PETROLOGIC AND STABLE ISOTOPE STUDY OF THE KAKANGARI (K-GROUP) CHONDRITE: CHONDRULES, MATRIX, CAI'S.

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The Kakangari chondrite has been studied by numerous investigators [e.g., 1-4] and is generally considered to be unique. It has some affinities to ordinary chondrites (Mg/Si, Ca/Si, Al/Si), but has higher FeS and chalcophile elements, and a lower oxidation state. Planetary noble gas data [5] indicate similarities to UOC's and C1 and C2 chondrites. Bulk rock oxygen isotopes are relatively near the Allende mixing line [6]. The matrix is Mg-rich, in contrast to typical Fe-rich matrices of other chondrites. Matrix mineralogy does not consist of fragmented chondrules, but formed mainly from poorly crystalline presolar or nebular dust and is generally similar in bulk composition to that of the chondrules [7]. Bischoff noted the presence of small CAIs' [8]. Thus, Kakangari does not conform to any established chondrite group. To develop a deeper understanding of this meteorite and its significance, a petrologic and oxygen isotopic study of its chondrules and matrix was undertaken. CAI's were also studied, but they are too small to be separated. Si isotopes were determined for 4 of the chondrules; 4 others are in progress.

Chondrules and Matrix. Chondrules were studied previously by Nehru et al. [2]. Ol is mainly Fo_{96} and opx $Wo_{1-2}En_{92-96}$. Some chondrules are layered, and some have reverse zoning. Chondrules make up about 30 vol.%, and matrix 70%, of the whole rock. Modal data for chondrules, matrix and whole rock show that chondrules have higher ol, cpx, plag and lower opx than matrix. Similar results are reflected in the bulk compositions of the chondrules, matrix and whole rock. The 30:70 chondrule:matrix ratio appears to be a reasonable estimate when these analyses are compared.

Eight condrules and a matrix sample were separated from Kakangari for oxygen isotopic anlaysis (Table 1; Fig. 1). The matrix sample was separated from a large (3mm) clast consisting of dark fine-grained material. Results indicate that the chondrules have oxygen isotopes similar to those in enstatite chondrites and aubrites, and lie on or near the terrestrial fractionation line. Nearby groups include IAB silicates and Cumberland Falls chondritic inclusions. Matrix has a unique isotopic composition in keeping with its unique mineralogy; it differs from all other analyzed matrix material. Chondrules have mass-fractionated Si isotopes (both positive and negative). The effects are larger than those typical of chondrules in ordinary chondrites or in Allende [9], and are comparable to those in CAI's. No nuclear anomalies have been resolved ($\leq 0.2‰$).

CAI's. Kakangari contains numerous refractory inclusions (cursory searching revealed more than 10 in each of the two thin sections), ranging in size from <50µm to ~400µm. Most are spinel-rich, ± perovskite, with rim sequences consisting of sodalite followed by an outer layer of aluminous diopside. One inclusion was found to contain hibonite. All of the inclusions examined thus far are irregularly-shaped aggregates, similar to the spinel-pyroxene aggregates found in Murchison [10], except for the sodalite rims and the absence of the pyhllosilicates characteristic of the CM inclusions. The spinel in Kakangari inclusions is generally zoned in composition, from aluminum-rich cores with 3-10 wt.% Cr_2O_3 and 2-3 % FeO to Cr-rich rims having up to 50% Cr_2O_3 and 8-10 % FeO. The Cr-rich regions commonly contain tiny (≤5µm) oriented blades of TiO_2, presumably formed by exsolution. The zoning patterns (as observed in back-scattered electron photos) follow grain boundaries and fractures, suggesting that the Cr-rich mantles were formed by secondary replacement of the aluminous cores.

The hibonite-bearing inclusion is an irregular aggregate of 10-20µm-sized hibonite crystals, each mantled successively by rims of Cr-Al spinel (10-20% Cr_2O_3), sodalite, and aluminous diopside (1-2% Al_2O_3, 2-4% Fe-O). The hibonite contains 3-4% MgO, 5-5.5% TiO_2, 0.9-1.0% SiO_2 and 0.65-0.86% FeO. The Cr-spinel-rimmed hibonite crystals from this object resemble a similarly-rimmed hibonite grain found in Dhajala [11]. Melilite has not yet been found.

Bulk Composition. The Kakangari whole rock oxygen isotopic composition previously reported [6] was so unusual that another sample was chosen for analysis. Results (Table 1) indicate a similar composition. Kakangari chondrules, matrix and whole rock analyses are shown in a line fitted to the data (Fig. 1). The whole rock composition can be mass balanced by the 30:70 ratio of chondrules:matrix. The small CAI's should be extremely enriched in light oxygen isotopes, if analagous to Allende CAI's, but they would have only a minor effect, at best, on the whole rock ^{16}O enrichment.

Discussion: The following points may be made with regard to the results of this study: (1) Kakangari is still unique in that the relationship of the oxygen isotopes of the chondrules to the matrix differs from that of all other meteorites known to date. (2) Whereas Kakangari chondrules are isotopically similar to those in enstatite meteorites, they do not appear to be directly related because the petrologic differences are considerable. Although Kakangari chondrules are reduced, they are more oxidized than EH3 chondrules (the most oxidized) and contain no Si-bearing metal, reduced sulfides, or other unusual minerals. (3) The differences in oxygen isotopic composition between Kakangari chondrules and matrix confirms that matrix is not fragmented chondrules, as indicated by Brearley [7]. As in other chondrite groups, matrix differs isotopically from its coexisting chondrules. Nevertheless, there are some strong similarities (Mg-rich mineralogy and bulk composition), and a relationship of some kind is possible. (4) The Kakangari chondrite is unusual and appears to represent a mixture of ^{16}O-rich and oxygen that was sampled by the enstatite meteorites. (5) Small CAI's are found in ordinary chondrites [12], enstatite chondrites [13], the unique ALH85085 chondrite [14], and now in Kakangari, in addition to those in CM2, CO3 and CV3 chondrites. Their presence in Kakangari does not imply a carbonaceous chondrite classification. (6) Since Kakangari differs significantly from all other chondrite groups, and belongs to none, it should be classified as the first member of a new group called the K-group chondrites.

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Table 1. Oxygen and Silicon Isotopic Data on Kakangari Chondrules, Matrix and Whole Rock.

		$\delta^{18}O$ (SMOW)	$\delta^{17}O$	$\delta^{30}Si$ (NBS 28)	$\delta^{29}Si$
Chondrules	K5	+4.34	+1.82		
	K6	+4.04	+2.04		
	K7	+8.10	+3.62		
	K8	+4.98	+2.41		
	K9	+4.99	+2.86	-2.9	-1.6
	K10	+4.48	+1.74	+2.4	+1.3
	K11	+5.94	+3.32	+4.3	+2.4
	K12	+5.66	+3.04	+2.8	+1.5
Matrix Clast		+0.84	-2.16		
Whole Rock		+2.25	-1.17	(From ref. [6])	
		+2.29	-0.56		

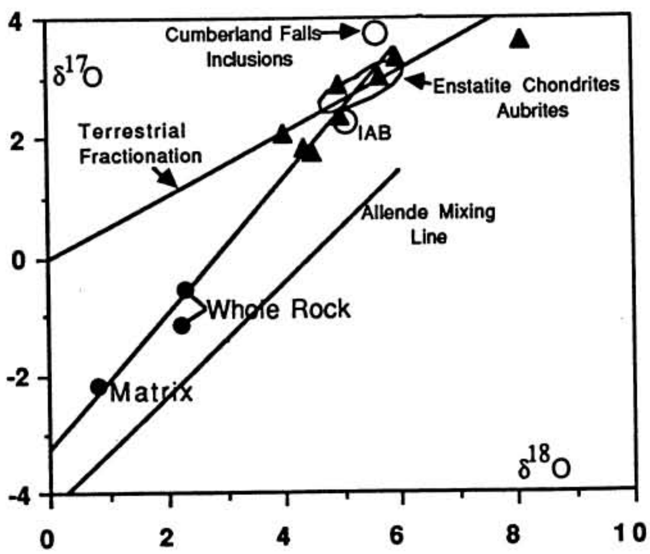

Fig. 1 Oxygen isotopic compositions of Kakangari chondrules (triangles), matrix and whole rock.