

A CLOSER LOOK AT CHONDRULES AND MATRIX IN KAKANGARI: EVIDENCE FOR WIDE-SPREAD REDUCTION AND SULFURIZATION. Jana Berlin, Rhian H. Jones and Adrian J. Brearley, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, U.S.A., e-mail: jberlin@unm.edu

Introduction: Kakangari was recognized as a unique chondrite in the 1970's [1,2] and since then only LEW 87232 and Lea County 002 have been identified as similar chondrites, forming the K chondrite grouplet [3]. (However, it has since been suggested that Lea County 002 is actually a CR chondrite [4].) Only a few studies have been carried out on the chemical and petrographic properties of chondrules in K chondrites [5-7]. It has been noted that chondrule silicates are rather FeO-poor (i.e., no type II chondrules are present [6]) and that chondrules and matrix are very similar in composition [8,9]. Here, we present new bulk chemical compositional data for chondrules and mineralogical observations that show evidence for wide-spread reduction and sulfurization.

Samples and methods: We studied 2 thin sections of Kakangari (UNM 559, UNM 585) and determined bulk compositions of 20 chondrules via modal recombination using a JEOL-8200 electron microprobe [10].

Results: Chondrules in Kakangari display quite a variety of properties. When compared to chondrules of carbonaceous and ordinary chondrites they show some similarities, but also characteristic differences in textures and compositions.

Chondrule textures. Most chondrules in Kakangari belong to one of the following categories:

(1) There is a continuum of porphyritic chondrules, (PO-POP-PP), which are comparable to type I chondrules in ordinary and carbonaceous chondrites. Porphyritic olivine chondrules (PO) commonly contain euhedral olivine grains of various sizes. Many of these have a fine-grained, mostly crystalline groundmass consisting of low-Ca pyroxene, Ca-pyroxene, albitic glass, and small Fe,Ni-metal and troilite grains. In such chondrules, larger Fe,Ni-metal/troilite intergrowths have a texture that is very typical for Kakangari chondrules, with very ragged outlines. When the groundmass is more coarse-grained and pyroxene-rich, the sulfides tend to be more rounded. In porphyritic olivine-pyroxene chondrules (POP), low-Ca pyroxene often contains olivine chadacrysts. These chondrules commonly contain large taenite grains (up to 200 μm). Porphyritic pyroxene chondrules (PP) are not very common. They contain less Fe,Ni-metal and sulfide than PO and POP chondrules.

(2) A suite of chondrules exhibits textures that are very characteristic of type II chondrules (Fig. 1), with euhedral olivine phenocrysts, abundant mesostasis and laths of Ca-pyroxene. However, olivine is typically

FeO-poor ($\text{Fa}_{2.5-3.5}$). Their shapes are often very irregular, but can be rounded. These chondrules typically do not have larger Fe,Ni-metal/sulfide intergrowths, but they often contain many small Fe,Ni-metal and sulfide beads within the olivine crystals and the groundmass.

(3) Fine-grained pyroxene chondrules (Fig. 2) show radial (R), barred (B) or cryptocrystalline (CC) textures. Many of these chondrules contain SiO_2 .

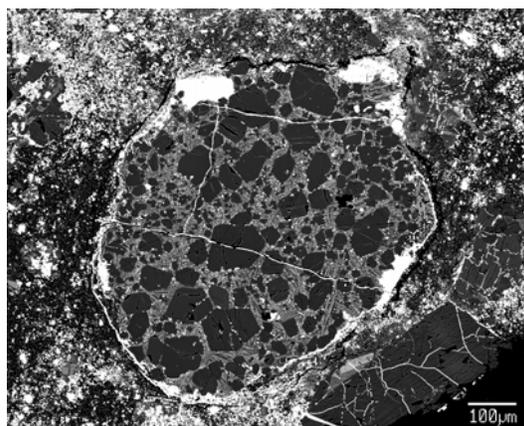


Fig. 1: Kakangari chondrule with a "type II" PO texture. The olivine composition is Fa_3 .

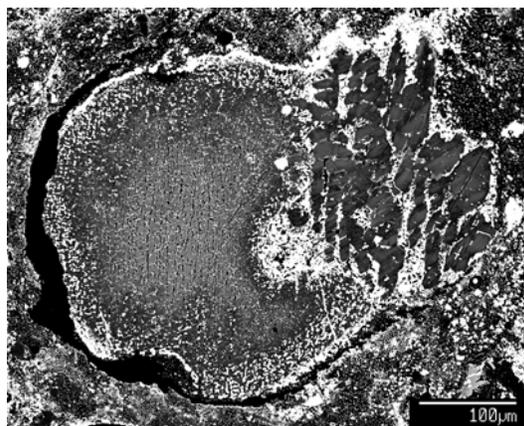


Fig. 2: Compound chondrule with PP chondrule on the right and RP/BP chondrule to the left. In the latter, pyroxene has a Fs -content of 12 mol% in the center and 7 mol% at the edge, where it is associated with fine-grained troilite.

In addition to the textures described above, we also observed a few chondrules that have unusual textures (e.g., layered chondrules [6] and a PP chondrule with high SiO_2 abundance). Very characteristic features of most Kakangari chondrules are metal-sulfide rims (e.g., Fig. 1 and 2) as well as cross-cutting sulfide veins that only rarely extend into the matrix.

Composition and mineralogy of chondrules and matrix. Figure 3 shows chondrule compositions in a Si-Mg-Fe ternary diagram. The variability in bulk chondrule compositions is largely caused by varying abundances of Fe, Ni-metal and sulfides, as can be seen when only the silicate portion of the chondrule is plotted (Fig. 4). Compositions of chondrule silicates mainly range from 2.5 to 5.5 mol% Fa (peak at 3 mol%, a few outliers up to 11 mol%) and 3 to 16 mol% Fs (peak at 6-7 mol%, some outliers up to 24 mol%). We did not find any chondrules with Fa < 2.5 mol% or Fs < 3 mol%. In fact, chondrules with the highest Fa and Fs contents show clear evidence for reduction of silicates, with Fe-rich cores but Mg-rich edges (e.g., Fig. 2). We also found small pure Fe beads within olivines (“dusty” olivines) in one PO chondrule.

Compositions of matrix silicates are more reduced than chondrules with $0 < Fa < 3.5$ and $2 < Fs < 5$ (AEM analyses, see [9]). Even though chondrule and matrix compositions are in general very similar, no free SiO₂ was found in the matrix [9], only within chondrules.

Two products of aqueous alteration are present in Kakangari. Ferrihydrite was observed replacing kamacite in the matrix [9,11], at the margins of chondrules [11] and also in the interior of chondrules. The same is true for chlorapatite.

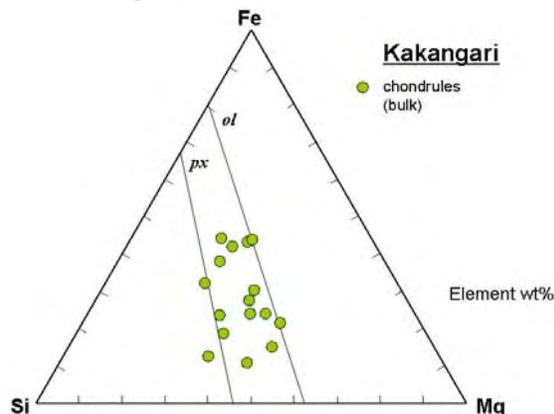


Fig. 3: Si-Mg-Fe ternary showing bulk compositions of Kakangari chondrules.

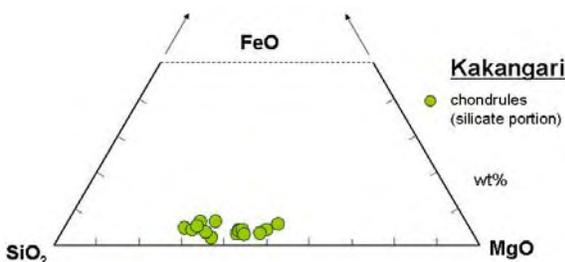
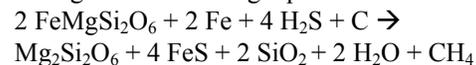


Fig. 4: SiO₂-MgO-FeO ternary showing only the silicate portion of Kakangari chondrules.

Discussion: Even though there is a significant range of Fa- and Fs-contents, we do not find chondrules with Fa < 2.5 mol% or Fs < 3 mol%. It is not clear whether the original chondrule population was comparable to the populations in most carbonaceous or ordinary chondrites (with a significant population having Fa ≤ 1), or if Kakangari originally had a unique suite of chondrules. If it originally was similar to carbonaceous or ordinary chondrite chondrules, we would expect to observe evidence for oxidation in type I chondrules and for reduction of type II chondrules. We have not found evidence for oxidation of Mg-rich silicates. We do find some evidence for reduction (Fig. 2), but not necessarily where we would expect it. For example, olivine in chondrules with a “type II” texture have a very narrow range of Fa-contents (Fa_{2.5-3.5}). Thus, the Kakangari chondrule suite might be unique.

The abundance of sulfur in Kakangari (10.5 vol% troilite [3]) is comparable to CI chondrites, but other chalcophile elements such as Ga, Sb, Br and Zn are depleted. This may point to the possibility that sulfides are the result of a reaction involving H₂S. We think that wide-spread sulfurization could have taken place according to the following equation:



We currently have three working hypotheses to explain the features we see in Kakangari chondrules and matrix:

- (1) Reduction took place first (in some cases maybe even during chondrule formation?), followed by sulfurization in a parent body environment.
- (2) Reduction and sulfurization happened at the same time in a parent body environment.
- (3) Instead of solid-state reduction, chondrule silicates simply started to equilibrate with the highly reduced matrix, sulfurization followed afterwards.

In a last stage, low-temperature aqueous alteration caused the formation of apatite and ferrihydrite throughout the whole chondrite.

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References: [1] Graham A. L. and Hutchison R. (1974) *Nature* 251, 128-129. [2] Davis A. M. et al. (1977) *Nature* 265, 230-232. [3] Weisberg M. K. et al. (1996) *GCA* 60, 4253-4263. [4] Krot A. N. et al. (2003) in *Treatise of Geochemistry* Vol.1, 83-128. [5] McSween H. Y. (1977) *GCA* 41, 1843-1860. [6] Nehru C. E. et al. (1986) *Meteoritics* 21, 468. [7] Genge M. J. and Grady M. M. (1998) *LPS* XXIX, #1670. [8] Nehru C. E. et al. (1983) *Meteoritics* 18, 361-362. [9] Brearley A. J. (1989) *GCA* 53, 2395-2411. [10] Berlin J. et al. (2005) *LPS* XXXVII, #2370. [11] Genge M. J. et al. (1998) *LPS* XXIX, #1665.