For the present study, Dr. E. Olsen kindly loaned me H.A. Ward's original sample, evidently hacksawed in Santiago by himself, and so far the only material distributed (Me 939, 20 x 15 x 8 mm, 10 g). The etched section clearly indicates that the Atacama corrosion has taken its toll. The α_2 zone is penetrated by sharp-edged pits and in many places completely removed. This part of the mass has on the average lost 2 mm by weathering. The α_2 zone is composed of serrated, unequilibrated grains, 10-40 μ across, and the hardness is 186±8 (hardness curve type I).

The Chañaral fragment exhibits a medium Widmanstätten pattern of straight, long ($\frac{L}{W} \sim 25$) kamacite lamellae with a width of 1.10±0.15 mm. Subboundaries with less than 0.5 μ precipitates are common but obscured by an overlapping hatched ϵ-structure, indicative of shock-hardening.

Taenite and plessite cover about 30% by area, mainly as dense fields with martensitic and unresolvable duplex interiors. The Narraburra plessite type, with concave taenite islands, is likewise common.

Schreibersite occurs as 20-100 μ wide grain boundary veinlets and as characteristic island arcs. The individual particles are subangular, 10-20 μ across and situated 5-20 μ outside the $\alpha - \gamma$-phase boundaries.

Troilite occurs as a 1 x 0.2 mm bleb, which is deposited upon a primary 1 x 0.08 mm straight chromite lamella. The troilite contains daubreelite lamellae; one of these is 20 μ thick and along its entire length in contact with the chromite backbone. The troilite is not shock-melted but recrystallized to an aggregate of 5-30 μ grains. The chromite-troilite-daubreelite aggregate has nucleated small particles of schreibersite, and all is enveloped in swathing kamacite.

Carlsbergite, graphite, carbides and silicates were not detected.

The specimen is small, and the ratio of exterior surface to interior mass is large. Therefore, it has been significantly annealed by the atmospheric flight. The ϵ-structure is thus softened by recovery to 225±25, and in the nickel- and phosphorus-depleted zones adjacent to schreibersite incip-

Figure 911. Ilimaes. Chañaral (Chicago no. 939). Shock-hatched and slightly annealed kamacite with indistinct precipitates. Etched. Oil immersion. Scale bar 20 μ.

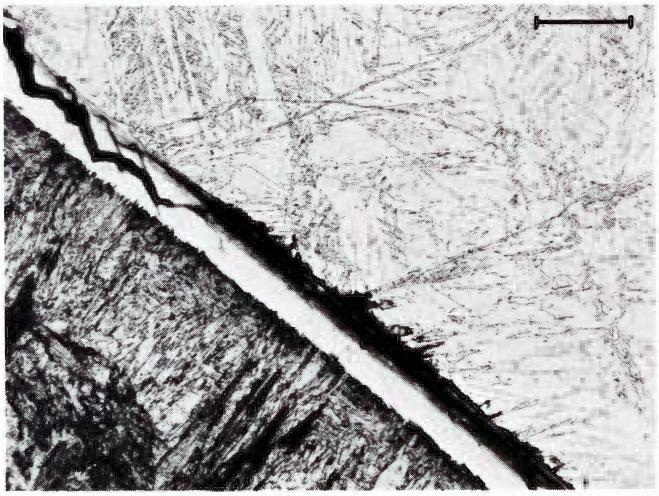

Figure 910. Ilimaes. Chañaral (Chicago no. 939). Plessite field with martensitic interior. Corrosion along taenite-kamacite interface and along crystallographic planes in the taenite rim. Etched. Oil immersion. Scale bar 20 μ.

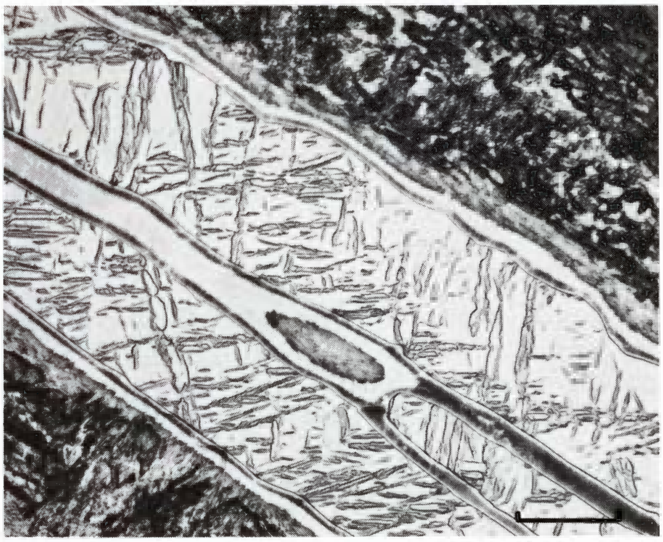

Figure 912. Ilimaes. Chañaral (Chicago no. 939). Two plessite fields with unresolvable duplex interiors. A forked taenite lamella with cloudy rims. Shock-hatched kamacite in between. Etched. Oil immersion. Scale bar 20 μ.

ILIMAES (CHAÑARAL) – SELECTED CHEMICAL ANALYSES

	percentage			ppm							
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Schaudy & Wasson 1971	8.00								22.0	43.2	0.17	

ient recrystallization to 5-15 μ α-grains is present. The troilite has recrystallized, and the taenite-martensite interfaces are blurred and cloudy. The taenite lamellae are softened to 325±25. Moreover, the metallic structure is plastically strained, and the included phosphide crystals are torn and rotated into alignment with the flow lines in the metal near the surface. This is a strong indication that Chañaral separated in the atmosphere from another mass by tensional and torsional fracture. It is estimated that the only available Chañaral section has been cut from a near-surface region that during flight was briefly reheated to above 400° C. Therefore, there are some slight structural differences from what is described for the 51 kg Ilimaes main mass.

The primary structure, the strained matrix, the state of corrosion, the chemical composition and the place of discovery all lead to the inevitable conclusion that Ilimaes and Chañaral are two fragments of the same meteorite that burst in our atmosphere and scattered two – or possibly more – fragments over the Atacama desert between Chañaral and Carrizalillo.

Ilinskaya Stanitza, Orenburg Oblast, RSFSR
51°14′N, 57°23′E

Medium octahedrite, Om. Bandwidth 0.70±0.10 mm. ε-structure. HV 260±15.

Group IIIB. 9.34% Ni, 0.54% Co, about 0.4% P, 19.5 ppm Ga, 39.2 ppm Ge, 0.29 ppm Ir.

HISTORY

A mass of 5.62 kg was found about 1915 near Ilinskaya Stanitza, which is about 80 km west of Orsk in Orenburg Oblast (Krinov 1947: 24). It was described with two figures by Zavaritskij & Kvasha (1952: 56), and analyzed by Dyakonova (1958a). Kvasha (1962: 138) stated that the main mass, of which she gave a picture, is in the Academy of Sciences, Moscow.

COLLECTIONS

Moscow (4,374 g main mass plus 261 g slices), Washington (184 g), Leningrad (about 50 g), London (37 g).

DESCRIPTION

The mass is an irregular, flattened triangle with the maximum dimensions 20 x 14 x 6 cm. It is thickest along the edges and reaches a minimum thickness of about 1 cm in the central part where a bowl-shaped depression, 7 cm in diameter, is located. It is heavily corroded and covered by 0.5-1.5 mm thick adhering oxide crusts. All traces of fusion crust and of heat-affected α_2 zone are removed, and corrosion also penetrates deep into the mass, partly as 10-20 μ wide oxide veinlets along grain boundaries and inclusions, partly as selective oxidation of the nickel-poor phases in the plessite.

The etched section displays a medium Widmanstätten structure of long ($\frac{L}{W} \sim 20$) kamacite lamellae with a width of 0.70±0.10 mm. The kamacite is transformed to the hatched ε-structure by shock pressures above 130 k bar. Subgrain boundaries with 0.5-1 μ precipitates are still visible in the previously clear kamacite. The microhardness is 260±15. Plessite occupies about 40% by area and is mostly in the form of comb plessite or duplex $\alpha + \gamma$ structures with individual γ-grains smaller than 2 μ. Martensitic interiors are also common. The hardness of the taenite rim zones is 360±20; the hardness increases to 475±25 in the martensitic transition zones then decreases again to 325±50 in the duplex interiors.

Schreibersite is present as Brezina lamellae in a dodecahedral arrangement. They are typically 20 x 5 x 1 mm in size and enveloped in 1-1.5 mm of swathing kamacite. Some take the form of angular, hook-like skeleton crystals. They are monocrystalline and slightly brecciated. Schreibersite is further common as 30-50 μ wide grain boundary precipitates and as 2-10 μ angular or vermicular precipitates in the plessite. Some of the schreibersite crystals have been nucleated by 25-50 μ subangular chromite crystals which later became almost completely enveloped by the precipitating phosphide. Rhabdites were not observed.

Large troilite nodules have not been disclosed by the sectioning. Small troilite blebs, e.g., 50-200 μ in diameter, do, however, occur in association with the Brezina lamellae. In some cases 25 μ chromite crystals and 50 μ phosphate (sarcopside ?) crystals are found enclosed in the small troilite blebs. The troilite is microcrystalline (1-2 μ grains), with iron grains of the same size, and displays ragged edges against the surrounding metallic matrix. The troilite was evidently briefly remelted due to shock while its inclusions did not melt.

Ilinskaya Stanitza is a medium octahedrite with Brezina lamellae and ε-shock structure; it is related to, e.g., Grant, Augustinovka and Treysa.

ILINSKAYA STANITZA – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Trofimov 1950				540								
Dyakonova & Charitonova 1960	9.40	0.54	0.57				100					
Scott et al. 1973	9.28								19.5	39.2	0.29	

The phosphorus value appears a little high. My point counting of 52 cm² yielded about 0.4%.

Specimen in the U.S. National Museum in Washington:
184 g slice (no. 2148, 14 x (3.5-1) x 0.8 cm)

Illinois Gulch, Montana, U.S.A.

46°41'N, 112°33'W; 1,600 m

Altered nickel-rich ataxite, D. α-spindles 40±20 μ wide. Martensitic matrix. HV 260±15.

Anomalous. 12.3% Ni, 0.08% P, 2.6 ppm Ga, 2.9 ppm Ge, 5.3 ppm Ir.

Although the structure is extremely anomalous, it appears to be genuinely cosmic.

HISTORY

A mass of 2.45 kg was found in 1897 by J. Parle in Illinois Gulch, Deer Lodge County. The meteorite was discovered under 1.2 m of alluvial deposits while Parle was mining for gold, and the exact locality was given as Illinois Gulch, 1.2 km from the mining town, Ophir. Ophir is a ghost town today, and the county name is Powell County not Deer Lodge County. The locality of find can, however, be reconstructed on the basis of the old information and has the coordinates given above. The meteorite was acquired and distributed by H.A. Ward, and it was simultaneously described by Preston (1900b) and Cohen (1900b: 351). Preston gave a cut of the exterior. Berwerth (1914: 1081) suggested that the meteorite had been artificially reheated, a conclusion which was supported by the present author (Hey 1966: 212), because the microstructure closely resembled that of rapidly cooled, technological iron-nickel alloys. Perry (1944: plate 21) gave two photomicrographs, clearly showing this structure.

COLLECTIONS

London (598 g), Chicago (570 g), New York (269 g), Paris (91 g), Vatican (88 g), Berlin (69 g), Vienna (27 g), Prague (27 g).

DESCRIPTION

According to Preston (1900b), the mass measured, before cutting, 105 x 104 x 63 mm in its greatest dimensions. It was somewhat ham-shaped and exhibited two large and numerous small pittings.

The specimens in London and Chicago have rather smoothly rounded surfaces which show only little corrosion. The fusion crust is preserved in several places, albeit in a weathered form; it is estimated that on the average only 0.5 mm of the meteorite is lost due to corrosion. The fusion crust is duplex, as usual, consisting of an exterior 50-200 μ thick magnetite plus wüstite crust and an interior, 10-50 μ thick, metallic, dendritic crust. Corrosion penetrates only insignificantly into the interior; here, following the γ - γ-grain boundaries creating 1-5 μ wide limonitic veinlets; there, attacking the matrix outlining the serrated martensitic structures.

Etched sections have a granulated appearance to the naked eye. No Widmanstätten structure is visible, but the section is subdivided in equiaxial grains ranging from 0.2-1.5 mm in size. The grains are clearly austenitic units that each, upon relatively rapid cooling from the austenite range, have transformed to independently oriented, fine-grained martensitic structures. The hardness is surprisingly high, HV 260±15 possibly due to deformation hardening. A 12% Ni - 0.1% P alloy, quenched in water, only attains a hardness of about 230, and subsequent tempering leads to

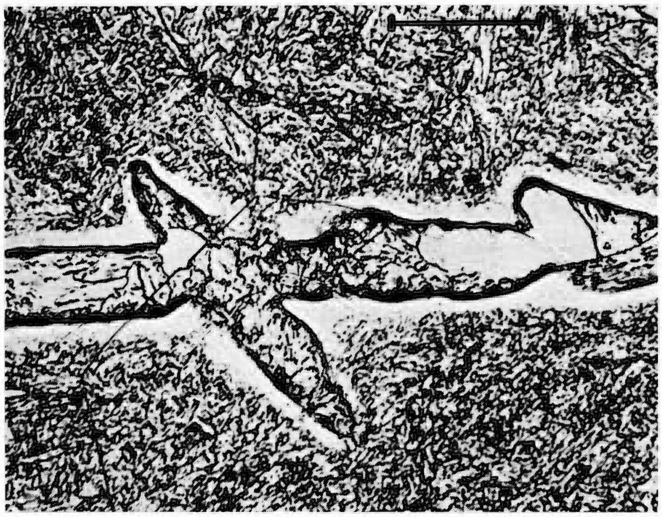

Figure 913. Illinois Gulch (New York no. 64). A very anomalous iron meteorite. An original ataxite structure, similar to that of Kokomo, has been obscured by secondary cosmic reheating and relatively rapid cooling. The photo shows primary kamacite spindles, secondary grain boundaries and secondary unequilibrated α_2 structures. Etched. Scale bar 100 μ. (Perry 1950: volume 2.)

Reed (1969) analyzed the kamacite spindles and found 7.5% Ni and 0.078% P in solid solution. The relatively high amount of nickel is probably due to the late secondary reheating and partial homogenization discussed below.

ILLINOIS GULCH – SELECTED CHEMICAL ANALYSES

References	percentage Ni	Co	P	ppm C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Fahrenhorst in Cohen 1900b	12.67	0.81	0.08			100	200					
Moss in Hey 1966	12.4											
Smales et al. 1967					21	269	108	<1	2.4	2.9		
Wasson & Schaudy 1971	11.68								2.8	2.8	5.3	

hardness decrease without precipitation hardening (Buchwald 1966: 18). No phosphides could be identified, and other minerals must also be very scarce. On a total of 50 cm^2 no troilite was observed; Preston (1900b) did, however, observe two small nodules, 5 and 8 mm in diameter, when he divided the main mass into five sections.

The structure described so far appears to be a secondary structure superimposed upon an almost obliterated primary structure. By defocusing the microscope one can perceive that the matrix originally was that of a rather normal nickel-rich ataxite, like Deep Springs, Hoba and Tlacotepec. The matrix consisted of a uniform, duplex $\alpha + \gamma$ structure where vermicular gamma-grains, 0.5-3 μ thick, were dispersed in an alpha phase. A number of kamacite spindles occurred in this matrix, scattered with a frequency of about one per 3 mm^2. The spindles were 40±20 μ wide and arranged parallel to the four octahedral planes, indicating that the mass, at an earlier date, had been homogenized to a single austenite crystal. The spindles are the best surviving part of the primary structure; although they exhibit diffuse edges against the taenite and are transformed to serrated α_2 or martensitic units, they are distinctly visible.

Illinois Gulch appears, then, to have followed the "normal" development for a nickel-rich ataxite of the Hoba-Iquique type in the beginning. It precipitated oriented kamacite spindles in the large single taenite crystal, and later the matrix decomposed to fine-grained duplex $\alpha + \gamma$. At a later stage, when the primary structure was fully developed, it was reheated into the taenite (austenite) range whereby a number of 0.5-1.5 mm austenite crystals, arbitrarily oriented, were formed. The time was insufficient for full homogenization to occur – the α-spindles and the duplex $\alpha + \gamma$ matrix are still visible as a ghost structure – and renewed, relatively rapid, cooling led to metastable martensitic structures which are untempered. The secondary structures have perhaps been formed during the transient temperature increase associated with a shock event.

The last reheating occurred in the atmosphere. Although no visible heat-alteration zone is present the hardness profiles clearly show a significant gradient against the edges. The hardness below a depth of 10 mm is 260±15, but outside it decreases homogeneously to 155±10 (hardness curve type V). The drop, caused by a brief reheating above 400° C in the atmosphere, shows manifestly how unstable the cold-worked martensitic matrix is.

Illinois Gulch is structurally highly anomalous and could easily be mistaken for a technological product were it not for the preserved fusion crust and other details. Chemically, it is also anomalous, as witnessed by the Ga-Ge-Ir contents.

Figure 914. Illinois Gulch (New York no. 64). Three austenite grains meet along secondary grain boundaries. The primary duplex $\alpha + \gamma$ matrix is superseded by a diffuse secondary structure of unequilibrated, tempered α_2. Etched. Scale bar 20 μ. (Perry 1950: volume 2.)

Imilac. See the Supplement

Indian Valley, Virginia, U.S.A.

36°55'N, 80°36'W; 800 m

Hexahedrite, H. Shocked and partly recrystallized. Neumann bands. HV 145±7.

Group IIA. 5.56% Ni, 0.49% Co, 0.27% P, 62 ppm Ga, 174 ppm Ge, 10 ppm Ir.

Mayodan is possibly a paired fall with Indian Valley.

HISTORY

A mass of 14 kg was plowed up in 1887 by John Showalter. His tobacco fields were located in Floyd

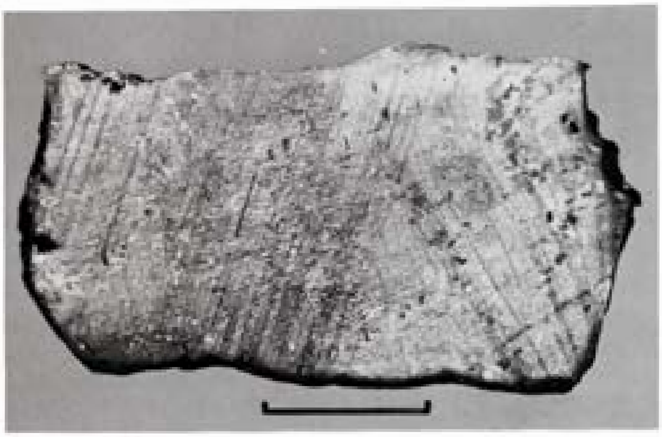

Figure 915. Indian Valley (Vienna no. G8430). Neumann bands cross the section, but have disappeared in recrystallized regions. Above right, the bands are violently bent; on the surface are hammer and chisel blows. It appears that the deformation is artificial, but it cannot be ruled out that it was caused by atmospheric breakup. Deep-etched. Scale bar 20 mm.

County, Indian Valley Township, near the Carroll and Pulaski county lines. Kunz & Weinschenk (1892), who described the mass, gave the location as "near the base of the south side of Floyd Mountain, six miles southeast of Radford Furnace." These names are not used on modern maps, but Radford Furnace could be located on Rand Mc Nally's 1882 edition: 469 and 496, as being about 20 km southwest of the present town of Radford. The combined information points to a site in the extreme western part of Floyd County with the approximate coordinates and altitude given above. Kunz & Weinschenk (ibid.) observed the patches of granular structure and presented two photomacrographs. Böggild (1927) found that the hexahedrite contained both plate-shaped and rod-like rhabdites and discussed the crystallographic relationships. Perry (1944) gave a photomicrograph of the recrystallized ferrite grains which reminded him of snowflakes on a dull background. Buchwald (1967a) gave a thorough description of the metallography accompanied by numerous photomicrographs. Nichiporuk & Chodos (1959) examined troilite nodules from various meteorites and found Indian Valley's nodules to have a surplus of iron, relatively to what was found in monocrystalline troilite. As discussed below, the effect is caused by shock melting of the troilite and rapid dissolution of some of the surrounding iron. Hulston & Thode (1965) and Kaplan & Hulston (1966) studied the sulfur isotope distribution.

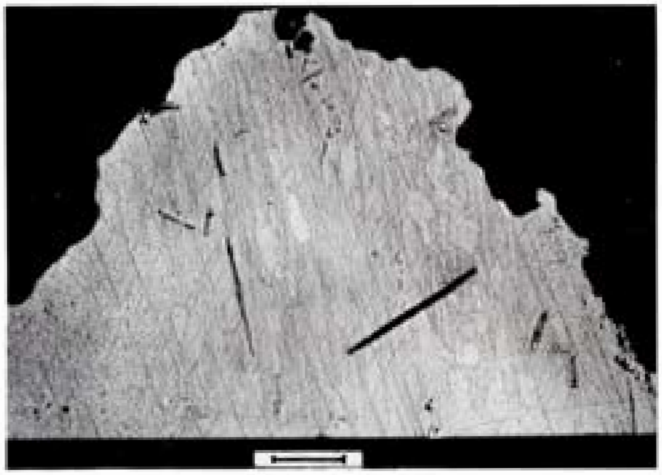

Figure 916. Indian Valley (Copenhagen no. 1905, 1748). The Neumann bands and the recrystallized portions are clearly seen. Profusion of rhabdite plates and minute rhabdite prisms. Etched. Scale bar 2 mm.

COLLECTIONS

Chicago (7,887 g), London (709 g), Tempe (702 g), Vatican (578 g), Washington (506 g), Berlin (455 g), Vienna (302 g), Budapest (179 g), Harvard (105 g), Bonn (90 g), Munich (78 g), Ann Arbor (70 g), Philadelphia (70 g), Paris (56 g), Ottawa (54 g), Copenhagen (10 g).

DESCRIPTION

According to Kunz & Weinschenk (1892) the mass had the dimensions of 28 x 20 x 13 cm, but these figures must certainly have been the very extreme measures, since the mass only weighed 14 kg. They stated that the mass was very much corroded and entirely covered with a limonite crust. The specimen in the U.S. National Museum does, however, display a 1 mm wide, heat-affected rim zone in places, and the troilite inclusions are locally burnt out and have left easily recognizable holes. The total loss by weathering is, therefore, estimated to be only 1-2 mm. In

Figure 917. Indian Valley (Tempe no. 62a; 702 g). The other half of this section is in London (no. 1959, 920). It shows a precursor grain boundary along which large and small troilite nodules are located. The Neumann bands and the rhabdites are differently oriented on either side of the boundary. Zones on either side are depleted in phosphorus. Deep-etched. Scale bar 20 mm.

INDIAN VALLEY – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Eakins in Kunz & Weinschenk 1892	5.56	0.53	0.27		100		tr.					
Goldberg et al. 1951	5.64	0.50							63			
Lovering et al. 1957		0.45				42	108		56	160		
Nichiporuk & Brown 1965											7.9	29.3
Wasson 1969	5.48								62.5	174	12	

accordance with this, the hardness curve of Indian Valley (100 g) is found to be of type III, with rim values of 200±10 and interior values of 145±7, suggesting that only a small part of the surface is rusted away, although irregularly. Selective oxidation has attacked the ferrite phase primarily, while the rhabdites survive for a long time and may be found in the weathered crust completely embedded in limonite.

There are indications that Indian Valley is one of the few truly polycrystalline hexahedrites. Specimen No. 1959, 920 in London contains a 5 cm long section of what may be a boundary between two large, differently oriented, ferrite crystals. Various troilite nodules, ranging from 1-10 mm in size, are located in the boundary.

The main components of Indian Valley are ferrite and phosphide; austenite has not been observed. The ferrite phase is developed in two forms. There is a coarse ferrite with a grain size larger than 15 cm, and, scattered in this single crystal, are groups of small ferrite grains, about 200 μ in diameter. The coarse ferrite is crossed by several sets of Neumann bands, some of which are partly obliterated or decomposed to cellular networks. They often terminate in a diffuse net of subboundaries near the inclusions. The microhardness is 145±7.

The recrystallized ferrite grains are particularly common around the rhabdite inclusions and Neumann band junctions where nucleation was facilitated. They cover an estimated 5% of the etched sections and are visibly elongated along the dominant Neumann band directions. Upon careful preparation, it may be seen that the grains contain concentric growth rings, indicating a discontinuous growth – possibly as a result of cyclic reheating. Many grains are visibly hampered in their growth by 2-5 μ rhabdites located in the boundaries. The microhardness is 142±6, and thus only slightly lower than the unrecrystallized material. Some recrystallized grains contain distinct, narrow Neumann bands which may be the result of deceleration and violent breakup in our atmosphere.

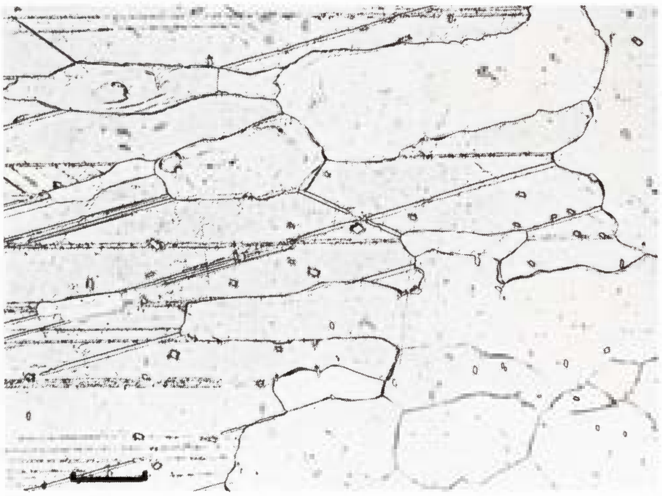

Figure 918. Indian Valley. Detail of Figure 916. The recrystallized grains show preferential growth along former Neumann bands. Concentric growth lines and spheroidized rhabdites inside the new grains. Etched. Scale bar 100 μ.

Rhabdites are common as up to 10 x 5 x 0.1 mm plates arranged in parallel planes with a distance of 0.5-5 cm. The matrix between these imaginary planes is rich in rod-shaped rhabdites, 5-10 μ across, and smaller. Rhabdites outside the recrystallized ferrite grains have rather sharp crystal facets and an adjacent diffuse network of subboundaries. Rhabdites inside the ferrite grains have adjusted their sides and have rounded edges, and the adjacent ferrite is poor in subboundaries.

Troilite occurs as 1-20 mm irregular nodules which have all been severely modified by shock melting. Daubreelite originally was present as parallel bars, covering about 15% by area, and schreibersite rims apparently also existed previous to the shock. Now the structure is a mixture of 1 μ eutectics of troilite and iron, in which are dispersed 3-10 μ daubreelite grains and 25-100 μ ferrite-phosphide eutectics. The nodules have serrated, fringed edges against the metal because this has been partly dissolved. Fine-grained, troilite-

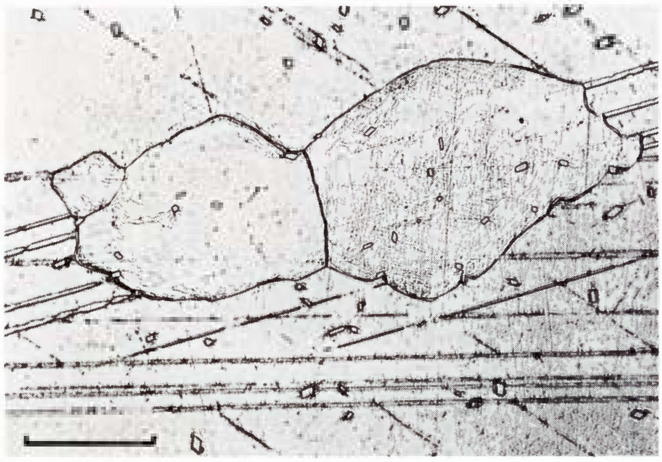

Figure 919. Indian Valley. Detail of Figure 916. The grain growth is impeded by phosphide particles. Sharp-edged rhabdites outside, but softly rounded rhabdites inside the recrystallized grains. Etched. Scale bar 200 μ.

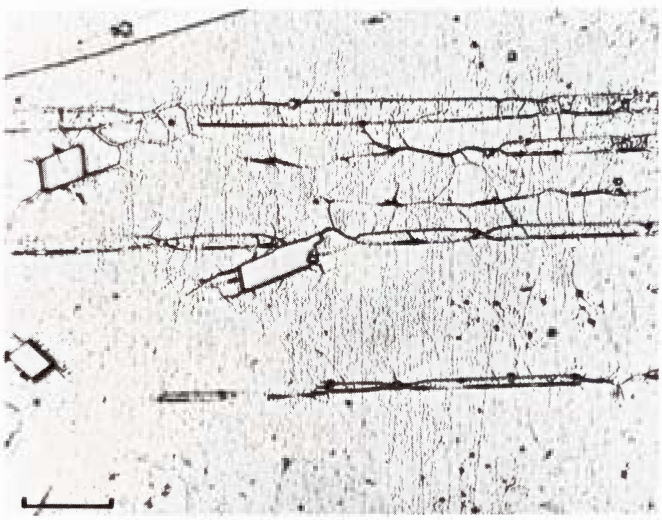

Figure 920. Indian Valley. Detail of Figure 916. Three sharp-edged rhabdites in a matrix which is recovered and polygonized but not recrystallized. Former Neumann bands (five horizontal and one oblique streak) are decomposed into cellular networks. Etched. Scale bar 20 μ.

metal eutectics penetrate up to 1 mm outwards through the metal. Where the troilite nodules happen to be situated in the reheated rim zone, the troilite has recrystallized to 2-5 μ equiaxial grains.

Some of the rhabdite plates are enveloped in a 100-200 μ wide zone of recrystallized ferrite in which are numerous graphite plumes. The ferrite has a grain size of 20-100 μ and is extremely soft, 95-115 HV (100 g), indicating that it is nickel-poor (~ 1% Ni) and well recrystallized. The graphite plumes are typically 60 x 10 μ and composed of unordered 1 μ grains. The microhardness, the morphology and the relative amounts of graphite and ferrite strongly suggest that the original mineral was cohenite which had nucleated upon the rhabdite but later decomposed upon the cyclic, cosmic reheatings which simultaneously started the recrystallization of the metallic matrix. The necessary temperature may be estimated as 450°-550° C.

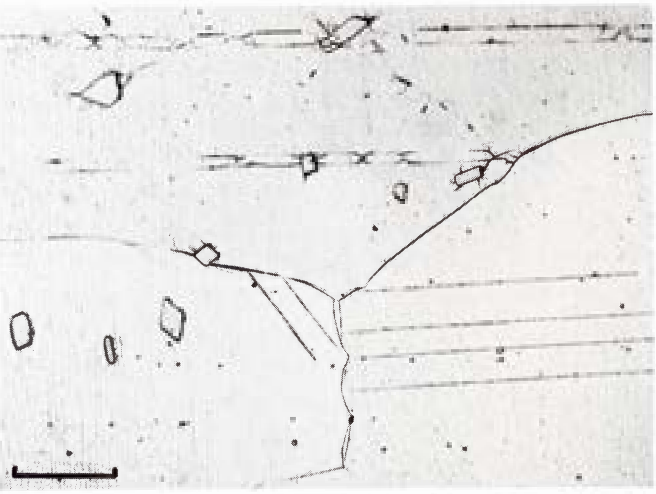

Figure 921. Indian Valley. Detail of Figure 916. Two recrystallized grains with rounded rhabdites and new Neumann bands. Above, old decomposed Neumann bands and subboundaries around sharp-edged rhabdites. Etched. Scale bar 50 μ.

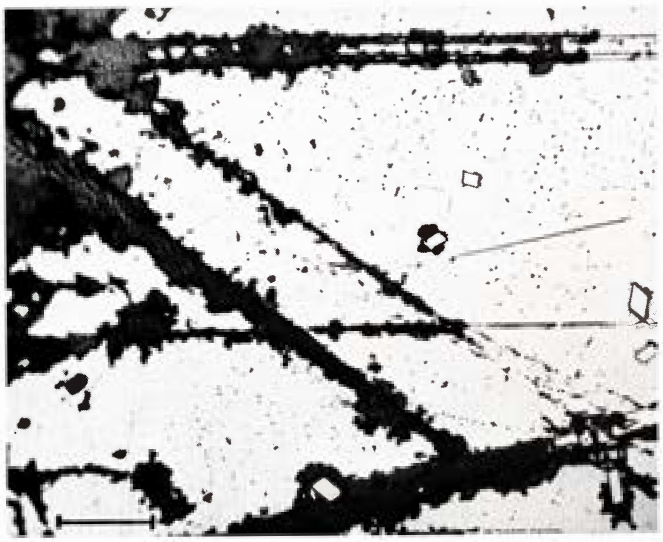

Figure 922. Indian Valley (Copenhagen no. 1905, 1748). Corroded surface. The terrestrial groundwater has selectively attacked the decomposed, cellular Neumann bands. The nickel- and phosphorus-depleted kamacite near phosphides was also attacked. Subboundaries are indistinctly seen in the kamacite. Etched. Scale bar 50 μ.

Indian Valley is a hexahedrite with indications of both shock and cyclic reheating; it is structurally closely related to, e.g., Hex River, Mayodan and Cedartown. Chemically, it belongs to group IIA, and the main and trace element concentration is almost identical to that of Hex River and Mayodan.

Some sections through Indian Valley, e.g., Vienna No. G8430, show distortion in certain near-surface parts. It resembles the plastic deformation associated with violent breakup in the atmosphere and would thus suggest that another mass fell simultaneously. This other mass might well be Mayodan.

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

481 g slice (no. 323, 15 x 7 x 0.9 cm)
25 g part slice (no. 323, 5 x 3 x 0.4 cm)

Iquique, Tarapaca, Chile

Approximately 20°13′S, 69°45′W

Nickel-rich ataxite, D. A few 20 μ wide α-spindles. Oriented sheen of well defined parallel bands. HV 204±8.

Group IVB. 16.0% Ni, 0.6% Co, 0.08% P, 0.17 ppm Ga, 0.051 ppm Ge, 28 ppm Ir.

A reported, artificial reheating appears to have little damaged the structure.

HISTORY

A mass of about 13 kg was found in 1871 about 10 Leguas (45 km) east of Iquique, in the western part of Pampa del Tamarugal. It was found in the stone-hard salt deposits with the underpart embedded in the saltpeter itself and the upper part covered by about 2 feet of the pampas soil. The workmen, expecting to find precious metals, heated the mass in a fire after which they succeeded in breaking off small fragments. The mass came to Lima, Peru, where approximately 1 kg was cut from it and examined by Raimondi. It was then purchased for the Berlin Museum

Figure 923. Iquique (Berlin). Main mass of 10 kg. Original regmaglypts have been severely modified by terrestrial corrosion in a very unusual way. The reason for the parallel ridges is obscure. Ruler measures 10 cm.

where it was fully described by Rose (1873) who presented five different lithographs of the exterior and a drawing of an etched section. The extremely fine-grained structure puzzled the early workers, like Brezina (1885: 219; 1896: 293), Cohen (1899: 153; 1905: 138, 153) and Klein (1906: 133), who believed they saw Neumann bands and vestiges of a hexahedric structure. Berwerth (1918: 419) was probably the first to observe that the matrix was a finely-divided, eutectoid-like mixture of nickel-poor kamacite and nickel-rich taenite. His photomicrograph is interesting historically, since it shows what could be accomplished with the metallographical microscope around World War I. Perry (1944: plate 22) gave two photomicrographs and dubbed the particular structure a paraeutectoid.

COLLECTIONS

Berlin (main mass of 10.0 kg), Washington (158 g), Moscow (140 g), New York (88 g), Vienna (41 g), Ann Arbor (40 g), Chicago (16 g).

DESCRIPTION

The meteorite is a rectangular, flat mass with the average dimensions 21 x 18 x 7 cm. The two sides, each of about 400 cm^2, are widely different. One, the underside is of the rather normal weathered type with shallow depressions on an otherwise little sculptured surface. The other side displays an arrangement of subparallel ridges and rilles, which immediately suggest the ripple marks on sandstone. Cohen (1899) believed that the sculpture was due to sand erosion produced on the unprotected upper surface before it eventually was buried under more than half a meter of soil. The individual ripples are up to 10 cm long and 1 or 2 cm from crest to crest. They are, therefore, pretty coarse and different from the pockmarking of other Chilean irons, like Maria Elena and Filomena. The pockmarked areas of Filomena do, however, locally merge into areas of subparallel ridges about 5 mm apart. The phenomenon is certainly unconnected with ablation during the atmospheric flight, but exactly what forces produced it is difficult to say. The Chilean salt desert environment appears to be an essential condition.

The fusion crust and the heat-affected zone are removed by the corrosion. Locally, on the underside there are crater-like pits filled with rhythmically deposited terrestrial oxides, and under these the alpha constituent of the matrix is selectively corroded but only to an insignificant depth. As usually is the case with the ataxites, no deep corrosion has taken place because no high angle grain boundaries and very few inclusions are present. Hammer marks and fractured surfaces, presumably due to the application of a hot chisel, are found at one end but, as will be seen below, the influence of the heating upon the structure is negligible. In the oxidized, burned crust glossy, hard spherules, 0.1-0.5 mm in diameter, are embedded. They are probably connected with the artificial reheating of the saltpeter incrusted iron.

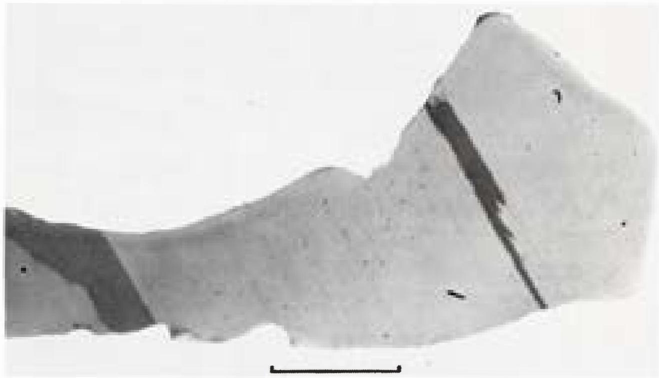

Figure 924. Iquique (U.S.N.M. no. 1230). A full slice showing the parallel "Schlierenbands" and a few troilite inclusions (black). Etched. Scale bar 20 mm. S.I. neg. M-1371.

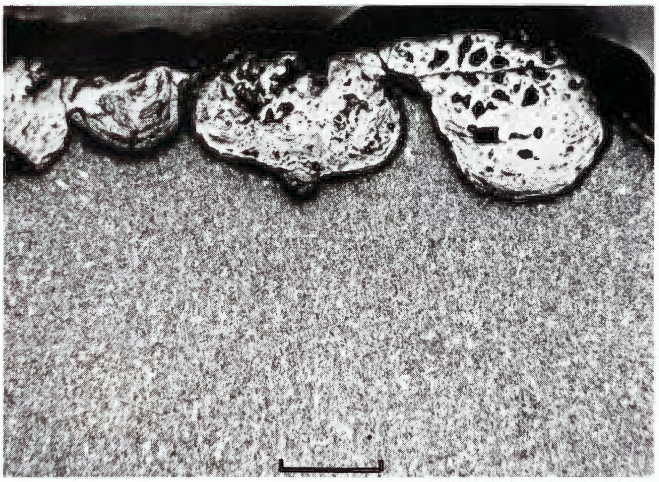

Figure 925. Iquique (Berlin). The corroded surface. Iron oxides (glossy gray) fill the bowl-shaped, millimeter-sized cavities. When the oxides spall off, the meteoritic surface has an extremely rough surface with razor-sharp crests, typical for corroded iron meteorites from Atacama and a few other arid regions of the world. Etched. Scale bar 400 μ.

IQUIQUE – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Rammelsberg in Rose 1873	15.86	0.19	0.05									
Sjöström in Cohen 1905	15.41	0.94	0.07	300	200	tr.	200					
Henderson 1941c	15.99	0.32	0.09		tr.							
Schaudy et al. 1972	16.03								0.17	0.051	28	

Iquique is thus an iron which, from the beginning, has been remarkably well analyzed.

Etched sections display a matte sheen with some nonmetallic inclusions scattered over the surface. A few parallel bands, from one to eight millimeters wide, cross the sections. The bands have a differently oriented sheen, but exactly the same microstructure as the adjacent part of the sections – except for a different orientation. At high magnification the matrix is seen to consist of 0.5-2 μ wide, winding, taenite lamellae in a matrix of kamacite. Where the taenite expands to amoeba- or wedge-like shapes its interior is decomposed to a submicroscopic duplex structure. Within areas of similarly oriented sheen, the alignment and pattern of the decomposition products are the same. One of the conspicuous taenite directions is parallel to the band edges. It is believed that larger sections through Iquique would reveal two or three more band directions, as known from Hoba and Tlacotepec. The hardness of the duplex matrix is 204±8. The low hardness, relative to Tlacotepec, Hoba and Cape of Good Hope, is probably an annealing effect from the artificial reheating, reported by Rose (1873).

Figure 926. Iquique (Berlin). A cluster of kamacite spindles indicating the $(111)_\gamma$ directions of the parent taenite crystal Etched. Scale bar 100 μ.

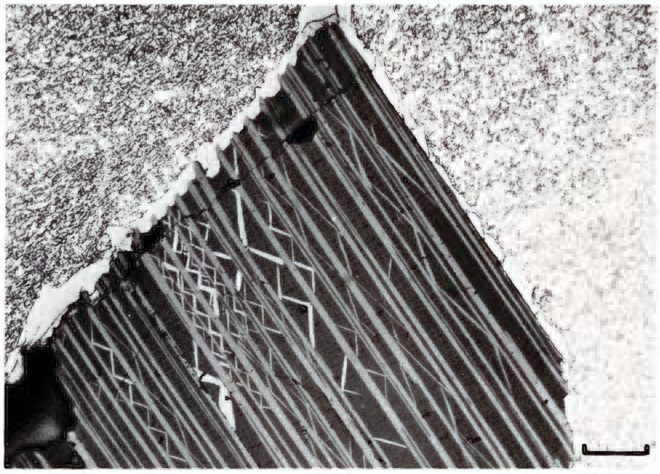

Figure 927. Iquique (Berlin). A troilite-daubreelite nodule. The daubreelite (light gray) forms lamellae parallel to (0001) of the hexagonal troilite. The troilite shows multiple twinning due to shock-deformation. Narrow rims of kamacite are also visible. Etched. Slightly crossed polars. Scale bar 50 μ. Compare Figure 170.

Acicular- to bar-shaped α-lamellae, typically 150 x 20 μ in size, occur with an average frequency of about eight per square millimeter. They are unevenly distributed and are often found in clusters around a tiny schreibersite crystal which may have acted as nucleus.

Schreibersite occurs as 5-25 μ irregular bodies in the α-spindles and as fine nodules, less than 2 μ across, in the plessitic matrix. Around some schreibersite crystals there appear 1-2 μ beads of taenite which evidently have become detached from the phosphides by annealing. It may be an indication of the heating by the workmen which Rose reported, but the temperature has probably not exceeded 600° C.

Troilite occurs as 0.5-3 mm lenticular and rhombic inclusions with a frequency of about one per 8 cm^2. It is the only mineral visible to the naked eye on the otherwise homogeneous sections. The inclusions are composed of stacks of alternating parallel lamellae of daubreelite and

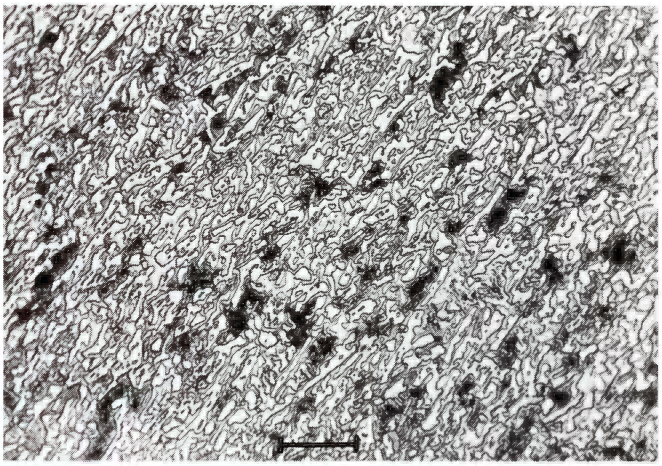

Figure 928. Iquique. Detail of Figure 926. The duplex mixture of α and γ is clearly seen; α is white; γ is gray or even darker, having decomposed on a submicroscopic scale. Etched. Scale bar 20 μ. See also Figure 129.

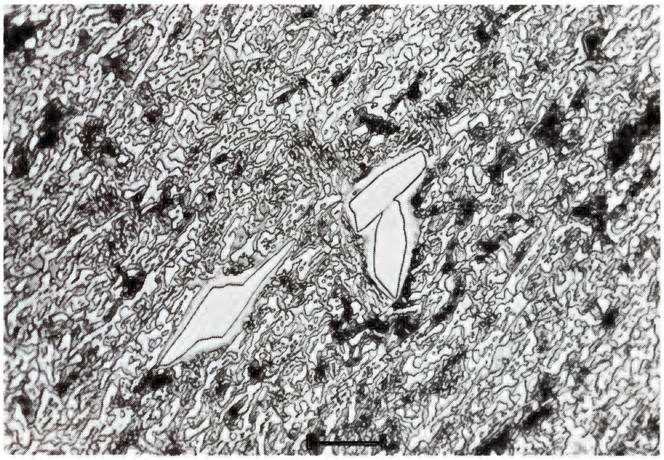

Figure 929. Iquique (Berlin). The duplex α + γ mixture in another area of a differently oriented sheen. In the center, small kamacite spindles with taenite rims. Etched. Scale bar 20 μ.

troilite. Individual lamellae range from 1 to 100 μ width, the troilite normally constituting about two-thirds of the inclusions. The troilite displays deformation twinning but is also recrystallized to 25-100 μ units in other places which, again, may be an indication of the artificial reheating.

The daubreelite lamellae frequently protrude 1-10 μ from the periphery of the sulfide nodules; α-spindles are nucleated in irregular ways on the inclusions, and some have started an acicular growth. Locally, a 10-15 μ wide, solid taenite rim is in direct contact with the troilite-daubreelite.

Iquique is closely related to such ataxites as Hoba, Kokomo and Tlacotepec. The reported reheating fortunately was so mild that only minor damage was induced. Chemically, Iquique is a typical group IVB. The peculiar surface sculpture deserves further study.

Specimen in the U.S. National Museum in Washington:
158 g slice (no. 1230, 11 x 4 x 0.8 cm)

Iredell, Texas, U.S.A.

31°54'N, 97°54'W; 350 m

Coarsest octahedrite, Ogg. About 5-15 mm thick kamacite fingers. Neumann bands. HV 222±10.

Group IIB. 6.0% Ni, above 0.2% P, 58 ppm Ga, 161 ppm Ge, 0.06 ppm Ir.

While two-thirds was lost about 500 g has been preserved, only little damaged. Perhaps a transported fragment of El Burro.

HISTORY

A mass of about 1.5 kg was found in 1898 by J.W. Jones, while he was prospecting, on the eastern end of the Dudley sheep ranch in Bosque County 9 km south of Iredell (Foote 1899b). The corresponding coordinates are given above. The mass lay exposed in a worn rut, 15 cm deep, in an old road; the finder broke the mass and distributed pieces to various people, some of whom forged knife blades from them. Only about 500 g could be secured by Foote who marketed the material and described it briefly with an analysis by Whitfield. A fragment of 15 g was examined by Cohen (1902a; 1905: 225) who concluded that Iredell was a normal hexahedrite, a conclusion which hitherto has not been disputed. Buchwald (Hey 1966: 215) drew attention to the fact that part of the specimen had been forged, implying that the whole mass might have been reheated artificially. A forged knife blade of 9 g is in Ottawa (Foote 1912: 57; Dawson 1963: 33). Bauer (1963) measured the ^{3}He and ^{4}He concentrations and found them to be significantly higher than in other hexahedrites. His estimated age of 450 million years is also high for a hexahedrite. But, as shown in the following, Iredell is not a hexahedrite.

COLLECTIONS

New York (180 g), Washington (97 g), Rome (92 g), Ottawa (17 g), Chicago (11 g), Greifswald (6.5 g), Berlin (5.5 g).

DESCRIPTION

The specimen in the U.S. National Museum is an irregular, angular fragment corroded along its entire surface. It is composed of several finger- or plate-shaped grains which are separated by more or less corroded grain boundaries. Also, the fragment in New York appears to be composed of several finger-sized kamacite individuals. When the finder broke the mass, his task was, therefore, not difficult; it is incomparably easier to split a corroded coarsest octahedrite than a corroded hexahedrite which generally possesses no weakened grain boundaries. No fusion crust and no heat-affected rim zones are preserved. The lawrencite reported by Foote (1899b) should not be taken as anything else than a statement to the effect that the iron is corroded and probably of considerable terrestrial age.

An etched section of 2 x 2 cm disclosed only two kamacite grains, but these were clearly separated by a high angle grain boundary, and the numerous rhabdites were oriented differently in the two grains. Neumann bands are common and straight except near the hammered surfaces where they are bent and offset by lenticular deformation bands. Subgrain boundaries are present, normally decorated with 0.5 μ phosphides. The hardness is 222±10, indicating significant cold-deformation; on the basis of the small examined specimen alone, it is difficult to decide whether the deformation is mainly cosmic or mainly artificial, but the first possibility appears most plausible.

Schreibersite is present as 12 x 3, 4 x 0.4, 2 x 2 and 1 x 0.5 mm monocrystalline crystals, the largest of which occupy central positions in the kamacite crystals. Schreibersite is further present as 10-40 μ wide precipitates in the high angle grain boundaries. Along each side of the grain boundaries is a 100-200 μ wide zone almost free of phosphide precipitates. The matrix, farther away, is loaded with 3-10 μ thick and up to 100 μ long rhabdite prisms. Most schreibersite and rhabdite crystals are severely broken – apparently mainly due to cosmic kneading.

Troilite and other minerals were not observed in the accessible sections.

Iredell is not – as is generally believed – a hexahedrite but a coarsest octahedrite related to El Burro, São Julião, Sikhote-Alin and other irons of group IIB. While most of

IREDELL – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Wasson 1970, pers. comm.	6.0±0.2								58	161	0.06	

the material was forged or otherwise lost, at least some fragments, e.g., the U.S. National Museum specimen, reached museums undamaged except for slight deformation from cold-chiseling.

Considering that the meteorite was discovered on an old road, the question arises whether Iredell was in fact a small mass transported from somewhere else. The only meteorite with which it might be associated is El Burro. The major and minor elements, macro- and microstructure, hardness and the state of corrosion of these two irons tally extremely well. Had they been found closer together, no one would hesitate to consider them fragments of the same fall. As it is, Iredell was discovered about 450 km northeast of El Burro, so we can only suggest the possibility that Iredell was transported.

Specimen in the U.S. National Museum in Washington:
97 g fragment (no. 261, 6 x 3 x 2 cm)

Iron Creek, Alberta, Canada

Approximately 53°N, 112°W

Medium octahedrite, Om. Bandwidth 1.05±0.15 mm. Annealed ϵ. HV 240±10.

Group IIIA. 7.72% Ni, about 0.17% P, 20.2 ppm Ga, 39.6 ppm Ge, 3.3 ppm Ir.

HISTORY

A mass of 175 kg (386 pounds) was seen in 1871 and reported by Butler (1872: 304) as being in the farmyard of the mission station of Victoria, a village now abandoned but previously located at the North Saskatchewan River about 140 km east-northeast of Edmonton. Butler stated that it had lain on the summit of a hill on the prairies south of Victoria and that it had been known by the Cree and Blackfoot Indians longer than any man could say. The mass was highly venerated, and tribute was paid in form of beads, trinkets or knives. When the mass was removed shortly before Butler arrived, the loss was regretted by the Indians and dire prophecies as to the effect were spelled out. A few months later severe smallpox plagued the Indians. It was Flight (1887: 53) who drew attention to Captain Butler's story. Additional information was provided by Coleman (1886) who stated that the mass had been transported about 1870 by Mac Dougall the 150 miles north to Victoria from Iron Creek, a tributary to Battle River. The meteorite was forwarded to the Victoria University, in Toronto. Brezina (1896: 279) gave a brief description, while Farrington (1907: 113) thoroughly discussed the exterior shape which he found resembled Cabin Creek. He gave three photographs of a cast of the meteorite. Farrington (1915) reviewed the literature.

COLLECTIONS

Toronto, Victoria University (main mass), Chicago (251 g), Washington (121 g), Vienna (117 g), New York (89 g), London (79 g), Berlin (28 g), Ottawa (12 g).

DESCRIPTION

According to Farrington, the overall dimensions of the mass, which is turtle-shaped, are 56 x 43 x 22 cm. There is a flat or slightly concave side, and there is a convex side with an apex offset relatively to the circumference. Although the symmetry is far from perfect, it is clear that the mass penetrated the atmosphere in a stabilized way whereby the low cone was created by ablation of the front side. Deep flutings, e.g., 7 x 2 cm, radiate more or less perfectly from the apex of the cone. On the slightly concave rear side the depressions are shallower and generally quite large, about 5-8 cm in diameter. Sections, like No. 8476 in Vienna and No. 1173 in the U.S. National Museum, indicate that the fusion crust is exceedingly thin on the convex side but increases irregularly to 1 mm and possibly more in the depressions on the rear side. The preserved fusion crust is composed of an exterior layer of 10-25 μ blackish oxides and an interior, laminated succession of metallic, dendritic crusts. The metallic fusion crust includes several oxide globules and has a hardness of 285±20. Under the fusion crust follows a 2-4 mm wide zone of α_2, in which micromelted phosphides are present in the outer 40-50%. The α_2 zone has a hardness of 215±15.

Etched sections display a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 30$) kamacite lamellae with a width of 1.05±0.15 mm. All distributed sections appear

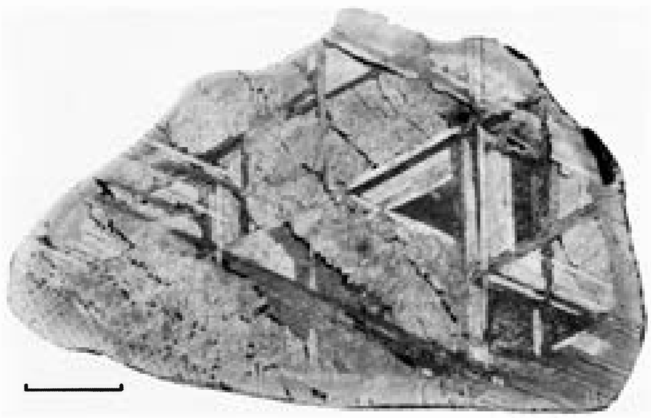

Figure 930. Iron Creek (U.S.N.M. no. 1173). Medium octahedrite of group IIIA cut almost parallel to $(111)_\gamma$ so that the fourth set of Widmanstätten lamellae appear as ragged plumes. Deep-etched. Scale bar 15 mm. S.I. neg. M-15.

IRON CREEK – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Scott et al. 1973	7.72								20.2	39.6	3.3	

to be successive cuts almost parallel to an octahedron face, and, therefore, the fourth Widmanstätten direction shows up as irregular, ragged, broad ribbons across the three other directions. The oriented sheen is silky or velvety because the kamacite is transformed by shock to the finely hatched ϵ-type. Subgrain boundaries decorated with 1 μ phosphides are common. The ϵ-structure is somewhat anomalous; it is not of the clear-etching type but is marked by a host of submicroscopic γ-precipitates, evidently due to a mild cosmic tempering. The relatively low hardness of 240±10 is in accordance with this interpretation. A further proof of the presence of numerous precipitates is found in the atmospheric alteration zone. Here we normally observe a clear $\alpha \rightarrow \gamma \rightarrow \alpha_2$ transformation producing marked, serrated α_2 units. But, in Iron Creek, the finely disseminated γ-particles prevented the clear structure from forming, and it is, in fact, difficult to identify the exact extent of the α_2 zone, unless other means, as microhardness, phosphides and taenite, are resorted to as a support.

Plessite occupies about 40% by area, mostly as open-meshed comb and net plessite with discontinuous taenite rims. Some fields display poorly resolvable $\alpha + \gamma$ mixtures or martensitic areas where the individual platelets are parallel to the gross Widmanstätten pattern. A typical plessite field will show a tarnished taenite rim (HV 240±10) followed by various martensitic transition zones (HV 365±25). The duplex, poorly resolvable $\alpha + \gamma$ mixtures (HV 325±25) are followed by easily resolvable $\alpha + \gamma$ mixtures with hardnesses that approach that of the adjacent kamacite.

Schreibersite occurs sparingly as 20-50 μ wide grain boundary precipitates and as an occasional 200 x 200 μ monocrystalline block. It is further present as 10-50 μ irregular blebs inside the plessite fields. Locally, well-developed, 15 μ thick rhabdite prisms were observed, but the matrix generally appears to have only much finer rhabdites about 1 μ thick. It is estimated that the meteorite contains 0.15-0.20% P.

Troilite is present as 0.5-4 mm nodules enveloped in 1-2 mm swathing kamacite. In the matrix are numerous hard, tiny platelets, 20 x 1 μ, of the chromium nitride, carlsbergite. In the heat-affected α_2 zone at the isotherm about 1200° C the rhabdites were melted, but the chromium nitride was unaffected.

Iron Creek is a well-preserved medium octahedrite, related to Frankfort, Norfork, Ivanpah and Briggsdale, and it belongs to group IIIA. Its structure and hardness suggest some annealing after a cosmic shock event.

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

12 g part slice (no. 417, 3 x 1.3 x 0.4 cm)
109 g slice (no. 1173, 10 x 6 x 0.3 cm)

Iron River, Michigan, U.S.A.

46°4′42″N, 88°35′30″W

Fine octahedrite, Of. Bandwidth 0.28±0.03 mm. Neumann bands.

Group IVA. 7.87% Ni, about 0.05% P, 2.1 ppm Ga, 0.12 ppm Ge, 2.1 ppm Ir.

HISTORY

A mass of 1.42 kg was listed in Hey's Catalog (1966: 215) as a recently recognized fine octahedrite from Michigan. Chamberlain (1969), who had acquired the mass for Michigan State University, stated that it had been found in 1889 near the town of Iron River, Iron County. The finder, a six-year-old boy, had kept the meteorite in his possession until 1965, and no examination had previously been carried out.

Jain & Lipschutz (1970) found that diffraction patterns of kamacite from Iron River resembled those of Bristol and Hill City and suggested deformation by exposure to high-stress processes, perhaps shock-loading to pressures near but below 130 k bar. Voshage (1967) examined the potassium isotopes and found a ^{41}K-^{40}K cosmic ray exposure age of 360±70 million years. Schaudy et al. (1972) included Iron River in their description of group IVA.

COLLECTIONS

Michigan State University, East Lansing (main mass).

DESCRIPTION

The following is only preparatory information based on insufficient material. The mass measures about 11 x 8 x 5 cm and is quite well-preserved. Fusion crust appears to be present, and an etched section shows a distinct α_2 zone which, in places, is considerably more than 3 mm wide. An examination should be made to see whether this is due to taper-sectioning or whether it is a true thickness since the latter case would be fairly unusual.

Iron River is a fine octahedrite with straight, long ($\frac{L}{W} \sim 40$) kamacite lamellae with a width of 0.25-0.30 mm. The kamacite displays Neumann bands and resembles that of Charlotte and Bristol. Plessite and taenite occupy about 40% by volume, the former occurring mainly as comb and net plessite. Open-meshed finger plessite and cellular plessite, so characteristic for Gibeon and other irons of group IVA, are also present in significant amounts.

Schreibersite was not observed, and it is estimated that the bulk phosphorus content is below 0.06%.

IRON RIVER – SELECTED CHEMICAL ANALYSES

	percentage			ppm							
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Schaudy et al. 1972	7.87								2.12	0.118	2.1	

Troilite was not present in the section examined. Daubreelite occurs as small subangular particles, 20-50 μ across, in the kamacite phase.

Iron River seems to be a normal fine octahedrite closely related to such well known irons as Gibeon, Charlotte and Bristol.

Further information with photographs of the exterior shape, micrographs of etched sections and microprobe examination of individual phases may be found in Chamberlain (1971), a paper which was published after the completion of this study.

Itutinga, Minas Gerais, Brazil
21°20'S, 44°40'W

According to Hey (1966: 217), who had his information from Walter S. Curvello, a mass of unknown weight was found near Itutinga before 1960.

The following notes are from a brief examination of a sample on loan to the Smithsonian Institution in 1968.

The sample weighed 338 g and was a full slice through the mass. Since it measured 11.5 x 8 x 0.6 cm, it is estimated that the whole mass weighs more than 4 kg. Fusion crust and heat-affected α_2 zones were not detected and were presumably lost by weathering. The examination is, however, considered insufficient due to the deep-etching of the section.

Itutinga is a medium octahedrite displaying straight, long ($\frac{L}{W} \sim 25$), often bundled kamacite lamellae with a width of 1.0±0.2 mm. Taenite occurs as numerous lamellae and the comb plessite is of the open, degenerate variety where little taenite is actually left. Schreibersite was not detected, so it appears that the bulk phosphorus content is less than 0.1%. Troilite occurs as scattered particles, 1-3 mm across. Cohenite and silicates were not observed.

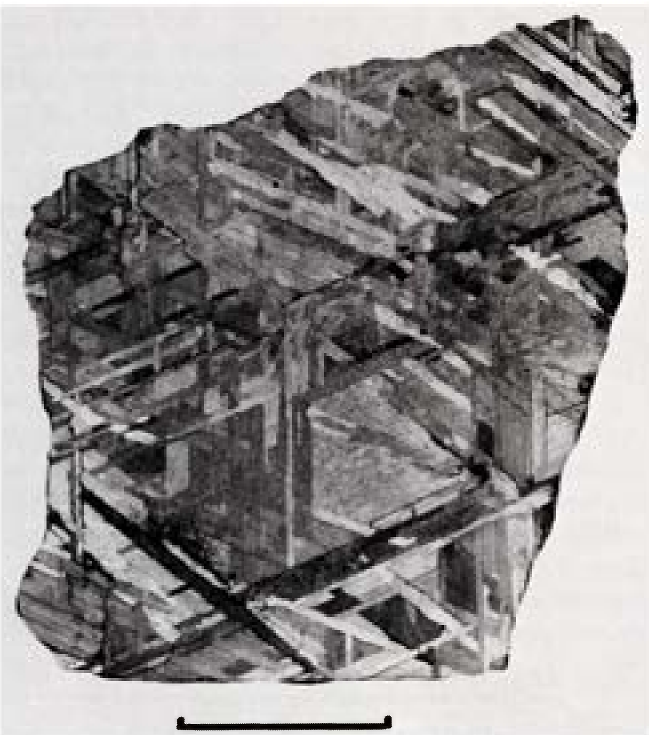

Figure 931. Itutinga. Loan from W.S. Curvello. A medium octahedrite of group IIIA with shock-hatched kamacite. Deep-etched. Scale bar 30 mm. S.I. neg. M-1483.

The preliminary structural examination suggests that Itutinga is a shock-hardened medium octahedrite of group IIIA, resembling, e.g., Henbury. It is different from the other iron meteorites reported from that part of Brazil, i.e., Angra dos Reis, Casimiro de Abreu, Para de Minas, Piedade do Bagre, Patos de Minas (H), Pirapora, and Santa Luzia.

On a brief visit to the Museum of Natural History, Rio de Janeiro, in March 1973, three further corroded cut pieces of Itutinga were recorded. They were labeled 49 Mt and weighed 2,120 g, 629 g, and 111 g, respectively. On the other hand, it was not possible to detect the original location and weight of the find. The author has a feeling that material from Itutinga, Barbacena and Cratheus (1950) has somehow been mixed up. New full descriptions and some detective work are, in the author's opinion, required in order to have all three (?) meteorites redefined.

Ivanpah, California, U.S.A.
35°20'N, 115°20'W; 1,050 m

Medium octahedrite, Om. Bandwidth 1.05±0.15 mm. ϵ-structure. HV 310±12.

Group IIIA. 7.51% Ni, about 0.17% P, 0.05% S, 21 ppm Ga, 38 ppm Ge, 3.8 ppm Ir.

HISTORY

A mass of 58 kg was found in 1880 about 15 km from Ivanpah in San Bernardino County. The meteorite was found on the surface, in a wash, by the prospector Stephen Goddard who was surveying the Colorado Basin (Shepard 1880). The exact locality was not given. The town Ivanpah has the coordinates given above. Cohen (1892) presented the only reliable analysis performed, and Brezina (1896) gave a short metallographic description. Nininger & Nininger (1950: plate 5) gave a photomacrograph. According to Linsley (1934) the main mass is almost undivided in The Ferry Building in San Francisco.

COLLECTIONS

Museum of the Division of Mines, San Francisco (about 53 kg), Washington (3,115 g), New York (508 g), Harvard (336 g), Chicago (220 g), Vienna (68 g), London (33 g), Tempe (20 g).

DESCRIPTION

The oval mass has the overall dimensions 35 x 23 x 18 cm and weighs about 58 kg. It displays numerous regmaglypts, generally 2-6 cm across, from the atmospheric sculpturing. Shepard (1880) mentions three round holes, 2 cm deep and the size of a little finger. They are probably due to troilite inclusions that burned away in the atmosphere. The exterior is covered with 0.1-0.8 mm terrestrial oxidation products, and the fusion crust has disappeared. A 1.5-2.5 mm thick, heat-affected α_2 zone is, however, preserved along the edge of several of the specimens studied, so the general from of the meteorite is well-preserved. The α_2 rim has a hardness of 210±10; the hardness increases to 310, a level which is reached in the unaffected interior at a depth of about 10 mm (hardness curve type I).

Etched sections disclose a well developed Widmanstätten structure of bundled, long ($\frac{L}{W} \sim 30$) kamacite lamellae 1.05±0.15 mm wide. The fourth Widmanstätten direction is represented on the U.S. National Museum sections by 3-6 mm wide kamacite fingers with ragged edges of shiny 10 μ wide taenite. All kamacite is, due to shock above 130 k bar, transformed to the marked, crosshatched ϵ-variety, with a hardness of 310±12. A former subboundary network in the ferrite is, however, clearly visible; it is in places decorated by 1-2 μ phosphides.

Plessite occupies about 40% by area, partly as comb and net plessite, partly as poorly resolvable, duplex $\alpha + \gamma$ structures. The taenite often tarnishes or etches in brownish hues, indicating a certain amount of carbon in solid solution. Where the taenite ribbons happen to be situated in the heat-affected zone, the tarnishing has disappeared, and the taenite is, instead, surrounded by a carbon-rich bainitic-martensitic rim 10-20 μ wide. Similar structures are discussed in, e.g., Thule, Kayakent and Bagdad.

Schreibersite is present as 20-50 μ wide grain boundary precipitates, substituting for taenite. It is monocrystalline but slightly brecciated. Schreibersite is further common as 2-10 μ angular blebs in the comb and net plessite. Rhabdites, 1-2 μ in diameter, are ubiquitous in the lamellae. The bulk phosphorus content is estimated to be 0.15-0.20%.

Troilite is common, mostly as 0.5-2 mm angular nodules, but occasionally a larger one may be found. On sections, totaling 360 cm^2, 76 nodules were counted, with a total area of 80 mm^2, corresponding to a total of about 0.05% S in the alloy. Many of the nodules are built around a 30-50 μ chromite crystal. The nodules have about 20% daubreelite in form of parallel lamellae, ranging from 1-200 μ in width (HV 380±30). Direct contact between daubreelite, chromite and troilite is frequently observed. The troilite itself shows slender, lenticular deformation twins which are particularly conspicuous under crossed Nicols (HV 260±25). A 20-50 μ discontinuous schreibersite rim surrounds the whole aggregate.

Ivanpah is a well-preserved medium octahedrite with ϵ-structure and heat-affected α_2 zone. It is closely related to such group IIIA irons as Canyon City, Bagdad and Kayakent.

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

310 g slice (no. 755, 9 x 8 x 0.6 cm)
1,469 g slice (no. 1369, 22 x 18 x 0.7 cm)
1,190 g slice (no. 1369, 19 x 16 x 0.7 cm)
29 g part slice (no. 1045, 3 x 3 x 0.5 cm)
85 g turnings and cuttings (no. 73; nos. 3323 and 3324)

Jackson County, Tennessee, U.S.A.

Approximately 36°20'N, 85°41'W

Medium octahedrite, Om. Bandwidth 1.20±0.20 mm. Artificial α_2. HV 176±8.

Probably group IIIA. 8.4% Ni, 0.2% P, based upon what remains of the structure.

Jackson County is artificially reheated to about 1050° C; it is highly probable that it is a fragment of Carthage.

HISTORY

A fragment of 425 g (15 ozs) was described briefly by Troost (1846). He had acquired it, accompanied by 85 g oxidized shale, from Samuel Morgan, of Nashville, Tennessee, but neither of them was able to get possession of the main mass, of unknown size, since its owner considered it a valuable silver ore. It was allegedly found in Jackson County. The coordinates given above are for the county seat, Gainesboro. Brezina (1886: 211) compared the material to Trenton, while Wülfing (1897: 163) suggested that it was a fragment of Cosby's Creek. Berwerth (1905: 353) noted that the granulated kamacite could be due to artificial reheating, a conclusion which was supported by observations of Buchwald (Hey 1966: 218).

ANALYSIS

No analysis is available.

COLLECTIONS

Chicago (116 g), London (91 g), Washington (46 g), New York (45 g), Vienna (13 g), Ottawa (13 g), Berlin (2 g).

DESCRIPTION

All known pieces are rough fragments, more or less cleaved along octahedral planes. Specimen No. 540 in the U.S. National Museum is no exception. It shows chisel and hammer marks and is partially opened along the octahedral cleavage planes. It is an internal fragment not extending to the natural crust.

The etched section displays an indistinct, medium Widmanstätten structure of distorted kamacite lamellae with a width of 1.20±0.20 mm. Comb and net plessite fields cover about 30% by area. Schreibersite is common as 30-60 μ wide grain boundary precipitates and as 5-40 μ blebs inside the plessite fields. Troilite was once present, but its mode of occurrence can not be learned since it has melted and seeped away. The mass is corroded, particularly along the phosphides and in the alpha phase of the plessite fields.

IVANPAH – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Scott et al. 1973	7.51								21.1	38.1	3.8	

The structure, as summarized above, is significantly altered by artificial reheating to about 1050° C. The kamacite is decomposed to lobed α_2 units, 50-300 μ across, and with a hardness of 176±8. The taenite is diffuse and spheroidized but not yet completely dissolved. All phosphides are micromelted and have formed rounded pools in the grain boundaries. The troilite has melted and reacted with oxygen and with the corrosion products present in the meteorite before the reheating took place. The resulting, low melting liquid was mobile enough to shift place and creep into many of the octahedral fissures opened by hammering. It solidified here to dendritic, ternary Fe-S-O eutectics which incorporated gray bars of various high temperature oxides. Some of these complexes are now 3 x 0.2 and 5 x 0.1 mm in size, filling the fissures partially.

From what is preserved of the original structure, it appears that Jackson County was a medium octahedrite with about 8.4% Ni and 0.2% P, and belonging to group IIIA. It is interesting to note that Carthage, an iron of 127 kg, is of this composition and structure and, moreover, was found in the neighboring county only a few years before. Not only this, but the Jackson County fragment was acquired by the same collector, Morgan, and described by the same professor, Troost, who learned about Carthage. It appears almost certain that Jackson County is a fragment of Carthage, even more heated and forged than this and only considered an independent mass because the original owners "kept the history, quantity and locality in profound secrecy" (Troost 1846).

Specimen in the U.S. National Museum in Washington:
46 g octahedral fragment (no. 540, 4 x 3 x 1 cm)

Jamestown, North Dakota, U.S.A.

46°42'N, 98°35'W; 400 m

Fine octahedrite, Of. Bandwidth 0.26±0.04 mm. Annealed ϵ-structure. HV 210±10.

Group IVA. 7.53% Ni, 0.38% Co, less than 0.05% P, 1.80 ppm Ga, 0.093 ppm Ge, 3.5 ppm Ir.

HISTORY

A mass of 4,015 g was found in 1885 during the construction of the James River Valley branch of the Northern Pacific Railway, about 15 or 20 miles southeast of Jamestown, Stutsman County (Huntington 1890). The exact locality is not known but must be close to the present Montpelier which has the coordinates given above. The meteorite was found within five feet of the railroad track by one of the workmen. It was acquired by Huntington, who cut and distributed it, and gave a description with figures of the exterior and of an etched slice. Cohen (1905: 370) gave a description, and Brezina & Cohen (1886-1906: plate 35) supplemented it with two photomacrographs. Farrington (1915) reviewed the literature. Reed (1969) found no rhabdites and found the composition of the kamacite phase to be 7.2% Ni and 160 ppm P. The phosphorus figure is very low for an octahedrite, but similar to that of Obernkirchen and probably comparable to what will be found in, e.g., Huizopa and La Grange. Bauer (1963) examined the $^3He/^4He$ concentrations and gave an estimated exposure age of 100 million years.

COLLECTIONS

London (1,563 g), Chicago (581 g), Washington (329 g), Paris (144 g), Berlin (128 g), Tübingen (103 g), Harvard (98 g), Vienna (98 g), New York (92 g), Vatican (52 g), Strasbourg (51 g), Ottawa (45 g), Bonn (36 g), Rome (7 g).

DESCRIPTION

The mass is one of the few irons, which like Arlington and Algoma, are very flat. Jamestown is in the shape of a low bowl with the approximate overall dimensions 26 x 13 x 3 cm. It has a smooth, convex side and an opposite, rather flat, pitted side; the sides meet along a curved edge, which is blunt along part of the periphery, but very sharp, wedge-like along the opposite parts. The many sections through the mass which have been taken resemble wing profiles of an airplane more than anything else, with a blunt leading edge and a sharp trailing edge. Although the meteorite is rust-brown and covered by terrestrial oxides that in places increase to a thickness of 0.4 mm, it is quite clear that the shape of the meteorite is only little influenced by corrosion and represents an aerodynamic shape, produced by ablation during the atmospheric entry. A little, weathered fusion crust with striae may still be seen on the convex side.

The heat-affected α_2 zone is 2-3 mm thick along the convex side but increases to 5 and 10 mm at the trailing edge where all the material is transformed to α_2. The hardness is 195±20 (hardness curve type II). On the opposite, pitted side the α_2 zone is absent or less than 0.2 mm in thickness. The spherical, branching pits are either empty or filled with fine-grained metallic eutectics with concentric and excentric growth rings which convey the impression that the metal has been deposited in whirlpools. It is surprising that the metal immediately below the melt-filled pits shows bent and deformed

JAMESTOWN – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Hey 1966: 619	7.6	0.38				359	145		1	1		
Schaudy et al. 1972	7.45								1.80	0.093	3.5	

structures, appearing compressed and sheared at the same time. The microhardness is accordingly higher than elsewhere, 240±15. Around a 4 mm spherical pit is a 2 mm α_2 zone, and around a 10 mm undercut, irregular pit, just behind the leading edge, is a 6 mm α_2 zone, but otherwise the heat-affected zone on the pitted side is quite thin, below 0.2 mm. Jamestown appears to be an extreme example of oriented flight, where relatively slow ablation took place on the convex side, particularly slow along the trailing edge, while cavity-producing air whirls on the flat underside rapidly devoured this part of the meteorite. The hardness variations are unexpected and interesting.

Etched sections display a contrastless, fine Widmanstätten structure with a silky sheen. The kamacite lamellae are distorted, long ($\frac{L}{W} \sim 30$) and have a width of 0.26±0.04 mm. The kamacite matrix is of the hatched type, ascribed to shock pressures above 130 kb bar, but it is evidently not alone a shock-transformation product since it is decomposed to a very fine, two-phase mixture with distinctly visible 0.3-1 μ grains, probably of austenite, all over. This is one reason why the etched surface appears dull and contrastless to the naked eye. The duplex kamacite lamellae have hardnesses of 210±10.

Plessite occupies about 40% by area as open-meshed comb and net plessite fields, as duplex, easily resolvable $\alpha + \gamma$ fields and, in minor amounts, as cellular plessite of the Chinautla type. The plessite areas are so nickel-poor, have so few interior taenite blebs and so thin a framing taenite that they are hardly recognizable, which is another reason why the etched surface appears dull to the naked eye. The plessite and taenite are locally severely distorted, sheared and folded. The taenite areas have hardnesses of 235±20.

Schreibersite was not observed and is probably not present at all, indicating a total phosphorus content below about 0.05%. The metal is very ductile and may, due to the absence of grain boundary precipitates, be bent repeatedly back or forth or rolled to thin plates, as demonstrated by Huntington (1890).

Troilite is present as 0.5-5 mm rhombic to lenticular bodies that occur with a frequency of about one per 3 cm^2. They contain 10-300 μ wide daubreelite lamellae which often are shattered and displaced. The troilite itself has been melted and has dissolved part of the surrounding metal, whereupon it has solidified to 1-20 μ fine-grained, metal-sulfide eutectics. It is interesting to note that what at first appears to be only corrosion-filled fissures are, in fact, zigzagging, 2-10 μ wide troilite melts that have been squeezed from the troilite nodules and injected millimeters or centimeters out into the fissured metal, mainly along (111) planes, but occasionally cutting across kamacite grains.

Daubreelite is common as 10-100 μ isolated, angular grains in the kamacite. Some appear to be two-phased and a little anisotropic, and they may contain brezinaite. What is particularly interesting is that the daubreelite often appears with only the remnants of a little troilite, the rest having been squeezed away as 2-10 μ wide stringers into the metal. The remaining daubreelite is then often in the shape of parallel lamellae with cavities or with metal between the bars; compare Willamette.

As well as the distorted metal structures, the sulfide morphology strongly indicates that Jamestown was exposed to shock that point melted the troilite, fissured the metal and injected the melt into it. The accompanying relaxation heat appears to have annealed the ϵ-structure without actually recrystallizing the metal. The event must have been preatmospheric and has created the structure that in several respects resembles Huizopa and La Grange.

Jamestown is further remarkable for its aerofoil shape and the large differences between the two sides of the "foil", notably in deformation and hardness. A somewhat similar shape is present in Washington County.

It is a fine octahedrite, structurally related to Huizopa, La Grange, Obernkirchen and Yanhuitlan, but it appears in its low nickel and phosphorus content and in its small bandwidth to be something of an end member. In its trace element content it is a typical IVA iron.

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

83 g slice (no. 350, 11 x 2.1 x 0.6 cm)
74 g slice (no. 1046, 11 x 2.3 x 0.4 cm)
68 g part slices (no. 2838, various specimens)
102 g slice (no. 3325, 11 x 2.5 x 0.6 cm)

Jefferson. See Bear Creek (Jefferson)

Jenkins, Missouri, U.S.A.

36°49′28″N, 93°45′40″W; 400 m

Coarse octahedrite, Og. Bandwidth 2.3±0.5 mm. Neumann bands. HV 200±15.

Group I. 6.85% Ni, about 0.2% P, 86 ppm Ga, 353 ppm Ge, 1.8 ppm Ir.

HISTORY

A mass of 55.2 kg (122 pounds) was found by Earl Patton in 1946 about five miles northwest of Jenkins, and 1.7 miles east of Mc Dowell in Barry County. It was recognized as a meteorite in 1965 and was acquired by

JENKINS – SELECTED CHEMICAL ANALYSES

	percentage			ppm							
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Wasson 1970a	6.85								86.2	353	1.8	

Read who gave a thorough description (1967) with photographs of the exterior and of an etched section. Read also provided a detailed map. The meteorite had been found on the surface of a field in Section 34, Township 25N, Range 26W; the corresponding coordinates are given above. In December 1966 the meteorite was purchased by the U.S. National Museum.

COLLECTION

Washington (55 kg).

DESCRIPTION

The mass is roughly in the shape of a triangular prism with the average dimensions of 36 x 20 x 20 cm. It is apparently much weathered and covered with loosely adhering, 0.2-1 mm thick flakes of terrestrial oxides. Sections perpendicular to the surface reveal, however, that a 0.1-2 mm thick, heat-affected α_2 zone is still irregularly preserved, and even micromelted phosphides may be identified in the outer part of the zone. It may, therefore, be concluded that on the average about 2 mm of the metal is lost by weathering and that the present shape almost truly reflects the ablation surface. The regmaglypts are 2.5-3.5 cm across and up to 3 cm deep, and there are some basin-shaped depressions, 12 x 10 cm in aperture and 4 cm deep. Five cylindrical pits are 5-10 mm in diameter, while three are 15-25 mm in diameter; one of these reaches a depth of 30 mm. The pits are holes left when troilite burned out in the armosphere. On sections it is seen that the graphite-rich troilite nodules were more refractory than the pure troilites and better resisted the ablation heat. The pits are somewhat modified by corrosion. One of the three roughly prismatic faces is rather flat and may represent a fracture surface from atmospheric breakup modified by ablation.

Etched sections display a coarse Widmanstätten structure of bulky, short ($\frac{L}{W} \sim 10$) kamacite lamellae with a width of 2.3±0.5 mm. Local grain growth has transgressed over many former lamella boundaries with taenite and schreibersite and created almost equiaxial kamacite grains, 5-15 mm in diameter. The kamacite has subboundaries decorated with phosphides, 1-10 μ thick. It displays numerous Neumann bands and has a hardness of 205±15. The hardness reaches a minimum of 150±5 just inside the heat-affected α_2 zone, and the α_2 zone itself is 190±10 hard (hardness curve II).

Taenite and plessite cover 3-5% by area, either as almost resorbed comb plessite or as taenite wedges and ribbons. The tarnished taenite has a hardness of 350±25, while taenite with acicular kamacite lamellae is softer, 260±30. The high-nickel, high-carbon areas of the taenite wedges have transformed to acicular martensite.

Schreibersite is present as scattered skeleton crystals, 1-10 mm in size. They are monocrystalline and are enveloped in 0.1-0.3 mm thick rims of cohenite, followed by 1-5 mm wide rims of swathing kamacite. Schreibersite is further common as 20-100 μ wide grain boundary veinlets and as 0.2-0.5 mm wide rims around the troilite nodules. Rhabdites are common. They are 5-25 μ thick normally but decrease to less than 1 μ in size near the larger schreibersite crystals. It is interesting to note that the Neumann bands are 2-10 μ wide where the rhabdites are coarse but less than 1 μ wide where the rhabdites are fine. This proves that all major precipitation had occurred when the Neumann-band-forming event took place, since the size of the precipitates was able to influence the dimensions of the mechanical twins. The bulk phosphorus content is estimated to be about 0.2%.

Cohenite occurs centrally in the kamacite lamellae as small elongated bodies and rosettes, typically 2 x 0.6 mm in size. The "black in the circle" on Figure 4 in Read (1967) is not schreibersite, but cohenite. The hardness is 1085±35. The cohenite crystals are clustered in patches, 2-4 cm across, while they are absent in many other areas.

Troilite is common as nodules which include varying amounts of graphite. One particular nodule had almost pure troilite at one end, while the other was an intimate spongy mixture of troilite and graphite. The nodules have nucleated the usual rims of schreibersite (0.2-0.5 mm wide) and of cohenite (0.1-0.5 mm wide). Daubreelite occupies about 5% by area of the troilite, but it is completely shattered and partly dissolved. The troilite is heavily distorted and decomposed into 50-100 μ units with undulatory extinction. In shear zones and along phase boundaries it is shock-melted and solidified to 1-5 μ aggregates. Troilite veins penetrate the adjacent schreibersite, and 5-50 μ fragments of the schreibersite are found dispersed in the troilite melt. What appears to be glass, possibly from shock-melted silicate grains, is also scattered through the nodules.

The meteorite is weathered. Limonitic veins, 0.1-1 mm wide, follow the grain boundaries and the phosphides; it appears that some intercrystalline cracks were already present when the meteorite landed and that these cracks were rapidly attacked by terrestrial ground water. The lawrencite, described by Read (1967), could not be identified. Only an ocher-brown rust spot indicates the location. It is along a deep crack between a troilite-schreibersite-cohenite nodule and the surrounding kamacite, and this crack is filled with corrosion products not preterrestrial magnetite as believed by Read. The chlorine-bearing mineral was probably not a cosmic mineral but a metastable corrosion product where most, if not all, of the chlorine had been provided by the ground water.

Jenkins is an inclusion-rich coarse octahedrite which is related to Seymour, Sardis, Yardymly and Cranbourne, and it is a typical member of group I. It may be a paired fall with Seymour.

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

50.0 kg main mass (no. 3201, 36 x 20 x 20 cm)
4.00 kg endpiece (no. 3201, 17 x 10 x 7 cm)
693 g part slide (no. 3201, 11 x 10 x 0.9 cm)
Minor slices and polished sections