

graphite plumes. A typical assemblage is a 1 x 0.1 mm rhabdite with a 0.1 mm wide halo of 5-25 μ ferrite grains, in which scattered moss agate-like graphite plumes, 100 x 20 μ , reach from the phosphide to the periphery of the recrystallized zone. The graphite is microcrystalline, composed of about 1 μ anisotropic crystallites. The cohenite, which previously occupied the space of the halo, is completely decomposed. The figure given by Perry (1944: plate 48) shows a typical configuration of phosphide (white plates), surrounded by granular ferrite (grayish) with graphite-plumes (black). A similar morphology is present in Uwet and Dungannon, and intermediate stages, where the cohenite is not yet completely decomposed, are found in, e.g., Goose Lake, Bolivia and Wichita County. The hardness of the serrated, granular ferrite is 110 \pm 10, indicating a low (1-2%) nickel percentage, which tallies with what one would expect in kamacite formed from a decomposed cohenite.

Troilite occurs as 1-20 mm irregular scalloped nodules which contain about 20% daubreelite and, as shown by Cohen (1905) and Frondel & Klein (1965), occasionally contain inclusions of millimeter-sized ureyite and unidentified silicates. The troilite is shock-melted and has dissolved part of the surrounding metal, whereupon it has solidified to fine-grained, 1-3 μ , sulfide-metal eutectics. The rimming schreibersite is partly shattered and dispersed as 1-100 μ fragments in the melt, while the daubreelite bars were shattered as well as partly dissolved, giving rise to numerous rounded 2-10 μ daubreelite blebs in the melt. Daubreelite is also present in the alpha matrix as 50-100 μ angular grains, occasionally with a little troilite but normally without. The daubreelite is surrounded by 5-20 μ schreibersite rims.

Fine, hard platelets, typically 20 x 1 μ , of carlsbergite are numerous in the metallic matrix. The platelets are relatively early precipitates since they are often found engulfed by 20-50 μ thick rhabdites.

Hex River is a hexahedrite characterized by its prominent parallel planes of rhabdites. It is closely related to Uwet, Chesterville, Bingera, Lombard, and Braunau. Its detailed structure indicates a gentle annealing in cosmos after the initial cooling period. Thereby, it acquired its peculiar network of subgrain boundaries and local recrystallization. The original cohenite presumably decomposed simultaneously. Hex River and Uwet are, in all respects, indistinguishable.

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

332 g part slice (no. 311, 8 x 9.5 x 0.6 cm)
132 g part slice (no. 1040, 6 x 5.5 x 0.5 cm)
118 g part slice (no. 2815, 5 x 4.5 x 0.6 cm)

Hill City, Kansas, U.S.A.

39°28'N, 99°58'W; 750 m

Fine octahedrite, Of. Bandwidth 0.38 \pm 0.05 mm. Decorated Neumann bands, HV 205 \pm 8.

Group IVA. 9.19% Ni, about 0.12% P, 2.3 ppm Ga, 0.14 ppm Ge, 0.88 ppm Ir.

HISTORY

A mass of 11.7 kg was found in 1944 by Delano Hardman while he was plowing in a field 15 km northwest of Hill City, Graham County. The exact location is Section 1, Township 7S, Range 24W of Graham County, which corresponds to the coordinates given above (letter from S.H. Perry of October 24, 1949 to the Smithsonian Institution). In 1947 the whole mass was donated by S.H. Perry to the U.S. National Museum. Only a few slices have been cut for analyses and exchange. A brief description appeared together with the analysis by Goldberg et al. (1951). Jaeger & Lipschutz (1967b) found no evidence of shock structures above 130 k bar. Schultz & Hintenberger (1967) determined the amount of occluded noble gases, while Voshage (1967) by the ⁴⁰K/⁴¹K method found a cosmic ray exposure age of 435 \pm 90 million years.

COLLECTIONS

Washington (main mass), Chicago (161 g), Sydney (149 g), New York (115 g).

DESCRIPTION

The mass is of lenticular shape with the average dimensions of 17 x 16 x 12 cm. While about half of its surface is rather smoothly rounded, two large depressions, 10-12 cm in diameter and 3-5 cm deep, cover two opposite sides. Each of the bowls is subdivided in numerous, faceted 15-30 mm pits, in which there may be observed, locally, the last remnants of an 0.1 mm thick, oxidic fusion crust. Etched sections display a 0.5-2 mm rim zone of heat-affected α_2 ; the phosphides were found to be micromelted in the outer 40% of this zone. The sculpture, which superficially resembles terrestrial corrosion pits, is therefore the result of ablation in the atmosphere, and at the most

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References	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Henderson 1948, pers. comm.	9.17	0.46										
Goldberg et al. 1951	9.32								2.35			
Schaudy et al. 1972	9.09								2.29	0.144	0.88	

about 1 mm of the skin has been removed by corrosion. Selective corrosion has, however, penetrated along fissures to a depth of several centimeters, particularly attacking the α -phase of the plessite fields and the nickel-poor kamacite around the phosphide inclusions. The Neumann bands are also lines of attacks because they have been sensitized by precipitation.

Etched sections show a fine Widmanstätten structure of straight, long ($\frac{l}{w} \sim 40$) kamacite lamellae with a width of $0.38 \pm 0.05 \mu\text{m}$. The kamacite contains many Neumann bands which are conspicuous because they are decorated along their two sides by $0.3\text{--}1 \mu\text{m}$ wide phosphide grains. The Neumann bands penetrate, as usual, the open-meshed comb and cell plessite, and are also particularly easy to detect here because of their decoration. Also, the kamacite matrix appears to host a large number of submicroscopic precipitates, presumably phosphides. The hardness of the kamacite is 250 ± 8 , indicating annealing after a shock-event. The hardness drops to a minimum of 175 ± 5 at the transition to the α_2 rim zone which is 215 ± 15 (hardness curve type II). Plessite covers about 50% by area, partly as comb and net plessite, partly as cellular areas of the type described in, e.g., Chinautla. The framing taenite is frequently followed by a $20\text{--}30 \mu\text{m}$ wide, poorly resolvable duplex $\alpha + \gamma$ mixture, that gradually merges with the interior open-meshed plessite types. The interior of some taenite wedges is martensitic, and the martensite plates, moreover, appear to be decorated by annealing.

Schreibersite is fairly common as $10\text{--}50 \mu\text{m}$ wide grain boundary precipitates and as $5\text{--}25 \mu\text{m}$ vermicular bodies in the plessite interiors. The schreibersite is monocrystalline and slightly brecciated.



Figure 861. Hill City (U.S.N.M. no. 1436). The 10.2 kg main mass in the Smithsonian Institution. The lenticular mass has on opposite sides two depressions, subdivided in regmaglypts. Scale bar 5 cm.

Small troilite nodules, about $0.5\text{--}2 \text{ mm}$ in diameter, occur with a frequency of about one per 20 cm^2 . Most of them are formed around nuclei of bluish-black chromite crystals. The chromite crystals may be cubes or extended plates, and they are generally only $100\text{--}400 \mu\text{m}$ across. After the troilite nodules had grown to full size, a small amount of phosphide precipitated as a $10\text{--}50 \mu\text{m}$ wide discontinuous rim. The troilite later micromelted, presumably due to shock compression and point heating. It dissolved part of the surrounding iron and solidified into fine-grained ($1\text{--}3 \mu\text{m}$) eutectics of iron and sulfide. The troilite shows two types: a dark-etching normal eutectic ($\text{HV } 225 \pm 15$), and a light-etching eutectic ($\text{HV } 350 \pm 15$), rich in an unidentified, cream-colored component. The schreibersite rim was shattered and became dispersed in the melt as $5\text{--}25 \mu\text{m}$ fragments, and the chromite nuclei were also fragmented and dispersed somewhat, but neither of these two minerals melted. It appears that the residual heat from the shock compression was sufficient to anneal the matrix and produce precipitation on Neumann bands and on martensite plates.

Hill City is a shock-annealed fine octahedrite with phosphides. Its overall structure places it close to, e.g., Boogaldi, Smithland, Duchesne and Chinautla, which is in harmony with Wasson's conclusions based upon trace-element concentrations.

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

- 10.2 kg main mass (no. 1436, $15 \times 16 \times 12 \text{ cm}$)
- 147 g endpiece (no. 1436, $6 \times 5 \times 1\text{-cm}$)
- 132 g slice (no. 1436, $8.5 \times 6 \times 0.3 \text{ cm}$)
- 100 g slice (no. 1436, $10 \times 6 \times 0.2 \text{ cm}$)
- 104 g part slice (no. 1436, $6 \times 5 \times 0.5 \text{ cm}$)

Hoba, Grootfontein, South West Africa

$19^\circ 35' \text{S}, 17^\circ 55' \text{E}$

Nickel-rich ataxite, D. A few $20 \mu\text{m}$ wide α -spindles. Oriented sheen in Widmanstätten directions. $\text{HV } 270 \pm 10$.

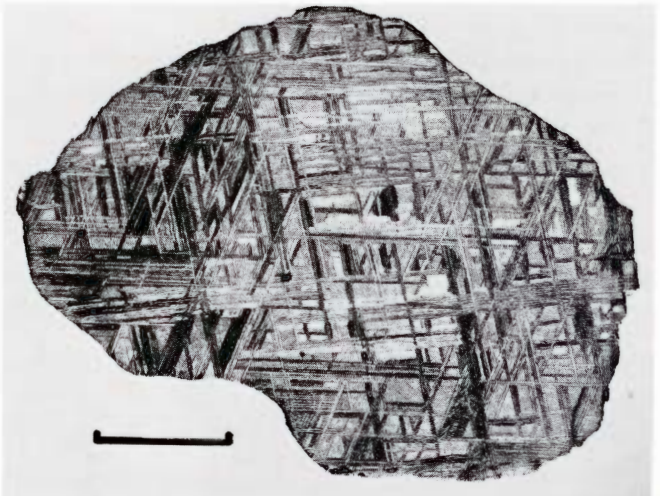


Figure 862. Hill City (U.S.N.M. no. 1436). A slice from Figure 861, showing the fine octahedral structure. Deep-etched. Scale bar 20 mm. S.I. neg. 37663B.

the weight is estimated to be about 60 tons (Spencer 1932). Luyten (1929), who also visited the meteorite, estimated the weight to be above 50 tons. To this must be added the 30 cm thick oxide-shale crust which separates the lower part of the meteorite from the Kalahari limestone in which it is embedded. No crater and no crushed rocks have been found associated with the impact site. McCorkell et al. (1968) proposes that the meteorite, since its fall on the granite surface, has become almost covered by a layer of calcareous tufa or surface limestone. "This probably formed by the evaporation of stagnant surface water, bearing calcium carbonate from the nearby Otavi dolomite. The region to-day is arid with an annual rain-fall of only 500 to 750 mm and little runoff. Thus, it seems probable that a period of moister climate occurred in the region during the last 80,000 years, probably at the time of the last pluvial and glacial period in the Northern Hemisphere. The oxidation crust or iron shale that covers the bottom and sides of Hoba contains Fe, Ni, and Co in the same proportions as does the metal (Spencer 1932), indicating that the oxidation occurred with no leaching. The oxidation probably took place rapidly during the moist period in which the surface limestone formed."

The mass has a horizontal upper surface with shallow pits and depressions, typical of corrosion pits. There are no prominent knobs or irregularities. At one edge is a scar several feet long from an attempt to detach specimens with an oxy-acetylene torch. In another place several kilograms

have been removed from an edge by drilling parallel, closely spaced holes. In a few more places material has been removed by chiseling and drilling but probably not more than a total of about 20 kg.

Etched sections display the typical ataxitic structure with no visible kamacite lamellae but with an oriented sheen in irregular lines, wedges and patches. Smaller sections show a uniformly dull surface, but the larger ones, as, e.g., U.S.N.M. no. 2618 with 135 cm² polished surface, are visibly subdivided in numerous bands and broad units which are bordered by straight lines in three or four directions. The units are irregularly joined and dovetailed into each other and correspond closely to those seen on Cape of Good Hope, Kokomo, Tlacotepec and certain other nickel-rich ataxites which, however, are only rarely available in such large sections.

At high magnification the matrix is disclosed as being composed of an oriented intergrowth of α and γ in what Perry (1944) termed a paraeutectoid. The 0.5-2 μ wide, slightly winding γ -ribbons are within areas of uniform sheen, oriented uniformly, and, moreover, parallel to one of the straight limits of the area. No more than a total of four main directions of gamma are found within the various patches of oriented sheen and these are parallel to the macroscopically visible straight lines of the section. By means of the tables of angles in the Widmanstätten structure (Buchwald 1968b) it is concluded that the said directions, in fact, represent Widmanstätten orientations, so

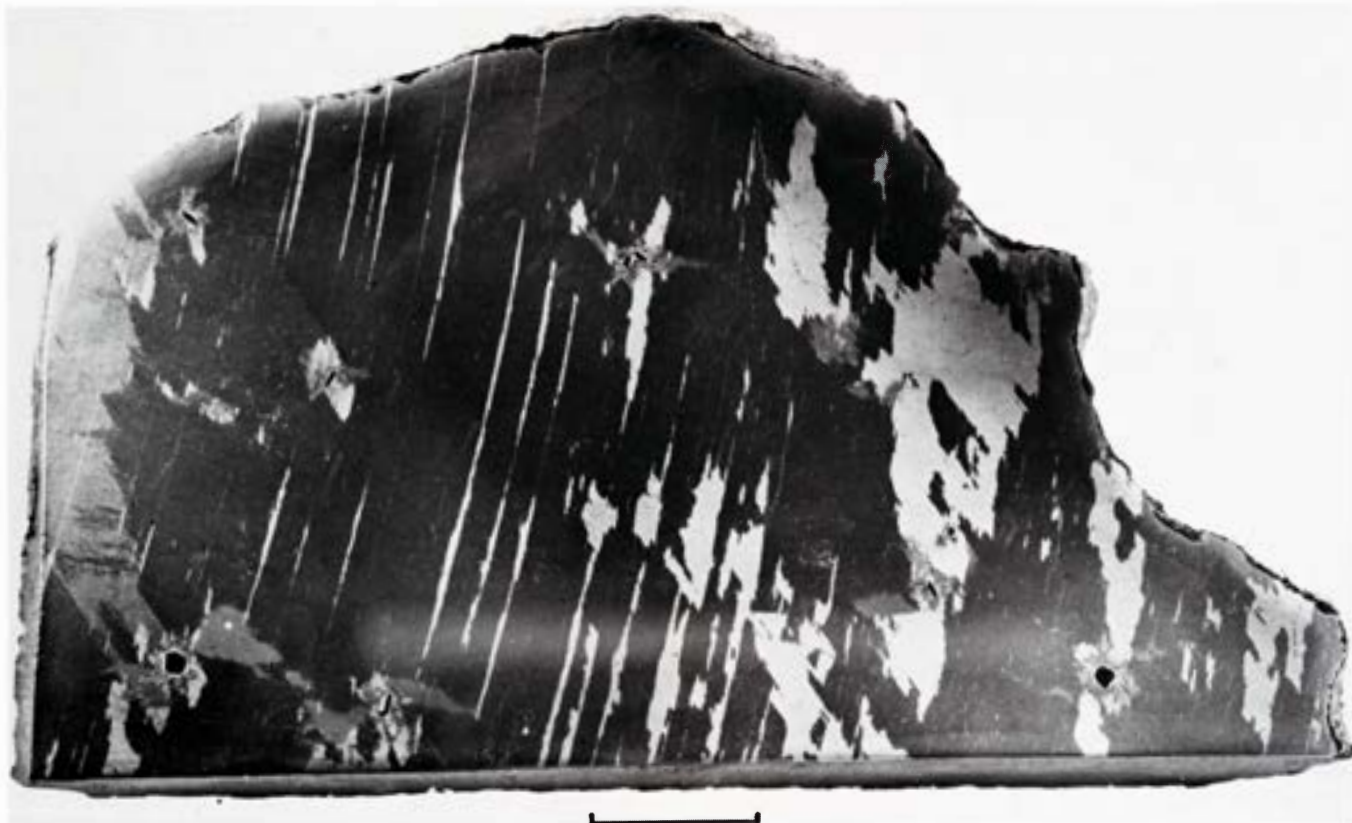


Figure 864. Hoba (U.S.N.M. no. 2618). Ataxite with oriented sheen that suggests an imperfect decomposition parallel to $(111)\gamma$. Deep-etched. Scale bar 20 mm. S.I. neg. M-1421A.

that even the ataxites, only on a microscopic scale, follow the α - γ precipitation laws. The few, larger kamacite needles, typically $200 \times 20 \mu$, which occur with a frequency of about one per 2 mm^2 , also appear to be aligned in the same Widmanstätten directions. A possible explanation for the formation of the paraeutectoid, or duplex, $\alpha + \gamma$ structure in the ataxites has been examined experimentally and discussed by Buchwald (1966: figures 11 and 36). It appears that the structure may be the result of relatively rapid cooling to temperatures where diffusion in γ is difficult. Then followed a two-step reaction through a disordered α_2 stage to precipitation of γ in α_2 , which created the uniquely orientated pattern, homogeneous within the same parent single crystal. The microhardness, averaging over several $\alpha + \gamma$ units, is 270 ± 10 . The microhardness of the scattered kamacite spindles is about 200.

Schreibersite occurs sparsely. It is present as up to $50 \times 5 \mu$ irregular bodies, but is usually much smaller, e.g., $3 \times 2 \mu$. Schreibersite is further present in small amounts as 0.5 - 2μ blebs in the duplex $\alpha + \gamma$ matrix. The phosphorus content of the meteorite is probably about 0.07%.

Troilite occurs as 0.5 to 3 mm lenticular to angular bodies with a frequency of about one per 15 cm^2 . Daubreelite is precipitated in the troilite as 5 - 100μ wide bars, parallel to $\{0001\}$ of the troilite. The larger troilite-daubreelite units have nucleated a 10 - 30μ wide kamacite rim zone, from which occasionally 10 - 25μ wide α -spindles have grown several hundred microns. The troilite was originally monocrystalline but is now partly transformed, probably due to shock-pressures and heating. It appears that the smallest troilite bodies, 0.1 - 0.3 mm across, shock-melted completely and dissolved part of the surrounding metal, whereupon they solidified to 2 - 5μ eutectic metal-sulfide structures. The larger troilite bodies only shock-melted along the phase boundaries against metal and daubreelite and along fracture zones, while the remainder

display various degrees of undulatory extinction in lenticular bands, probably due to plastic deformation alone. The daubreelite lamellae are somewhat bent and fragmented but normally not melted.

The inclusions of schreibersite, troilite and daubreelite have, to some extent, acted as nuclei for kamacite during the primary cooling period. Most of them are sheathed in 5 - 20μ rim zones of kamacite, and around several of them the kamacite has started to grow in thin lamellae, 10 - 25μ wide, apparently in the well-known Widmanstätten directions. The nucleation and growth of the α -phase occurred around particles as small as $2 \times 2 \mu$, whatever their nature.

The puzzling, "tin-white specks of schreibersite" (Spencer 1932: 9, figures 6, 10, 11) are kamacite needles, cut in various directions.

No fusion crust and no heat-affected rim zone are, of course, preserved. The fluting and pitting of the surface appear to be mainly due to corrosion.

Graphite has been reported by Gordon (1931) and cohenite by Spencer (1932), but neither could be confirmed in this study.

Hoba is a nickel-rich ataxite closely related to Cape of Good Hope, Kokomo, and Tlacotepec, as well as to several other ataxites on the 15-16% nickel level. Common to all are the duplex $\alpha + \gamma$ plessite with scattered, tiny kamacite needles, the low phosphide content and the oriented sheen, producing irregular bands and rhombic and triangular patches in one, two or occasionally three or four (particularly Hoba and Tlacotepec) Widmanstätten directions. These meteorites belong to group IVB. See also the Supplement.

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

- 173 g part slice (no. 1741, $12 \times 3.5 \times 0.8 \text{ cm}$)
- 2,140 g part slice (no. 2618, $16 \times 9.5 \times 2.6 \text{ cm}$)
- 42 g fragment (no. 3390, $3 \times 2 \times 1.5 \text{ cm}$)
- 1,800 g oxide-shales and fragments of adhering Kalahari Kalk (porous, conglomeratic limestone) (no. 1297 and no. 2816)

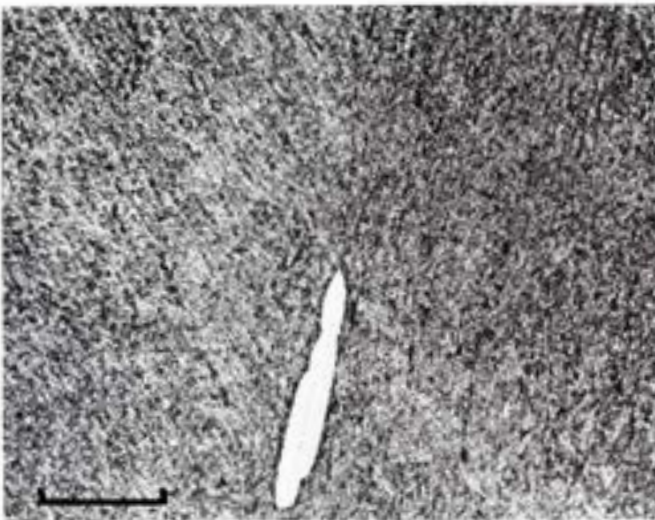


Figure 865. Hoba (New York no. 2681). Transition between two areas of differently oriented sheen. The kamacite spindles are situated near the boundary. The $\alpha + \gamma$ orientation shifts across the boundary. Etched. Scale bar 200μ . (Perry 1944: plate 24.)



Figure 866. Hoba (New York no. 2681). A kamacite spindle enveloped in taenite, unresolvable transition zones and easily resolvable duplex $\alpha + \gamma$ mixtures. Etched. Scale bar 20μ . (Perry 1950: volume 2.)

Holland's Store, Georgia, U.S.A.

 34°21'N, 85°24'W; 200 m

Shocked and recrystallized hexahedrite, H. 0.5-15 mm equiaxial new grains. HV 190±15.

Group IIA. About 5.35% Ni, 0.5% Co, 0.25% P, 60.9 ppm Ga, 184 ppm Ge, 20 ppm Ir.

Although two-thirds was lost in forging and cutting by a blacksmith, the remainder appears to be relatively undamaged.

HISTORY

A mass of about 12.5 kg was found by W.J. Fox in 1887 on his farm in Holland's Store, Chattooga County (Kunz 1887c). The present name of the locality is Holland, about 15 km south of Summerville, the coordinates of which are given above. "The mass fell into the hands of parties from Alabama who were interested in developing iron mines, and was broken into pieces, three of which, weighing 9, 1 1/2 and 1/2 pounds respectively, came into my possession, while the balance were worked into nails, horseshoes and other forms by the local blacksmiths" (Kunz 1887c). Kunz also gave a brief description, with a woodcut and an analysis by Whitfield.

Brezina (1896: 292) briefly described the 2 kg fragments which were acquired for Vienna with the Kunz collection. His photograph illustrates very well the granulated appearance of an etched section with an extreme variation in grain size, from 0.5 to 100 mm. Cohen (1905: 239) gave a brief description together with a new analysis. Berwerth (1914: 1067) thought that the anomalous structure was due to artificial reheating, but Leonhardt (1928: 206) correctly interpreted it as a partial recrystallization which took place in cosmos. Perry (1944) presented four photomicrographs, and Henderson & Perry (1954) included Holland's Store in their discussion of the density of meteoric irons. Vogel (1952: 347) conducted heating experiments in order to investigate the rate of dissolution of the individual phosphide inclusions.

COLLECTIONS

Vienna (2,157 g on four fragments and slices), Chicago (247 g), New York (213 g), London (190 g), Ann Arbor (117 g), Yale (92 g), Budapest (64 g, lost in 1956), Washington (53 g), Berlin (51 g), Prague (47 g), Bonn (40 g),

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The cobalt and chromium results are no doubt erratically high, while the nickel values appear somewhat low.

Paris (30 g), Rome (27 g), Tempe (27 g). This adds up to 3.3 kg. Only 11 pounds or 5 kg were received by Kunz. A major part of the balance, i.e., 1.7 kg was probably lost in cutting and analyzing the meteorite.

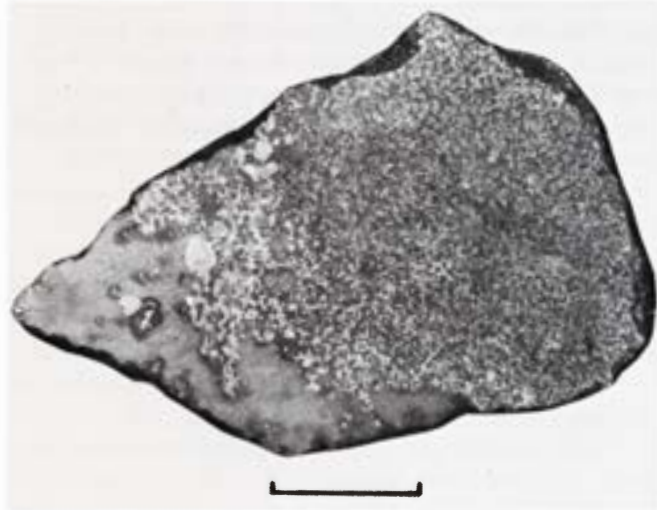


Figure 867. Holland's Store (Vienna no. F6474). Shocked and recrystallized hexahedrite of a very unusual type. Deep-etched. Scale bar 30 mm. See also Figure 76.

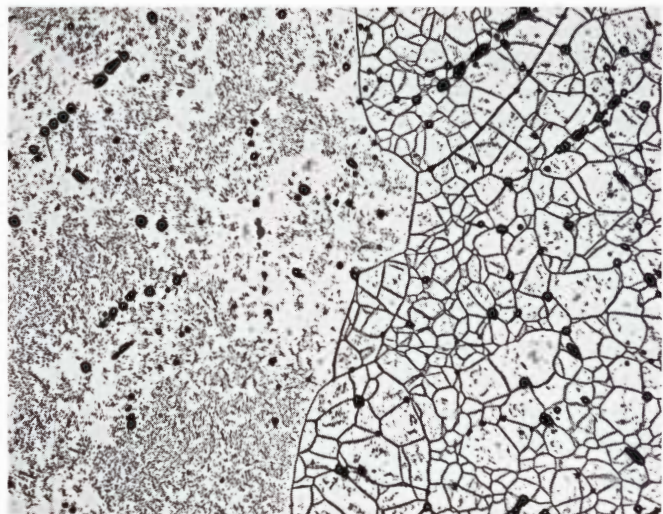


Figure 868. Holland's Store (U.S.N.M. no. 2819). The boundary between recrystallized and unrecrystallized material. The meteorite is very difficult to polish and etch; the numerous black holes are artifacts and neither oxides – as believed by Perry – nor magnetite – as believed by Brezina. Etched. Scale bar 200 μ. (Perry 1944: plate 6.)

References	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Zaubitzer in Cohen 1905	5.35	1.00	0.31		800	2300						
Wasson 1971, pers. comm.	5.35								60.9	184	20	

Kunz (1887c) reported lawrencite, but this could not be confirmed in the present examination.

DESCRIPTION

The original dimensions and the shape of the mass are not known. Fragments with some of the preserved exterior, e.g., Vienna No. H 3541 and Yale No. 148, show that the mass is considerably corroded, with 0.1-0.5 mm thick, adhering oxide crusts. There are several chisel marks and fractures due to violent treatment when detaching pieces, but otherwise most of the surviving samples in collections appear to have escaped forging and reheating. No fusion crust and no heat-affected α_2 rim zone are preserved.

Considering that sections through most iron meteorites display a rather homogeneous structure, constantly repeating itself, Holland's Store is very confusing in its apparent heterogeneity. Etched sections generally show a fine-grained aggregate of equiaxial 0.3-1 mm grains at one end. Then follows a zone where irregular, lobed 2-10 mm grains become frequent, and eventually, at the opposite end, the structure superficially resembles a normal hexahedrite. All grains are ferritic, and some Neumann bands occur with variable and unpredictable frequency in the different grains. The bands are narrow ($< 1 \mu$) and indistinct and perhaps most common in the "hexahedrite" end. At least some of them formed very late, either by atmospheric cracking or by artificial hammering. Cold-work from hammering has locally squeezed the grains and introduced numerous lenticular deformation bands, e.g., in U.S.N.M. No. 127. The microhardness is here correspondingly high, 235 ± 15 .

The "hexahedrite" end of the specimen displays normal indistinct subboundaries with few precipitates. The boundaries are wavy and sometimes arranged in subparallel textures. Numerous transformed inclusions occur, both original rhabdites and sulfides. The microhardness is 195 ± 10 .

The "granulated" end is composed of 0.3-10 mm almost equiaxial grains, each of which is subdivided into thousands of almost equiaxial subgrains, about 50μ in diameter. The microhardness is 190 ± 15 , slightly lower than in the "hexahedrite" end. The lower hardness of the kamacite in the "granulated" end may be due to a somewhat lower amount of phosphorus and nickel in solid solution, these atoms having precipitated on the subboundaries as microrhabdites. The subboundaries are consequently richly decorated by oriented rhabdites, 1μ across.

Schreibersite was originally present as 1-2 mm inclusions, and the ghost structures of 1-15 μ rhabdite prisms may also be identified, both in the "hexahedrite" and the "granulated" parts. All original phosphides have been severely altered, probably by a cosmic shock event.

The larger phosphides became partly dissolved and subdivided in scalloped fragments, each composed of many 10-50 μ anisotropic crystallites. The phosphorus and nickel which at the shock-reheating were dissolved from the schreibersite, reprecipitated either upon the schreibersite or the ferrite boundaries. The precipitates form a zone rich in 2-20 μ particles of cavernous taenite and massive phosphides, in much the same way as mentioned in, e.g., Forsyth County, Kopjes Vlei and Mejillonos.

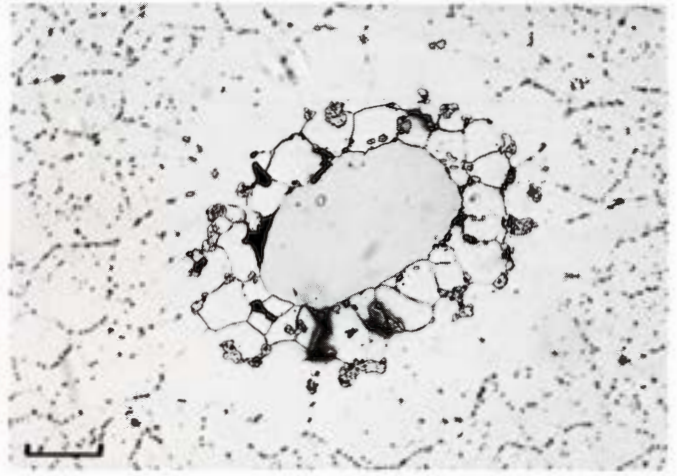


Figure 869. Holland's Store (Tempe no. 766). Altered schreibersite crystal surrounded by fine γ -amoebae and angular phosphides. Subboundaries with precipitates are further out in the kamacite. Etched. Scale bar 50μ .

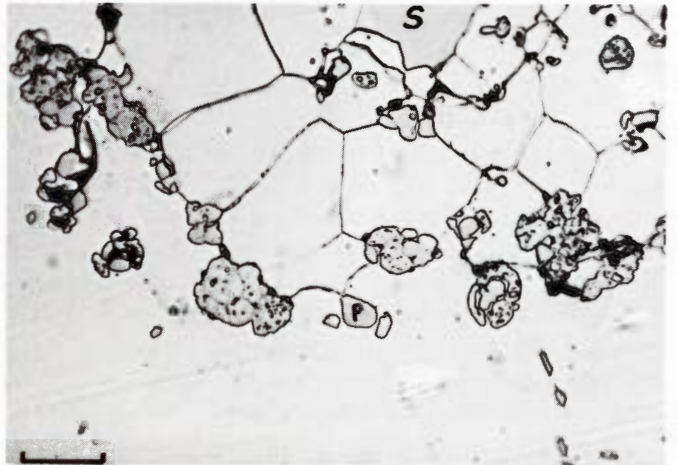


Figure 870. Holland's Store (Tempe no. 766). Altered schreibersite. Close-up of the unequilibrated, cavernous γ -amoebae and the angular phosphides (P). Etched. Scale bar 20μ .

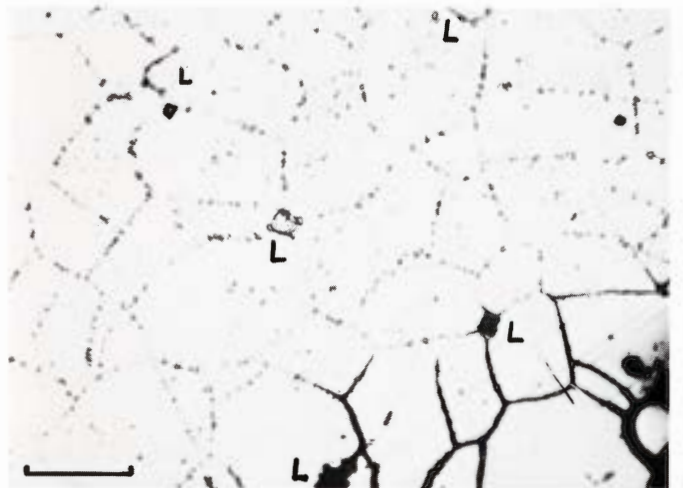


Figure 871. Holland's Store (Tempe no. 766). Corroded near-surface section. Corrosion invades subboundaries, and the sensitized loops (L) are selectively attacked. Lightly etched. Scale bar 40μ .

As discussed under Forsyth County, standard preparation procedures tend to give micropitted surfaces (see, e.g., Perry 1944: plates 6 and 68; most of the black dots are etching pits). Careful repolishing with diamond, plus light-etching, reveals that the pits are cavities formed after an easily attacked phase, 10-15 μ in diameter. The fact that the phase is little resistant to Earth's environment is also witnessed by its early limonitization in the corroded surface zone where otherwise only grain boundaries, and to a minor degree subboundaries, are attacked.

A close examination of the shape, distribution and size of this sensitized phase, which normally is separated from the adjacent metallic matrix by a grain boundary decorated by 1 μ phosphides, indicates that it is a shock-transformation product of preexisting rhabdites. What exactly makes the small 10-15 μ loops so sensitive to corrosion and etching could not be detected. More research is needed to solve this interesting problem.

Troilite-daubreelite nodules, 0.3-8 mm in diameter, were originally present, with rim zones of 50-100 μ schreibersite. They are now completely transformed to polycrystalline aggregates of troilite-metal (1-2 μ grains) in which 5-10 μ well rounded grains of daubreelite and schreibersite are distributed. While the troilite must have been completely remelted to create this structure, the temperature and length of time were not sufficient to melt all the schreibersite, since angular fragments and bars may still be found in situ. The daubreelite has either been melted or partly dissolved, since it is dispersed as rather uniform, almost spheroidized blebs. The complete aggregate is surrounded by a zone with frequent phosphides and taenite "amoebae" of the same shape and composition as around the phosphides proper.

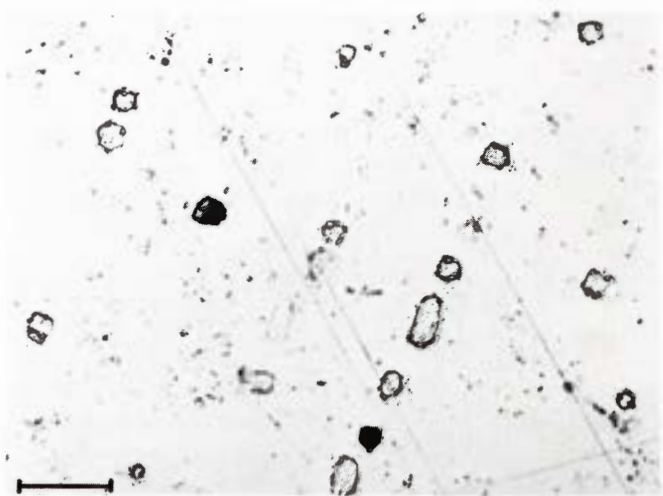


Figure 872. Holland's Store (Tempe no. 766). About twenty sensitized loops are visible in this typical picture. They are often arranged in parallel planes, and they exhibit very fine phosphide particles along their interface with the less altered kamacite. There are strong indications that the loops represent shock-altered rhabdites. In the kamacite, three parallel Neumann bands and a dense network of subboundaries are indistinctly seen. Lightly etched. Scale bar 40 μ .

Graphite is present as altered 20-50 μ spherulites, composed of radiating sheaves. They are often located in the grain boundaries and have, themselves, served as nuclei for some precipitation of phosphides. They survive for a long time in the weathered parts of the meteorite.

The complex mineralogy discussed above may perhaps best be explained if we assume that a shock event rapidly reheated a normal hexahedrite. Due to reflections from internal phase boundaries and external bounding surfaces, the resulting shock pressures and relaxation temperatures were of various intensities. The compressible troilite nodules would be expected to absorb a significant part of the shock, whereby they melted and also partly melted their associated, more passive, minerals. Smaller intensities were just sufficient to recrystallize the larger phosphides and bring a part of their rim zone in solid solution. Shortly after, the supersaturated metal reprecipitated taenite (amoebae) and phosphide in discrete, irregular blebs. Cohenite may be assumed to have been present originally in small amounts, as shown in Bruno, Coahuila and Angra dos Reis. This decomposed by the relaxation heating, and the released carbon precipitated as graphite spherulites.

The metallic matrix itself recrystallized, whereby the Neumann bands disappeared. In the non-recrystallized parts, however, we still have a rather undisturbed monocrystalline structure with indistinct Neumann bands preserved. Accordingly, we may cautiously suggest that the relaxation temperatures ranged from about 400° to 600° C in the metallic phase, through 700° C in the schreibersite to 900° or 1000° C in the troilite nodules. The temperature peaks have probably only lasted about a minute, but the lower temperatures, about 500° C, must have persisted for some time (a few hours?) in order to create the observed diffusion and recrystallization structures. Finally, as the meteorite entered our atmosphere and became violently decelerated, several fissures and new Neumann bands were

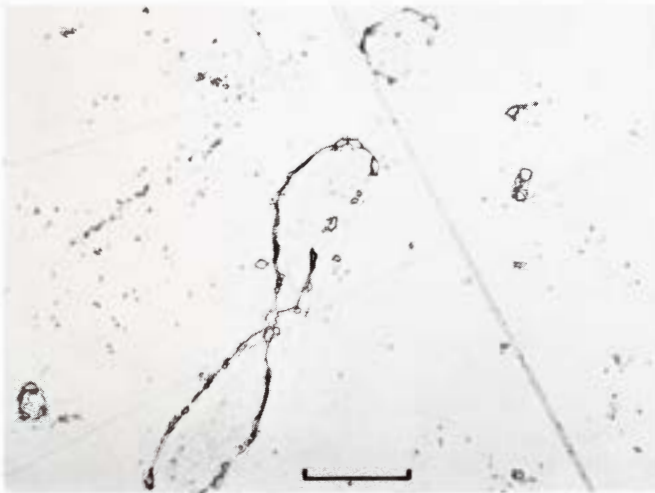


Figure 873. Holland's Store (Tempe no. 766). Close-up of sensitized loops showing their interior unequilibrated α_2 (?) structure and the beads of phosphides along their periphery. Former Neumann bands are indistinctly visible. Lightly etched (heavy-etching would destroy the loops). Oil immersion. Scale bar 20 μ .

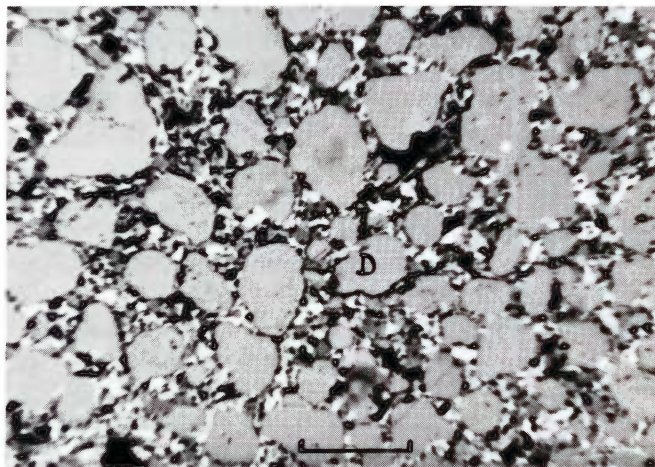


Figure 874. Holland's Store (Tempe no. 766). Shock-melted troilite-daubreelite nodule. Subangular fragments of daubreelite (D) are dispersed through an iron-sulfur eutectic. Polished. Slightly crossed polars. Scale bar 20 μ .

introduced. The detailed structure of the matrix is different from the shock-reheated Canyon Diablo rim specimens. It appears that the α -phase in Canyon Diablo transformed through the austenite phase back to α_2 , thereby creating the peculiar serrated α_2 structures. The structure of Holland's Store, on the other hand, is more compatible with a recrystallization proper of the alpha phase in the 500°-600° C range, without moving into gamma. While the granulation of the Canyon Diablo specimens is believed to be associated with the forming of Meteor Crater, the shock event that modified the structure of Holland's Store must have been preatmospheric and probably dates far back in time.

Holland's Store is an extremely interesting meteorite, closely related to Forsyth County. Before its shock-alteration it was probably a normal hexahedrite displaying the features of, e.g., Bruno, Angra dos Reis and Boguslavka. It contains several important clues to the understanding of shock histories in iron meteorites. It is thus important that if the above explanation is correct, it must be accepted that the various parts of even small meteorites may display grossly different macrostructures due to inhomogenous relaxation heating. The various structures of Willamette, originally a medium octahedrite, may perhaps be interpreted this way.

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

19 g cold-hammered, polished fragments (no. 127)
34 g part slice (no. 2819, 8 x 6 x 0.05 cm)

Hope, Arkansas, U.S.A.

33°41'N, 93°36'W; 100 m

Coarse octahedrite, Og. Bandwidth 2.1 \pm 0.4 mm. Neumann bands. HV 180 \pm 8.

Group I. 6.77 Ni, about 0.2% P, 86 ppm Ga, 398 ppm Ge, 0.59 ppm Ir.

In a few preliminary notes this mass has been called Boaz.

HISTORY

A mass of 6.8 kg was listed by Leonard (1956a), Mason (1962a), Hey (1966) and Buchwald (1968a) as coming from Boaz, Alabama. In letters to the Smithsonian Institution from the present owner of the main mass, Oscar E. Monnig, Fort Worth, the following information was kindly supplied: the meteorite was allegedly found during plowing near Hope, Arkansas, not too many years before 1955. It passed through several hands and became known when it was in the possession of a school teacher in Boaz, Alabama. It was acquired in 1955 by Monnig, who let it be cut and presented a portion of it to the U.S. National Museum. The iron is undescribed.

COLLECTIONS

Two endpieces in Monnig's Collection (3 kg and 950 g). Two slices of 475 and 410 g in Washington.

DESCRIPTION

The mass is a badly weathered, well rounded, but slightly oblong ball with the overall dimensions 14 x 12 x 12 cm. When loose, adhering shale had been removed, the weight was assessed as 6.6 kg. All fusion crust and heated α_2 zone is weathered away, and the mass continues to spall under room conditions unless special precautions are taken. Original thumbprint markings have long since disappeared and general corrosion is probably responsible for the present rounded shape.

Etched sections display a coarse octahedral structure with 2.1 mm bandwidth and a length-width ratio of about eight. Numerous lamellae are in a state of grain growth, spreading irregularly and engulfing the scattered taenite and plessite fields. Particularly around the schreibersite and troilite inclusions there are large, more or less equiaxial, ferrite grains 8-15 mm in diameter, while on the other hand, the Widmanstätten structure, as usual, is best preserved in the cohenite-taenite rich regions, that normally are about 3 x 4 cm in size. Neumann bands are common, and the hardness is 180 \pm 8. Taenite and plessite cover about 1% by area, mostly as comb plessite and acicular martens-

HOPE – SELECTED CHEMICAL ANALYSES

Reference	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Wasson 1970a	6.77								85.7	398	0.59	

ite, often in direct contact with cohenite. Pearlitic plessite with 0.5-2 μ wide taenite lamellae is present locally, the alpha phase having been selectively corroded.

Schreibersite occurs as up to 50 x 10 x 2 mm lamellae and as irregular 3 x 2 mm hooks and skeleton crystals. All are surrounded by 2-6 mm rims of swathing kamacite. Grain boundary veins, 50 μ wide, are also common. Rhabdites, 2-20 μ across, are scattered in the matrix. The bulk phosphorus content is estimated to be about 0.2%.

Troilite is present as scattered nodules, 2-10 mm in diameter. They are enveloped in 0.5 mm thick schreibersite plus 0.2 mm thick cohenite rims. The troilite is monocrystalline and contains 10-15% of daubreelite. The troilite and the daubreelite lamellae are brecciated and later recemented by terrestrial corrosion products. Wide pentlandite veins

are quite common. Chromite occurs as an accessory mineral in contact with troilite, mostly as 0.1-0.3 mm wide, angular grains. Graphite is not uncommon in the troilite; it is also present locally in the kamacite phase as 75-125 μ wide cliftonite grains.

Cohenite is common, both as 0.2 mm wide rims around most of the schreibersite skeleton crystals and as scalloped, irregular, 2 x 0.5 mm bodies centrally in the α -lamellae. No decomposition to graphite has occurred.

A silicate, which might be olivine, was observed in one place as a 6 x 0.15 mm rod, completely enveloped in a 200 μ wide graphite sack.

Hope has a structure and a mineral association which indicates that it is closely related to such inclusion-rich

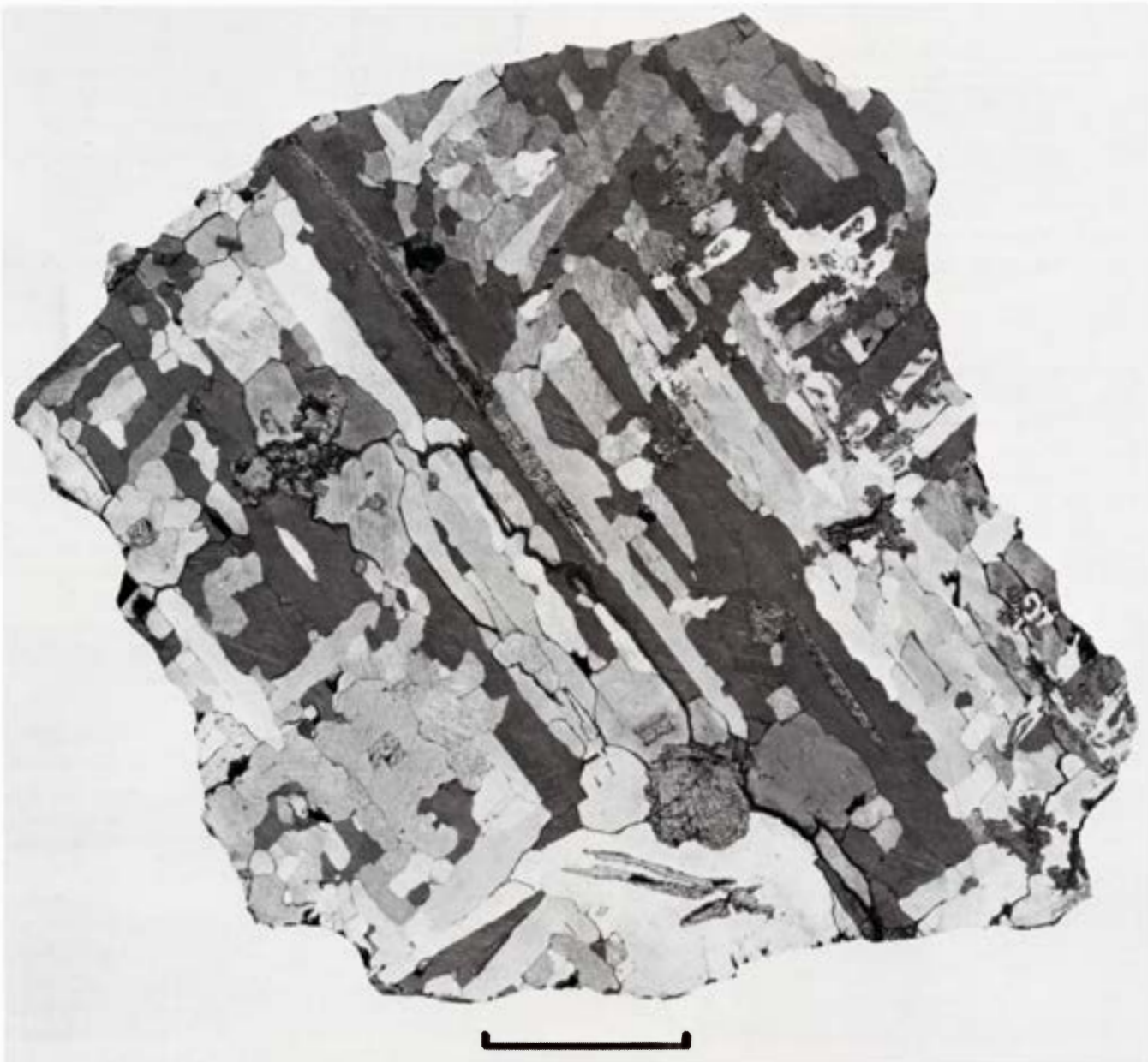


Figure 875. Hope (U.S.N.M. no. 3476). A coarse octahedrite of group I. Irregular troilite-graphite-silicate nodules with rims of schreibersite and cohenite. Deep-etched. Scale bar 20 mm. S.I. neg. 1519A.



Figure 876. Hope (U.S.N.M. no. 3476). Grain growth of kamacite has engulfed former Widmanstätten taenite fields. Schreibersite skeleton crystals with cohenite rims and wide zones of swathing kamacite. Deep-etched. Scale bar 5 mm. S.I. neg. 1519B.

coarse octahedrites as Cookeville, Canyon Diablo and Coolac, all belonging to group I. Since the place of find obviously was not Boaz, but Hope, about 700 km farther west, it is suggested that the meteorite in the future be treated under the name Hope.

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

475 g slice (no. 3476, 9.5 x 8.5 x 0.8 cm)

410 g slice (no. 3477, 9 x 9 x 0.7 cm)

Hopewell Mounds, Ohio, U.S.A.

39°23'N, 83°2'W

Pallasite, i.e., polycrystalline medium octahedrite with olivine inclusions. Bandwidth about 0.8 mm. Neumann bands.

Pallasite. 10.81% Ni, 0.55% Co, 0.14% P, 25 ppm Ga, 66 ppm Ge, 0.045 ppm Ir.

Identical to the meteorite Brenham, Kiowa County, Kansas.

HISTORY

Meteoritic iron artifacts have been found in several of the mounds of the Great Earthwork Builders in Ohio. The builders, who have been called the Hopewell people, are evidently ancestors of the Indians later met by Europeans. Archaeological evidence indicates that the Hopewellians were settled, though primitive, farmers and that their culture lasted for about 1,000 years, from 500 B.C. to 500 A.D. The huge mounds demanded the labor of the whole community and were sacred places where the dead were buried or cremated with their treasures according to complex rites. Some of the meteoritic material has been found among ashes and may thus have been artificially reheated during the burial process, or perhaps during accidental fires. According to Arnold & Libby (1951),

charcoal from the Hopewell Mounds had a radiocarbon age of 1951±200 years, conch shells had an age of 2285±210 years, and bark was 2044±250 years old.

In the Field Museum, Chicago, there are ear ornaments and buttons covered with meteoritic iron, and an adze blade entirely of meteoritic iron, all from the Liberty Group of mounds in Scioto Valley, Ohio (Willoughby 1922: 66).

Atwater (1820) reported a completely oxidized large knife and a plate of iron from the great mound in the center of the circular embankment at Circleville, Ohio.



Figure 877. Hopewell Mounds (Chicago no. 480; 103 g). Cold-worked sample with olivine inclusions. Deep-etched. Scale bar 2 cm. S.I. neg. 37839.

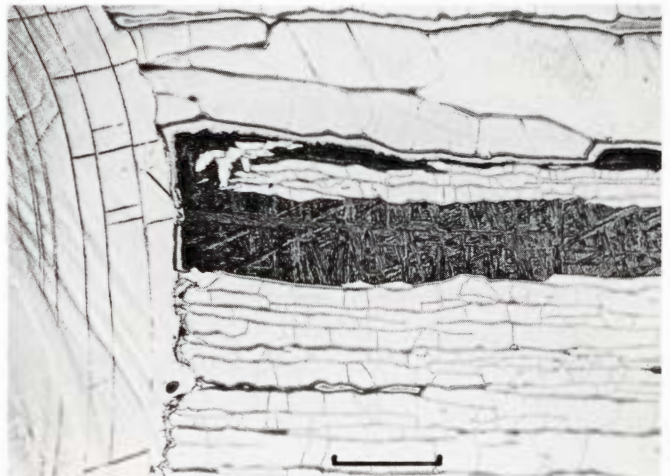


Figure 878. Hopewell Mounds (Chicago no. 481). Section through cold-worked Indian bead showing bent Widmanstätten structure and deformation bands in the kamacite (left). Etched. Scale bar 400 μ.

Kinnicutt (1884) reported a 767 g meteoritic iron nugget, found in 1882 on the central altar (No. 1) of mound No. 4 of the Turner group of earthworks in the Little Miami Valley, Ohio. He described the mass as consisting of metal with 5-10 mm olivine crystals and gave a woodcut and a fine analysis, by J. Lawrence Smith; see below. Brezina & Cohen (1886-1906: plate 25) presented a photograph of a macroetched section (the material was called by its synonym, Anderson). Huntington (1891) and Willoughby (1922: 65) also described and pictured the mass.

Additional meteoritic nuggets and worked objects, totaling about 834 g according to Palache (1926a), were found on the central altar of mound No. 3, but the bulk of the metallic artifacts here consisted of copper nuggets and beads, buttons and ornaments wrought from native copper (Willoughby 1922: 46, 50).

At an early date Kunz (1890a: 316) correctly pointed out that the meteoritic nuggets had a remarkable similarity with the Brenham pallasite, and this was supported by Brezina (1896: 263, 339) who reported that the Vienna collection had also received some artificial objects from the various Ohio mounds. Huntington (1891), Farrington (1902) and Palache (1926a) however, could not support the conclusion that the pallasitic material should be associated with the Brenham fall. Wülfing (1897: 47) and Farrington (1915: 32, 78) gave rather good bibliographies.

Among the objects obtained from the famous Hopewell Mounds, in southern Ohio, are a number made of meteoritic iron, all found associated with a single human skeleton near an altar on one of the mounds. The objects include several beads, head plates and ear ornaments, an adze blade, a drill, and small chisels with portions of antler handles still adhering. "It is interesting to note that the above chisels are curved and have the form of the upper incisors of the beaver, which were so widely used as cutting tools by the Indians. It seems that in making the chisels of

iron they copied the shape of the most effective tool of this nature which they possessed" (Willoughby 1922: 66).

A small meteoritic mass from the Hopewell Mounds, weighing about 130 g and in its natural state, was described by Farrington (1902: 310) with two photographs of etched slices. He compared the material to that of Turner Mounds but rejected the idea that the two types of material were related and concluded that Hopewell was part of a rather normal medium octahedrite with only 4.6% Ni. Unfortunately, this classification has been accepted by all catalogs, e.g., Horback & Olsen (1965: 233) and Hey (1966: 205). The old description is, however, clearly inadequate, both with respect to structure and analysis. Wasson & Sedwick (1969) have recently shown that the material contains 10.6% Ni and has trace element compositions referring it to the pallasitic group of meteorites. They concluded that the material from the Turner mounds and the Hopewell mounds is virtually identical and similar to the Brenham

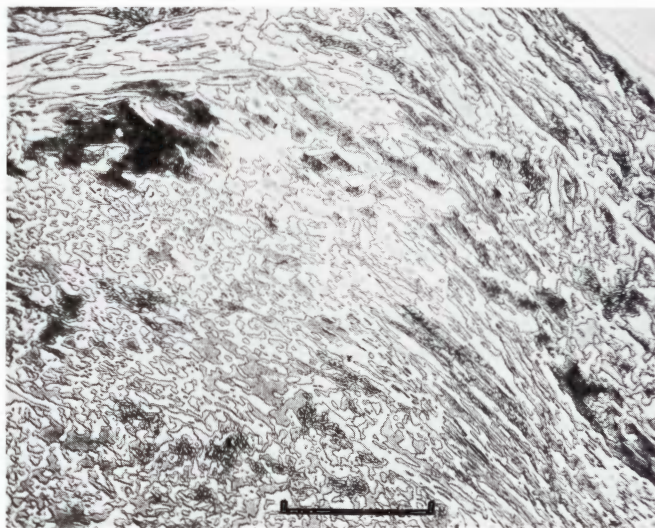


Figure 880. Hopewell Mounds (U.S.N.M.). Cold-worked duplex plessite. Etched. Scale bar 100 μ . (Perry 1950: volume 7.)

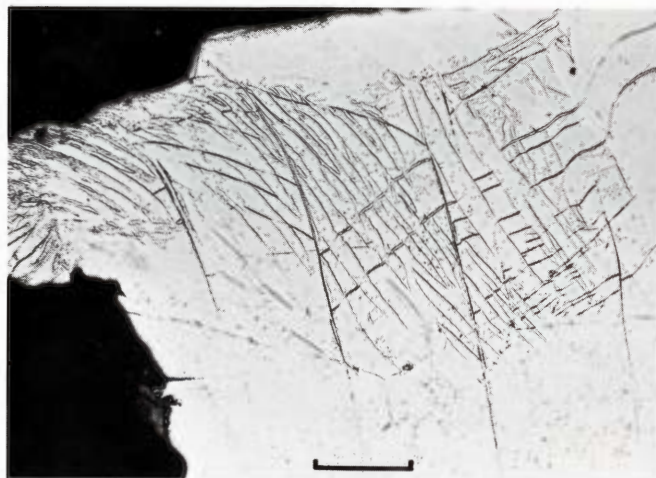


Figure 879. Hopewell Mounds (Chicago no. 481). The cosmic Neumann bands have become distorted by artificial hammering. Deformation bands in the kamacite to the left indicate where the material was detached from another mass. Etched. Scale bar 200 μ .

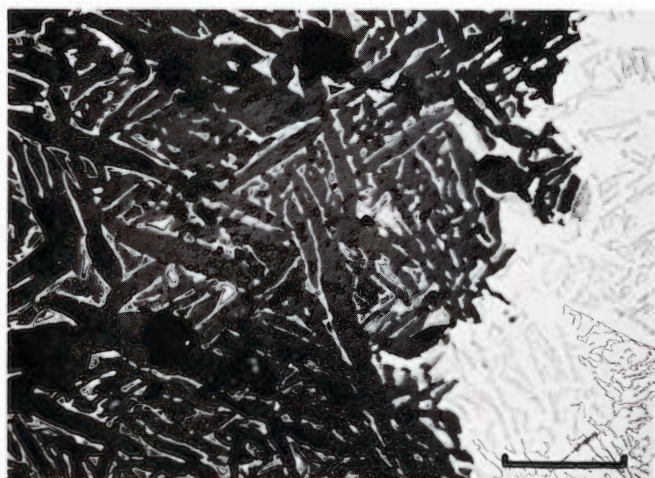


Figure 881. Hopewell Mounds (U.S.N.M.). Near-surface area, exhibiting terrestrial corrosion. The kamacite is selectively converted to limonite. Etched. Scale bar 200 μ . (Perry 1950: volume 7.)

pallasitic material. The Brenham locality, in Kiowa County, Kansas, at 37°36'N, 99°12'W, is about 1500 km west of the Great Mounds in Ohio. However, it is quite certain that the Hopewellian burial grounds include other objects which have been transported from distant localities, such as mica from the Appalachians, native copper from Michigan, obsidian from Yellowstone, and conch shells from the Gulf area. No doubt the Indians were accomplished traders, and could easily acquire meteoritic iron from Kansas.

The occurrence of meteoritic iron in the form of nuggets or worked into various objects shows that its malleability was generally understood by the people of this region. The Hopewellians cold-worked the metal; the art of smelting was at that time unknown. They excelled, however, in crafts and so skillful was the workmanship on many of the objects deposited with the dead that these are often treasured museum pieces today. Willoughby (1916; 1922) has shown several photographs of iron knives, chisels and a corrugated plate, apparently bent into a pan-whistle, all of which were produced from the iron. The Indians have probably had some initial experience with the working of the more abundant native copper. They have also had the fortune to work with pallasitic material which could be easily divided and worked. Perhaps some of the incisor-shaped chisels derived their overall form from the cavities left when olivine crystals were removed from the metallic part of the meteorite.

Nearly all the artifacts of meteoritic origin from Ohio are now severely oxidized and more or less broken. Meteoritic iron, when worked into ornaments, does not have the lasting quality of silver, gold and copper. On the other hand, the more massive unworked fragments have survived relatively well, displaying only superficial limonitic crusts and some grain boundary corrosion.

For additional information on the archaeological background, the reader is referred to Putnam (1883), Willoughby (1916; 1922) and Prufer (1965). The reader should also consult the Ohio State Archaeological and Historical Quarterly, especially papers by William C. Mills

and Henry C. Shetrone, who excavated the area after the first World War. A related occurrence of worked meteoritic iron from Illinois is treated under Havana; see page 635.

COLLECTIONS

Chicago (99.5 g fragment, and 23 g beads), Washington (fragment). The artifacts and the other nuggets of meteoritic iron are mainly in Harvard University and Harvard Peabody Museum (Palache 1926a; Frondel 1965).

DESCRIPTION

The 130 g fragment found near an altar of one of the Hopewell Mounds measured approximately 4 x 3 x 2 cm and was slightly weathered (Farrington 1902: figures 5 and 6).

In the present study the main specimen (Chicago Me 480) was cursorily examined and a piece cut from it was thoroughly examined before it was subjected to chemical

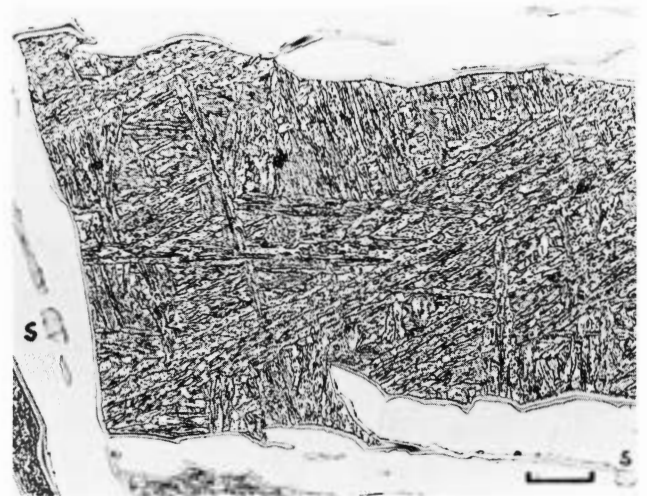


Figure 882. Hopewell Mounds (Chicago no. 481). Plessite field of martensitic appearance. The platelets are developed parallel to the bulk Widmanstätten directions. Schreibersite (S). Etched. Scale bar 50 μ .

HOPEWELL MOUNDS – SELECTED CHEMICAL ANALYSES

The original values in the analyses of Wasson & Sedwick (1969) are slightly changed due to later improve-

ments (personal communication 1971).

References	percentage			S	Cu	Ga	Ge	ppm Ir	Material
	Ni	Co	P						
J.L. Smith in Kinnicutt 1884	10.65	0.45	tr.		tr.				Turner Mound No. 4
Eakins in Kunz 1890a	10.35	0.57	0.14	800	300				Brenham
Cobb 1967		0.62			79	21		<0.4	Brenham
Wasson & Sedwick 1969	11.10					26.1	70.8	0.041	Brenham
Wasson & Sedwick 1969	11.34					24.8	65.6	0.045	Anderson, i.e., Turner Mounds.
Wasson & Sedwick 1969	10.63					24.0	61.8	0.049	Hopewell Mounds

analysis by Dr. Wasson. The etched sections display a pallasitic appearance, with metal alternating with olivine. Most of the olivine crystals have, however, been lost due to hammering and weathering. Their original positions are indicated by small surviving splinters and by the presence of continuous 0.8-1 mm wide rims of swathing kamacite.

The metal shows a medium Widmanstätten structure of long, bundled ($\frac{l}{w} \sim 40$) kamacite lamellae with a width which is badly defined. It decreases monotonically from about 1.3 mm to 0.5 mm in a way which is very rarely seen in iron meteorites. The kamacite displays subboundaries with inconspicuous 1μ precipitates, and Neumann bands are well developed.

The ratio (taenite + plessite):kamacite is difficult to estimate because kamacite lamellae of all sizes repeatedly dissect the plessitic areas. A typical plessite field will display cloudy taenite edges, narrow martensitic transition regions and duplex interiors. These may be dark-etching, unresolvable, or easily resolved duplex $\alpha + \gamma$ mixtures, or acicular fields with bayonet-shaped α -spindles. Only insignificant annealing has occurred.

Schreibersite is common as cuneiform crystals, e.g., 2×0.2 mm in size. More common are $20-100 \mu$ wide grain boundary veinlets and $5-50 \mu$ particles inside plessite, substituting for taenite of similar sizes. Rhabdites were not observed. The bulk phosphorus content is estimated to be $0.15 \pm 0.03\%$.

Troilite and other meteoritic minerals were not seen on the sections but will undoubtedly be detected on further sectioning.

The mass is plastically deformed. Near the surface the kamacite lamellae are strongly bent and filled with lenticular deformation bands. Consequently, the Neumann bands are distorted and the schreibersite is sheared and brecciated. The reason for this may be dual. Atmospheric breakup can have caused the deformations, and/or the Indian artisans may have hammered the material. The deformations corres-



Figure 883. Hopewell Mounds (Chicago no. 481). Cloudy taenite rim with duplex unresolvable transition zones to interior net plessite. Etched. Scale bar 20μ .

pond pretty well to what is known to occur on the surface of multiple falls, such as Cape York, Glorieta Mountain, Gibeon and Campo del Cielo. Farrington (1902: 312) assumed that the mass had been heated and worked by the Indians, but this is out of the question. There are no indications of artificial reheating.

Samples from the Turner mounds were examined by Palache (1926a) and found to be severely distorted, with completely bent and elongated kamacite lamellae. In such cases the olivine crystals have been crushed and almost lost. It appears that the samples are the result of vigorous

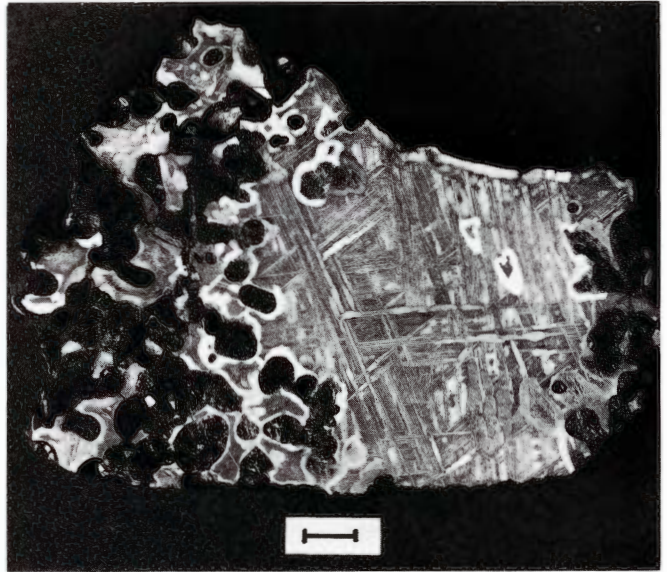


Figure 884. Brenham (U.S.N.M.). A fragment which shows transition between pallasite material with olivine (left) and almost olivine-free material (right). Deep-etched. Scale bar 10 mm. S.I. neg. 13527.

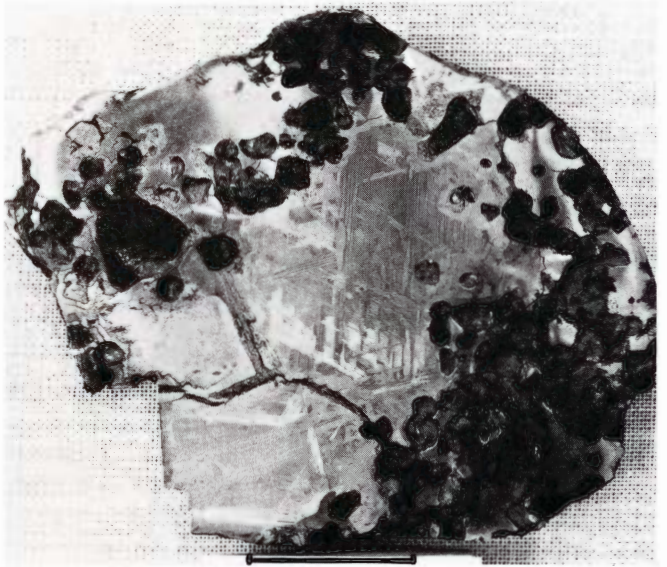


Figure 885. Brenham (University of California, Los Angeles). A slice of 1100 g displaying olivine crystals (black) and three large precursor austenite crystals. The black angular mineral on the left is a chromite crystal, measuring 18×15 mm. Abundant schreibersite: In grain boundaries, as rims and as independent skeleton crystals. Deep-etched. Scale bar 30 mm.

hammering in order to eliminate the olivine and consolidate the iron.

The material is weathered. No fusion crust or heat-affected α_2 zones were detected, indicating that the material is terrestrially old. Selective oxidation has converted the α -phase of the plessite to limonite, to depths of at least 1 mm. Limonitic veinlets, 10-100 μ wide, penetrate the material, particularly along the shattered phosphides, thereby partly recementing them. It appears very unlikely that the Indians witnessed the fall.

The nugget from the Hopewell Mounds corresponds completely in macro- and micro-structure, degree of weathering and detailed chemical composition to the masses from the Turner Mounds and to the Brenham pallasite fragments. The conclusions by Kunz (1890a), Brezina (1896) and Wasson & Sedwick (1969) can be wholly supported. The Brenham pallasite was scientifically recognized in 1890, when Kunz (1890a) reported about 20 masses, ranging from 30 g to 200 kg in weight. Monnig (1948), Nininger & Nininger (1950: 35, 106) and Nininger (1952a: 199, 217, etc.) described the site and estimated that about 4.3 tons of material had been removed over the years from the Brenham field. The material available at the time of the Hopewell culture must have been several times greater. The field was probably a veritable "iron mountain" which was systematically "mined" in a way similar to the working of the Cape York meteorites by the Eskimos, except that the Hopewellians – or their neighboring tribes – had an easier task when splitting pallasitic masses.

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

Small fragments (< 1 g)

Hopper, Virginia, U.S.A.

36°33'N, 79°47'W; 200 m

Medium octahedrite, Om. Bandwidth 0.70±0.15 mm. Neumann bands. HV 220±20.

Group IIIB judging from the structure. About 9.5% Ni, 0.5% P.

HISTORY

A weathered mass of 1.9 kg was plowed up in 1889 by Nathaniel Murphy, in Henry County (Venable 1890b). Farrington (1903: 100) pointed out that the locality was close to the post office of Hopper and that applying this name would prevent confusion with Locust Grove, from another Henry County. Hopper is a very small community, which has the coordinates given above. According to Venable (1890b) the mass went through several hands, the last known owner being Dr. H.B. Battle of Raleigh, North Carolina. The U.S. National Museum specimen was obtained from Battle in 1890; other small fragments have also been distributed. It appears, however, that the main mass is either lost, in private possession or in a minor state collection. Farrington (1903) suggested that Hopper might

be a fragment of Smith's Mountain, a 5 kg mass found only 21 km farther southwest. As discussed below the present author, upon detailed structural comparison of the two irons, comes to a different conclusion.

COLLECTIONS

Chicago (47 g), Washington (25 g), New York (8 g).

ANALYSIS

The only known analysis is by Venable (1890b), who found 7.70% Ni and 0.13% P. The analysis is not in harmony with the structure, which rather indicates about 9.5% Ni and 0.5% P. Venable also reported a substantial amount of lawrencite. This is, however, an unwarranted extrapolation from the observed chlorine content of 0.35%, which no doubt mainly comes from the terrestrial ground water.

DESCRIPTION

Venable (1890b) gave the average dimensions as 7.5 x 7 x 6 cm and stated that the mass was crumbling. Even during his examination 0.22 kg oxidized shale broke off. The three pieces extant today are all cleavage fragments, resulting from weathering and splitting along octahedral planes. They are penetrated by 10-500 μ wide veinlets of terrestrial oxidation products, and corrosion has further selectively attacked the alpha phase of the plessite and the relatively nickel-poor zones adjacent to schreibersite and rhabdite. No fusion crust or heat-affected rim zones are preserved.

An etched section through the Washington fragment disclosed a medium Widmanstätten structure of straight, long ($l/w \sim 30$) kamacite lamellae with a width of 0.70±0.15 mm. A better bandwidth determination was not possible on the small fragment. The kamacite displays numerous subboundaries decorated with 0.5-1 μ thick rhabdites. The kamacite has Neumann bands and a micro-hardness of 220±20. Large kamacite areas, e.g., 4 x 5 mm in size, are present locally. This appears to be characteristic of some group IIIB irons, but is rather unexpected at these relatively high-nickel levels.

Taenite and plessite cover about 40% by area. The acicular plessite, which is so dominant in Narraburra, is typical. The intercalated, concave taenite islands have martensitic interiors. Comb and net plessite are also present, and, locally, a 6 x 6 mm field of spheroidized plessite is observed. The taenite spherules are 10-20 μ across and relatively densely spaced.

Schreibersite is common as 1-2 mm skeleton crystals, monocrystalline but brecciated and altered by terrestrial weathering. It further occurs as 20-60 μ wide grain boundary veinlets and as 10-20 μ blebs inside the comb plessite. Characteristic are the 10-20 μ islands, occurring in rows 5-10 μ in front of taenite and plessite. Rhabdites are present as a few, large crystals, 20-50 μ thick, and as prisms, 1-2 μ across, evenly distributed through the matrix.

Troilite was not present in the examined fragment.

Hopper is a medium octahedrite related to Ilinskaya Stanitza, Apoala and Smith's Mountain. Its chemical composition is not sufficiently known. Its structure resembles Smith's Mountain very much, but there appear to be three significant differences: (i) Hopper has Neumann bands; Smith's Mountain has ϵ -structure; (ii) Hopper's kamacite hardness is 220 ± 20 ; Smith's Mountain's is 280 ± 20 ; (iii) Hopper appears to have a higher terrestrial age than Smith's Mountain. It is, therefore, tentatively concluded that the two irons are separate falls.

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

25 g weathered, octahedral fragment (no. 159, 2.5 x 1.5 x 1 cm)

Horse Creek, Colorado, U.S.A.

Approximately $37^{\circ}35'N$, $102^{\circ}46'W$; 1350 m

Anomalous hexahedrite with abundant nickel silicide. No Neumann bands. HV 252 ± 12 .

Anomalous enstatite chondrite. Bulk composition: 6.3% Ni, 0.34% Co, 0.5% P, 2.5% Si, 47 ppm Ga.

HISTORY

In 1937, when H.H. Nininger made a survey for meteorites in a sparsely settled area of southeastern Colorado, he obtained from Charles W. Moore a small mass of 570 g. The specimen had been discovered at an Indian Camp site on Horse Creek, 20 miles north of Springfield, Baca County (A.D. Nininger 1937: 449; Nininger & Nininger 1950: 62, 111). Since the mass was found at a camp site, it had possibly been transported; the coordinates above are, therefore, very approximate.

The meteorite was described by Perry (1944; 61, plates 60 and 61), who realized that it was highly anomalous and not an octahedrite although superficially resembling one of

the finer varieties. He gave eight photomicrographs and discussed the kamacite and the inclusions which were assumed to be schreibersite. However, about 1958, E.P. Henderson showed that most of the lamellar material was a new mineral, a nickel silicide, with the approximate composition $(Ni,Fe)_xSi_y$ (unpublished). Ramdohr (1963a: 2014) observed a similar mineral in the St. Marks, Indarch and Grady No.2 meteorites and noted that this was isotropic and displayed octahedral cleavage.

Fredriksson & Henderson (1965) examined Horse Creek with the microprobe and found the mineral, for which they proposed the name perryite, to consist of 81% Ni, 3% Fe, 12% Si and 5% P. They assumed that the silicide of Horse Creek was identical to that of St. Marks, as have all later authors also erroneously done. Perryite of variable compositions was found in the St. Marks enstatite chondrite (Fredriksson & Reid 1967). Reed examined the silicides in Horse Creek and in the enstatite chondrites, Kota-Kota and South Oman, where the mineral was more massively developed than in Horse Creek, so that a better microprobe analysis could be obtained. The compositions were found to lie within the limits 75-81% Ni, 3-7% Fe, 12-15% Si and 2-5% P.

Wai & Wasson (1969) and Wasson & Wai (1970) analyzed the anomalous meteorites Mount Egerton and Horse Creek, and compared them to the enstatite achondrites, of which Norton County in particular was found to show similar features, such as a highly reduced kamacite phase with 0.6-2.5% Si, and the presence of perryite.

Strunz (1970: 97) and Fleischer (1972) do not agree with respect to the stoichiometric formula of perryite, giving, respectively, $(Ni,Fe)_2(Si,P)$ and Ni_5Si_2 . It appears that the mineral is quite insufficiently described. From the examination that follows here, it furthermore appears that two different minerals, or perhaps two allotropic forms of the same mineral, are involved, one being a cubic mineral as typified in the St. Marks enstatite chondrite, and the other being an anisotropic mineral, present only in Horse Creek.

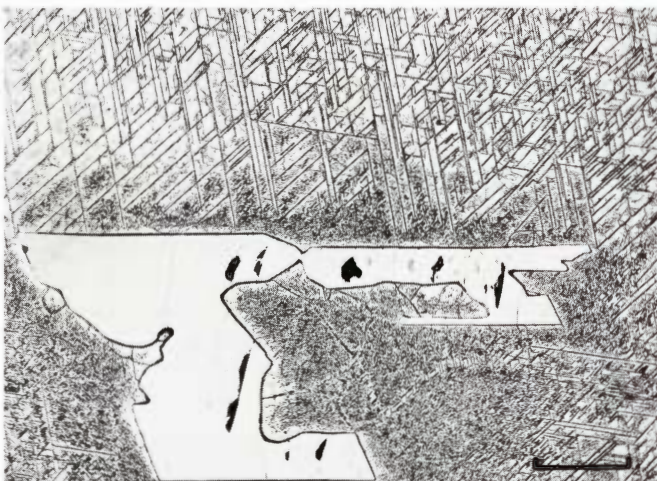


Figure 886. Horse Creek (U.S.N.M. no. 1237). An extremely anomalous iron meteorite. A large skeleton crystal of schreibersite. Etched. Scale bar 400 μ . (From Perry 1944: plate 60.)

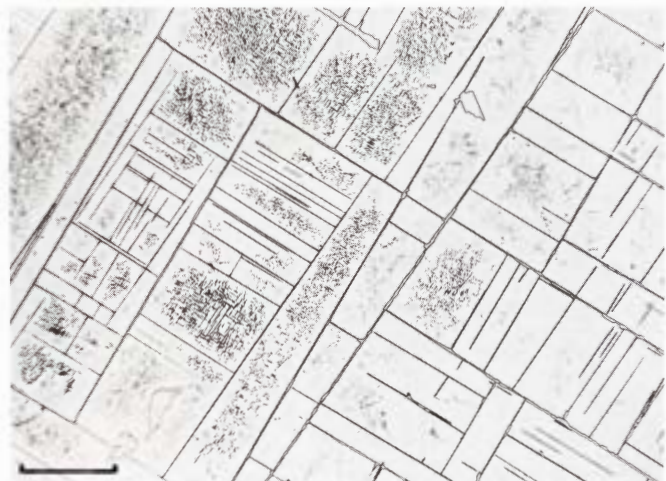


Figure 887. Horse Creek (U.S.N.M. no. 2499). A view of a section through the mass, cut at a different angle from Figure 886. Etched. Scale bar 300 μ .