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# The metal phase of Horse Creek, Mount Egerton, and Norton County enstatitic meteorites

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SUMMARY. Results of an electron microprobe study of the metal phase and perryite inclusions in the metal of Horse Creek, Mount Egerton, and Norton County enstatitic meteorites are given. The origin of the 'pseudo-octahedral' structures observed in the metal phase of the Horse Creek and Mount Egerton 'anomalous enstatitic meteorites' is discussed.

ENSTATITIC meteorites are highly reduced so that silicon is generally found in solid solution with the metal (Ringwood, 1961; Keil, 1968; Wasson and Wai, 1970). There are two unusual meteorites, Horse Creek and Mount Egerton, whose chemical properties are closely related to enstatitic meteorites. A considerable amount of silicon has been found in the metal of these two meteorites. In addition, a nickel silicide mineral, perryite, has been found as major inclusions in their metal phase. Based on their chemical properties, Wasson and Wai (1970) suggested that this pair be called 'anomalous enstatitic meteorites'. There are some interesting structures so far found only in the metal phase of this pair (McCall, 1965). This paper reports the results of a study on the chemical composition, structure, and perryite inclusion in the metal phase of these two meteorites. The metal phase of a typical enstatite achondrite, Norton County, is also included in this study. Comparisons between the metal phase of three enstatitic meteorites and discussions about the origin of the structures in the two anomalous ones are given.

Analyses were carried out using an ARL-EMX type of electron microprobe. The standards used for this study were pure Fe, Ni, and Si metals and Nat. Bur. Stand. steels and irons containing Ni, Si, and traces of P, Co, and Cu. The P concentration in schreibersite of Norton County (15·4 %) was used as the standard for P determination in perryite. Absorption and fluorescence of elements in perryite have been corrected using procedures described by Adler and Goldstein (1965) and by Wittry (1964). The experimental procedures have been described elsewhere (Wai and Wasson, 1969).

Upon etching with acid, the metal phase of Mount Egerton reveals an oriented fine structure that looks very similar to a Widmanstätten pattern (fig. 1A). A similar 'pseudo-octahedral' structure has been observed in the metal of Horse Creek (fig. 1C), which was for this reason classified as a fine octahedrite after its discovery (Hey, 1966). Fredriksson and Henderson (1965) showed that this 'pseudo-octahedral' structure in Horse Creek consists of thin lamellae of a nickel silicide of the composition: Fe 3 %, Ni 81 %, Si 12 %, and P 5 % in a kamacite matrix. They proposed the name 'perryite'

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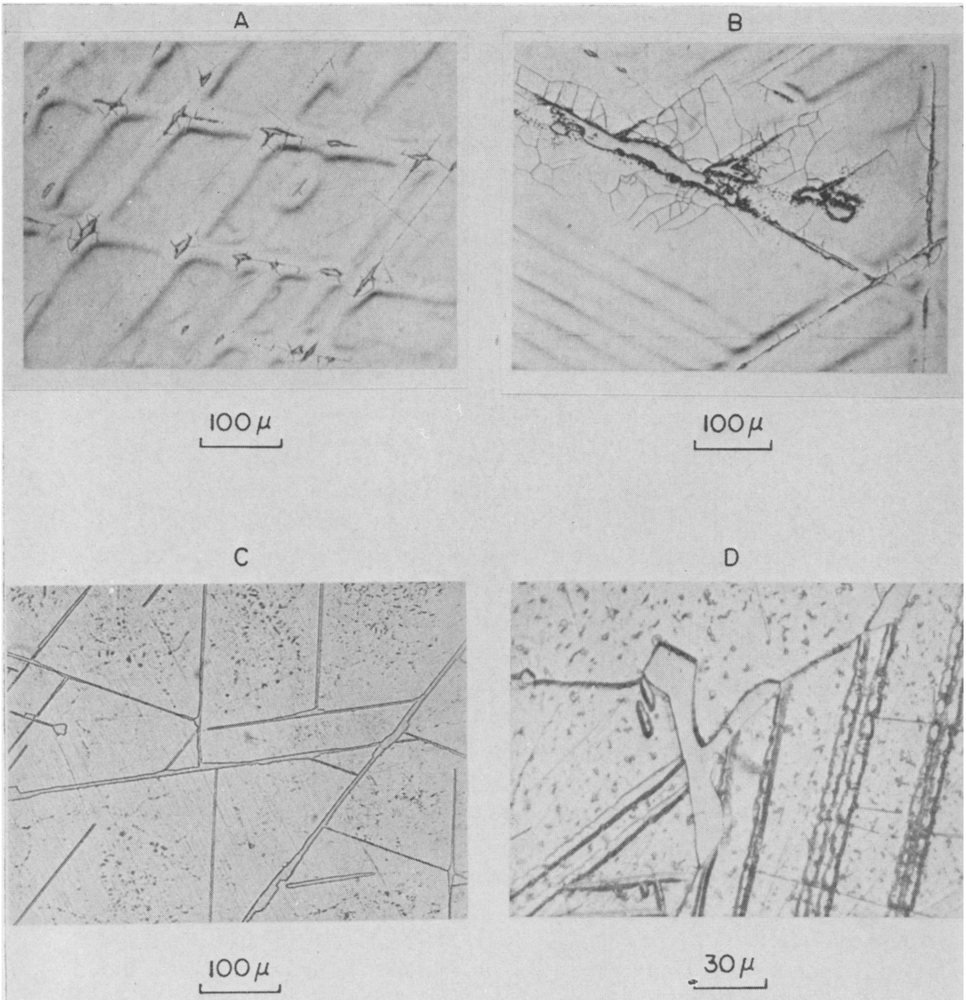


FIG. 1. A. Etched metal phase of Mount Egerton showing the 'pseudo-octahedral' structure and perryite inclusions. B. Perryite inclusions in the metal of Mount Egerton. C. Etched metal phase of Horse Creek showing lamellae of perryite inclusions. D. Etched metal phase of Norton County showing a Y-shaped perryite inclusion at the intersection of three kamacite crystals.

for this nickel silicide in honour of S. H. Perry. Perryite of variable compositions has been found in St. Marks (Fredriksson and Reid, 1967) and recently in Kota-Kota and South Oman (Reed, 1968).

The structure observed in the etched metal phase of Mount Egerton consists of perryite inclusions imbedded in 'bands' of Ni–Fe with width around 50 μm. There is no evidence of a phase boundary between these 'bands' and the remainder of the kamacite. The 'bands' are enriched in nickel, and hence dissolve less rapidly in acid than the remaining kamacite. Perryite inclusions in the metal of Mount Egerton are found mainly at the intersections of the nickel-rich bands, but are in fact also present above or below exposed Ni-rich bands showing no perryite in the polished sections. In some cases, inclusions as large as 50×200 μm have been observed (fig. 1B). The compositions of perryite in Horse Creek and Mount Egerton are given in table I, and their amounts in the metal, determined by point-counting, are 3·0 % and 2·2 % respectively.

TABLE I. *Compositions of kamacite and perryite in Horse Creek, Mount Egerton, and Norton County enstatitic meteorites*

| *Meteorite* | | Fe | Ni | Si | P | Co | Cu |
|---|---|---|---|---|---|---|---|
| Horse Creek | kamacite | 93·7 % | 3·8 % | 2·5 % | 0·05 % | 0·29 % | < 0·02 % |
| | perryite | 4·0 | 80·5 | 12·0 | 4·1 | 0·04 | 0·29 |
| Mount Egerton | kamacite | 94·0 | 4·0 | 2·1 | 0·15 | 0·30 | < 0·02 |
| | perryite | 9·4 | 75·6 | 11·8 | 3·4 | 0·05 | 0·20 |
| Norton County | kamacite | 94·8 | 4·5 | 0·7 | 0·04 | 0·28 | < 0·02 |
| | perryite | 4·1 | 81·6 | 10·3 | 5·2 | < 0·02 | 0·16 |

Perryite lamellae in the metal of anomalous enstatitic meteorites probably formed by solid phase exsolution from kamacite or precursor taenite, analogous to the formation of schreibersite and rhabdite in iron meteorites (Goldstein and Ogilvie, 1963; Reed, 1965). The metal must have been saturated with Si for such exsolution to take place. The measured Si concentrations in the kamacite of Horse Creek and Mount Egerton are 2·5 % and 2·1 % respectively. Adding the known percentage of perryite inclusions, we can estimate that the original metal phase had approximately 2·8 % Si and 6·3 % Ni for Horse Creek and 2·3 % Si and 5·6 % Ni for Mount Egerton. These Si and Ni contents in kamacite are close to the composition of metal for type-1 enstatite chondrites (Keil, 1968), which is one reason that Wasson and Wai (1970) suggested an association between these two different types of object. The textures of this pair and type-1 enstatite chondrites are clearly at variance, which Wasson and Wai (1970) interpret in terms of different thermal histories. That lamellae of perryite have not been found in the metal of enstatite chondrites is probably related to the absence of a high-temperature period during the history of these objects. The absence of high temperatures is also necessary to explain other properties of the type-1 enstatite chondrites, as noted by various authors (Binns, 1967; Keil, 1968).

A scan across the Ni-rich 'bands' in the metal of Mount Egerton indicates that the Ni concentration gradually increases from 4 % in kamacite to a maximum of 8 % at the perryite boundary. It appears that this Ni concentration gradient was caused by diffusion of Ni out of perryite into kamacite. The nickel content in perryite of Mount Egerton (75·6 %) is lower than that of Horse Creek (80·5 %), whereas the P concentration in kamacite is much higher for the former (0·15 %) than for the latter (0·05 %). It has been shown in the Fe–Ni–P ternary system that phosphide formed in equilibrium with kamacite increases in nickel content with decreasing temperature, and that the solubility of phosphorous in Fe–Ni decreases with decreasing temperature (Vogel, 1958; Goldstein and Ogilvie, 1963; Reed, 1965). The Fe–Ni–Si–P quarternary phase diagram is, however, not known. The lower Ni concentration in the perryite and the higher P concentration in the kamacite of Mount Egerton probably suggests a higher equilibrium temperature relative to Horse Creek.

Norton County is a typical enstatite achondrite and has 0·7 % Si in the metal. Perryite inclusions in the metal of Norton County are common and usually are found along kamacite grain boundaries. The Y-shaped perryite inclusion shown in fig. 1D, which grows at the intersections of three kamacite crystals of the metal, is a typical example. The largest perryite inclusions found directly in the metal of Norton County were about $30 \times 100$ $\mu$m. Exsolution lamellae of perryite were not observed in the metal of Norton County although various lines of evidence (such as the large grain size of the enstatite crystals) suggest that this meteorite is of high-temperature origin; their absence is probably related to the lower bulk Si concentration in the metal (0·7 %), which thus became supersaturated with respect to perryite at temperatures that were lower than for Mount Egerton or Horse Creek. Lamellar perryite exsolution may not be favoured at these lower temperatures.

The concentrations of Co and Cu in kamacite and perryite of these three enstatitic meteorites are given in table I. The ratio of Co in kamacite to Co in perryite is greater than 6. Copper, on the contrary, is concentrated in perryite relative to kamacite, the ratio of Cu in kamacite to Cu in perryite being $< 0{\cdot}1$.

From the microprobe data, the formulae of perryite based on one atom Si+P per unit cell are $(Fe_{0\cdot13}Ni_{2\cdot45})$ $(Si_{0\cdot76}P_{0\cdot24})$ for Horse Creek, $(Fe_{0\cdot33}Ni_{2\cdot43})$ $(Si_{0\cdot79}P_{0\cdot21})$ for Mount Egerton, and $(Fe_{0\cdot12}Ni_{2\cdot31})$ $(Si_{0\cdot62}P_{0\cdot38})$ for Norton County. The ratio of (Fe,Ni):(Si,P) is close to 5:2. The crystal structure of perryite has not been determined. R. J. Davis (private communication) has suggested that perryite might have different structures dependent upon the different compositions found in several enstatitic meteorites. X-ray studies of perryite in these meteorites would be desirable.

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