

NATURE AND ORIGIN OF MATRIX IN THE UNIQUE CHONDRITE, KAKANGARI: A TEM INVESTIGATION Adrian J. Brearley, Institute of Meteoritics, Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131

Kakangari is a unique Type 3 chondrite [1,2,3,4] which possesses many unusual characteristics. Chemically Kakangari has some affinities to ordinary chondrites (e.g. similar Mg/Si, Ca/Si and Al/Si), but has significantly higher FeS and chalcophile element contents, a lower oxidation state and distinctive oxygen isotope composition [5]. On an oxygen isotope diagram Kakangari plots near the stony irons Bencubbin and Weatherford on the extension of the mass fractionation line defined by C2 matrix material. Based on their noble gas data Srinivasan and Anders [6] noted that there were similarities between the planetary noble gases of Kakangari and ordinary and C1,C2 chondrites. Kakangari is also unusual in having an extremely high abundance of matrix material (around 50 volume%). In their mineralogical study Mason and Wiik [1] suggested that the matrix of Kakangari resembled (optically) the fine-grained material of C1 chondrites and proposed, on the basis of a bulk chemical analysis, that it might contain a hydrated phase such as serpentine. However, X-ray data [2] showed that the matrix consists largely of enstatite and troilite. The chondrule mineralogy consists of olivine, pyroxene, Fe,Ni metal and troilite [1,2].

The matrix of Kakangari has been studied by transmission electron microscopy to enable a comparison with matrices of C1, C2, C3 and O3 chondrites and examine possible genetic links between chondrules and matrix. Optically two distinct types of matrix were identifiable in Kakangari: i) regions of matrix containing abundant troilite (10-50 $\mu$ m), and ii) regions of matrix rich in grains of Fe,Ni metal. In addition, distinct clasts of matrix material also occur within the main regions of matrix.

The TEM observations show that the main component of the matrix is enstatite in accord with the published X-ray data [2]. Two distinct grain size distributions are present: one group consists of angular, anhedral grains (5-15 $\mu$ m in size) (5-10 volume %) which are visible by light microscopy. These clastic grains are surrounded by fine-grained material, 200nm to 1.5 $\mu$ m in size which consist predominantly of enstatite (80-90 volume%). Compositionally, the fine-grained enstatites have a very restricted range from  $Fs_{2.7}$ - $Fs_5$  ( $n=25$ ), compared with the electron microprobe data of Graham and Hutchison [2] ( $Fs_{4.6}$ - $Fs_{14.5}$ ) and Scott ( $Fs_{2.5}$ - $Fs_{14}$ ) (unpubl. data) from both chondrules and matrix. The fine-grained enstatites have at least two distinct morphological occurrences: they occur both as discrete euhedral to anhedral grains and as clusters of elongate (parallel to the c-axis) or equant crystals which frequently display reentrant grain boundary features with one another. Mutual pyroxene grain boundaries are frequently curved, suggesting that they are not at textural equilibrium. Observed along a-b sections many grains show planar crystal faces parallel to {100} and {110}. High resolution electron microscopy has shown that both the clastic and fine-grained enstatites are intergrowths of ortho and clino forms, as is frequently encountered in meteoritic enstatites [7,8]. The field widths of clinopyroxene lamellae in the enstatites in Kakangari consist of both odd and even multiples of the 9 $\text{\AA}$  clinopyroxene repeat and the concentrations of clinopyroxene in the intergrowths are high. Twinning is also frequently observed. According to the criteria established by Buseck and Iijima [7] for distinguishing between clino-ortho pyroxene intergrowths produced by different mechanisms, these features indicate that the matrix enstatites formed by high temperature inversion from protopyroxene. As well as the clinopyroxene lamellae with widths of multiples of 9 $\text{\AA}$ , single lamellae with a periodicity of  $(2n+1)4.5\text{\AA}$  (where n is usually 1) have been observed in high resolution images. This phenomenon has also been noted in chondrule enstatites from Tieschitz by Topel-Schadt and Muller [9].

Many of the pyroxene grains contain abundant, incoherent inclusions, which are usually <100nm in size. These are almost invariably forsteritic olivine, although larger, rare inclusions of twinned albite have also been observed. Forsteritic olivine ( $Fa_2$ - $Fa_5$ ) is also a relatively common phase as discrete, euhedral and clastic single crystals (<0.5 $\mu$ m) within the matrix as well as in fine-grained clusters, often associated with pure anorthite crystals. These clusters appear to

have been annealed and texturally equilibrated as they have a granoblastic texture with 120° triple point grain boundary junctions. The presence of olivine within the matrix was not detected by X-ray diffraction [2], although it is a significant component.

Other minor phases such as augite have also been found as well as a Cr-bearing spinel which compositionally is a solid-solution between chromite and magnesiochromite. Grains of this spinel also contain inclusions of forsteritic olivine. Troilite (<2 $\mu$ m) grains within the matrix are frequently intergrown with other phases and may contain rare inclusions of olivine.

A commonly encountered phase in Kakangari matrix is a cryptocrystalline Fe-oxide phase which occurs as aggregates of microcrystals (<50Å) with a featherlike morphology. It has been observed occasionally forming narrow rims around troilite grains. This phase is probably hydrated, and may, in part be the source of 2.3wt% H<sub>2</sub>O<sup>+</sup> quoted in the wet chemical analysis of Mason and Wiik [1]. The significance of this phase is unclear, but it undoubtedly gives rise to the red brown coloration of the matrix. Even though Kakangari is a fall, this weathering product may be of either terrestrial or cosmic origin.

Optical data suggest that Kakangari has undergone at least some minor shock as indicated by the occurrence of fine sulfide veins. The presence of solar wind gases in Kakangari, demonstrate that it is a regolith breccia. There is some evidence in the matrix for shock, such as the presence of angular clastic mineral fragments and, locally, a quite high intragranular porosity. However, few of the phases present contain significant deformation features such as dislocations or sub-grain boundaries, suggesting that shock levels were low.

The matrix minerals may have diverse origins, but it seems improbable that a significant component could have been derived by fragmentation of chondrules. Certainly a small component, probably the large, clastic grains of pyroxene and some of the smaller angular grains in the very fine-grained matrix, were probably derived from chondrules. This contention is supported by the lack of clastic olivine grains, either fine- or coarse-grained in the matrix (olivine is relatively abundant in the chondrules). The remainder of the matrix components appear to have morphologies which are inconsistent with a chondrule fragmentation origin, unless they have undergone significant post-fragmentation annealing or melting at high temperature followed by rapid cooling. This seems extremely improbable. The euhedral nature of many of the crystals suggests that unimpeded crystal growth occurred, possibly from a melt or vapor phase or by annealing of poorly crystalline presolar dust or nebula condensates. Certainly a high temperature origin is demonstrated by the microstructures present in the clino-ortho pyroxene intergrowths. Additionally, the inclusions of forsteritic olivines within many enstatite grains may be the result of partial fusion of forsterite aggregates accompanied by reaction with Si in the vapor phase. Rapid quenching, consistent with exposure to a chondrule heating event, must have followed in order to produce clino-ortho pyroxene intergrowths.

**Conclusions:** It is clear that the matrix of Kakangari does not appear to have any affinities either texturally or mineralogically to C1 or C2 chondrite matrices which are rich in FeO-bearing silicates. Mineralogically, it is also quite distinct from the matrix materials found in CV3 chondrites [10] and type 3 ordinary chondrites [11], most notably in the lack of Fe-rich olivine. The marked mineralogical and compositional similarities between matrix and chondrules in Kakangari appears to be a unique relationship which has not yet been observed in any other chondrite. The exact relationship between chondrules and matrix cannot be determined on the basis of the mineralogical data alone. However, direct derivation of the chondrules from some component of the matrix material is clearly a distinct possibility. Further chemical data, particularly oxygen isotope analysis, might help to resolve this problem.

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**References.** 1) Mason, B. and Wiik, H.B. (1966) *Am. Mus. Novit.* 2272, 1-24. 2) Graham, A.L. and Hutchison, R. (1974) *Nature*, 251, 128-129. 3) Davis, A.M., Grossman, L. and Ganapathy, R. (1977) *Nature*, 265, 230-232. 4) Graham, A.L., Easton, A.J. and R. Hutchison (1977) *Mineral. Mag.* 41, 201-210. 5) Clayton, R.N., Onuma, N. and Mayeda, T.K. (1976) *Earth and Planet. Sci. Lett.* 30, 10-18. 6) Srinivasan, B. and Anders, E. (1977) *Meteoritics* 12, 417-424. 7) Buseck, P.R. and Iijima, S. (1975). *Am. Mineral.* 60, 758-770. 8) Mackinnon, I.D.R. and Buseck, P.R. (1979) *Proc. Lunar Planet. Sci. Conf. X*, 937-949. 9) Topel-Schadt, J. and Muller, J. *EPSL* 74, 1-12. 10) Peck and Wood (1984) *LPSC XV*. 11) Nagahara, H. (1984) *Geochim. Cosmochim. Acta* 48, 2581-2595.