HOW THE FUZZY CREEK IVA IRON GOT SO FUZZY.

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Introduction: Several lines of evidence suggest that the IVA irons had a more complex history than most magmatic iron meteorite chemical groups. Most IVA irons have been shocked and some IVA irons have been thermally altered [1]. Metallographic cooling rates of the IVA irons vary by over an order of magnitude [2, 3] and there are silicates in four IVA irons [4]. No simple fractional crystallization model seems to fit all the element distribution patterns [5, 6].

Fuzzy Creek is a IVA iron [5, 7] and is the highest Ni member of this chemical group. The meteorite may have formed during late stages of fractional crystallization of the IVA metal mass. However, Fuzzy Creek does not contain a Widmanstatten pattern. The thermal history of this unique meteorite is of interest with regard to the development of the IVA chemical group.

Methods: The optical microscope was used to observe the microstructure and the electron probe microanalyser (EPMA) was used to identify the phases, the phase distribution, and the phase composition (Fe, Ni, Co and P) of the Fuzzy Creek meteorite.

Results: The microstructure of Fuzzy Creek lacks a Widmanstatten pattern (Fig. 1). Three phases (kamacite, taenite and phosphide) are observed. Kamacite is polycrystalline and taenite and phosphide occur primarily at the junctions of kamacite grains. Taenite is 2-10 µm in size and phosphide is 1-2 µm in size. Kamacite precipitates, ~1 µm in size, can be seen within the taenite. Kamacite contains 7.0 ±0.2 wt.% Ni. Taenite contains ~24-32 wt.% Ni. Phosphide is difficult to analyze given its small size, but a traverse across a phosphide yields 37 wt.% Ni.

Using a point counting method in several areas of the sample, we calculate that phosphide accounts for 0.5% of total area. A microprobe trace across several hundred microns of the phosphide-free microstructure yields an average composition of 86.2 wt% Fe, 12.4 wt.% Ni, 0.49 wt.% Co, and 0.1 wt.% P. Including the wt% phosphide equivalent to 0.5% of the sample area, the bulk composition of Fuzzy Creek is 86.2 wt% Fe, 12.4 wt.% Ni, 0.49 wt.% Co, and 0.178 wt.% P.

Discussion: *Bulk composition.* The measured bulk Ni and Co content is a little higher than the previous measurement (11.8 wt.% Ni, 0.42 wt.% Co) based on the INAA and RNAA techniques [7]. The P content of Fuzzy Creek was not measured previously. The Ni-P relationship for IVA irons [8] and for Fuzzy Creek is shown in Fig. 2. Fuzzy Creek appears to form a plausible extension of group IVA irons. This is also true for the highly siderophile trace elements [5].

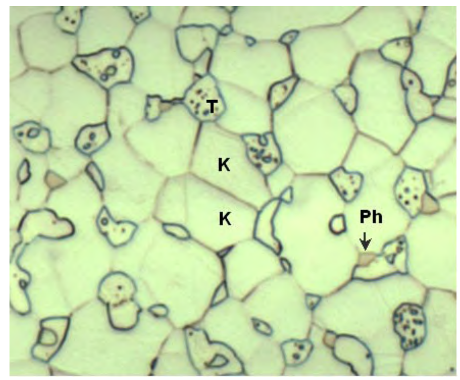

Fig. 1. Microstructure of Fuzzy Creek as observed with the optical microscope. K = kamacite, T = taenite, Ph = phosphide (Micrograph: 80 µm x 70 µm).

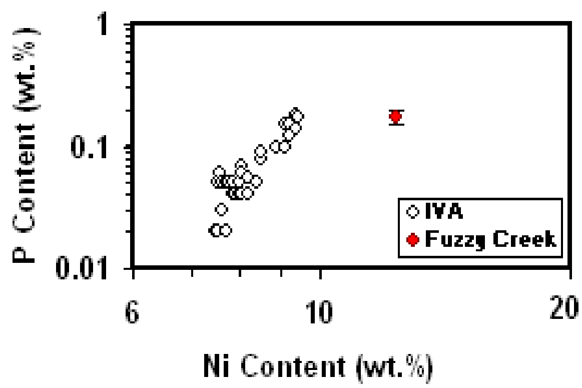

Fig. 2. Ni and P bulk composition of the IVA irons [8] and Fuzzy Creek.

Formation of Fuzzy Creek. Based on chemical distribution patterns, it is believed that Fuzzy Creek formed during the late stage of fractional crystallization of the IVA metal core. However, no simple fractional crystallization model can account for all the elements. For example, on the plot of Re vs. $^{187}Re/^{188}Os$ [5], a fractional crystallization model can account for most IVA compositions as primary solids, or mixtures of solids and equilibrium liquids. However, Fuzzy Creek can not be accounted for by this model. Also, Ge, Ga, Ir vs. Au trends cannot be generally fit with a single S content and the process of fractional crystallization [6].

Thermal constraint on formation of microstructure. We propose that the microstructure of Fuzzy Creek developed by three sequential thermal steps: 1) formation of taenite, 2) formation of martensite and 3) formation of a 3-phase assemblage kamacite + taenite + phosphide.

1) Taenite formed by the solidification process or by reheating the meteorite from low temperature after the Widmanstatten pattern formed to a temperature above 680 ºC.

2) Martensite formed by cooling the taenite phase relatively fast (weeks or less) from above 680 ºC to below 350 ºC.

3) The 3-phase assemblage (kamacite, taenite and phosphide) formed by reheating martensite to a higher temperature in the solid state. The bulk composition and chemical composition of kamacite, taenite and phosphide in Fuzzy Creek can be mapped to the Fe-Ni-P phase diagram [9]. The compositions of the 3 phases are in equilibrium in the 3 phase triangle $\alpha + \gamma +$ Ph at about 500^{O}C. Therefore, the observed microstructure formed at about 500 ºC. After heat treatment, Fuzzy Creek cooled quickly (weeks or less) to below 500 ºC where no further diffusion on the µm scale could take place.

Shock constraint on formation of microstructure. The method for developing the microstructure involves a complex thermal process and it is probable that shock plays a critical role. In fact several cycles of shock may be required.

First shock was probably necessary to remove the meteorite from its parent core in order to form taenite and then martensite. If shock occurred above 680 ºC, the meteorite would have a taenite micro-structure and then cooled relatively fast in order for taenite to be converted to martensite. Alternatively, if shock took place below 680 ºC, Fuzzy Creek would have developed a Widmanstatten pattern on cooling in the parent IVA asteroid. The strong impact would separate the meteorite from its IVA parent body at low temperature and was in part responsible for reheating Fuzzy Creek. The Widmanstatten pattern was erased through a diffusion process after reheating to 680 ºC or above. The minimum diffusion time decreases with increasing reheating temperature. Subsequent fast cooling is necessary to form martensite and prevent the reformation of the Widmanstatten pattern.

After formation of martensite, Fuzzy Creek was reheated to about 500 ºC. The process for reheating could result from another shock event on the IVA parent body. Recrystallization of kamacite, and the nucleation and growth of taenite, and phosphide took place at this temperature. Another scenario might be proposed if one assumes that Fuzzy Creek with a martensite structure lands on the surface of a hot-large fragment of the IVA parent body or on another parent body after the shock process which formed the martensite. If Fuzzy Creek landed on the hot surface, it could be reheated directly to 500 ºC where the bulk chemical composition of Fuzzy Creek is located in the three-phase (kamacite-taenite-phosphide) region. Recrystallization of kamacite, and the nucleation and growth of taenite, and phosphide took place at this temperature and the observed structure.

Uniqueness of the Fuzzy Creek structure. Other IVA irons such as Maria Elena have a rycrystallized structure; one impact may be responsible for reheating and producing the observed microstructure. On the other hand, the microstructure and chemical composition of Fuzzy Creek suggest that it may have experienced multiple impacts. Multiple impact events are consistent with the suggestion that Duchesne, another high Ni IVA iron, resulted from secondary breakup of a large asteroidal fragment produced by the major impact based on the cosmic-ray exposure age [10]. In addition, the presence of silicates in four IVA irons also indicate that shock may have been a key process for implanting the silicates in the meteorites [4]. No matter what impact and thermal history in other IVA irons, they all have the Widmanstatten pattern. However, the microstructure in Fuzzy Creek is unique among the IVA irons.

References: [1] Jain A. V. and Lipschutz M. E. (1970) *GCA, 34*, 883-892. [2] Yang et al. (2005) *LPS XXXVI,* Abstract #1347. [3] Rasmussen K. L. (1995) *GCA, 59,* 3049-3059. [4] Scott E.R.D. et al. (1996) *GCA, 60,* 1615-1631. [5] Walker R. J. et al. (2005) *LPS XXXVI,* Abstract #1313. [6] Chabot N. L. (2004) *GCA, 68,* 3607-3618. [7] Malvin D. J. et al. (1985) *GCA, 48,* 785-804. [8] Buchwald V. F. (1975) *HIM*, UC press. [9] Romig A. D. and Goldstein J. I. (1980) *Metall. Trans. 11A*, 1151-1159. [10] Voshage H. (1967) *Z. Naturforsch, 22A*, 477-506.

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