MELTING EXPERIMENTS ON A YAMATO CHONDRITE

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Abstract: One-atmosphere melting experiments have been carried out on Yamato L6 chondrite 74354 at temperatures 1125°, 1200° and 1275°C and at P_{O_2} (oxygen partial pressure) between 10^{-16} and 10^{-8} atm. The compositions of olivine, Ca-poor pyroxene, Fe-Ni metal and liquid have been determined as functions of temperature and P_{O_2}; for example, the composition of olivine varies from Fo_{62} to Fo_{87} and that of metal varies from $Fe_{20}Ni_{80}$ to $Fe_{94}Ni_6$ as P_{O_2} varies from 10^{-12} to 10^{-16} atm at 1125°C, and from Fo_{66} to Fo_{77} and from $Fe_{40}Ni_{60}$ to $Fe_{84}Ni_{16}$ respectively as temperature varies from 1125° to 1275°C at 10^{-14} atm P_{O_2}. Based on these experimental data, P_{O_2} for equilibration of this chondrite is estimated as about 10^{-20} atm. The compositions of liquids coexisting with olivine, Ca-poor pyroxene and Fe-Ni metal at P_{O_2} lower than $10^{-8.5}$ atm are within the compositional ranges of howardite and eucrite, suggesting that chondrites may have a genetical relationship with these basaltic achondrites.

1. Introduction

Experimental studies on chondrites or related synthetic systems are useful for understanding the conditions of formation of chondrites. Such experimental studies were previously made on Allende carbonaceous chondrite (SEITZ and KUSHIRO, 1974; KUSHIRO and SEITZ, 1974; MYSEN and KUSHIRO, 1976). These experiments, particularly those at 1 atm were made in narrow temperature and P_{O_2} ranges and the results are quite preliminary. As an extension of these studies, we have made melting experiments on a Yamato chondrite over wider temperature and P_{O_2} ranges. The Yamato L6 chondrite 74354 has been chosen for the present experiments because this chondrite has been studied in detail (NAGAHARA, 1979) and is suitable for the experimental studies. The experiments were made in the melting temperature range because equilibrium can be more easily obtained among coexisting phases in the presence of liquid. The experiments are not completed but the results obtained so far in the present studies can be used for estimating P_{O_2} of the formation of chondrules and the equilibration of chondrites. In addition a genetical relation between chondrites and some achondrites can be suggested based on the compositions of liquids obtained in the experiments.

2. Experimental Methods

All the experiments were made at 1 atm using a platinum-wound quenching furnace. Oxygen fugacity was controlled by CO_2-CO gas mixing technique. The sample (sintered powder) was suspended with a thin Pt wire (0.2 mm in diameter) without containers. Uncertainty of temperature measurements was ±2°. The duration of the runs except one ranged from 23 hours to 73 hours depending on temperature. After the runs the samples were quenched in air and observed under the microscope. Microprobe analysis of the phases in the charge was made with a MAC electron microprobe, and the homogeneity of the phases was checked with a GEOLCO electron microprobe.

The starting material was Yamato L6 chondrite 74354, which consists of olivine (Fo_{76-75}), orthopyroxene ($En_{78.5-79.3}$), clinopyroxene ($\sim Ca_{45}Mg_{48}Fe_7$), plagioclase ($\sim An_{9.2}Ab_{84.0}Or_{6.8}$), chromite ($Cr_2O_3$ 54.1 wt.%, Al_2O_3 5.76 %, FeO* 30.9%, MgO 2.67%), Fe-Ni metal, and troilite (NAGAHARA, 1979). The compositions of these phases except Fe-Ni metal are homogeneous throughout the sample.

3. Results and Discussion

The runs were made at three different temperatures, 1275°, 1200° and 1125°C,

Table 1. Results of the experiments on 74354 chondrite.

Run No.	Temperature (°C)	P_{O_2} (atm)	Time (hours)	Phases identified
824	1275	10^{-8}	23	ol, sp, gl
823	1275	10^{-10}	26	ol, sp, gl
882	1275	10^{-12}	71	ol, sp, px, mtl, gl
881	1275	10^{-14}	24	ol, sp, px, mtl, gl
835	1200	10^{-8}	48	ol, sp, gl
826	1200	10^{-10}	48	ol, sp, mtl, gl
825	1200	10^{-12}	66	ol, sp, px, mtl, gl
884	1200	10^{-14}	143	ol, px, mtl, gl
921	1125	10^{-12}	73	ol, sp, px, mtl, gl
906	1125	10^{-14}	71	ol, sp, px, mtl, gl
920	1125	10^{-16}	72	ol, px, cpx, mtl, gl

Abbreviations: cpx, Ca-rich clinopyroxene; mtl, Fe-Ni metal; ol, olivine; px, Ca-poor clinopyroxene; sp, spinel; gl, glass.

in the P_{O_2} range between 10^{-8} and 10^{-16} atm. Phases encountered are olivine, Ca-poor pyroxene, Ca-rich pyroxene, spinel, Fe-Ni metal and liquid (glass). Olivine and liquid are present in all the runs, but other phases are present under limited conditions. Table 1 shows the phases identified both by the microscope and by the electron microprobe.

The compositions of the phases change systematically with temperature and P_{O_2}. The composition of olivine becomes more magnesian (Fo rich) with decreasing P_{O_2} at constant temperature or with increasing temperature at constant P_{O_2} as shown in Fig. 1. The most magnesian olivine observed is $Fo_{87.2}$ in the run made at 1125°C at 10^{-16} atm P_{O_2}, whereas the most iron-rich one is $Fo_{61.8}$ in the run made at 1125°C at 10^{-12} atm P_{O_2}. The compositional change of olivine between 10^{-14} and 10^{-16} atm P_{O_2} at 1125°C is very large compared to those in other P_{O_2} ranges. The results are now being reexamined. The compositional change of Ca-poor pyroxene is more or less similar to that of olivine, although the analyses are not enough to draw isopleths.

Fe-Ni metal becomes Ni-poor with decreasing P_{O_2} at constant temperature or with increasing temperature at constant P_{O_2}, as shown in Fig. 1. These results are consistent with the Prior's rule; with decreasing P_{O_2} iron in silicate phases is

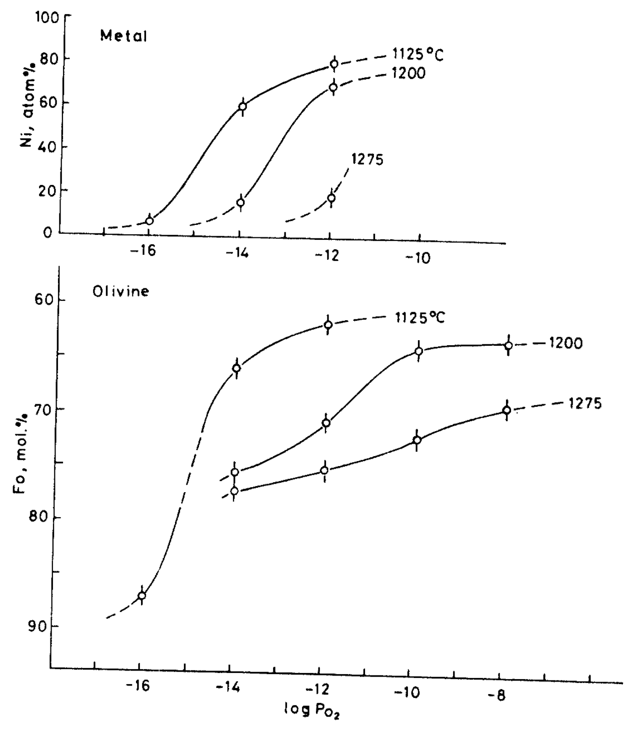

Fig. 1. Compositional variations of Fe-Ni metal and olivine coexisting with liquid as functions of temperature and P_{O_2}. Starting material is Yamato-74354 chondrite.

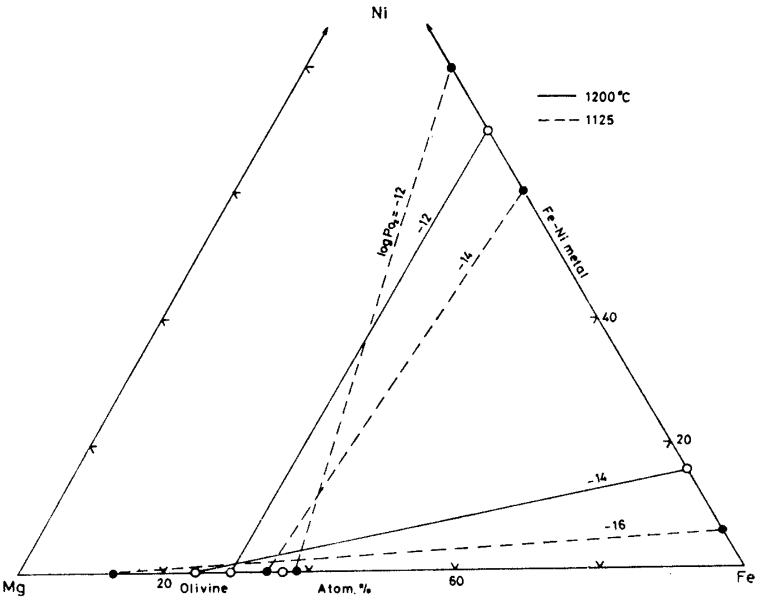

Fig. 2. Tie lines connecting coexisting olivine and Fe-Ni metal under different temperature and P_{O_2} conditions.

reduced to form metallic iron, so that the silicate phases become magnesian and the Fe content in Fe-Ni metal increases (or the Ni content decreases). The tie lines connecting the coexisting olivine and Fe-Ni metal in the system Mg-Fe-Ni illustrate these relations (Fig. 2).

Using the results obtained in the present experiments, P_{O_2} for equilibration of 74354 chondrite is estimated. The average composition of Fe-Ni metal in this chondrite is about $Fe_{70}Ni_{30}$, and equilibration temperature of the chondrite is estimated as about 900°C on the basis of the pyroxene geothermometer (NAGAHARA, 1979). From the results given in Fig. 1 curves for equilibration of Fe-Ni metal of composition $Fe_{85}Ni_{15}$, $Fe_{80}Ni_{20}$ and $Fe_{70}Ni_{30}$ are drawn in the temperature-P_{O_2} diagram (Fig. 3). If all the curves can be extrapolated linearly to 900°C, values $10^{-20.5}$–$10^{-19.5}$ atm are obtained as P_{O_2} for equilibration of Fe-Ni metal of these three compositions. The P_{O_2} value of 10^{-20} atm is close to that estimated for chondrites based on the phase equilibrium relations in the system $MgO\text{-}SiO_2\text{-}Fe\text{-}O$ (*e.g.* LARIMAR, 1968). The estimation based on the present experiments is, however, made by assuming linear extrapolation of the curves for Fe-Ni metal of fixed compositions. For better estimation of P_{O_2}, the experimental data at lower temperatures are needed.

The compositions of glass (quenched melt) formed in the experiments have been determined with the electron microprobe. The results of the analyses are given in Table 2. The composition of the liquid changes with both temperature

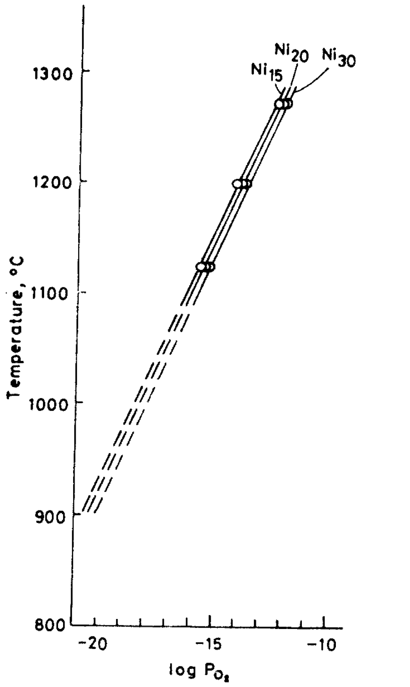

Fig. 3. Temperature and P_{O_2} conditions for the equilibration of metal ($Ni_{15}Fe_{85}$, $Ni_{20}Fe_{80}$ and $Ni_{30}Fe_{70}$).

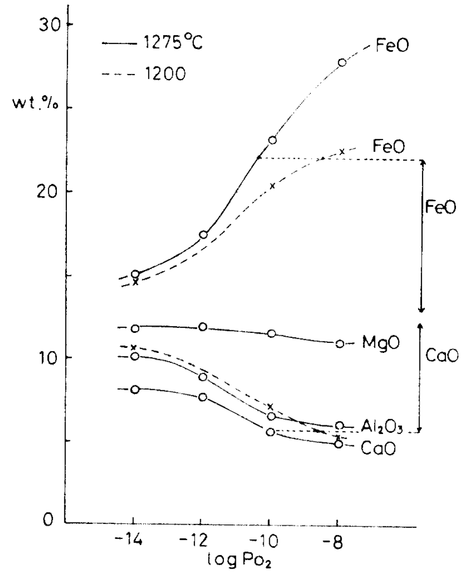

Fig. 4. Compositional variations of liquids formed in the melting of Yamato-74354 chondrite at 1200° and 1275°C and at P_{O_2} between 10^{-14} and 10^{-8} atm. The ranges for FeO and CaO of howardite and eucrite are shown with vertical bars.

and P_{O_2}. At constant temperature, the liquid becomes enriched in iron and depleted in Al_2O_3, Cr_2O_3 and CaO with increasing P_{O_2}. At constant P_{O_2} the liquid becomes enriched in MgO and Cr_2O_3 and depleted in SiO_2, Al_2O_3 and Na_2O with increasing temperature. These compositional variations are shown in Fig. 4.

The compositions of the liquids formed under certain P_{O_2} conditions are similar to those of pigeonite-plagioclase achondrites such as howardite and eucrite. The compositional ranges of these achondrites are given in Table 2 for comparison. The ranges for SiO_2, Al_2O_3, MgO and Na_2O of these achondrites include those of the liquids. However, the ranges for FeO and CaO do not cover those of the liquids. As shown in Fig. 4, the ranges for FeO and CaO of the achondrites cover those of the liquids under relatively low P_{O_2} conditions; that is, P_{O_2} of partial melting is lower than 10^{-10} atm at 1275°C and lower than $10^{-8.5}$ atm at 1200°C. It is suggested from these results that some of howardite and eucrite may have been formed by partial melting of chondrites or chondritic bodies.

Table 2. Chemical composition of glass.

P_{O_2}	1275°C				1200°C			Howardite and eucrite
	10^{-14}	10^{-12}	10^{-10}	10^{-8}	10^{-14}	10^{-10}	10^{-8}	
SiO_2	50.0	51.1	50.6	46.0	52.4	53.6	52.4	47.2 -53.1
TiO_2	0.55	0.58	0.28	0.30	0.51	0.48	0.46	
Al_2O_3	10.1	8.92	6.49	6.09	12.3	8.63	8.96	5.90–15.6
Cr_2O_3	0.55	0.72	0.41	0.17	0.34	0.17	0.06	
FeO	15.1	17.5	23.2	27.8	14.7	20.4	22.5	13.2 -21.9
MnO	0.54	0.44	0.13	0.41	0.32	0.34	0.43	
NiO	0.02	0.00	0.13	0.33	0.02	0.36	0.18	
MgO	11.8	12.0	11.6	11.0	8.41	7.43	7.57	6.50–17.6
CaO	8.06	7.65	5.59	4.98	10.6	7.09	5.14	5.79–12.2
Na_2O	0.07	0.06	0.34	0.79	0.13	1.52	1.12	0.15– 2.04
K_2O	0.09	0.04	0.10	0.14	0.00	0.27	0.40	
X_{Fe}	0.418	0.450	0.529	0.587	0.495	0.606	0.625	0.30– 0.65
K_D^{ol-li}	1.80	1.72	2.68	2.93	1.79	2.54	2.59	

$X_{Fe}=Fe/(Fe+Mg)$; $K_D^{ol-li}=(X_{Fe}/X_{Mg})_{liquid}/(X_{Fe}/X_{Mg})_{olivine}$

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(*Received May 18, 1979*; *Revised manuscript received July 19, 1979*)