Specimens in the U.S. National Museum in Washington:

cohenite-rich	85 g slice, (no. 310, 7 x 2.5 x 0.5 cm)
cohenite-rich	90 g slice (no. 672, 7 x 5 x 0.3 cm)
cohenite-rich	117 g half mass (no. 672, 6 x 3 x 2 cm)
intermediate	107 g fragment (no. 800, 5 x 3 x 2 cm)
	59 g weathered fragments (no. 1075, Shepard
	Collection no. 35)
	45 g various fragments (nos. 1662, 2894, 3337)
cohenite-poor	79 g endpiece (no. 2893, 4 x 4 x 0.8 cm)
cohenite-poor	101 g endpiece and fragments (no. 2895, 5 x 5 x
	1 cm)
	56 g half shale ball (no. 3250, 5 x 5 x 1.5 cm)
troilite-bearing	22 g part slice (no. 3336, 3 x 2 x 0.6 cm)

Majorca, Spain

Probably a pseudometeorite.

HISTORY

A small mass of 809 g is said to have fallen on July 17th, 1935, at 11:37 a.m. The hunter who allegedly observed the fall recovered the mass from a 90 cm deep hole. He gave the location as the junction of the highway from Palma to Manacor, 8 km from Palma. The material was described by Morales (1936) but unfortunately in a very insufficient way, without substantiation of the circumstances of fall, without a chemical analysis and with an inappropriate discussion of the structure.

It is unknown where the material is at present, but it is most likely in the National Museum in Madrid. Hey (1966: 287) only records the summarical data given by Morales, without further comments.

When reading Morales' paper, one is left with the impression that Majorca is a pseudometeorite, probably a piece of cast iron. The pseudometeoritic nature is suspected because (i) an 800 g mass would not penetrate to a depth of 90 cm, exept perhaps in a very loamy soil; (ii) the spectrographically detected nickel appears to be on a low level; (iii) no fusion crust and heat-affected α_2 zones are reported; and finally (iv) the photomacrograph of an etched section (Morales 1936: figure 2) is not that of any recorded meteoritic structure, but rather that of an artificial, rapidly solidified material, such as dendritic cast iron.

It is strongly recommended that the small mass be reexamined. If it is not an artificial product it must be a highly anomalous meteorite, perhaps as unusual as Nedagolla and Ysleta. Maldyak, Khabarovsk Region, RSFSR 63°20'N, 148°10'E

A mass of 992 g was found in 1939 and acquired by the Academy of Sciences in Moscow. The locality and the coordinates above are from Zavaritskij & Kvasha (1952: 53) and Hey (1966: 287), but there seems to be some discrepancy, since the coordinates correspond to a point near Susuman in the Magadan Region. According to Vronskij (1960) it was found under 4.6 m of alluvium, only 4.5 km west of Frunze's Mine, the place where Susuman was discovered.

Maldyak was thoroughly described by Krinov (1949), Zavaritskij & Kvasha (1952: 53), Zavaritskij (1954) and Vronskij (1960), and several photographs of the exterior and of etched sections may be found in these papers. The meteorite was classified as a medium octahedrite and on various occasions assumed to be another fragment of the Susuman mass (Vronskij 1960; Hey 1966: 288). This appears, however, to be an erroneous assumption (Kirova 1962), since the analyses for Maldyak and Susuman are entirely different.

Manitouwabing, Ontario, Canada 45°26'24"N, 79°52'32"W

Medium octahedrite, Om. Bandwidth about 1 mm. ϵ -structure. HV 260±10.

Perhaps group IIIA. About 7.8% Ni, 0.1% P.

HISTORY

A mass of about 39 kg (85 pounds) was discovered in 1962 by Philip Johnson on his property south of Lake Manitouwabing, between the villages of Hurdville and Broadbent in the Parry Sound District (Meteoritical Bulletin, No. 26, 1963). According to Knox (1964), who described a fragment and gave some excellent photomicrographs of the shock-hatched kamacite, Johnson had done some blasting in 1950 and had placed the loosened blocks in a pile. Reexamining this pile in 1962, he discovered the black meteorite and felt that it was not part of the original pile. Considerable evidence – not yet conclusive – has been amassed by interested parties that the meteorite fell early one winter morning in 1954. Heard (1964) also discussed the problems associated with the alleged fall.

COLLECTIONS

University of Toronto (main mass), Ottawa (19 g).

MALDYAK – SELECTED CHEMICAL ANALYSES

From a brief examination of the two main pieces in Moscow, I must support the observations by Kirova (1962). Maldyak is an independent fall, constituting a shockhardened medium octahedrite, with imperfect Brezina lamellae of schreibersite. It appears to be closely related to Bartlett, Orange River, Wonyulgunna and Ilinskaya Stanitza, and is probably transitional between the resolved chemical groups IIIA and IIIB. Susuman, on the other hand, is a low-nickel, low-phosphorus member of group IIIA.

	p	ercentag	e					ppm				
Reference	Ni	Co	Р	С	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Dyakonova &	******						_					
Charitonova 1963	8.95	0.63	0.21	_			300					

798 Manitouwabing – Mantos Blancos

ANALYSES

No analytical work has been published.

DESCRIPTION

The following information has been extracted from the description by Knox (1964).

A small etched section of 1.7 g suggests that Manitouwabing is a medium octahedrite with a bandwidth of about 1 mm. Subboundaries in the kamacite occur but are somewhat obscured by a distinct shock-hatched ϵ -structure with a hardness of 260±10.

Taenite is present as discontinuous bands with broadened extremities and as a component of plessite fields. The interiors of some plessite fields have apparently resulted from a martensitic transformation.

Oriented rhabdites are common in the kamacite. Schreibersite, troilite and other meteoritic minerals were not mentioned.

The heat-affected α_2 zone is 1.5 to 3.0 mm wide. As usual when formed from shocked ϵ -structures, it is composed of small 25 μ serrated units. Its hardness is about 180 (hardness curve type I).

From the very incomplete information available, it appears that Manitouwabing is a shock-hardened medium ocathedrite of group IIIA. Some hundred kilometers farther east, another Ontario meteorite, Madoc, was found in 1854. On the basis of what has been published about Manitouwabing up to now, the two meteorites appear to be closely related.

Considering the uncertainties about the circumstances of discovery and the possible relationship to the other well-preserved Ontario meteorite, Madoc, it is unfortunate that the main mass has not yet been analyzed and described.

Manlai, Mongolia 44°20'N, 106°30'E

A mass with the approximate dimensions $95 \times 40 \times 25$ cm (300-400 kg?) was found in the Gobi Desert and, in 1954, transferred to Ulan Bator, the capital of Mongolia. According to a preliminary examination by Vorobyev & Namnandorzh (1958), Manlai is a nickel-rich ataxite or a fine octahedrite.

Mantos Blancos, Antofagasta, Chile 23°23'S, 70°5'W

Fine octahedrite, Of. Bandwidth 0.35 ± 0.05 mm. Neumann bands. HV 245±15.

Group IVA. 8.86% Ni, 0.10% P, 2.42 ppm Ga, 0.13 ppm Ge, 0.91 ppm Ir.

HISTORY

A mass of 10.3 kg was found about 1876 on the southeastern side of Mount Hicks, which is located 40 km northeast of Antofagasta. Nearby is the small railway station of Mantos Blancos. Fletcher (1889: 257), who acquired the meteorite for the British Museum in 1879, described it briefly and gave the coordinates quoted above. Brezina (1896: 270) and Cohen (1905: 366) gave short descriptions and added in their Atlas (1886-1906: plate 34) two photomacrographs. Owen & Burns (1939) determined the α -parameter to 2.8628Å by X-ray diffraction, and Owen (1940) presented a photomacrograph. Reed (1969) found 7.3% Ni and 0.11% P in the kamacite but found no rhabdites.

COLLECTIONS

London (9,012 g main mass and 92 g filings), Vienna (399 g), Washington (356 g), Chicago (72 g), Calcutta (64 g), New York (34 g), Ottawa (13 g), Vatican (8 g).

DESCRIPTION

According to Fletcher (1889) the mass is a portion of a shell, roughly triangular in outline, each side being about 21 cm long. The maximum thickness is about 6 cm. On the convex side there are numerous sharp-edged pittings, 3-5 mm in diameter, but on the concave side the depressions are larger and shallower, generally about 1-2 cm, but, locally, up to 5 cm in diameter.

The morphological differences between the two sides correspond well to what may be observed on other iron meteorites discovered in the Chilean deserts, as, e.g., Maria Elena, Iquique, Filomena, Juncal and Ilimaes. It appears that the sharply pitted surface was for a long time resting upwards on the desert floor and exposed to corrosion, while the underside, in this case, became partly covered by caliche and only corroded slowly. On Mantos Blancos the fusion crust and the heat-affected α_2 zone are removed on the pitted side, but on the opposite side with the regmaglypts a 0.5 mm thick fusion crust may be found locally, while the α_2 zone varies between 1 and 2 mm in thickness. The fusion crust consists of an exterior layer of oxides, and an interior $20-120 \mu$ thick, dendritic, metallic layer, composed of numerous, more or less discordant laminae (HV 360±20). Below this is the α_2 zone in which micromelted phosphide blebs and zigzagging fine fissures may be found in the outer 50%. The hardness of the

MANTOS BLANCO	DS – SELECTED	CHEMICAL ANALYSES	

	. p	ercentag	e					ppm				
References	Ni	Co	P	С	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Fletcher 1889 Schaudy et al. 1972	8.83 8.88	0.55	0.10						2.42	0.133	0.91	

The cobalt determination appears to be too high; 0.40% would be more acceptable.

 α_2 zone is 215±10 (hardness curve type I). Part of the surface has unfortunately been molested by hammering and chiseling, whereby the fusion crust has spalled off and the Widmanstätten lamellae have become distorted.

Etched sections display a fine Widmanstätten structure of straight, long ($\frac{L}{W} \sim 50$) kamacite lamellae with a width of 0.35±0.05 mm. The kamacite shows Neumann bands and subboundaries, some of which are decorated with 0.5 μ phosphides. The hardness of the kamacite is 245±15.

Plessite covers about 50% by area, mostly as comb, net and cellular plessite, but further as duplex $\alpha + \gamma$ fields, which may be easily resolvable with a 40x objective and, therefore, light-etching (HV 245±15), or poorly resolvable and, therefore, deep-etching and giving rise to the term black taenite (HV 280±30). The light-etching martensitic parts of the taenite ribbons have hardnesses of 365±15. while the brown-etching martensite decreases to 335±15. The undecomposed taenite ribbons have hardnesses of 250±15. The cellular plessite is particularly well developed and is evidently closely related to the duplex fields, since many transitions may be observed. The typical cellular plessite is several square millimeters in area and subdivided in 50-200 μ lobed kamacite grains in which oriented taenite bars, plates and spindles are rhythmically deposited; compare Chinautla and other IVA meteorites.

Schreibersite is present as $10-20 \mu$ wide grain boundary precipitates, that attain lengths of $50-200 \mu$. Further as $5-25 \mu$ irregular, vermicular bodies inside the more openmeshed plessite fields. No large schreibersite crystals are present, in harmony with the analytical value of 0.10% P.

Troilite is present as 0.5-4 mm angular inclusions, of which at least the smaller are shock melted and now composed of 5 μ anisotropic grains. The narrow, enclosed daubreelite lamellae are distorted but not melted. Locally, in the α -phase are 10-50 μ bluish, angular grains that appear to be two-phase mixtures of an isotropic (daubreelite) and a weakly anisotropic mineral (brezinaite ?). In the corroded crust are several microscopic, emerald green crystals of an unidentified mineral, produced by weathering. Or, perhaps the meteorite for a while reposed in a pile together with copper mineral specimens, such as atacamite and malachite?

Mantos Blancos is a typical fine octahedrite of group IVA. It is closely related to Bushman Land and Duchesne.

Specimen in the U.S. National Museum in Washington: 356 g endpiece (no. 732, 7.5 x 2.5 x 3.5 cm)

Mapleton, Iowa, U.S.A.	
42°10′47″N, 95°43′18″W; 400 m	

Medium octahedrite, Om. Bandwidth 1.00 ± 0.15 mm. ϵ -structure. HV 315±15.

Group IIIA. 7.73% Ni, about 0.15% P, 20.3 ppm Ga, 40.6 ppm Ge, 1.4 ppm Ir.

HISTORY

A mass of 49 kg (108 pounds) was found in 1939 by Harvey Meevers, while he was cultivating corn on the east slope of a rather steep hill on his prairie farm, 5 km east-northeast of Mapleton, in Monona County. He removed the iron from the field and probably would have forgotten it if he had not accidentally read F. B. Coulton's "News of the Universe" in the National Geographic Magazine (Volume 76, No. 1, 1939), which appeared a few days later. He sent a small sample to the Field Museum who confirmed the meteoritic nature and immediately purchased the whole mass. The history was reported by Wilson (1944), and the mass was fully described, with numerous photographs, by Roy & Wyant (1949a). A brief notice had appeared already in 1939 (S. K. Roy, Field Museum News, Volume 10, No. 9: 4). Some publications and some labels state that the meteorite fell June 17, 1939, but this is certainly not the case as clearly seen from the corrosion discussed below.

COLLECTIONS

Chicago (21.3 kg endpiece, 15.1 kg endpiece and 3,450 g slices), Washington (3,728 g), London (15 g), Tempe (10 g).

DESCRIPTION

According to Roy & Wyant (1949a) the maximum dimensions of the irregular, flattened cone are about 42 x 22 x 15 cm. It is covered by regmaglypts, 2.5-4 cm in diameter and appears to have penetrated the atmosphere in an oriented, stabilized way. The warty and striated magnetite fusion crust is preserved over several square centimeters, but it is corroded and somewhat difficult to recognize. On sections it is seen that the heat-affected rim zone is absent on one side but increases to about 2 mm width on the side where the fusion crust is preserved. It appears to be mainly a result of differential, terrestrial weathering. Corrosion has created 0.1-1 mm thick, laminated oxides on one side, and it has penetrated along the octahedral grain boundaries, particularly along those which already were fissured and partly filled with brecciated troilite; see below. Etched specimens continue to corrode somewhat along the grain boundaries under normal room conditions, probably because circulating ground water has transported significant amounts of chloride into the meteorite.

Etched sections display a medium Widmanstätten structure of straight, long ($\frac{U}{W} \sim 40$) kamacite lamellae with a width of 1.00±0.15 mm. The "anomalous," 3 mm wide ribbons of kamacite, reported by Roy & Wyant (1949a),

MAPLETON -	SELECTED	CHEMICAL	ANALYSES

	p					ppm						
Reference	Ni	Со	P	C	S	Cr	Cu-	Zn	Ga	Ge	Ir	Pt
Scott et al. 1973	7.73								20.3	40.6	1.4	

are nothing else than the fourth set of Widmanstätten lamellae, which happens to be cut almost across their greatest "height." As usual, the height-width ratio for the lamellae is about 3:1. The kamacite has subboundaries, decorated with rhabdites, about 1 μ in cross section. Due to shock the kamacite is converted to a densely hatched, martensitic appearing ϵ -structure, which is present in various shades in all kamacitic areas. The structure is unannealed and has a hardness of 315±15. Taenite and plessite cover about 40% by area. The comb and net plessite are open-meshed structures in which the interior grain boundaries are conspicuous, but little taenite is present. The framing taenite is discontinuous. Some wedges have acicular interiors that are a densely spaced precipitate of 1-3 μ wide kamacite platelets. A typical plessite field will have a yellow-tarnished taenite rim (HV 370±25) followed by an acicular, martensitic transition zone (HV 460±20). Then follow "tempered" martensites (HV 390±30) and finally duplex $\alpha + \gamma$ mixtures, with hardnesses approaching that of the adjacent kamacite lamellae.

Schreibersite is absent as larger bodies but common as 5.25μ wide grain boundary precipitates and as 2.10μ bodies inside the plessite, substituting for taenite of the same general shape and size. It is monocrystalline but frequently shattered and somewhat sheared. Rhabdites occur abundantly as 1.2μ thick, sharp prisms. The bulk phosphorus content is estimated to be $0.15\pm0.02\%$.

Troilite is not very common but occurs as 1-10 mm angular nodules. They contain about 10% daubreelite in the form of parallel bars. At least the smaller nodules are brecciated and subdivided in 25-100 μ units, and from them radiate 20-100 μ wide veinlets which are filled with a breccia of which troilite was once an important component. The fissures follow the octahedral planes for many centimeters outward from the troilite crystals. It appears that the fissures were partially filled with minute debris from the shattered troilite nodules and that the fissures provided easy access for terrestrial solutions once the meteorite landed. The fissures are now composed of angular troilite fragments, veined with pentlandite, and cemented together by "limonite."

Daubreelite occurs as scattered grains in the kamacite, generally 20-50 μ across. Some of them are subdivided in a stack of parallel, densely spaced, alternating troilite and daubreelite lamellae.

Mapleton is a shock-hardened medium octahedrite which is related to Billings, Dexter and Frankfort. Chemically, it is a typical group IIIA iron.

Specimens in the U.S. National Museum in Washington: 2,153 g slice (no. 1478, 23 x 14 x 0.9 cm)

1,575 g slice (no. 1478, 23 x 15 x 0.8 cm)

Maria Elena, Antofagasta, Chile 22°18'S, 69°40'W Fine octahedrite, Of. Bandwidth 0.30 ± 0.05 mm. Recrystallized, duplex $\alpha + \gamma$ structure. HV 172±8.

Group IVA. 7.72% Ni, 0.40% Co, 0.02% P, 1.75 ppm Ga, 0.096 ppm Ge, 3.1 ppm Ir.

HISTORY

A mass of 15.5 kg was discovered before 1935 in the Chilean desert near Maria Elena, in the province of Antofagasta. It went through several hands before 1935 when it was donated to the U.S. National Museum where it was described with a photograph of the exterior and of an



Figure 1100. Maria Elena (U.S.N.M. no. 1221). The 15.5 kg main mass with its characteristic densely spaced corrosion pits. A central drill hole. Scale bar approximately 3 cm. S.I. neg. 32479H.



Figure 1101. Maria Elena. The main mass from the opposite side, presumably the side which was below the level of the soil and covered by it. It shows normal, only slightly weathered regmaglypts which are partly encrusted with caliche. Scale bar approximately 3 cm. S.I. neg. 32479K.

etched slice by Meen (1938). A corrected analysis was given by Meen later (1941). Since the exact locality of find is unknown, the coordinates above are those of the town Maria Elena. Jaeger & Lipschutz (1967b) found that Maria Elena was recrystallized. Hintenberger et al. (1967) determined the amount of occluded noble gases, while Voshage (1967) by his $\rm ^{40}K/^{41}K$ method found a cosmic ray exposure age of 745±50 million years.

COLLECTIONS

Washington (11.80 kg), Ann Arbor (531 g), New York (327 g), Tempe (no. 388.1 of 235 g and no. 392.1 of 70 g), London (40 g). An endpiece of about 1 kg is in the possession of the donor, Mr. Coope, Antofagasta.

DESCRIPTION

The mass originally had the average dimensions of 23 x 18 x 11 cm, but now, after it has been cut at both ends, it measures 19 x 15 x 11 cm and weighs 10.5 kg. It is roughly in the shape of a flat lens with a very pronounced difference between the two major sides. The concave topside, which has been exposed above the desert floor, displays the well known Chile corrosion, developed as a rather regular polygonal grid of 3-4 mm wide and 1 mm deep cavities. The opposite side shows irregular, shallow pits, mostly 10-25 mm in diameter. One of the pits is, however, a large bowl-shaped cavity, 6 x 8 cm in size and 4 cm deep. Oxide-shales, 1-2 mm thick, line the interior of this cavity, while most of the surface is free of thick oxide crusts. A little weathered fusion crust may, in fact, be seen over a few square centimeters on the underside. Part of the underside is covered with brownish-yellow caliche deposits; perhaps the fusion crust is well-preserved under the caliche. While the heat-affected α_2 zone is removed on the pockmarked topside, corrosion has only attacked the 1-2.5 mm thick α_2 zone locally on the underside. It appears that Maria Elena has lost about 5-10 mm of the present topside, while almost all the original atmospheric sculpture is preserved on the underside.

Etched sections display a fine Widmanstätten structure of long ($\frac{L}{W} \sim 30$) kamacite lamellae with a width of 0.30±0.05 mm. Plessite covers about 40% by area, but the fields are somewhat difficult to recognize because their

interior resembles the kamacite lamellae and because the taenite rims are completely altered.

The kamacite is partly recrystallized to 50-300 μ units with scalloped edges. Recrystallization is particularly well developed around the troilite nodules. The former Neumann bands are either pinned along both edges by numerous, tiny, rounded platelets, typically $10 \ge 2 \ge 1 \mu$ in size, or they have completely disappeared. Everywhere in the kamacite are fine, orientated precipitates of the same general size (0.5-2 μ thick) and shape as upon the Neumann bands, in a concentration which is unknown in most meteorites. The morphology, hardness and general appearance of the precipitates indicate unambiguously that they are small taenite grains, somewhat better developed than in Jamestown, and almost similar to the taenite of the duplex matrix of Cratheus (1931). The hardness of the recrystallized kamacite is 172±8. It decreases in the recovered transition zone to 140±5 and again increases to 185±10 in the heat-altered rim zone (hardness curve type II).

The taenite frames of the plessite fields are decomposed to scalloped, duplex structures, similar to that found in, e.g., Hammond. It appears that the duplex zone is somewhat cavernous. The microhardness testing reveals hardnesses ranging from 172 to 55, with an average of 150 ± 15 . The hardness values below 100 can hardly be explained if microporosities are not assumed to be present;



Figure 1102. Maria Elena (Tempe no. 388.1; 235 g slice). Previously erroneously labeled "Chile" (Nininger & Nininger 1950: 44) and "Dehesa" (Hey 1966: 131). Fine octahedrite of group IVA with shock-melted troilite nodules (black). Deep-etched. Scale in centimeters. (Courtesy C.B. Moore.)

	р	ercentage	e					ppm				
References	Ni	Co	Р	С	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Goldberg et al. 1951	7.76	0.53							1.76			
Lovering et al. 1957		0.40				392	140		< 2	< 1		
Wasson & Kimberlin												
1967	7.75								1.73	0.096	3.1	
Moore & Lewis 1968*	7.66	0.40	0.02	100	210		150					

MARIA ELENA - SELECTED CHEMICAL ANALYSES

*On an unknown specimen, "Chile" no. 388.1, in Tempe, at that time not yet identified as Maria Elena.

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and also the polished and etched sections suggest numerous microporosities.

Phosphides were not observed, and are probably not present at all, in harmony with the chemical analysis (0.02%). Daubreelite is common as 10-100 μ angular blebs in the α -lamellae.

Troilite is present as 0.5-3 mm rhombic or lenticular bars which occur with a frequency of about one per 6 cm². The troilite has been micromelted and has dissolved part of the surrounding matrix. Daubreelite appears to have composed 20-30% of the nodules originally, but they are now completely disintegrated and dispersed as angular fragments, 5-20 μ in size, in the eutectic, fine-grained sulfidemetal mixture. From many of the nodules, 5-50 μ wide veinlets of sulfide-metal melts have been injected 1-40 mm out into the metallic matrix, particularly along the octahedral planes. The hardness of the complex troilite eutectics is



Figure 1103. Maria Elena (U.S.N.M. no. 1221). The meteorite is cosmically altered to a degree rarely seen in group IVA. Etched. Scale bar 200 μ . See also Figure 115.



Figure 1104. Maria Elena (U.S.N.M. no. 1221). On the left a former finger-plessite field (similar to the rectangular field in Figure 1103), on the right a kamacite lamella. All taenite lamellae are thoroughly spheroidized, and fine taenite particles have been precipitated in the kamacite lamella. Etched. Scale bar 40 μ .

195±10. The troilite morphology can hardly be understood, unless we imply that the meteorite at one time, after the formation of the Widmanstätten structure, was subjected to a heavy shock, which point melted the troilite and fissured the metal somewhat. It is, however, not entirely clear whether the associated relaxation heat would be sufficient to decompose the taenite to the extent observed, or whether we will have to accept a later, independent annealing period of somewhat greater duration. The maximum temperature of the metal phase appears to have been about 700° C but of the troilite about 1000° C.

Maria Elena is a fine octahedrite – not medium as believed by Meen (1938; 1941) and Hey (1966) – which has a primary structure similar to that of Gibeon. Cosmic shocks and annealing events have created secondary, duplex structures which appear to be related to those of Cratheus (1931) and Jamestown. Chemically, it is a typical group IVA iron.



Figure 1105. Maria Elena (U.S.N.M. no. 1221). Above, a Neumann band which is decomposed into cells and decorated with γ -particles. Below, a plessite field the rim of which is entirely spheroidized. Compare Figure 131. Etched. Scale bar 40 μ .



Figure 1106. Maria Elena (U.S.N.M. no. 1221). To the left, a kamacite lamella with decomposed and decorated Neumann bands. To the right, an open-meshed plessite field with a spheroidized taenite rim. Etched. Scale bar 40 μ . See also Figure 131.



Figure 1107. Maria Elena (U.S.N.M. no. 1221). A triangular plessite field which is entirely decomposed. Upon grinding, polishing and etching, small fragments of the components are often torn out, leaving irregular pits (black). Etched. Scale bar 40 μ .

Specimens in the U.S. National Museum in Washington:

- 10.56 kg main mass (no. 1221, 19 x 15 x 11 cm)
- 771 g slice (no. 1221, 18 x 8 x 0.8 cm)
- 446 g slice (no. 1221, 16 x 6 x 0.6 cm)
- 45 g smaller sections (no. 1221)

Mariaville, Nebraska, U.S.A.

Approximately 42°43'N, 99°23'W

A mass of 340 grams is said to have fallen on October 16, 1898, after appearance of light and detonations (Barbour 1903; Hey 1966: 291). Since the repository of the material was unknown at the time of this study, it was neither possible to examine the meteorite nor to verify that it really was an observed fall on the postulated date.

Marshall County, Kentucky, U.S.A. Approximately 36°51'N, 88°21'W

Medium octahedrite, Om. Bandwidth 1.20 ± 0.25 mm. α_2 structure. HV 195±15.

Group IIIA. Probably about 8.5% Ni, 0.3% P.

Although not reported by the original owner, this iron has been reheated artificially to between 900° and 1000° C.

HISTORY

Little is known of this meteorite which was first reported by Smith (1860). He received a fragment of a mass, found in Marshall County and estimated to weigh 15 pounds (6.8 kg), and he analyzed it. Brief comments were given by Brezina (1885: 214), Klein (1906: 116) and others. Berwerth (1905: 353; 1914: 1080) noted that the kamacite structure indicated artificial reheating, a conclusion which was supported by the observations of Buchwald (1966: 33) who gave a photomacrograph of the distorted structure.

It appears that J.L. Smith acquired the whole mass shortly after his brief description had been published. Many specimens were cut, and his catalog number "16" was chiseled into the slices, whereupon they were exchanged from 1862 onwards. Smith conducted a considerable exchange business, as may be seen from his little pamphlet of eight pages, published privately in 1876, "Catalogue of Meteorites in the Collection of J. Lawrence Smith, Louisville, Kentucky, January 1, 1876." In this he listed 204 different iron and stone meteorites, of which many were specifically listed as available on an exchange basis. Marshall County was at that time still offered as 50 g slices or smaller. Somehow Shepard had, at an early time, acquired an almost 3 kg endpiece, part of which was later deposited in the Amherst Collection. Summation of the slices known today yields 3.5 kg; see below. The individual sizes of the slices and the total weight preserved make it plausible that the original weight of Marshall County was close to the 6.8 kg originally estimated. The coordinates given above are those of Benton, the county seat.

COLLECTIONS

Amherst (1,963 g endpiece), London (276 g), Tempe (205 g), Paris (172 g), Göttingen (142 g), Copenhagen (135 g), Harvard (127 g), Vienna (73 g), Berlin (73 g), Washington (66 g), Hamburg (50 g), Tübingen (45 g), Leningrad (44 g), New York (19 g), Vatican (17 g), Chicago (17 g).

DESCRIPTION

The approximate dimensions of the original mass may have been $20 \times 10 \times 8$ cm, estimating from the known slices. It is considerably corroded; terrestrial oxides are found along the octahedral grain boundaries and along the larger phosphide inclusions to several centimeters depth. All



Figure 1108. Marshall County (Copenhagen no. 1863, 755). Comb plessite field with associated schreibersite crystals. The kamacite is converted to unequilibrated α_2 due to artificial reheating. Etched. Scale bar 500 μ .

specimens examined by the author, but seen most clearly on the Amherst endpiece, display heavy hammer and chisel marks; and sections normal to the surface show how the near-surface kamacite lamellae have been bent and distorted by the hammering. It is no longer possible to determine whether a fusion crust and a heat-affected zone were present when found, since the structure is significantly altered artificially.

Etched sections display a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 20$) kamacite lamellae with a width of 1.20±0.25 mm. The kamacite subboundaries are decorated with rhabdites, about 1 μ in thickness. Taenite and plessite cover 25-30% by area. The plessite is of the comb and the net variety, but unresolvable, duplex $\alpha + \gamma$ fields do also occur.

Schreibersite is common. Large skeleton crystals and plates, e.g., $20 \times 5 \times 0.4$ mm in size, are enveloped in 1.0-2.0 mm wide rims of swathing kamacite. Smaller schreibersite bodies, 0.2-0.5 mm wide, occur centrally in some of the Widmanstätten lamellae. Finally, schreibersite is ubiquitous as $10-50 \mu$ wide grain boundary precipitates, and as irregular 10-50 μ bodies inside the plessite fields. The bulk phosphorus content is estimated to be about 0.3%.

Troilite was not observed on any of the sections examined. A few holes, shaped like troilite, may indicate that it was present before it sweated out and reacted with the atmosphere upon the artificial reheating.

The structures mentioned above are altered by artificial reheating to between 900° and 1000° C. All sections show



Figure 1109. Marshall County (Copenhagen no. 1863, 755). Nearsurface section showing distorted structure due to forging. The kamacite is converted to α_2 ; several fissures are opened along schreibersite-filled grain boundaries. Etched. Scale bar 500 μ .

a granulated serrated α_2 structure, indicative of air-cooling from above 800° C, and all sections show diffuse taenite with thorns protruding into the matrix. The altered kamacite has a hardness of 195±15 but scatters widely because the reheating led to unequilibrated structures with considerable compositional gradients. Some sections (Copenhagen no. 1863.755 and U.S.N.M. no. 1076) contain partially melted phosphides which suggests that the temperature briefly was 1000° C. Other specimens (e.g., Harvard no. 253c) have unmelted phosphides, enveloped, however, in 2-5 μ wide, creamcolored reaction zones, indicating that the temperature was about 900° C. It appears, then, that the mass was only heated briefly and was not thermally equilibrated before it was air-cooled again.

Along the surface and in the corroded fissures are high temperature oxidation products and a beginning intercrystalline oxidation attack, revealing an austenitic grain size of $20-50 \mu$. Fine laceworks of oxides and sulfur-oxygen-iron eutectics are found locally. Some specimens are hammered and have consequently fractured along the octahedral planes which were weakly coherent because of the presence of oxidation products and (micromelted) phosphides.

As far as the preserved structure permits observations, Marshall County originally resembled Bartlett, Lenarto and Spearman. Chemically, it is probably intermediate between group IIIA and IIIB.



Figure 1110. Marshall County (Harvard no. 253). Two schreibersite crystals enveloped in terrestrial limonite. Artificial reheating above 800° C decomposed the limonite and formed lace-like interfaces with kamacite. Polished. Scale bar $50 \,\mu$.

MARSHALL COUNTY - SELECTED CHEMICAL ANALYSES

None of the analyses correspond with the author's opinion of authentic Marshall County material. I would estimate the meteorite to contain $8.5\pm0.3\%$ Ni and

0.30±0.05% P, and to be intermediate between group IIIA and IIIB. Could Smith's and Shepard's material possibly come from two different meteorites?

	р	ercentag	e					ppm				
References	Ni	Co	Р	С	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Smith 1860	8.72	0.32	0.10				trace					
Scott et al. 1973	7.92								21.1	44.3	2.6	

Specimens in the U.S. National Museum in Washington:

12 g chiseled fragments (no. 1076, 1-2 cm across, Shepard Collection no. 62)

54 g part slice (no. 2555, 5 x 4.5 x 0.4 cm)

Mart, Texas, U.S.A.	
31°32'N, 96°50'W; 150 m	

Fine octahedrite, Of. Bandwidth 0.38±0.05 mm. Partly recrystallized. HV 190±10.

Group IVA. 9.23% Ni, 0.41% Co, 0.15% P, 2.16 ppm Ga, 0.14 ppm Ge, 0.64 ppm Ir.

HISTORY

A mass of 7.1 kg was plowed up in 1895 on the farm of H.T. Vaughan south of Mart, in Mc Clellan County. It lay about 20 cm below the surface when the plow scraped against it. It was, in 1899, sent to the U.S. National Museum, where an endpiece was cut and described with two photographs by Merrill (1900). H.A. Ward further cut about 2 kg, but the rest was returned to Baylor University, Waco, Texas (Charlton 1900; Barnes 1939a: 597). Cohen (1905: 270) was, like Merrill (1900; 1916a), of the opinion that Mart resembled Carlton so much that the two might be paired falls. Brezina & Cohen (1886-1906: plate 35) gave two photomacrographs, and Nininger & Nininger (1950: plate 4) gave a photomacrograph of the specimen now in Tempe. Hey (1966: 294) and others erroneously listed Mart as a finest octahedrite which is impossible under any classification system.

COLLECTIONS

Baylor University, Waco, Texas (3.74 kg), Chicago (1.13 kg endpiece), Tempe (472 g), Washington (453 g), London (415 g), New York (202 g), Vienna (23 g).

DESCRIPTION

According to Merrill (1900) the mass was of an irregular oval shape. The model preserved in the U.S. National Museum shows the overall dimensions to be 21 x 14 x 7 cm, which are in good agreement with the reported weight of 7.1 kg. The mass is corroded, with 0.5-1 mm thick terrestrial oxide crusts, and on sections no indications of fusion crust could be found. Selective corrosion has converted the α -phase of the plessite fields to limonitic products and penetrated along the microcell boundaries of the α -phase. No distinct α_2 zone is present; however, the

hardness of the interior (190) drops to about 160 a few millimeters below the surface and then increases again to 195 ± 5 in the immediate surface, suggesting that both the soft recovered zone and a trifle of the heat-affected α_2 zone are present. The mass is estimated to have lost 2 mm on the average by terrestrial weathering.

Etched sections display a fine Widmanstätten structure of straight, long ($\frac{L}{W} \sim 40$) kamacite lamellae with a width of 0.38±0.05 mm. At low magnification the kamacite appears to be loaded with Neumann bands, and there is a strong, oriented sheen. At high magnification (40x objective) the Neumann bands are seen to have "recrystallized," being decomposed to 1-5 μ microcells, aligned along the former bands and decorated along both sides with 0.5-1 μ taenite grains. Also the α -matrix itself is decomposed to an irregular network of microcells, 1-10 μ in diameter, in which are dispersed numerous 0.3-2 μ taenite grains. The structure appears to represent a complex stage of recrystallization, probably following a shock event. The hardness is 190±10, except in the recrystallized, nickel-depleted zones around schreibersite (HV 175±5).

Plessite covers about 50% by area. The various types of comb, net and martensitic plessite have evidently previously been present but are almost unrecognizable now, since the annealing has produced rather homogeneously spheroidized mixtures of 0.3-3 μ taenite grains in microcellular kamacite. The difference between the inside and the outside of the plessite fields are, indeed, not great. It is unusual to find all duplex $\alpha + \gamma$ fields so easily resolvable as in Mart. Locally, the annealing has led to almost pearlitic structures of the plessite with long, winding 0.5-1 μ thick taenite lamellae. A



Figure 1111. Mart (Tempe no. 82a). A fine octahedrite of group IVA, sprinkled with shock-melted troilite nodules (black). The kamacite is annealed and rich in fine exsolved taenite particles. Deep-etched. Scale in centimeters. (Courtesy C.B. Moore.)

MART – SELECTED CHEMICAL ANALYSES

	р	ercentage	e					ppm				
References	Ni	Co	Р	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Stokes in Merrill												
1900	9.20	0.33	0.16		170	tr.	370					
Moore et al. 1969	9.29	0.41	0.13	295	150		135					
Schaudy et al. 1972	9.20								2.16	0.136	0.64	

typical plessite field will exhibit a yellow taenite rim (HV 220±10) followed by a duplex $\alpha + \gamma$ zone, rich in taenite (HV 220±10). Then follows easily resolvable $\alpha + \gamma$ mixtures (HV 205±10) and finally an open-meshed interior of the same hardness as the adjacent kamacite lamellae.

Schreibersite is common as 10-40 μ wide grain boundary precipitates, and further as 1-40 μ rounded grains inside the plessite fields. The coarser the plessite, the coarser the co-precipitated phosphides. The larger schreibersite grains are sheared and brecciated, and the immediate surroundings are invariably recrystallized to 25-100 μ ferrite grains.

Troilite is common as 0.5-1 mm spherical nodules that, in several cases, are associated with 0.1-0.4 mm chromite grains. The troilite occurs with a frequency of about one nodule per 4 cm²; they have (or had) a discontinuous rim of schreibersite. The troilite has been shock melted and has dissolved part of the surrounding metal. The chromite and schreibersite crystals have been badly shattered and more or less dispersed as angular 5-100 μ fragments in the melt that solidified to a metal-sulfide eutectic of 1μ grains. Numerous fissures were opened by the shock, particularly along the octahedral planes in which the schreibersite veinlets were precipitated. The melts were injected several millimeters or even centimeters away from the original troilite nodules. It is interesting to note that recrystallization has taken place on both sides of the fissures, giving rise to a zone, one or two grains wide, of 25-100 μ ferrite grains. Presumably the latent heat of the injected melt contributed in starting recrystallization in the nickel- and phosphorusdepleted kamacite along the fissures. Unfortunately, terrestrial corrosion has particularly attacked the fissure zones and to some extent blurred the original conditions.

Daubreelite was not observed, but chromite is not uncommon as cubic crystals that are 0.1-0.4 mm in size and mostly shattered somewhat by the same shock wave that created the sulfide melts. Cohenite was reported by Brezina & Cohen (1886-1906), but this could not be confirmed and appears unlikely.

Mart is a fine octahedrite, unrelated to Carlton, but closely related to Chinautla, Mantos Blancos and other phosphide-containing octahedrites of group IVA. In its detailed structure it is different however, probably due to a shock event that melted the troilite and annealed the metallic matrix thoroughly.

Specimen in the U.S. National Museum in Washington: 451 g endpiece (no. 221, 11 x 6 x 1.5 cm)

Mayerthorpe, Alberta, Canada
53°47'N, 115°2'W

Coarse octahedrite, Og. Bandwidth 2.0±0.4 mm.

Group I. 7.19% Ni, 75.5 ppm Ga, 283 ppm Ge, 2.4 ppm Ir.

HISTORY

A mass of 8.74 kg was found in September 1964 by M. Dmitroca while he was cultivating a field 16 km southsoutheast of the town of Mayerthorpe, west of Edmonton. Two earlier finds of iron meteorites in the neighboring fields have unfortunately been lost (Folinsbee, in Meteoritical Bulletin, No. 32, 1964). A second individual of 3.87 kg was found – or recovered – later in 1964 (Folinesbee, in Meteoritical Bulletin, No. 33, 1965). Evidently Mayerthorpe was a shower of which at least three samples have been found, and two have been preserved.

COLLECTIONS

University of Alberta, Edmonton (8.7 kg mass No. 1), Ottawa (3.6 kg mass No. 2, 142 g slices; Douglas 1971).

DESCRIPTION

A small deep-etched specimen was briefly examined with a hand lens. It appears that Mayerthorpe is an inclusion-rich coarse octahedrite with a bandwidth of 2.0 ± 0.4 mm. Taenite and plessite occupy 3-5% by area and take the forms so typical of the resolved chemical group I. In its structural characteristics Mayerthorpe is closely related to Canyon Diablo. It is unrelated to Alberta's other iron meteorites, Edmonton and Iron Creek.

> Mayodan, North Carolina, U.S.A. 36°25'N, 79°54'W; 210 m

Hexahedrite, H. Shocked and partly recrystallized. Neumann bands. $HV 143\pm7$.

Group IIA. 5.60% Ni, 0.46% Co, 0.25% P, 59.3 ppm Ga, 180 ppm Ge, 14 ppm Ir.

Mayodan may be a fragment of Indian Valley.

HISTORY

A mass of 15.4 kg (34 pounds) was found by a Mr. Beaver in 1920 while he was improving a dirt road in Rockingham County, 7 km east-northeast of Mayodan. The coordinates and altitude of the find, as verified on a modern map, are given above. The meteorite was in private possession until 1950 when James E. Beaver, the son of the discoverer reported it to the U.S. National Museum. It was purchased by S.H. Perry who donated it to the Museum, where a few slices were cut. Henderson & Perry (1953) published a full description of the circumstances of find and of the metallographic structure, accompanied by an

MAYERTHORPE – SELECTED CHEMICAL ANALYSES												
	pe	ercentage	e					ppm				
Reference	Ni	Со	Р	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Wasson 1970a	7.19				_				75.5	283	2.4	

analysis and nine photomicrographs. Bauer (1963) measured the 3 He/ 4 He concentrations and discussed the unusually low ratio of 0.09. Hintenberger et al. (1967) confirmed this ratio and concluded that it was caused by tritium loss while the small mass circled in cosmos. Chang & Wänke (1969) measured the 36 Ar/ 10 Be concentrations and estimated a cosmic radiation age of 40±20 million years. They also estimated the terrestrial age to be above 1,200,000 years, because the 36 Cl and 10 Be activities were found to be very small. Buchwald (1971d) discussed the helium and tritium contents and showed that the low 3 He/ 4 He ratio was associated with a cosmically annealed structure.

COLLECTIONS

Washington (13.2 kg), Tempe (559 g), Madrid (267 g), Moscow (210 g), Rio de Janeiro (197 g).

DESCRIPTION

The mass is roughly hemispherical with the overall dimensions of $17 \times 16 \times 12$ cm. Very conspicuous is the 17×16 cm almost plane surface that terminates against the rather smoothly rounded remainder of the meteorite. At an early date the discoverer chiseled a few small fragments,



Figure 1112. Mayoden (U.S.N.M. no. 1,487). A 1,541 g slice cut parallel to $(100)_{\alpha}$. Cleavage cracks that follow the two other $(100)_{\alpha}$ planes are distinctly visible. Shock-melted troilite inclusions are black. Recrystallized kamacite grains occur as scattered white or gray islands. Deep-etched. Scale bar 20 mm. S.I. neg. M-1479.

totaling some hundred grams, from the edge of the mass. The resulting cleavage plane clearly shows that the large, plane surface is itself a cubic cleavage plane which is only little modified by atmospheric ablation and terrestrial weathering. It is thus almost certain that another large fragment fell simultaneously with this mass.

The rounded surfaces have shallow regmaglypts 2-3 cm in diameter, but they are modified by corrosion. One large bowl-shaped depression, 12×11 cm in aperture and 2.5 cm deep, is clearly a result of atmospheric ablation, since the heat-affected rim zone was found to be present under it.

In some places the meteorite is covered by 1-2 mm thick limonitic products, and loose scales continue to spall off slowly in the collection. Lawrencite is, however, not present. On sections it is observed that corrosion penetrates along rhabdite inclusions and Neumann bands (which are decorated by small rhabdites) and also selectively dissolves the finely dispersed grains of the shocked troilite nodules. Corrosion further attacks along some cubic cleavage fissures that probably were created during the atmospheric breakup. From the exterior morphology and from the presence of the heat-affected zone it is estimated that on the average only 1-2 mm iron has been removed by weathering. How this result can be reconciled with a terrestrial age of 1.2 million years as determined by Chang & Wänke (1969) is difficult to understand.

Etched sections display a hexahedrite structure with a single ferrite crystal larger than 16 cm, consistent with the large cubic cleavage fracture. Neumann bands cross the



Figure 1113. Mayodan (U.S.N.M. no. 1487). Hexahedrite with annealed bands and recrystallized kamacite grains. Deep-etched. Dark field illumination. Scale bar 4 mm. (Henderson & Perry 1953.)

	n	ercentag	P					ppm				
References	Ni	Co	P	С	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Henderson & Perry	- 1 N											1
1953	5.63	0.49	0.17	30	30							
Wasson 1969	5.54								59.3	180	14	
Lewis & Moore 1971	5.64	0.43	0.25	60								

MAYODAN – SELECTED CHEMICAL ANALYSES

The P analysis by Moore best represents the bulk P content. The older value was obtained on material free of visible inclusions.

entire surface, but they are degenerated somewhat, decomposed to cellular networks, decorated with $1-2 \mu$ rhabdites, and broken into shorter units. The microhardness of the kamacite is 143 ± 7 . Recrystallization has begun from a number of nuclei, particularly from Neumann band intersections and from fissured rhabdite crystals. The resulting new ferrite grains range in size from about 50 μ to 1.5 mm and cover about 2% by area. The hardness is unusually low and suggests a quite significant cosmic annealing, probably of late date.

Rhabdites occur as plate-shaped crystals, typically 5 x 2 x 0.04 mm in size, arranged in parallel planes with a mutual distance of 5-20 mm. The planes coincide as usual with one of the prominent Neumann band directions, but in Mayodan it is seen that in addition another set of Neumann bands has large rhabdite precipitates, so that two different sets of planes of the type {211} have been favored with platy precipitates. The matrix in between has a large number of rod-shaped rhabdites, typically 5-10 μ across and hundreds of microns long. Henderson & Perry (1953) found the platy rhabdites to average 25.1% Ni, while the needles averaged 33.6% Ni. They commented that many of the rhabdites, found in the residue when dissolving the meteorite for analysis, had holes. At least some of these holes were now observed to be due to troilite, daubreelite, kamacite and graphite. In several cases the rhabdites have nucleated upon a 10-50 μ troilite or daubreelite crystal and during growth enveloped the nucleus. In one case a $15 \,\mu$ daubreelite crystal had nucleated two independently oriented phosphide crystals, which later coalesced around the nucleus, as clearly indicated by the anisotropic behavior of the phosphides under crossed Nicols.

Graphite occurs as inconspicuous $10-30 \mu$ wide bodies, associated with some of the rhabdites. The plumes are $100-200 \mu$ long and subdivided in 1μ grains. Henderson & Perry (1953) reported graphite as an undissolvable residue,



Figure 1114. Mayodan (U.S.N.M. no. 1487). Plate-shaped rhabdites in a kamacite with Neumann bands. The four sets are two and two mutually perpendicular. A fact which supports the conclusion that the examined section is parallel to $(100)_{\alpha}$. Etched. Scale bar 400 μ . (Henderson & Perry 1953.)

but they believed that it was associated with and responsible for the particular troilite nodules in Mayodan, which it is not.

Troilite occurs as 1-15 mm irregular nodules and lenses. which all have been severely altered by shock. The original daubreelite bars and the previously existing schreibersite rims have been shattered and partly melted and dispersed in the troilite melt, which even found time to dissolve some of the parent metal, bordering the cavity, Rapid solidification created fringed borders against the metal and a 1μ sulfide-iron eutectic in which 5-20 μ daubreelite fragments and 10-100 μ ferrite islands with phosphide became dispersed. The melted nodules are as usual subdivided in 1-10 mm cells by gently curving, isotropic walls which have a bluish-gray color. While these parts normally are so corroded that it is difficult to identify the original minerals, Mayodan had several well-preserved nodules, which were examined under the electron microprobe. It turned out that the walls are composed of iron, nickel and phosphorus, apparently in eutectic mixtures; they are very sensitive to corrosion and among the earliest material to become altered under terrestrial conditions.

It is interesting to note that schreibersite and daubreelite, alone or in aggregates, rarely if ever shock melt, while, when associated with an appropriate amount of the compressible troilite phase, the two minerals will fragment and sometimes melt completely.

Mayodan is a shocked hexahedrite which has partly recrystallized. The tritium loss noted by Hintenberger et al. (1967) may have occurred during recrystallization. Mayodan is closely related structurally and chemically to Indian Valley, Cedartown and Hex River. Its exterior morphology suggests that it parted from another mass in the atmosphere, and, if so, Indian Valley is a likely candidate, since it corresponds in all details to Mayodan. The distance between the two finds is 80 km which, until recently, was considered a prohibitively large separation between individuals. Considering the evidence herein and elsewhere for large scattering during showering (Campo del Cielo, Cranbourne, Cape York, Bingera, Allende, etc.), it is not at all impossible that Mayodan and Indian Valley are a paired fall.

Specimens in the U.S. National Museum in Washington:

- 11.4 kg main mass (no. 1487, 17 x 16 x 10 cm)
- 1,541 g slice (no. 1487, 16 x 16 x 1.1 cm; cut parallel to $(100)_{\alpha}$)
- 237 g part slice (no. 1605, 8 x 7 x 0.6 cm)

Mazapil, Zacatecas, Mexico Approximately 24°35'N, 101°57'W

Medium octahedrite, Om. Bandwidth 1.10±0.20 mm. Neumann bands. HV 190±10.

Group I. 8.53% Ni, 0.47% Co, 0.3% P, 60 ppm Ga, 221 ppm Ge, 5.5 ppm Ir.

Mazapil 809

HISTORY

A mass of 3.95 kg was seen to fall about 9 p.m. on November 27th, 1885, near Mazapil. According to the map and description given by Hidden (1887), the locality was the Conception del Oro Ranch, 13 km east of the town of Mazapil, corresponding to the coordinates given above. The locality and the coordinates should be verified with the aid of modern topographical maps, as these were unfortunately not at my disposal.

The ranchman, Eulogio Mijares, gave the following account printed by Hidden (1887; in English) and Brezina (1896: 308; in Spanish and German):



Figure 1115. Mazapil. The 4 kg main mass in Vienna. Regmaglypts and a few circular depressions from ablated troilite nodules are visible. Scale bar approximately 4 cm.





Figure 1117. Mazapil (Brit. Mus. no. 67451). Dendritic metallic fusion crust, on the right, invading low-melting taenite lamellae. The taenite lamellae are annealed and transformed to polycrystalline, martensitic units. Carbon from taenite has caused dark reaction rims of nickel bainite. Etched. Scale bar 50 μ .



Figure 1116. Mazapil (Brit. Mus. no. 67451). Dendritic metallic fusion crust, composed of several independent layers. Below, heat-affected α_2 zone. Etched. Scale bar 40 μ . See also Figures 44 and 47.



Figure 1118. Mazapil (Brit. Mus. no. 67451). View of the heataffected zone. The polycrystalline austenite of a former taenite lamella is indistinctly seen; each grain has, upon cooling, transformed independently to martensitic α_2 blocks. On the edge three schreibersite crystals, fused and with gasholes. Etched. Oil immersion. Scale bar 20 μ .

ground and in it a ball of light. We retired to a distance, fearing it would explode and harm us. Looking up to the sky we saw from time to time exhalations or stars, which soon went out, but without noise. We returned after a little and found in the hole a hot stone, which we could barely handle, which on the next day looked like a piece of iron; all night it rained stars but we saw none fall to the ground as they seemed to be extinguished while still very high up.

Professor Bonilla, of the Zacatecas Astronomical Observatory, visited the place and was shown a 30 cm deep hole from which he succeeded in recovering additional small bits of iron, evidently detached from the meteorite upon impact with the ground. Bonilla (quoted in the references already cited) noted that the "raining stars" mentioned by the finder must have been meteors associated with the comet Biela-Gambart, which had been discovered in 1826. The comet, for which all orbital elements had been calculated (e.g., period: 6.62 years), had also been observed in 1832, but had been considered lost since it, in 1846, was seen to separate in two parts, and to steadily diminish in size during 1852. Bonilla concluded that the Mazapil iron meteorite, which fell when the Earth passed through the Biela cometary orbit, represented cometary debris. Unfortunately, it appears that nobody at the time of fall collected such information from eye witnesses so that a trajectory and a radiant could be calculated in order to verify Bonilla's conclusion. As the case is now, the proposed association between the Mazapil meteorite and the Biela comet must remain a postulate.

Hidden (1887) gave a photograph of the exterior and of an etched section. Brezina (1896: 236, 282: plate 9), who purchased the entire mass for the Vienna collection, described it briefly and gave another photomacrograph of an etched slice. He classified it correctly as a medium octahedrite related to Toluca. Both Hidden and Brezina noted the prominent troilite-graphite nodules which appeared in slight relief on the surface and may be indistinctly seen upon the engraving provided by Hidden. Perhaps they are seen somewhat better in a photograph reproduced by Merrill (1929: plate 6).

COLLECTIONS

Vienna (3.46 kg main mass, 86 g slice), New York (93 g), Chicago (19 g), Berlin (17 g), Mexico Institute of Geology (15 g), London (14 g), Tempe (2.6 g).

DESCRIPTION

The flat irregular mass had the maximum dimensions in three perpendicular directions $17.5 \times 14.5 \times 6 \text{ cm}$ and

weighed 3,950 g. The surface is boldly sculptured with distinct regmaglypts, 1.5-3 cm across, separated by smoothly rounded ridges. In 11 places graphite-troilite nodules extrude from the surface, one of them being 2 cm in diameter. If they had not been so rich in refractory graphite – and possibly some silicates as well – they would have melted before the adjacent metal and would have left cylindrical holes like those so commonly seen on other irons, e.g., Chupaderos, Bogou and Bahjoi.



Figure 1119. Mazapil (Brit. Mus. no. 67451). In the heat-affected A zone the fused rhabdites are often connected by thin grain boundary veins of fused phosphides. Etched. Oil immersion. Scale bar 20μ .



Figure 1120. Mazapil (Brit. Mus. no. 67451). In the interior part of the heat-affected α_2 zone the phosphides (S) are unmelted; but the kamacite is transformed to α_2 , and the taenite is imperfectly homogenized to a mosaic structure. Compare Figure 114. Etched. Oil immersion. Scale bar 20 μ . See also Figure 53.

MA	ZA	PIL	-	SEL	ECT	ГED	CHE	MIC	AL	AN	AL	YSES	

	р	ercentage						ppm				
References	Ni	Co	Р	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Cobb 1967	8.42	0.47					195		49		4.8	
Wasson 1970a	8.64								60.2	221	5.5	

In an otherwise inappropriate analysis, Mackintosh (Hidden 1887) found 0.30% P.



Figure 1121. Mazapil (Brit. Mus. no. 67451). A coarse octhedrite of group I related to Toluca. Plessite fields with cloudy taenite rims. Subboundaries, fine rhabdites and Neumann bands in the kamacite. Etched. Scale bar 300μ .

A black fusion crust, displaying warts and striae, covers the surface irregularly. On sections, the fusion crust is seen to be a composite of oxides and metallic, dendritic melts. The oxides form an exterior $20-60 \mu$ thick layer, composed of magnetite and wüstite, in which numerous tiny metallic globules are dispersed. Oxides are also present as irregular 50μ thick layers, intercalated between metallic layers, and discordantly wedging out and reappearing. Finally, oxides form numerous tiny (0.5-15 μ) dendritic spherulites dispersed through the metallic parts of the fusion crust.

The metallic fusion crust is $10-200 \mu$ thick and composed of several sheets of dendritic metal, each $10-40 \mu$ thick. The dendrites have often grown perpendicular to the cold metallic substrate as 5μ wide branching units (HV 260±20). The melts form complex eutectics of Fe, Ni, P, S and C in places, as would be expected from the bulk composition of the meteorite. Locally, a yellowish, homogeneous metallic layer, up to 40μ thick, can be distinguished. From its appearance and its low hardness (HV 130±10) it may be concluded that it is a nickel-rich austenite (>40% Ni?), formed by the selective burning of iron, and, thus, enriching the remaining melts in nickel.

Below the fusion crusts is a 0.8-2.0 mm wide heataffected α_2 zone. The phosphides of the exterior 50% of this zone are micromelted, and the larger ones, which often are connected with the surface, are now replaced by oxide-phosphide melts to a depth of 1 mm. Microfissures are common in the same range, probably due to hot-cracking along grain boundaries infested with small amounts of phosphide melts. The micromelted rhabdites are clearly seen to have solidified by heat conduction from the cool interior of the meteorite.

The α_2 zone has a hardness of 200±15. The transition zone from α_2 to kamacite with Neumann bands is recovered to relatively low hardnesses of 160±10 (hardness curve type II).



Figure 1122. Mazapil (Brit. Mus) no. 67451). Plessite field with cloudy taenite rims, pearlitic transition zones and spheroidized interior. Decorated subboundaries in the kamacite. Etched. Scale bar 100μ . See also Figure 118.

The taenite has lost its brown stain, is relatively soft (HV ~ 200) and etches in a yellow mosaic structure (800° -1000° C isotherm) or whitish yellow (above the 1000° C isotherm). Simultaneously, a 10-20 μ wide dark-etching zone has developed along the taenite, evidently due to carbon diffusing outwards from the taenite while all phases were austenitic above 700°-800° C. The dark-etching material appears to be carbon-nickel-martensite-bainite about 100 Vickers-units harder than the adjacent α_2 material.

Etched sections display a medium Widmanstätten structure of straight, long ($\frac{U}{W} \sim 15$), but somewhat bulky kamacite lamellae, with a width of 1.10 ± 0.20 mm. The kamacite shows subboundaries, richly decorated with $1-5 \mu$ phosphides. Neumann bands are well developed and the hardness is 190 ± 10 .

Taenite and plessite cover about 15% by area. Comb plessite occurs as fields up to 4 x 1.5 mm in size. The smaller wedges display pearlitic or martensitic interiors. A fully developed field will show a stained taenite rim (HV 355±15) followed by indistinct martensitic transition zones (HV 370±15). Next comes brown-etching martensite (HV 415±30) and dark-etching duplex, but unresolvable structures (HV 300±30) and finally, easily resolvable structures with hardnesses similar to the adjacent kamacite lamellae. The pearlitic fields and lamellae display $\alpha + \gamma$ decomposition where individual γ -lamellae range from $0.5-2 \mu$ in width (HV 215±20). In such fields carbides are common, as late precipitates filling 100-1,000 μ irregular patches of the plessite interior. Their hardness range is 725-850, and they are possibly identical to the haxonite described by Scott (1971). Annealing effects are not apparent in any of the phases.

Schreibersite occurs as a few cuneiform or irregular skeleton crystals, 1 x 0.2 mm in size, but otherwise mainly as $10-100 \mu$ wide grain boundary veinlets and as $5-50 \mu$ particles in the plessite fields. Rhabdites, $1-10 \mu$ across, are common.



Figure 1123. Mazapil (Brit. Mus. no. 67451). Close-up of the edge of a plessite field similar to that of Figure 1122. Kamacite (K), high-nickel taenite rim (T), submicroscopic duplex $\alpha + \gamma$ plessite (D), and pearlitic interior. Etched. Scale bar 20 μ .

Unfortunately, the troilite-graphite nodules could not be examined in a polished section. Cohenite crystals of the type so common in Canyon Diablo, Toluca and other group I irons are probably present, but were not seen on the small sections available. The same applies to the silicate particles.

Mazapil is a medium octahedrite unrelated to most other octahedrites of about 1.1 mm bandwidth, such as Merceditas, Cape York, Casas Grandes and Rowton. The plessite morphology and the troilite-graphite nodules indicate a close relationship to Misteca, Balfour Downs and Shrewsbury, particularly to the last mentioned, which is, however, annealed by a cosmic reheating event. These relationships are supported by the Ni-Ga-Ge-Ir values, as reported by Wasson and others.

A 112 g fragment in Mexico City, listed as the independent Chichimeguilas meteorite, is a mislabeled section cut from Mazapil. For further discussion, see Chichimeguilas below.



Figure 1124. Mazapil (Brit. Mus. no. 67451). The edge of a deformed taenite lamella showing a dense grid parallel to $(111)_{\gamma}$ apparently of slipplanes. On the sloping edge of the taenite, which has been exposed by dissolving part of the kamacite (K), a rough relief is revealed. Etched. Oil immersion. Scale bar 10 μ .

Mazapil, (Chichimeguilas), Zacatecas, Mexico

Very little information is available on the material which has been listed as Chichimeguilas by Ward (1904a: 7) and Hey (1966: 103). Evidently Ward learned about the material in 1901 on a visit to Mexico City and acquired 40 g for his collection. While most of his collection was later purchased by the Field Museum in Chicago, these 40 g have apparently been lost. They are not listed by Farrington (1916), nor by Horback & Olsen (1965).



Figure 1125. Mazapil (The Chichimeguilas fragment.) (no. 53, Institute of Geology, Mexico City). The fusion crust and the regmaglypts are well-preserved. The sample is a small endpiece cut from a larger mass. Scale in centimeters.



Figure 1126. Mazapil. Chichimeguilas. The same fragment from the opposite side. Medium octahedrite with schreibersite skeleton crystals, partly ablated away. Deep-etched, except along the edge which was protected by wax and now appears as a matte zone. Scale in centimeters.

On a visit to Mexico City in 1968, I had the opportunity to examine a 112 g deep-etched endpiece, measuring $6.5 \times 4 \times 2$ cm (Institute of Geology No. 53; Haro 1931: 78 and plate 37, figure 1 B). This is the only material presently known; a 6 kg main mass, allegedly in the same collection (Ward 1904a: 7; Hey 1966: 103), does not exist, or at least has never been in the collection.

The 112 g sample is cut from some larger mass that must have been a recent fall. The fusion crust and the heat-affected α_2 zone are extremely well-preserved and beautiful regmaglypts, about 2 cm across, cover the exterior surface. The material is slightly marred by a few hammer and chisel marks, but otherwise it appears undamaged.

The etched section displays a medium Widmanstätten structure with straight, long ($\sqrt[4]{w} \sim 15$) kamacite lamellae with a width of 1.1 ± 0.2 mm. Neumann bands are well developed. Taenite and plessite cover about 15% by area, but their structural details could not be examined in the deep-etched section.

Schreibersite is present as a few cuneiform skeleton crystals, up to 7×1 mm in size, and as less than 0.1 mm wide grain boundary veinlets. A deep groove in the surface indicates that a larger (~1 cm) troilite nodule was once present, but was partly ablation-melted, partly broken free artificially.

On the basis of the structure, I would estimate that Chichimeguilas contains 8.5-9.0% Ni and 0.2-0.3% P.

According to the attached label and to Haro (1931: 78), the material came from the Hacienda de Chichimeguilas, in the Municipalidad (i.e., county) of Fresnillo, Zacatecas, and it was donated to the Institute of Geology in Mexico City by Colonel M.J. Amador. However, the information may also be read as if the Chichimeguilas locality is the address of the donor, Amador, and thus does not refer to the place of discovery.

I have, however, such a strong case to support the theory that the 112 g Chichimeguilas material is an endpiece cut from Mazapil between 1885 and 1896, that a dispute regarding the discovery site is without interest. The evidence is the following: (i) Chichimeguilas is a fresh fall, like Mazapil; (ii) Mazapil is the only reported iron meteorite fall in the State of Zacatecas, and (iii) the macro- and microstructures of Chichimeguilas and Mazapil are identical. When I had discovered these similarities, I compared the Chichimeguilas endpiece to the cut and etched surfaces on the Mazapil main mass in Vienna. It turned out that not only were the structural details and the sizes of the regmaglypts identical, but the Chichimeguilas sample could be fitted to the Mazapil main mass.

Thus, Chichimeguilas should be deleted as an independent meteorite.



Figure 1127. Mazapil. Chichimeguilas. Transition between heataffected α_2 zone (left) and unaffected interior. Comb plessite with cloudy taenite edges. Neumann bands. Schreibersite, partly removed by tearing (black). Etched. Scale bar 500 μ .