

PHASE RELATIONS IN TWO Na- AND Al-RICH CHONDRULES AND THE FORMATION OF THE CHONDRULE PRECURSOR MATERIAL. A. Pack¹ & D. Hezel², ¹Institut für Mineralogie, Universität Hannover, Callinstrasse 3, D-30167 Hannover, Germany (a.pack@mineralogie.uni-hannover.de). ²Institut für Geologie und Mineralogie, Universität Köln, Zùlpicher Strasse 49b, D-50674 Köln, Germany.

Introduction: Chondrules are believed to have formed by a brief but intense heating and melting event in the early solar system. Melting erased most mineralogical information about chondrules' precursors.

A sub-group of chondrules is rich in alkali elements and was classified as Na- and Al-rich chondrules [1]. We describe two Na-rich chondrules and discuss their phase relations in order to disentangle primary and secondary processes. Concepts of chondrule precursors, nebular and parent body metasomatism will be discussed.

Petrography: We describe two chondrules from UOCs Dar al Gani 369 and 378. Trace elements in these chondrules were previously published [2]. Chondrule DaG369-RF02 is ~600 µm in diameter and consists of forsteritic olivine in a glassy mesostasis of approximately albitic composition. The vitreous structure of the mesostasis was proven by means of micro-Raman spectroscopy. The mesostasis is Na-rich (~10 wt.%) throughout and notably poor in CaO and MgO (<1 wt.%). The porphyritic olivine exhibits cathodoluminescence and is poor in FeO (0.29 wt.%) and moderately enriched in CaO (0.40 wt.%) [3].

The largest phenocryst contains a melt inclusion with shrinkage bubble (Fig. 1). The inclusion is partly devitrified to nepheline.

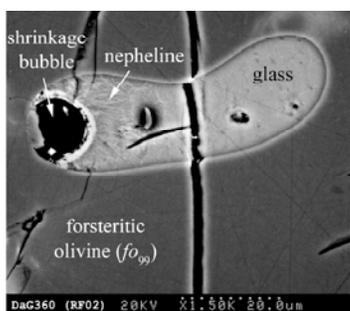


Fig. 1: Na-rich melt inclusion in olivine phenocryst in chondrule DaG369-RF02.

Chondrule DaG378-RF10 is a low-FeO barred olivine chondrule. It is depleted in Ca and shows with low concentrations of Mg in the mesostasis (<1 wt.% MgO). It is concentrically zoned with 25 wt.% FeO in olivine at the rim and ~2 wt.% FeO in olivine in the core. The FeO-content of coexisting

mesostasis is much lower throughout with ~1.5 wt.% along the rim and ~0.5 wt.% in the core.

Chondrule DaG369-RF02 exhibits fractionated REEs with negative Sm-, Eu- and Yb-anomalies. The pattern was explained by means of incorporation of highly reduced ultrarefractory condensates in the chondrule's precursor [2]. The precursor may have been oldhamite (CaS) for which such REE-patterns were suggested on base of condensation calculations [4]. REEs in chondrule DaG378-RF10 are largely unfractionated with exception of a negative Eu-anomaly [2].

MgO in mesostasis: Crystallization of olivine as liquidus phase in CMAS decreases the MgO-content of the residual melt, but can only occur in melts containing >12 wt.% (Fig. 2). Equilibrium crystallization of forsterite at the expense of mesostasis hence cannot lead to the observed MgO-contents of <1 wt.%, because these melts are far away from being forsterite saturated. Addition of Na₂O to the CMAS system expands the forsterite stability field towards lower MgO-concentrations in the residual liquid. An extreme case is the binary eutectic system *fo-ab*. In this system, forsterite crystallizes as primary phase down to MgO-concentrations of 0.6 wt.% before reaching the *fo-ab* eutectic point at $T = 1103^{\circ}\text{C}$ (Fig. 2).

Crystallization of forsterite in DaG369-RF02 and DaG378-RF10 can account for the low MgO-concentrations only if the chondrules were initially rich in alkalis. This conclusion implies that the chondrule was Na-rich at the time when olivine crystallized.

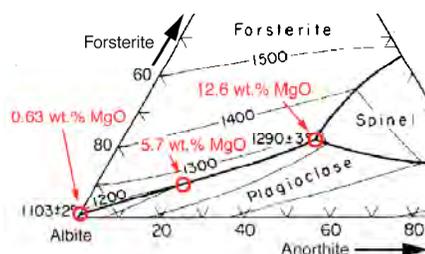


Fig. 2: Albite-rich side of the *fo-ab-an* phase diagram [5].

Kita et al. [8] reported Al/Mg-isotope data of glass from a type-IIAB chondrule from Semarkona with that contains <0.5 wt.% CaO and MgO,

1.1 wt.% FeO and 8.5 wt.% Na₂O. This mesostasis has a composition resembling that of the chondrules described here. The chondrule has a high Al/Mg-ratio with an initial ²⁶Al/²⁷Al-ratio of $9.0 \pm 1.6 \times 10^{-6}$. These chondrules must have had a much higher initial ²⁶Al/²⁷Al-ratio if Mg was lost by secondary processes. Increasing the MgO-concentration from <0.5 to initially 5 wt.% would increase the initial ²⁶Al/²⁷Al-ratios to $>9 \times 10^{-5}$. This value exceeds the initial ²⁶Al/²⁷Al-ratio that was determined for bulk CAIs [9].

CaO in DaG369-RF02 & DaG378-RF10: Bulk concentrations of Ca in chondrules DaG369-RF02 and DaG378-RF10 are low. With exception of rare tiny (<20 μm) Ca-rich pyroxene crystals in the outer part of the chondrule DaG369-RF02, no Ca-rich host phase is observed. A Ca-Kα element map revealed some inward migrating enrichment of Ca along cracks and grain boundaries. These enrichments are due to crack-filling secondary minerals (probably calcite), possibly of terrestrial origin.

Low Ca may be explained in terms of a precursor that was mainly composed of forsterite and albitic feldspar. This interpretation is in agreement with presence of alkalis during chondrule melting and initial chondrule compositions close to the *fo-ab* eutectic composition.

Ca-alkali metasomatism? An alternative model is olivine crystallization from a CMAS melt and secondary metasomatism [6,7]. In such a model, crystallization of olivine was succeeded by loss of ~14 wt.% CaO (assuming originally chondritic Ca/Al) from the residual mesostasis and gain of ~10 wt.% Na₂O [7]. This intense metasomatism must have been accompanied by loss of ~12 wt.% MgO from the mesostasis after olivine crystallization ceased.

The apparent negative correlation between Na and Ca in chondrule glasses can be interpreted by means of variable *ab/an*-ratios in the feldspar precursor components, which would lead to an 1:1 Na-Ca-exchange trend. Originally high concentrations of alkalis at time of olivine crystallization are also suggested by the presence of a Na-rich and nepheline saturated fluid inclusion in one of the olivine phenocrysts (Fig. 1).

Chondrule precursors: The depletion of the bulk chondrules in Ca is discussed in terms of fractionation (*i. e.* removal or isolation) of a specific mineral from the crystalline precursor. Fractionation of perovskite (CaTiO₃) would lead to a simultaneous depletion of the chondrule in Ti. This is not observed. Fractionation of oldhamite (CaS) from the chondrule precursor would explain the unique depletion of the

bulk chondrule in Ca. The presence of small amounts of high-REE CaS in the precursor of chondrule DaG369-RF02, however, was suggested by Pack et al. [2]. Another possibility is pure akermanite (Ca₂MgSi₂O₇) fractionation that would have little effect on the Mg- and Si-budget. Other refractory Ca-rich phases, like hibonite, gehlenite-rich melilite or anorthite would lead to a simultaneous depletion of the bulk chondrule in Al that is not observed.

A plausible interpretation is that the chondrule precursor consisted of forsteritic olivine and albite. The observed chondrule composition was not or only little modified by processes accompanying or following the chondrule's melting event. Chondrule melting did probably not result in major loss of Na. This implies either a very brief melting event and/or an environment with high alkali activity. Na must have been present during olivine crystallization in order to explain the low MgO in the mesostasis.

The alkali-rich precursor component may either have formed by fractional condensation of alkali feldspar at <1000 K [10] or by recycling of Na-rich mesostasis from a previous generation of chondrules [11]. These chondrules, however, must have been already depleted in Ca. Recycling of chondrule mesostasis will eventually lead to a homogenization of REEs that are hosted by chondrule mesostasis. Preservation of highly fractionated ultrarefractory REEs in DaG369-RF02 indicates either formation of the precursor by condensation or only a small number of chondrule recycling events.

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