METALLOGRAPHIC AND MAGNETIC PROPERTIES OF ANTARCTIC METEORITES: ALLAN HILLS A77255, DERRICK PEAK A78003 AND A78007, AND RUSSIAN METEORITE SIKHOTE-ALIN

R. M. FISHER, A. SZIRMAE

U. S. Steel Corp., Research Laboratory, Monroeville, Pennsylvania 15146, U.S.A.

and

Takesi NAGATA

National Institute of Polar Research, 9–10, Kaga 1-chome, Itabashi-ku, Tokyo 173

***Abstract*:** The metallographic and magnetic properties of three iron meteorites from Victoria Land in Antarctica have been studied along with similar analyses of the Russian meteorite Sikhote-Alin. Allan Hills A77255 contains 12.2% Ni, 0.61% Co, and 0.026% P, and consists of a fine intergrowth of kamacite spindles in a microplessitic matrix. Derrick Peak A78003 contains 5.4% Ni, 0.51% Co, and 0.40% P, and was heavily deformed during entry through the earth's atmosphere. Derrick Peak A78007 contains 7.3% Ni, 0.38% Co, and 0.75% P. Extensive shear deformation of schreibersite veins and the occurrence of some comb plessite are evident in the structure. The iron meteorite Sikhote-Alin is a heavily deformed, coarse octahedrite containing 5.94% Ni, 0.38% Co, and 0.46% P.

1. Introduction

The metallographic and magnetic properties of three iron meteorites and one stony-iron from Antarctica have been described in the Proceedings of previous symposia (NAGATA *et al.*, 1976; FISHER *et al.*, 1978, 1979). In this paper we discuss the metallographic and magnetic properties of three other iron meteorites found in the Trans-Antarctic Mountains designated Allan Hills A77255 and Derrick Peak A78003 and A78007. Similar studies on a sample from the famous meteorite fall in the Soviet Union, known as Sikhote-Alin, have also been carried out for comparison.

2. General Description of Allan Hills A77255 Meteorite

Allan Hills iron meteorite, ALHA77255, was boomerang-like in shape and about 15 cm in overall length perior to cutting for metallographic and magnetic studies. The photograph of this sample in Fig. 1 shows the relatively smooth appearance and the occurrence of only very shallow regmaglypts. The fusion crust is very dark brown and exhibits patches of an irridescent golden brown.

Chemical composition:

	Weight	Density	Ni	Co	P
ALHA77255	765 (gm)	7.8630 (gm/cc)	12.2	0.61	0.026 (wt%)

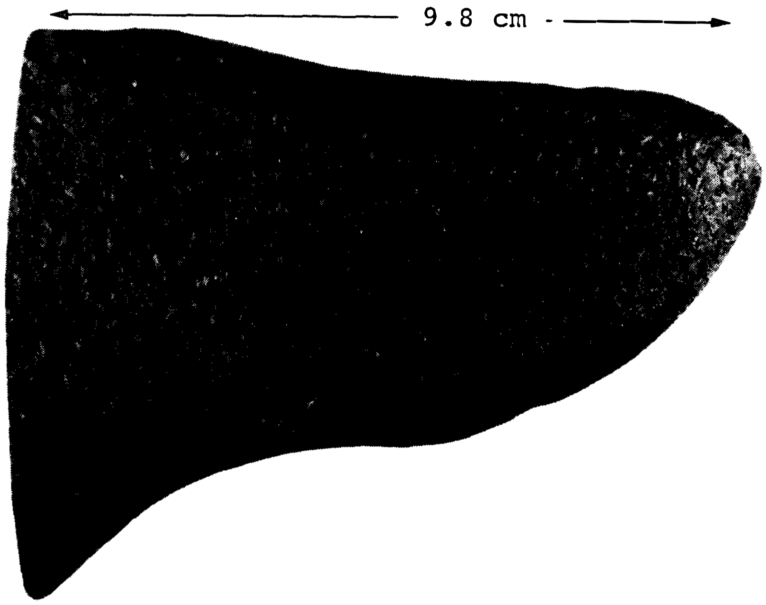

Fig. 1. Photograph of approximately one-half of Antarctic iron meteorite sample ALHA77255 showing the relatively smooth fusion crust.

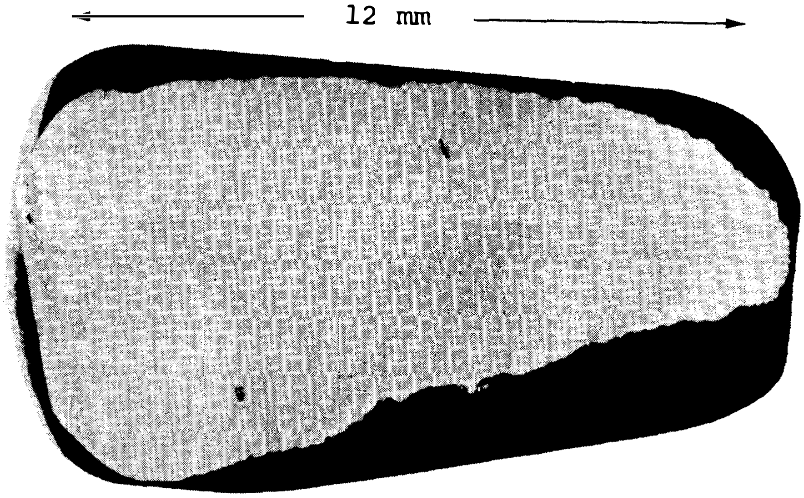

Fig. 2. Full cross-section of ALHA77255 showing the fine ataxite structure and shallow ablation regmaglypts.

3. Metallographic Examination

A low magnification photomicrograph in Fig. 2 shows the full cross-section of one end of this sample. The shallow regmaglypts and the lack of a pronounced heat-affected iron are quite evident. Apparently heating during passage through the earth's atmosphere was not intense as the Vickers hardness of 221 DPH is typical of meteorites of this composition. The very fine-grain kamacite structure is not resolvable at this magnification but does indicate that this meteorite is an ataxite.

At higher magnification in the light micrograph of a polished and etched section shown in Fig. 3, the fine-grained intergrowth of kamacite and taenite is readily observable. This structure is produced from transformation of a homogeneous taenite matrix. The same four Widmanstatten orientations of the kamacite spindles occur throughout the sample indicating that it consisted of a single taenite crystal. This structure is even more clearly defined in the scanning electron microscope especially after heavy etching, as shown in Fig. 4.

Higher magnification produces quite striking micrographs of the etch-resistant high-nickel taenite shells of the kamacite spindles and the residual taenite in the microplessitic matrix, as illustrated in Figs. 5 and 6. Qualitative chemical analysis by non-dispersive X-ray spectroscopy in the SEM indicates that the nickel content of these regions is greater than 40 percent nickel.

In some areas a striated structure is very prominent on the taenite shell, as shown in Fig. 7. The lines correspond to steps or ledges on the transformation surface and are a remanent of the crystallographic features of the change in structure from fcc (taenite) to bcc (kamacite). It may also be seen that the cell-like structure of the very fine plessite is well defined. The cell walls, remaining when the taenite decomposes at low temperatures, are also enriched in nickel and strongly resist etching. The hardness of this sample, very similar to that of other ataxites such as Nordheim found in Texas, USA, in 1932 (BUCHWALD, 1975), is determined by the plessitic matrix.

4. General Description of Derrick Peak A78003 Meteorite

Derrick Peak iron meteorite DRPA78003 was roughly oblong in shape and about 7.5 cm in length prior to cutting for metallographic and magnetic studies. The photograph in Fig. 8 shows the deep central scallops and spots where the typical brown fusion crust has weathered to powdery yellow where the bottom surface was in contact with the soil.

Chemical composition:

	Weight	Density	Ni	Co	P
DRPA78003	144 (gm)	7.3706 (gm/cc)	5.4	0.51	0.40 (wt%)

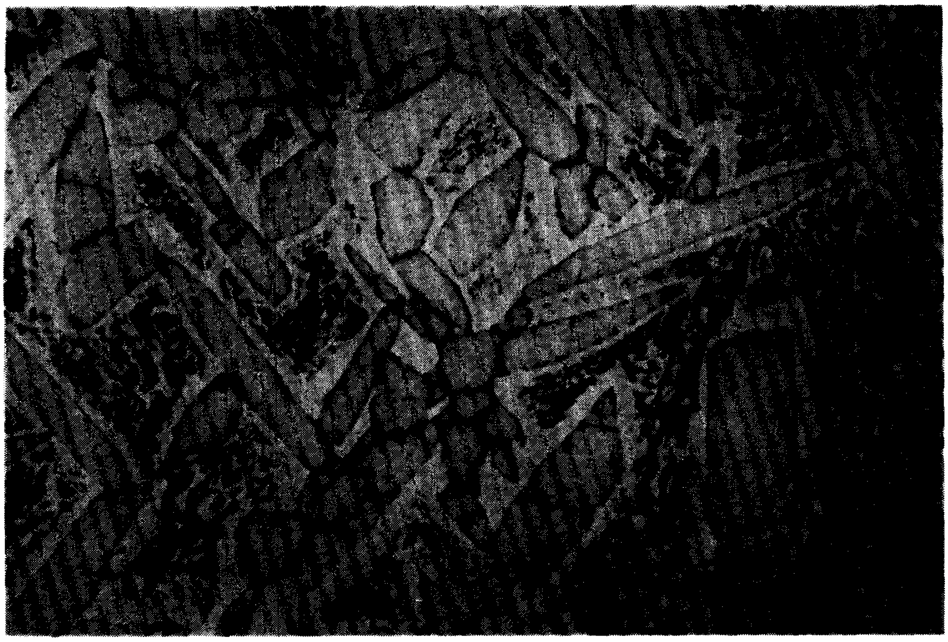

Fig. 3. Optical micrograph showing intergrowth of kamacite and taenite in ALHA77255. 200 ×.

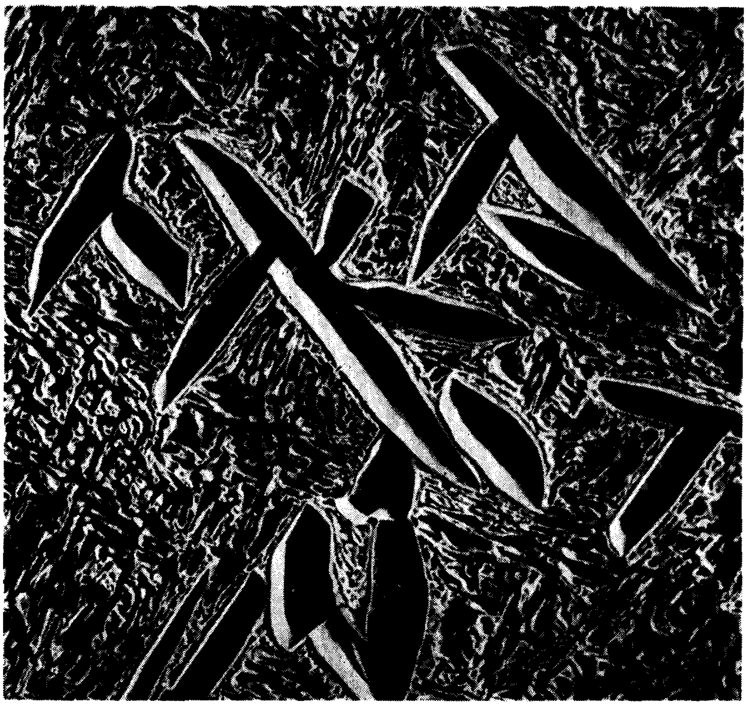

Fig. 4. SEM of heavily etched ALHA77255 showing intergrowth of kamacite and taenite. 200 ×.

Fig. 5. SEM of ALHA77255 showing etch-resisting high-nickel taenite shells enclosing kamacite spindles and the microplessitic matrix. 500×.

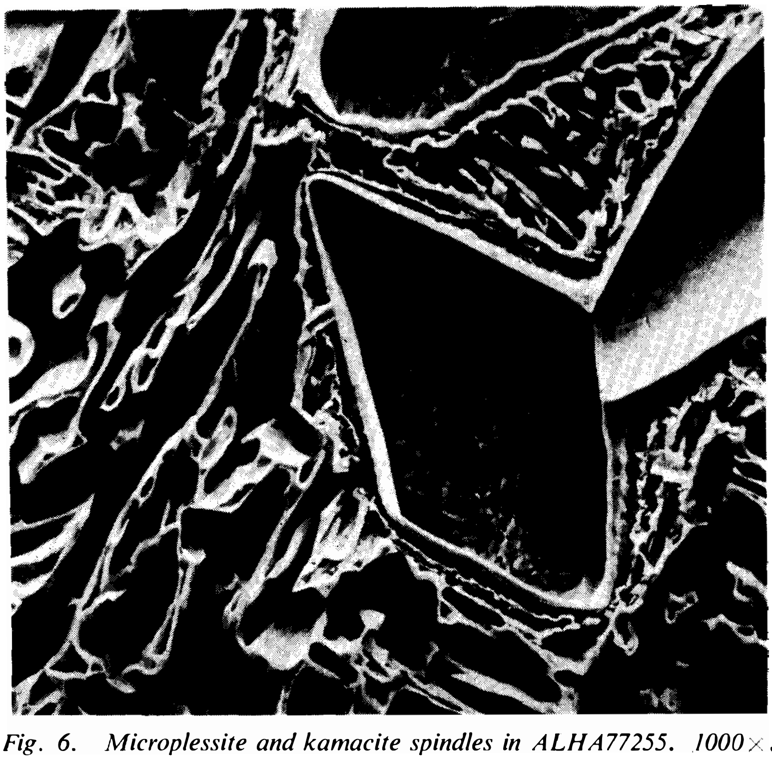

Fig. 6. Microplessite and kamacite spindles in ALHA77255. 1000×.

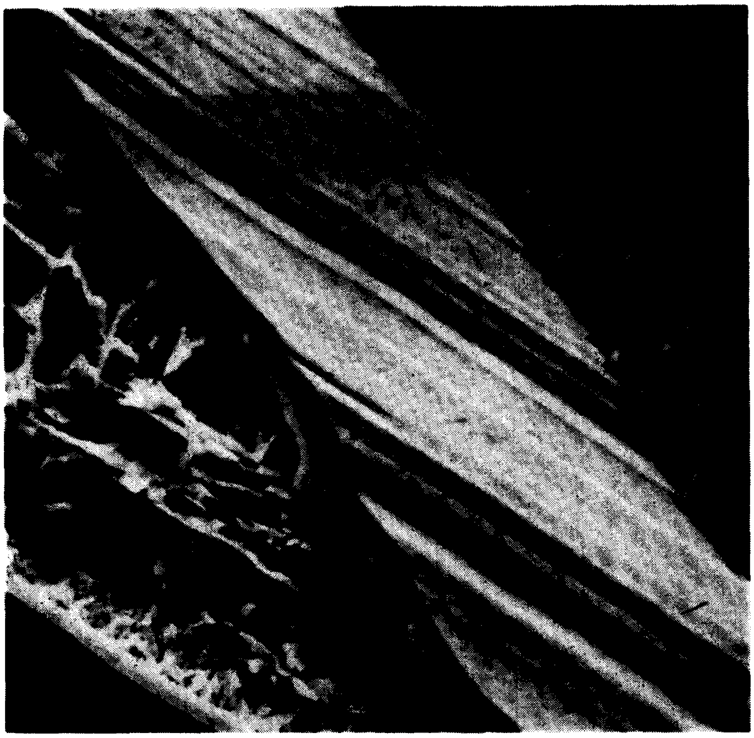

Fig. 7. SEM of ledge structure on taenite shells in ALHA77255. 2000 ×.

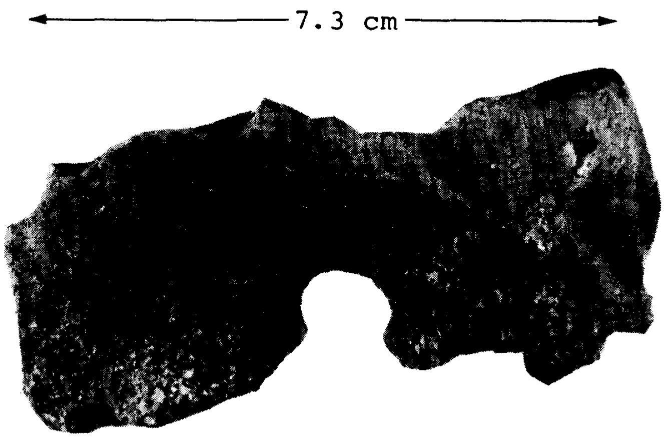

Fig. 8. Photograph of Antarctic iron meteorite sample DRPA78003.

5. Metallographic Properties

A low power optical micrograph of a one-half cross-section of a Derrick Peak meteorite, DRPA78003 is shown in Fig. 9. Evidence of extensive deformation may be seen in the form of deformation and Neumann bands. Numerous shallow regmaglypts and a very narrow heat-affected zone may also be seen in this figure.

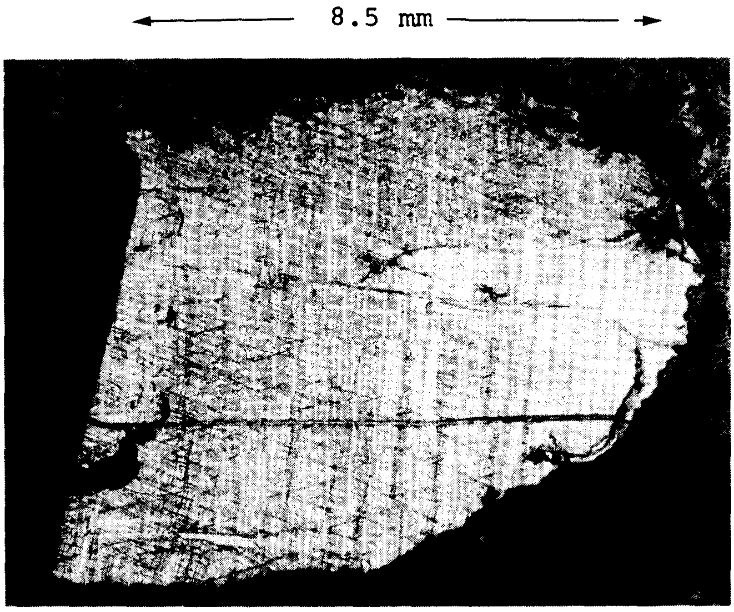

Fig. 9. One-half cross-section of DRPA78003 showing deformation structure of this coarse octahedrite.

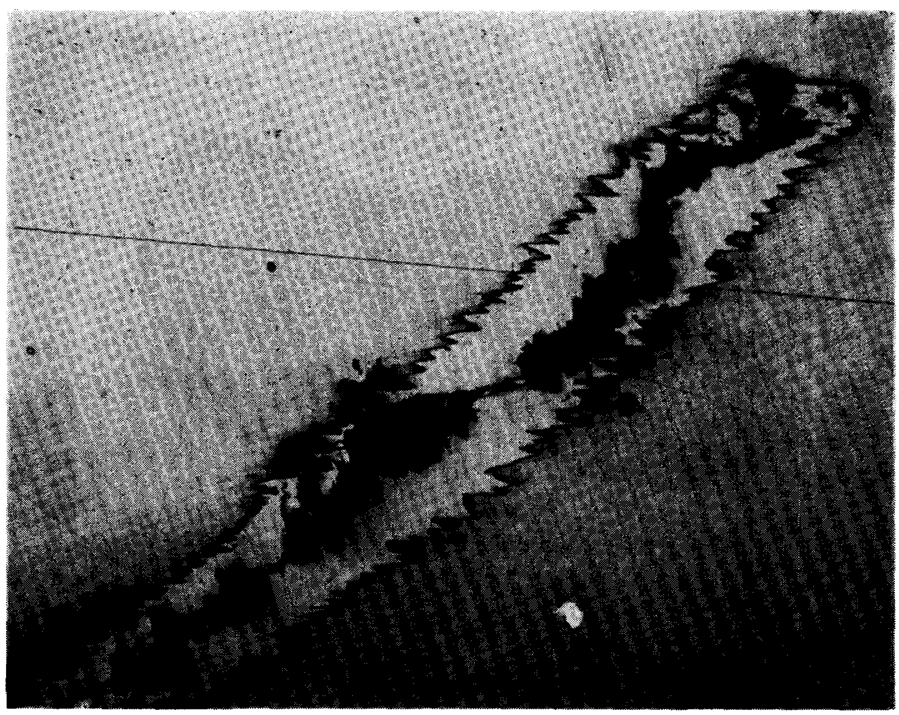

Fig. 10. Typical appearance of schreibersite with interpenetrating oxide in DRPA78003. 100 ×.

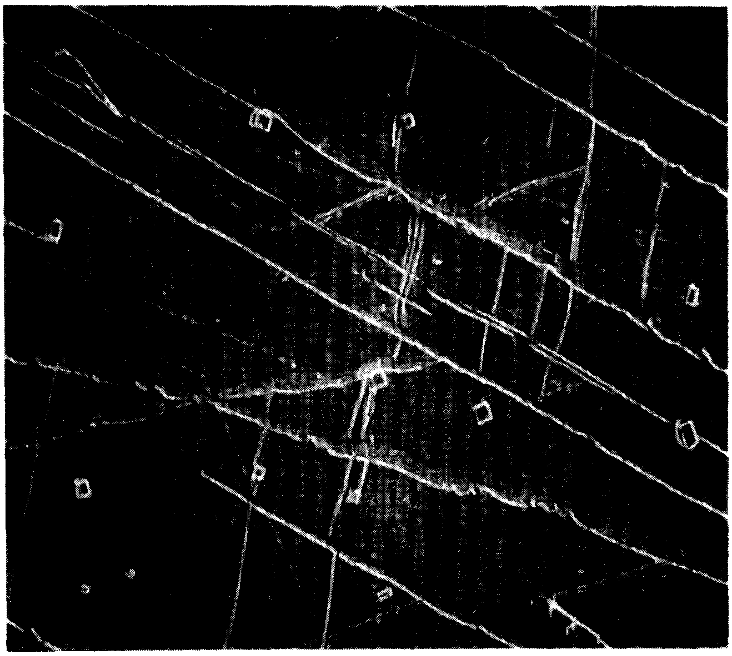

Fig. 11. SEM of DRPA78003 showing deformation twins and small rhabdites. 300×.

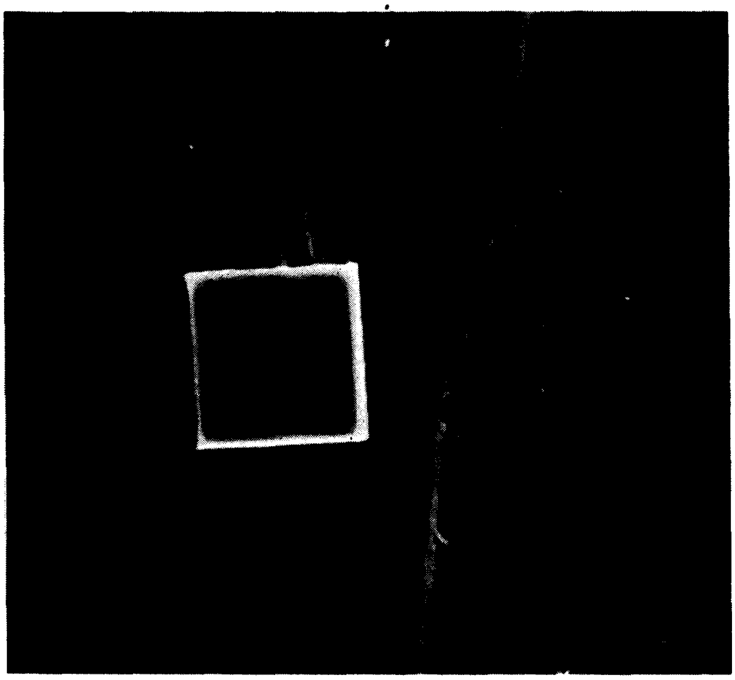

Fig. 12. High magnification of rhombohedral (Fe, Ni)$_3$ P particle in DRPA78003. 3000×.

The hardness of this sample of 212 Vickers DPH results from the extensive shock deformation.

A typical schreibersite region with interpenetrating oxide is illustrated at intermediate optical magnification in Fig. 10. The jagged edges of the phosphide vein result from extreme localized shear deformation. In other areas the phosphide phase occurs as rhombohedral rhabdites. After etching, the scanning electron microscope reveals the Neumann bands and rhabdites very clearly, as shown in Fig. 11, and at higher magnification in Fig. 12. The higher than normal hardness of this sample is due in part to this extensive shock deformation.

6. General Description of Derrick Peak A78007 Iron Meteorite

Small cut pieces from this rather large Derrick Peak meteorite, DRPA78007, were supplied for analysis. The surface areas were severely weathered and the original appearance of the meteorite is obscured by several mm of corrosion products and soil. Extremely deep regmaglypts up to 3 to 4 cm in dimension occur and large (1 cm) silvery laths of what appear to be schreibersite were observed on the surface.

Chemical composition:

	Weight	Density	Ni	Co	P
DRPA78007	11700 (gm)	7.8536 (gm/cc)	7.3	0.38	0.75 (wt%)

An essentially theoretical density for Fe-Ni is to be expected as the test sample was cut from the interior of this meteorite.

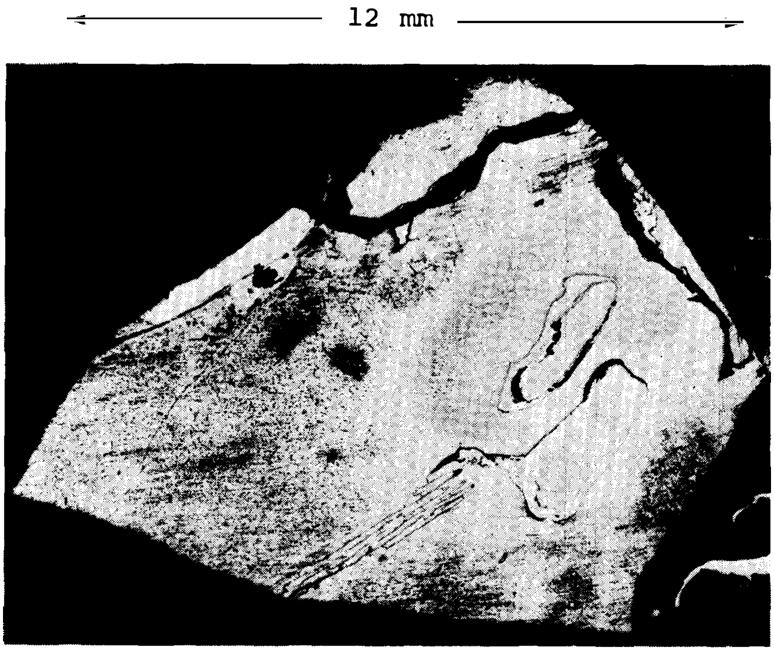

Fig. 13. One-half cross-section of Antarctic iron meteorite DRPA78007.

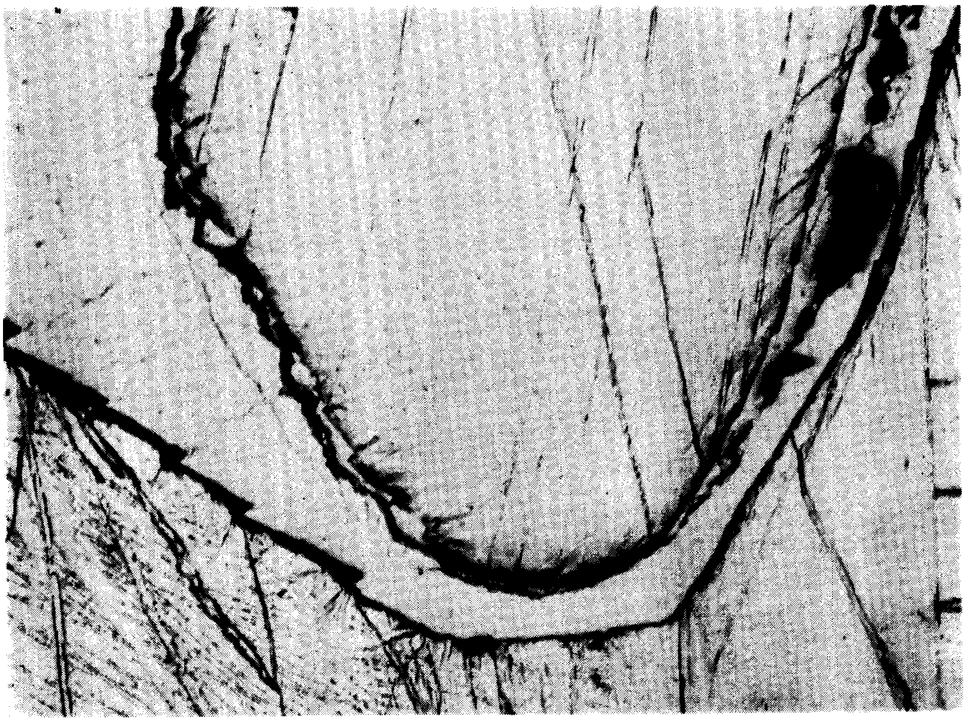

Fig. 14. Shear deformation steps on large schreibersite veins and Neumann bands in DRPA78007. 150×.

Fig. 15. Example of comb plessite in DRPA78007. 100×.

7. Metallographic Properties

A low power optical micrograph of the one-half of a corner piece of Antarctic meteorite, DRPA78007, is shown in Fig. 13. Fissuring due to thermal and mechanical shock is extensive and large areas of phosphide occur in this relatively high phosphorus meteorite. It is of interest to note that needles of schreibersite were found on the outer surface of the heavily corroded meteorite.

Higher magnification in the optical microscope shows evidence of extensive deformation evident by very unusual shear steps on some large schreibersite veins as well as by numerous Neumann bands, as illustrated in Fig. 14.

A few narrow taenite-plessite bands were observed which exhibited a dark etching pattern in the taenite and in the plessite indicating that further transformation occurred during cooling of this meteorite.

Occasional regions of comb plessite, *i.e.*, narrow ribbons of residual Ni-rich taenite, occur as shown in an SEM micrograph at intermediate magnification in Fig. 15.

8. General Description of Sikhote-Alin Meteorite (USSR)

Many pieces resulted from the entry and surface impact of the meteorite Sikhote-Alin which fell in Eastern Siberia in 1947. Extensive mechanical and thermal shock damage occurred during entry. This meteorite is a coarse octahedrite with a bandwidth of around 10 mm and belongs to group IIB, as discussed in detail in BUCHWALD (1975).

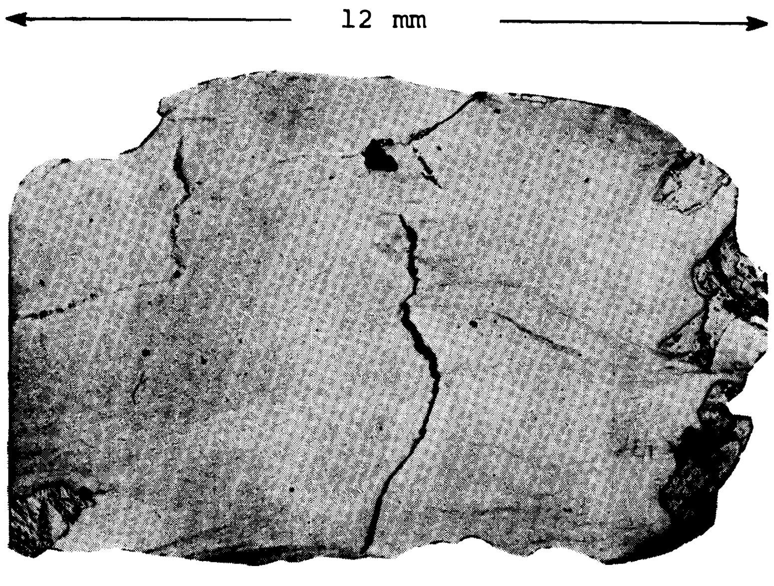

Fig. 16. Cross-section of a part of iron meteorite Sikhote-Alin 12 II–1947.

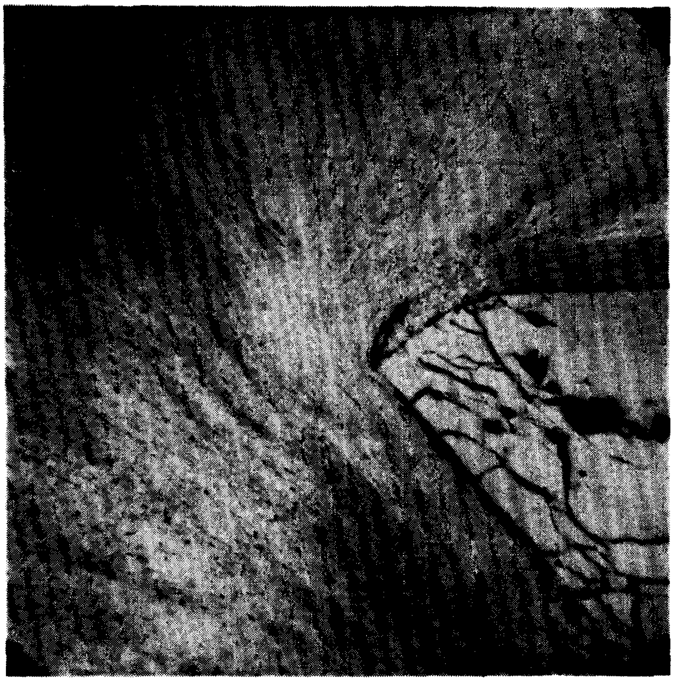

Fig. 17. Illustration of heavy deformation around schreibersite vein in Sikhote-Alin meteorite. 200×.

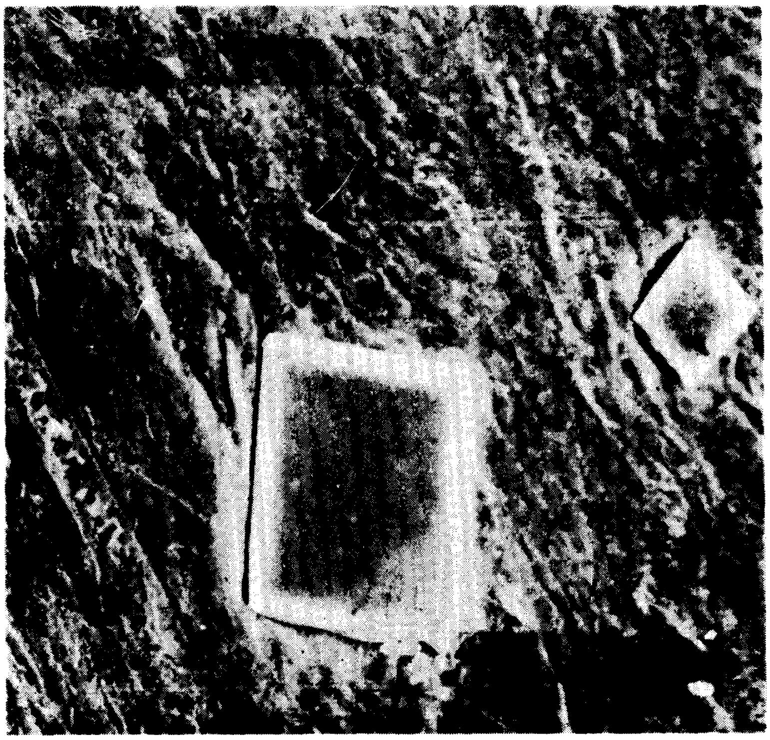

Fig. 18. Illustration of fine rhabdttes and heavily deformed matrix in Sikhote-Alin meteorite. 3000×.

Chemical composition:

	Density	Ni	Co	P
Sikhote-Alin 12 II - 1947	7.2267 (gm/cc)	5.94	0.38	0.46 (wt%)

9. Metallographic Properties

The extensive shear deformation and cracking which resulted from impact is illustrated in a cross-section view of a piece of the Sikhote-Alin meteorite fall in 1947 shown in Fig. 16. Deformation of the matrix and cracking of schreibersite veins are even more visible at higher magnification as illustrated in Fig. 17.

The matrix of the meteorite contains numerous fine rhabdites which are shown in a high magnification SEM micrograph in Fig. 18. These particles and the heavy deformation of the matrix are responsible for the high hardness of this meteorite.

10. Magnetic Properties of Three Antarctic Iron Meteorites

The magnetic properties of three Antarctic iron meteorites, ALHA77255, DRPA78003 and DRPA78007, have been examined for the purpose of comparing with their metallographic properties.

The saturation magnetization (I_s), the coercive force (H_c), the remanence coercive force (H_{RC}), the transition temperature from α to γ in kamacite phase in the heating process ($\Theta^*_{\alpha\to\gamma}$), the transition temperature from γ to α of kamacite in the cooling process ($\Theta^*_{\gamma\to\alpha}$) and Curie point of FeNi-phosphide (Θ_c(ph)) of the three Antarctic iron meteorites are summarized in Table 1, together with chemical composition data of the contents of Ni, Co and P on the basis of Fe.

Table 1. Magnetic and chemical properties of Antarctic iron meteorites.

	ALHA77255	DRPA78003	DRPA78007	(unit)
(Magnetic)				
I_s	184.5	199	196	emu/gm
H_c	9.0	7.5	4.0	Oe
H_{RC}	223	67	272	Oe
$\Theta^*_{\alpha\to\gamma}$	740-680	755	760	°C
$\Theta^*_{\gamma\to\alpha}$	550-400	635	655	°C
Θ_c(ph)	None	360	210	°C
(Chemical)				
Ni	12.2	5.4	7.3	wt %
Co	0.61	0.51	0.38	〃
P	0.026	0.40	0.75	〃

10.1. ALHA77255

$\Theta^*_{\alpha\to\gamma}$ and $\Theta^*_{\gamma\to\alpha}$ temperatures of this iron meteorite range from 740°C to 680°C and from 550°C to about 400°C respectively, which suggest that the Ni-content in this iron meteorite ranges from 9 to 15 wt%, the average being about 11 wt%, provided that the ferromagnetism at temperatures above the atmospheric temperature is due to the kamacite phase in this sample. No presence of FeNi-phosphide can be detected on the thermomagnetic curve of this iron meteorite. If the considerably small value of I_s of this iron meteorite (I_s=184.5 emu/gm) is attributed to the presence of taenite whose Curie point is lower than the atmospheric temperature, the amount of taenite phase is estimated to be 12 wt%.

10.2. DRPA78003

$\Theta^*_{\alpha\to\gamma}$=755°C and $\Theta^*_{\gamma\to\alpha}$=635°C of DRPA78003 indicate that the Ni-content in kamacite phase in this iron meteorite is about 6 wt%. The chemical composition of FeNi-phosphide of 360°C in Curie point is approximately expressed by $(Fe_{21/8}Ni_{3/8})P$ whose saturation magnetization is about 140 emu/gm (GAMBINO *et al.*, 1967). The observed contribution of saturation magnetization of the FeNi-phosphide to I_s is 2.4% or 4.8 emu/gm. Then, the bulk content of P can be estimated as about 0.5 wt%, which is in approximate agreement with chemical composition data.

10.3. DRPA78007

$\Theta^*_{\alpha\to\gamma}$ and $\Theta^*_{\gamma\to\alpha}$ temperatures of DRPA78007 indicate that the Ni-content in kamacite phase in this iron meteorite is about 5 wt%, which is smaller than the chemical determination data of Ni-content. This result may be due to segregation of Ni into the relatively large amount of schreibersite that results from the high P content and into the γ phase in the comb plessite. The chemical composition of FeNi-phosphide of 210°C in Curie point is approximately identified to $(Fe_{17/8}Ni_{7/8})P$ whose saturation magnetization is about 100 emu/gm. The observed contribution of the FeNi-phosphide to I_s is 2.6% or 5.1 emu/gm. Therefore the bulk content of P is estimated to be about 0.8 wt%, which is in approximate agreement with the chemical composition data.

11. Summary and Discussion

Chemical, magnetic, and metallographic analyses of three Antarctic meteorites have shown them to be illustrative in terms of composition and microstructure of both relatively rare and the more common types of iron meteorites.

Allan Hills A77255 contains 12.2% Ni, 0.61% Co, and 0.026% P, and exhibits a duplex $\alpha+\gamma$ structure with numerous clusters of 120×20 μm kamacite spindles in the microplessite matrix. It is quite similar in composition to anomalous Ni-rich ataxites, *e.g.*, Deep Springs and Nordheim, and somewhat similar in microstructure to the group IVB Ni-rich ataxite Iquique (BUCHWALD, 1975). Inasmuch as Deep

Springs has the oldest cosmic ray exposure age ever recorded (2250 million years), radioisotope analysis of Allan Hills A77255 could produce an interesting comparison of their respective ages.

Derrick Peak A78003 contains 5.4% Ni, 0.51% Co, and 0.4% P, and was heavily deformed during its fall. It appears to be a typical hexahedrite with no especially significant microstructural features.

Derrick Peak A78007 contains 7.3% Ni, 0.38% Co, and 0.75% P. It was heavily deformed during entry through the earth's atmosphere. The large schreibersite veins resulting from the high phosphorous content are sheared producing sawtooth edges, and small amounts of comb plessite are present. It appears to be a coarsest octahedrite (Ogg) with a bandwidth of 6 to 8 μm, and probably belongs to group IIB. Radiochemical analysis will facilitate positive assignment to the appropriate classification.

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