

**THE EFFECT OF SODIUM VAPOR ON THE SODIUM CONTENT OF CHONDRULES** Robert Dean Lewis, University Northern Iowa, Cedar Falls, IA 50613; Gary E. Lofgren, SN-2 NASA-JSC, Houston, TX 77058

**INTRODUCTION:** Many dynamic crystallization experiments have been conducted on chondrule-like compositions under cooling, oxygen fugacity, and pressure conditions thought to be appropriate for chondrule formation in the solar nebula. The Na content of these simulated chondrules, however, is lower than those of naturally occurring chondrules even though they must have experienced similar conditions (1). Therefore, a part of the chondrule forming process has not been adequately reproduced in the experiments. Because Na is very volatile, it may be a major constituent of the solar nebula. If that is true, a higher Na partial pressure could increase the Na retained by the chondrules (1). Chondrules have been found with Na enriched rims (2, 3). It is possible that Na, which volatilizes at high temperatures, diffuses back into chondrules at lower temperatures.

Tsuchiyama (4) has determined experimentally the rate of volatilization of Na from melt droplets of chondrule composition as a function of time, temperature, oxygen fugacity, and size of the charge for a temperature range of 1450-1600°C and oxygen fugacities at and above the IW buffer. Similar work has been done by Donaldson (5) at temperatures of 1230-1300°C. Both find that as temperature increases and oxygen fugacity decreases the rate of Na volatilization becomes greater. At the conditions appropriate for chondrule formation, nearly all the Na is lost from the experimental charge because in gas-mixing furnaces typically used to study chondrules the redox controlling gases continually flow through the system (6). This method flushes any volatilized Na from the sample environment. Ikeda and Kimura (3) showed that glass beads held in contact with molten NaCl would develop a Na enriched rim. Based on these experiments they proposed that chondrules were surrounded by a dense NaCl vapor prior to final agglomeration on the parent bodies. To test the hypothesis of whether a Na vapor would equilibrate with a molten sample and maintain the Na value of the melt, we designed experiments where a Na vapor could be maintained around the sample. We have shown that, if the Na vapor can be maintained throughout the experiment, the Na level of the sample can be maintained.

**EXPERIMENTAL:** Experimental constraints on temperature imposed by the need to control the volatilization temperature of Na required a composition with a melting point lower than typical chondrule melts. The Knippa basalt, a MgO rich alkali olivine basalt, with a melting temperature of 1320°C and a Na<sub>2</sub>O content of 3 wt. % (Table 1), was used as the starting material. The Na loss behavior of the Knippa basalt was determined using powdered samples of about 100 mg of Knippa basalt pressed into pellets and placed in a one-atmosphere, gas-mixing furnace (6) on an Fe-plated, Pt-wire loop. The samples were melted at 1300°C, 1325°C, and 1350°C for durations of up to 72 hours with an oxygen fugacity at the IW buffer and air quenched. Charges melted at 1325°C and above for over 12 hours were glassy, others have a few olivine crystals.

The Na vapor experiments were conducted in a gas-mixing furnace with a reduced flow rate of the oxygen fugacity controlling gases. A ceramic crucible with approximately 8 grams of NaCl was placed in the bottom of the furnace so that the temperature of the crucible was just above the volatilization temperature of Na. The temperature was kept to a minimum so that there was Na remaining in the crucible at the end of the experiment confirming that a Na vapor was present throughout the experiment. A 100 mg pellet of Knippa basalt was attached to an Fe-plated, Pt-wire loop and placed in the gas-mixing furnace. The samples were run for 16 hours at 1330°C and then quenched in air. Polished sections were prepared for microprobe analysis.

All samples were analyzed with a Cameca electron microprobe at 15KV accelerating voltage with 10nA sample current, a large (40 KX) rastered beam, and a counting time of 20 seconds to minimize Na loss.

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**RESULTS:** The Na loss experiments are summarized in Figure 1 and show that at constant temperature and oxygen fugacity, the  $\text{Na}_2\text{O}$  content of the Knippa glass decreases with time. In runs of 72 hours nearly all (up to 98%)  $\text{Na}_2\text{O}$  is volatilized. Similar results have been recorded for chondrule-like compositions by Tsuchiyama (4) and Donaldson (5). The loss of  $\text{Na}_2\text{O}$  from the charge seems to follow a first order reaction. Tsuchiyama (4) calculated rates of  $\text{Na}_2\text{O}$  volatility to be  $2.6 \times 10^{-4} \text{ cm min}^{-1}$  at  $1450^\circ\text{C}$  compared to  $4.25 \times 10^{-5} \text{ cm min}^{-1}$  calculated for  $1300^\circ\text{C}$ , the lowest temperature used in this study. Other volatiles (e.g. K, P) were also depleted from the charge. Some Fe was lost by diffusion into the platinum wire

When a Na vapor was maintained around the sample throughout the experiment, the  $\text{Na}_2\text{O}$  content of the glass was maintained or increased. The temperature of the Na was critical because if it was too high the Na volatilized too quickly and if too low, it did not volatilize. In the five experiments in which the vapor environment was maintained, the Na content of the glass remained near the original value (the composition of one of those experiments is shown in Table 1).

**CONCLUSIONS:** The Na content of chondrules is most likely controlled by the Na vapor pressure in the solar nebula. It is probably a combination of Na vapor being present during the formation and Na diffusing into the chondrules after formation. Hewins (1) proposes a transient heating event in an opaque cloud; this cloud must have contained Na in the vapor. He also suggests that higher oxygen fugacities are present. That would also contribute to a higher Na content in the chondrules. The higher fugacities are thought to occur late in the chondrule forming process, and if that is the case, the Na would already be volatilized before the chondrule encountered these fugacities. The presence of a Na vapor during melting may be the primary reason for high Na content of some chondrules.

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Figure 1. Plot of the  $\text{Na}_2\text{O}$  content of Knippa basalt as a function of run temperature and time.

Table 1. Knippa starting composition and runs melted at  $1330^\circ\text{C}$  for 16 hrs both with and without Na vapor present.

OXIDE	Knippa start	Na vapor	no Na vapor
$\text{SiO}_2$	42.49	44.04	45.42
$\text{TiO}_2$	3.27	3.44	3.55
$\text{Al}_2\text{O}_3$	11.76	12.54	13.07
$\text{FeO}$	12.23	10.19	11.04
$\text{MnO}$	0.22	0.20	0.19
$\text{MgO}$	12.33	13.08	13.75
$\text{CaO}$	11.59	12.13	12.29
$\text{Na}_2\text{O}$	3.05	3.06	0.45
$\text{K}_2\text{O}$	2.03	nd	nd
$\text{Cr}_2\text{O}_3$	nd	0.05	0.06
$\text{P}_2\text{O}_5$	0.83	0.65	0.65
TOTAL	99.66	99.37	100.47

