phases in the mesostasis are too small for precise analysis and identification. No Ni was detected in the silicates. The totally melted core of the sample is surrounded by a partially melted zone. It is about ?? cm thick and preserves a chondritic texture. In this zone olivine is heavily shocked and shows mosaicism, intragranular brecciation and recrystallization. Some olivines are isotropic and could be ringwoodite. In the inner part of this zone there are large (up to 300 μm) sulfide nuggets associated mainly with the shock melt. They consist of pentlandite (10-58 wt.% Ni), pyrrhotite (up to 5 wt.% Ni), and a Ni-rich (up to 75 % Ni) metal. Representative analyses of the phases are given in Table 2. Some nuggets consist of intergrowths of an iron oxide, fayalite, anorthite, and sulfide. There are also nuggets

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pockets in the zone. Metal and troilite in this zone have of a normal L chondritic composition and do not show a significant oxidation.

Table 2. Metal and sulfide compositions of partially melted zone(wt. %)

	1	2	3	4
Si	0.04	0.05	0.02	0.06
Fe	25.6	42.1	29.3	58.8
Co	0.60	1.96	0.52	0.46
Ni	73.5	55.3	37.6	4.5
S	0.22	0.56	32.5	36.1
Total	99.96	99.97	99.94	99.92

1 and 2 - metal; 3 - pentlandite;
4 - pyrrhotite; P not detected.

Discussion. Our samples show a progressive oxidation of Fe,Ni metal with increasing shock pressure toward the center. In the core about 50% of the metallic Fe was oxidized and dissolved in the shock melt (Table 1). Olivine compositions indicate that the melt was already FeO-rich before olivine began to crystallize. Also, the high Ca/Al ratio of the residual glass cannot have been generated by crystallization of a chondritic melt under normal pressure but rather could be the result of precipitation of an Al-rich high-pressure phase (possibly garnet or pyroxene). This implies that the melt solidified before the pressure dropped to atmospheric conditions and that the oxidation was caused by the high pressure. Thus, the experiments support the possibility of high pressure metal-silicate reactions proposed earlier [1-4]. However, in contrast to data given by [1-3] no reduction of Si or other elements was detected in the Saratov shocked samples, and, therefore, the chemical

nature of the oxidation is still unknown.

Similar to the Allende high pressure experiments [6], no stable liquid metal was recognized in the Saratov samples, and only a Fe,Ni-sulfide melt and a Fe-rich silicate melt are co-existing. The sulfide liquid shows a miscibility gap from about 7 to 22 wt.% S, whose existence was already suggested by thermal data in 1906 [7]. The bulk composition of the sulfide liquid calculated from the Saratov bulk chemistry [8] after oxidation of 50% of the Fe metal is: Fe 70.6, Ni 10.4, S 18.9 (wt.%), and this is close to that of the Allende high pressure sulfide liquid [6]. Thus, similar sulfide liquids could be produced from different chondritic materials under high pressure. We may suggest that these are the liquids which should be a main constituent of the Earth's core and which should control the partitioning of siderophile elements in the mantle-core system. This conclusion is compatible with current geochemical models [e.g., 9].

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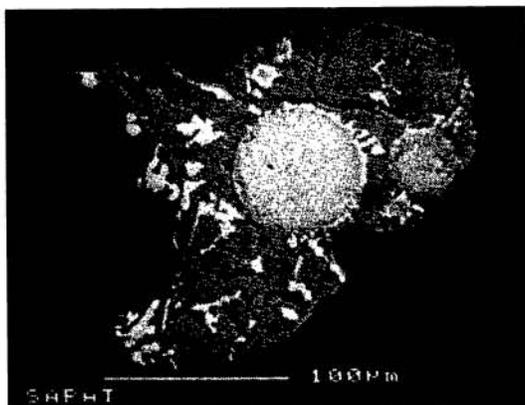


Figure : Co-existing sulfide-metal liquids; grey: sulfides, white: metal, black: silicates; BSE image.