

part. Complex melts of phosphides and sulfides, somewhat altered by corrosion, also occur. The α_2 phase consists of serrated unequilibrated grains, 10-150 μ across, with a hardness of 200 ± 15 (hardness curve type II). Surprisingly enough, the Neumann bands apparently survive in the α_2 phase. High magnification reveals, however, that it is only the fine precipitates, previously exsolved in the bands, that are retained, while the bands themselves of course disappeared on the rapid transformation $\alpha \rightarrow \gamma \rightarrow \alpha_2$.

Colomera is an anomalous meteorite, an iron-with-silicate inclusions. If it were not for the detailed trace element analyses and the minute examinations of the silicates, it would be difficult to point to related iron meteorites. As it is, it appears that Colomera belongs to the rather heterogeneous group, comprising Elga, Kodaikanal and Weekeroo Station, and possibly some others, too, such as Arlington and Barranca Blanca, in which silicates have not been detected.

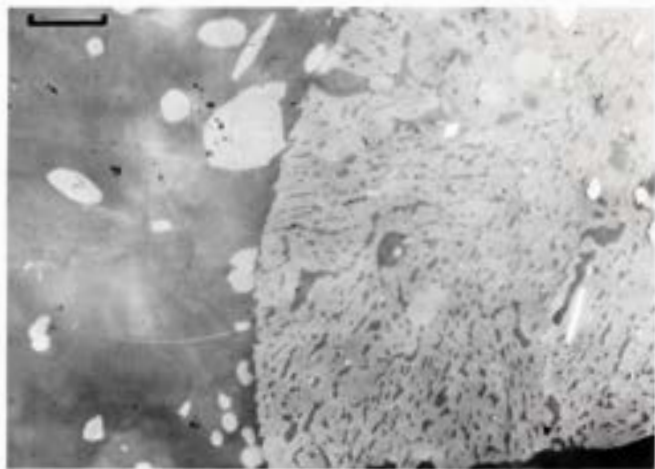


Figure 661. Colomera. Detail of the crescent-shaped inclusion in Figure 660. Polished. Scale bar 50 μ .

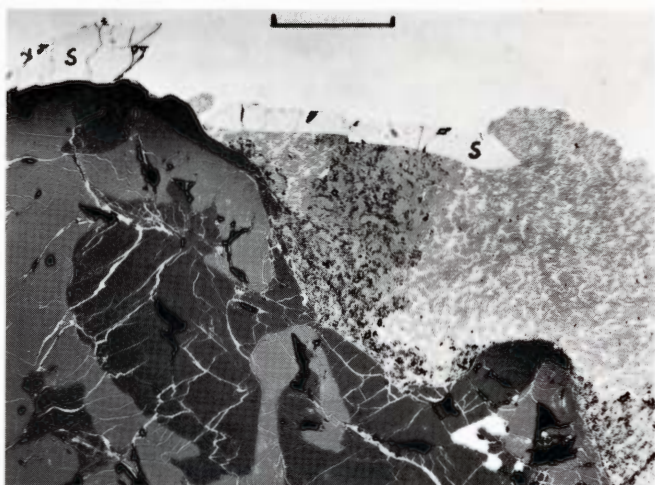


Figure 662. Colomera (U.S.N.M. no. 3396). Shock-melted troilite (right) with metal particles. Shear-displaced schreibersite (S) and altered silicates (gray, black). Polished. Scale bar 200 μ .

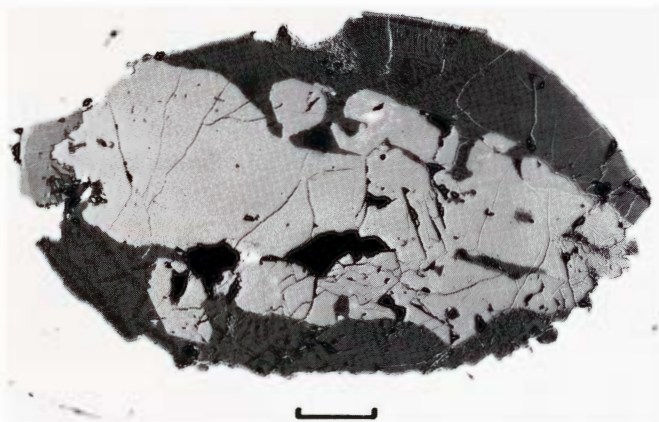


Figure 663. Colomera (U.S.N.M. no. 3396). Massive silicate nucleus surrounded by silicate glass with bar-shaped silicates. Polished. Scale bar 200 μ .

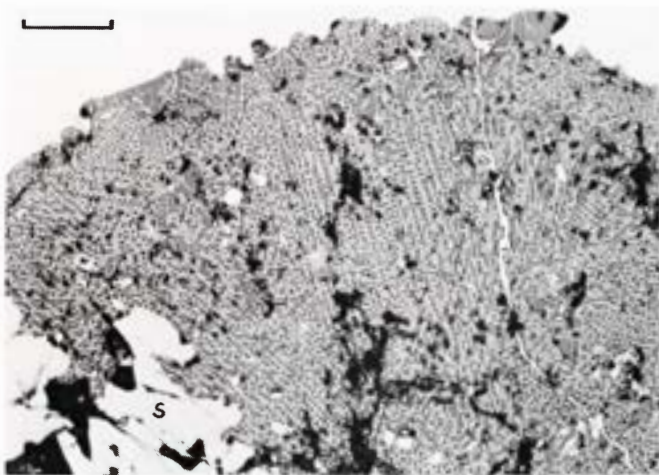


Figure 664. Colomera (U.S.N.M. no. 3396). This particular silicate nodule was located only 1 mm under the surface in the heat-affected α_2 zone. Its dendritic structure seems, however, to be preatmospheric. Schreibersite (S). Polished. Reflected light. Scale bar 100 μ .

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

- 133 g part slices (no. 1514)
- 1,224 g slice (no. 3396, 40 x 10 x 0.5 cm)
- 1,200 g slice (no. 3396, 40 x 10 x 0.5 cm)
- 781 g slice (no. 3396, 40 x 10 x 0.5 cm)

Comanche, Texas, U.S.A.

32° 1'N, 98° 42'W; 400m

Coarse octahedrite, Og. Bandwidth 1.50 ± 0.30 mm. Neumann bands. HV 170 ± 15 .

Group I. 8.1% Ni, about 0.25% P, 73.9 ppm Ga, 269 ppm Ge, 2.2 ppm Ir.

HISTORY

A mass of 19.7 kg was listed as an octahedrite by Leonard (1956a: 8, 46). The main mass is still in private possession, but, through the kind cooperation of Mr. O.E. Monnig, a 550 g specimen was acquired by the U.S. National Museum in 1964. According to information supplied by Mr. Monnig in letters to the Museum (Decem-

ber 4, 1963; December 15, 1963), the iron was dug up in 1940 with a mechanical scraper during excavation for a surface water tank. The place is only about two miles from the place where the Comanche stone meteorite was found in 1956 or 1957; it is about 15 km northwest of Comanche in Comanche County and has the coordinates given above.

DESCRIPTION

The 550 g specimen in the U.S. National Museum is a badly rusted, and still rusting, angular fragment with the dimensions of 7 x 5 x 3 cm. Most of the surface is covered by 1-2 mm thick iron oxide flakes that easily spall off. One edge shows an area of 4 x 2.5 cm thickly covered with cavernous globules and slags of the kind that develop when iron is cut with an oxy-acetylene torch. A note attached to the specimen confirms that the fragment unfortunately was detached from the main mass with a cutting torch.

A small etched section displays a coarse Widmanstätten structure with bulky, short ($\frac{L}{W} \sim 10$) lamellae of an average width of 1.5 mm. The ferrite shows numerous Neumann bands. The subgrain boundaries are decorated with tiny precipitates, $<1 \mu$, most of which are phosphides. The microhardness of the kamacite lamellae is 170 ± 15 .

Plessite occupies about 10% by area, mostly in the form of comb plessite the rims of which have pearlitic and spheroidized interiors. The taenite lamellae of the pearlite are 0.5-2 μ wide and have a similar spacing; the α -phase between the lamellae is locally corroded and transformed to bluish-black oxides. The larger taenite ribbons are stained due to carbon in solid solution, except in the reheated rim zone where the carbon has had a chance to diffuse away.

Schreibersite occurs as 8 x 1 mm hieroglyphs that are monocrystalline and a little brecciated and as 20-50 μ wide grain boundary precipitates and as ubiquitous 5-50 μ tetragonal rhabdite prisms. The bulk phosphorus content is estimated to be 0.25%.

Troilite is present as from 20 μ to 1 mm monocrystalline nodules embedded in, or adjacent to, the larger schreibersite crystals. The troilite shows lenticular twins due to mild deformation. In several places there are 50-100 μ silicate grains (olivine?) embedded in the troilite. Tiny, angular beads of troilite and iron are situated inside the silicates. Graphite is present in the troilite as aggregates of 25-50 μ spherulites of radiating sheaves. Daubreelite occurs as 25 μ thick lamellae in the troilite. Chromite was observed as a 150 x 50 μ straight bar. What appeared to be a eutectic intergrowth of chromite and troilite occurred inside a 100 μ silicate grain. Some unidentified grains, 50-100 μ across, of a grayish, anisotropic opaque mineral were observed. Cohenite was not observed but is expected to be present in other sections.

The specimen examined possessed locally millimeter-thick α_2 zones very similar to the heat-affected zones on a fresh fall. However, since the specimen contained part of the oxy-acetylene torch cut, a full slice was carefully prepared to disclose what was artificial and what was original. It turned out that the cut zone was recognizable upon the slag with included dendrites of metal and upon the laceworks around the corroded fissures. As discussed under, e.g., Burlington, these laceworks represent high temperature decomposition zones of terrestrial hydrated oxides and show definitively where the temperature was above 600-700° C for a few minutes. No laceworks and no α_2 were present 10 mm from the cut face, so the main mass was not heated very much during cutting.

The unheated part contains a genuine 0.5-3 mm thick heat-affected α_2 zone and, in places, even a laminated fusion crust is preserved under a 1 mm thick corrosion crust. The fusion crust is composed of 8-10 laminae of dendritic, cellular metal, with cells 2-10 μ across. The remainder of the overlying, fused oxides are locally preserved as 10 μ thick, dendritic material. Two-phased dendritic oxide spherules, 1-20 μ in diameter, are embedded in the metallic fusion crust. The microhardness of the kamacite along a trace perpendicular upon the surface varies from 200 ± 10 in the α_2 zone through a minimum of 150 to an interior level of 170 ± 15 (hardness curve type II).

Comanche is a coarse octahedrite which resembles Odessa. It is corroded, and it was heated artificially at one end, but the main mass appears to be undamaged and preserves a little fusion crust and a heated rim zone. This seems to indicate that it is an independent fall and not, for example, a fragment of Odessa.

Specimen in the U.S. National Museum in Washington:
550 g endpiece (no. 2246, 7 x 5 x 3 cm)

Cookeville. See Smithville (Cookeville)

Coolac, New South Wales, Australia

34°58'S, 148°7'30''E

Coarse octahedrite, Og. Bandwidth 2.10 \pm 0.30 mm. Neumann bands. HV 154 \pm 12.

Group I. 7.0% Ni, 0.53% Co, about 0.2% P, 92 ppm Ga, 379 ppm Ge, 2.4 ppm Ir.

HISTORY

A mass of 19.3 kg was found about 1874 by T. McMahon while prospecting for gold in the Happy Valley,

COMANCHE – SELECTED CHEMICAL ANALYSES

Reference	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Wasson 1970a	8.1 \pm 0.2								73.9	269	2.2	

Parish Bongongolong, County Harden, about 5 km west of Coolac. It was used as a firestop in an open fireplace for four or five years and stayed in possession of the McMahon family for several generations until it became known and was described by Hodge-Smith (1937), who concluded that the mass had been heavily altered structurally due to its serving in the kitchen. Hodge-Smith gave here and later (1939: plate 7) a couple of photographs of the exterior and of a macroetched section. Henderson (1951) reexamined the iron and presented a new and better analysis, along with four photomicrographs. He concluded that the iron was not adversely affected by its former treatment. Agrell et al. (1963) showed a microprobe line scan across kamacite-taenite; as the nickel distribution is perfectly "normal," it must be concluded that the heatings certainly did not allow nickel to diffuse. Lovering (1964) analyzed the cohenite crystals and found 92.8% Fe, 1.34% Ni, 0.05% Co and less than 0.1% of each of P, Mn, Cr, V and Ti. Reed (1965a, b; 1969) determined the composition of the kamacite, taenite, schreibersite and rhabdite.

COLLECTIONS

London (2,307 g), Washington (2,067 g), Canberra (1,403 g), Sydney (510 g), Tübingen (about 500 g), New York (256 g), Harvard (155 g), Chicago (14 g). Where is the main mass?

DESCRIPTION

The mass was pyramidal in shape, with the maximum dimensions 22 x 20 x 18 cm. The specimen in the U.S. National Museum shows broad thumbprints but is also covered by 0.5-1 mm iron oxides. On sections it is seen that the fusion crust and the α_2 zone have been removed by corrosion, so at least 2-3 mm is lost. The exterior morphology does, however, still roughly reflect the original form of the iron.

Etched sections show structures varying from typical coarse, inclusion-rich Widmanstätten patterns with bandwidth of 2.10 ± 0.30 mm to rather inclusion-free regions of almost equiaxial ferrite grains 5-15 mm in diameter. The variation is extreme between the two parallel, polished faces, 6 cm apart, on no. 1370. It appears here, as elsewhere in group I irons, that the late grain growth responsible for the equiaxed, granulated structures particularly took place in inclusion-free regions, while cohenite-

rich parts preserved the distinct Widmanstätten structure and the intercalated taenite-plessite fields for a long time.

Neumann bands are common. Plessite occurs in minor amounts (about 1%) as degenerated comb plessite, but particularly as pearlitic (0.3μ wide lamellae) and spheroidized plessite, adjacent to the cohenite crystals. Some acicular and martensitic plessite is also observed.

Schreibersite occurs as 50-100 μ wide grain boundary precipitates, as 0.5 mm rims around troilite, and as 20-50 μ inclusions in cohenite. Rhabdites are very common as 5-20 μ tetragonal prisms. The bulk phosphorus content is estimated to be $0.20 \pm 0.04\%$.

Troilite is present as scattered nodules and lenses, 5-20 mm in diameter. They appear to be monocrystalline, but some of them are sheared and displaced 1-2 mm. Graphite and enstatite in small amounts have been reported (Hodge-Smith 1937), but were not present in the U.S. National Museum specimen.

Cohenite is the distinguishing mineral on most sections. It has the usual rounded, branched, lamellar shape with numerous windows of 100 μ ferrite, austenite and phosphide. It is usually 4 x 1 mm and centrally located in the Widmanstätten lamellae, with some adjacent taenite and plessite. It is further present as 50-200 μ rim zones upon the larger schreibersite crystals. It is only slightly brecciated and shows only incipient stages of decomposition to graphite.

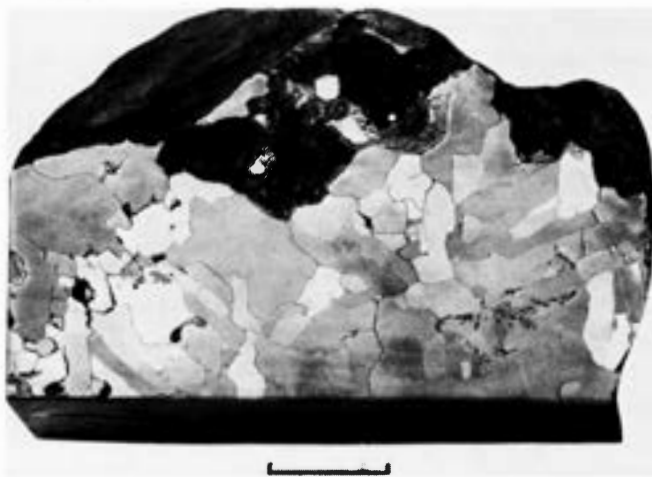


Figure 665. Coolac (U.S.N.M. no. 1370). Coarse octahedrite of group I exhibiting kamacite grain growth. Several clusters of cohenite crystals. Deep-etched. Scale bar 20 mm. S.I. neg. 41053C.

COOLAC - SELECTED CHEMICAL ANALYSES

Reed (1965b) found the kamacite to be homogeneous at the 6.90% Ni level, but corrected it (1968) to 6.60% Ni.

Hodge-Smith (1937) found 0.68% C.

References	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Henderson 1951	6.78	0.87	0.03									
Lovering et al. 1957	6.95	0.53				4.6	158		93	335		
Bothwell in Hey 1966	6.86											
Wasson 1973 pers. comm.	7.4								91.5	423	2.4	

Terrestrial corrosion penetrates along the octahedral planes and along the grain boundaries of the granulated areas. The subgrain boundaries are little attacked, and the selective oxidation around rhabdites has not yet started; so the corrosion picture shows a stage intermediate between a fresh fall and a weathered fall like Cookeville. No indications were found of diffuse taenite, haloes around rhabdites or high temperature reactions between terrestrial oxides and the matrix, so the heating by the finder's grandmother in the kitchen (Hodge-Smith 1937) has been mild. On the other hand, the kamacite was found to have the unusual low hardness of 154 ± 12 ; other similar meteorites normally display a kamacite hardness of about 175. This indicates that recovery has taken place, suggesting some annealing in the kitchen at $400\text{--}450^\circ\text{C}$.

Coolac is a typical inclusion-rich, coarse octahedrite, that is related to such irons as Cranbourne, Seeläsgen and Wichita County.

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

2,044 g block with four polished faces (no. 1370, $8.5 \times 6 \times 5$ cm)
23 g part slice (from above, $4 \times 3 \times 0.3$ cm)

Coopertown, Tennessee, U.S.A.

$36^\circ 26' \text{N}$, $87^\circ 0' \text{W}$; 180 m

Coarse octahedrite, Og. Bandwidth 1.50 ± 0.20 mm. ϵ -structure. HV 285 ± 25 .

Group IIIE. 8.47% Ni, 0.48% Co, 0.19% P, 17 ppm Ga, 35 ppm Ge, 0.51 ppm Ir.

HISTORY

A mass of 16.8 kg was discovered by Mr. D. Crockett near Coopertown, Robertson County. In 1860 the iron was sent to Professor J. Lawrence Smith who cut it in parallel slices and briefly described it (1861). Huntington (1866; 1888: 79) presented sketches of the Widmanstätten structure but argued, incorrectly, that dodecahedral planes were also present. Merrill (1916a: plate 20) gave an excellent photomicrograph of a typical section, while Böggild (1927) discussed the orientation of the rhabdites. Nininger & Nininger (1950: plate 4) reproduced a photograph of another etched section. Jaeger & Lipschutz (1967a, b) reported ϵ -structure to be present, indicating shock pressures of about 600 k bar.

COLLECTIONS

Amherst (1,763 g), Harvard (1,325 g), Washington (1,149 g), Vienna (885 g), Yale (815 g), New York (681 g),

Tempe (358 g), Paris (296 g), Chicago (213 g), London (173 g), Berlin (172 g), Philadelphia (154 g), Copenhagen (85 g) and numerous other collections.

DESCRIPTION

The wedge-shaped mass had, according to Smith (1861), the following extreme dimensions: $25 \times 23 \times 14$ cm. The larger specimens preserved indicate that Coopertown is a corroded fall with no fusion crust visible. Instead, 0.5–2 mm thick limonitic crusts are common, and locally the surface is disintegrating into octahedral fragments. On sections it is seen that corrosion attacks the α -phase selectively, particularly around rhabdites, and in plessite fields. The heat-affected α_2 zone is completely removed and shallow oxide-filled pits are common along the surface. A few oxide-filled cracks along the $\{111\}$ planes penetrate the mass, but elsewhere the interior is well preserved.

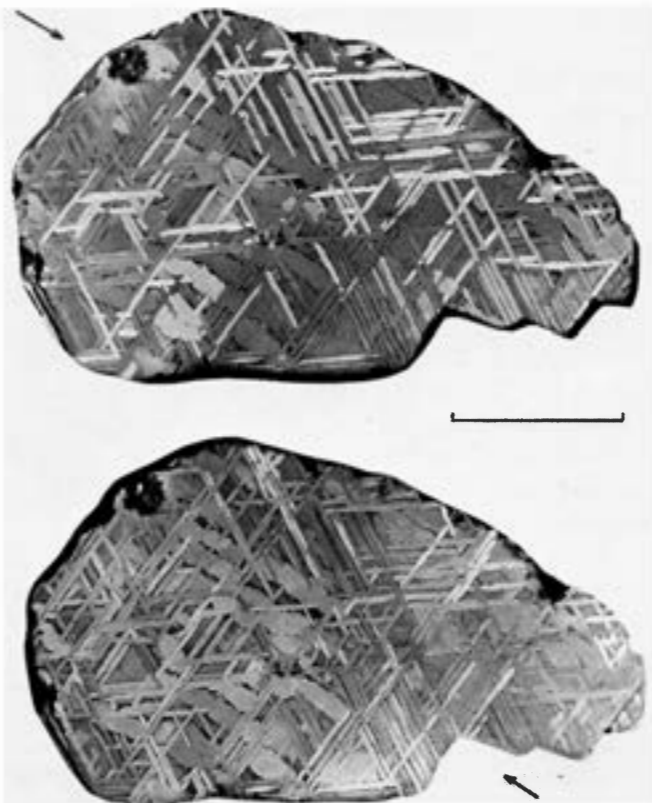


Figure 666. Coopertown (Vienna no. F 6355). A section through the whole 16.8 kg mass. The section is parallel to $(111)\gamma$ so that the fourth Widmanstätten direction appears as irregular horizontal kamacite plumes. The slice has been photographed from above, with the illumination coming as indicated from left (above) and right (below). Deep-etched. Scale bar 50 mm.

COOPERTOWN – SELECTED CHEMICAL ANALYSES

References	percentage			C	S	Cr	Cu	ppm				Pt
	Ni	Co	P					Zn	Ga	Ge	Ir	
Lovering et al. 1957		0.49				49	113		17	32		
Moore et al. 1969	8.47	0.47	0.19	285	40		130					
Scott et al. 1973	8.47								17.0	34.9	0.51	

Etched sections display a beautiful Widmanstätten structure with somewhat swollen, long ($\frac{L}{W} \sim 20$) α -lamellae. They are unusually broad for this type of meteorite, 1.50 ± 0.20 mm; with this nickel-phosphorus content the normal width is 10-20% lower. It is also anomalous to find, roughly, only one generation of equally broad lamellae while the remainder of the alloy is plessitic. Since the original slicing by Smith was done almost parallel to an octahedral plane of the Widmanstätten structure, the three directions of the structure form almost equilateral triangles, while the fourth direction appears as 5 mm broad, parallel fingers bisecting one angle of the triangle. These broad lamellae are undoubtedly what Huntington (1888) erroneously termed dodecahedral lamellae.

The α -lamellae have numerous subboundaries decorated with $<1 \mu$ phosphide precipitates. Due to shock the lamellae all show ϵ -crosshatching between long lines that resemble the normal Neumann bands closely. Jaeger & Lipschutz (1967a) compared it with shock standards and concluded that this particular structure was similar to an Odessa specimen shocked to 600 k bar in the laboratory. It appears that the kamacite contains numerous submicroscopic particles precipitated in a regular, very fine grid. The microhardness of the matrix is 285 ± 25 due to shock hardening.

Plessite covers about 30% by area. The larger fields are very regularly developed comb plessite with 20-50 μ wide, parallel α -lamellae, separated by 2-5 μ wide taenite lamellae, all repeating the gross Widmanstätten pattern. Some fields are densely acicular and of the type commonly found in Toluca and other group I meteorites. In the interior of these are often found scalloped to palmate carbide aggregates up to 0.5 mm in diameter. The carbide has small inclusions of schreibersite and is closely intergrown with kamacite and taenite. It is rare to have carbide of this morphology and it is almost unique in a group IIIA meteorite, but it has been reported in this work from several other irons, e.g., Rhine Villa, Carlton, Edmonton, Mungindi, Chihuahua City, Colfax, and Santa Rosa. The carbide has a microhardness of 1040 ± 40 ; it is cubic and has been named haxonite by Scott (1971).

Schreibersite occurs primarily as 20-50 μ wide grain boundary precipitates, although a 20 x 0.1 mm vein may occasionally be found. It is further common as 5-20 μ vermicular bodies in the plessite fields where it is easily overlooked among the similar-sized taenite blebs; it is, perhaps, best distinguished from taenite and carbide in a polished, unetched section. Rhabdites are ubiquitous as 5-20 μ tetragonal prisms. Some displacement and brecciation of schreibersite and rhabdite is seen locally. The few schreibersite grains measured had a microhardness of 825 ± 40 .

Troilite occurs sparsely as 2-10 mm irregular bodies. It is shock-melted and solidified to a polycrystalline aggregate of 1-10 μ grains. The associated 10-400 μ wide daubreelite lamellae are somewhat brecciated and sheared and locally dispersed in the troilite. Some troilite grains are still

monocrystalline but show lenticular anisotropic subzones, presumably from plastic deformation. The unbroken troilite and daubreelite crystals have microhardnesses of 225 ± 20 and 460 ± 20 , respectively.

Daubreelite occurs also as 10-25 μ wide blebs, scattered in the kamacite lamellae.

Tiny, hard needles or slender plates, typically 10 x 0.5 μ , are common in the matrix. They are also found embedded in rhabdites and, to a smaller degree, in schreibersite and carbide. They look rosy and are hard enough to stand in strong relief against both phosphide and carbide! The same inclusions have been reported in this work from Angelica, Costilla Peak, Madoc, Morito and numerous other irons. They were identified as chromium nitride, carlsbergite (Buchwald & Scott 1971).

Coopertown is structurally and chemically an anomalous group IIIA meteorite. Compared to its closest relatives, irons, such as Aggie Creek, Bartlett, and Drum Mountains, it has 10-20% too large a bandwidth and too few bands of an intermediate size. It displays a significant amount of carbide roses in many plessite fields. It is 10-20% too low in phosphorus and, therefore, poor in phosphides. It contains the hard, needle-like carlsbergite which normally is only associated with a lower nickel level. And, finally, its gallium and germanium content is 10-20% too low for a smooth plotting of these elements versus nickel with the other group IIIA meteorites. As noted, page 102, Coopertown forms with several other irons a rather well defined group IIIE.

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

620 g slice (no. 30, 17 x 10 x 0.6 cm)
 191 g block (no. 1003, 4.5 x 2.5 x 2 cm)
 48 g block (no. 1003, 3 x 1.5 x 1.4 cm)
 76 g part slice (no. 1003, 4 x 3.5 x 0.7 cm)
 121 g part slice (no. 1588, 6.5 x 5.5 x 0.4 cm)
 93 g part slice (no. 3301, 5 x 5 x 0.5 cm)

Copiapo, Atacama, Chile

Approximately 27°20'S, 70°23'W

Coarse to granular octahedrite with silicate inclusions. Neumann bands. HV 170±8.

Group I – Anomalous. 7.0% Ni, about 0.25% P, 70 ppm Ga, 252 ppm Ge, 2.5 ppm Ir.

HISTORY

Very little is known of the origin of this meteorite which has often been confused with Dehesa and the mesosiderite Vaca Muerta. Copiapo was first mentioned by Haidinger (1864) who examined a three-pound rounded specimen which, in 1863, had been sent to Germany with a collection of minerals from the silver mine in Copiapo. Haidinger divided the specimen into a midsection and two endpieces of 140, 592 and 510 g weight, respectively, and described them with galvanoplastic prints of the etched surfaces. Daubr e (1868a: 571, part II) received two pieces of 1,305 and "800 g" from Domeyko in Chile and gave a

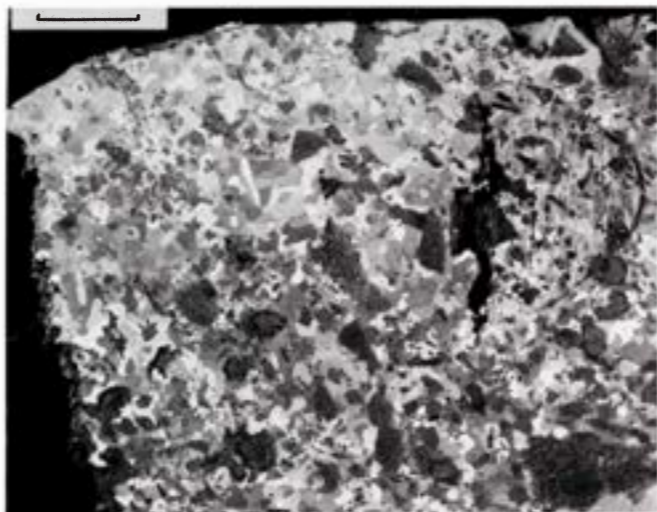


Figure 667. Copiapo (one of the Paris samples). Anomalous iron meteorite with angular silicate inclusions. (The crescent-shaped indentation is due to imperfect grinding and polishing). Deep-etched. Scale bar 20 mm. S.I. neg. M-1418.

preliminary description. However, due to some exchange of labels, Daubrée gave an erroneous locality, Cordillère de Dehesa; this misunderstanding was corrected by Domeyko (1879: 132) and Fletcher (1889: 255). I might add that Daubrée also erred in the weights given. He received 1,305 and 80 g, not 800 g. This may be seen by comparison with Meunier's extensive description (1884: 153) and Labat's catalog (1909: 36, 280). This conclusion was confirmed by a personal examination of the acquisition protocols in Paris in May 1972. Domeyko, the general inspector of mines in Santiago, appears to have known only one mass of 7 kg which he obtained with a mineral collection from Mr. Ludeve. Nevertheless, more material must have become available through other channels, for soon after (Meunier 1898: 80) Paris could announce the possession of a total of 13.9 kg, the largest piece weighing 9.50 kg, while Berlin (Klein 1906: 129) had obtained 3.40 kg. The situation is confused, the locality is not known with any accuracy at all, and the total weight recovered is unknown. So much appears certain, however, that at least four individuals with a minimum weight of 20 kg were discovered. Below is listed what presently is believed to be authentic material in collections.

In addition to the descriptions by Haidinger, Daubrée, and Klein, Brezina (1885: 217) briefly examined the material in Vienna, while Meunier (1884: 152) identified olivine, hypersthene and some odd silicates in the Paris specimens. Wülfing (1897) collected the references to the old literature. Quite recently Bunch & Keil (1969) have reexamined the silicates with the electron microprobe.

COLLECTIONS

Paris (about 8.5 kg), Berlin (3 kg), Vienna (1.2 kg), London (466 g), Dresden (339 g), Harvard (333 g), Lenin-grad (283 g), Moscow (274 g), Chicago (195 g), Washington (158 g), Copenhagen (138 g), New York (75 g), Calcutta (24 g), Vatican (6 g), Bonn (4 g).

DESCRIPTION

The following individuals appear to be authentic: No. 1 of about 1.5 kg, average dimensions 8.5 x 7.5 x 6.0 cm (Haidinger 1864), No. 2 of 1.30 kg, average dimensions 9 x 7 x 5 cm (Meunier 1884: 152), No. 3 of 7 kg (Domeyko 1879: 132) and No. 4 of 9.5 kg (Meunier 1898: 80). Whether the pieces in Berlin and London are individuals or slices I do not know, but Copiapo was, no doubt, a small shower. The specimen in the Smithsonian Institution is a slice cut from the Paris material. It exhibits a weathered surface of the type characteristic of irons exposed to the North Chilean desert conditions. The surface is covered by densely spaced pits, 2-5 mm across and 1-2 mm deep, and with jagged edges as seen on, e.g., Filomena, Baquedano and Maria Elena. No fusion crust and no heat-affected α_2 zone are preserved. Corrosion penetrates some millimeters and forms 10-50 μ wide limonitic veinlets; it also selectively attacks the iron phase of the shock-melted troilite and the pearlitic plessite.

Polished and etched sections display an unusual mixture of metal and dark inclusions. The inclusions constitute anything from 5 to 40% by volume of the various sections, with an estimated average of 15%. The largest pure metallic areas appear to be 4 x 4 cm while, on the other hand, the largest inclusions are 3 x 2 cm; they are generally much smaller.

The metal forms a continuous phase in which the irregular or angular inclusions are scattered. The metal was never a single austenite crystal, but an aggregate of many austenite crystals, each 2-5 cm across, which independently have transformed to a granular or to a Widmanstätten structure. Because the silicates are so widely scattered there have been abundant nucleation sites for kamacite upon cooling, and the resulting structure is, therefore, mostly a granular aggregate of more or less equiaxial kamacite grains 1-5 mm across. Squeezed between the kamacite grains are several taenite and plessite fields the outlines and interiors of which reveal the orientation of the parent taenite crystals. Only in the almost silicate-free regions a rather normal, coarse Widmanstätten structure may be observed. The bandwidth is here 1.5 ± 0.5 mm and the lamellae have a length:width ratio of about 6. The kamacite has subboundaries decorated with 0.5-1 μ phosphides, and Neumann bands are common. The hardness is 170 ± 8 .

COPIAPO - SELECTED CHEMICAL ANALYSES, METAL PHASE

Reference	percentage			ppm								
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Wasson 1970b	7.01								69.8	252	2.5	

Taenite and plessite occur irregularly, covering 1-5% by area. While comb and net plessite appear to be absent, a very beautiful pearlitic plessite is common. A typical field, 1 x 0.5 mm in size, may be composed of pearlite with 0.5-4 μ wide taenite lamellae that locally merge with spheroidized plessite where the taenite spherules are 2-20 μ across. The hardness of the pearlite is only slightly higher (180 \pm 10) than that of the kamacite. Occasionally a minute haxonite crystal may be detected, intimately intergrown with plessite.

Schreibersite occurs as 1 mm wide skeleton crystals (HV 900 \pm 15) and is particularly common as 0.1-0.8 mm wide rims around the silicates. It also forms 20-100 μ wide grain boundary veinlets (HV 750 \pm 50). Rhabdites proper were not observed, but in the matrix are numerous phosphide precipitates, 0.5-1 μ across. The bulk phosphorus content is estimated to be 0.20-0.25%.

The inclusions are mainly silicates that form rounded grains, 50-800 μ across. They are scattered or they form loose or dense aggregates up to 3 cm in size. The interstices and also some grain interiors are filled with kamacite, troilite and graphite in various proportions. The silicates are mainly ortho- and clinopyroxene, olivine and plagioclase, as shown by Bunch & Keil (1969). Chromite occurs in very modest quantities as euhedral crystals, 50-200 μ across, often intergrown with the silicates. Whitlockite was, in addition, reported by Bunch & Keil.

Graphite is ubiquitous among the silicates, either as 1-10 μ inclusions or as 5-15 μ wide discontinuous rims that exhibit crystallographic outlines. Graphite fills the frequently deeply-frayed edges of the silicates. It also forms massive patches, e.g., 2 x 1 mm in size, with horsetail extinction and minute inclusions of troilite. Finally, it occurs in the kamacite and schreibersite, near the silicates, as rather well developed cliftonite crystals, 10-50 μ in diameter. These are often clustered to larger aggregates. Cohenite appears to be absent.

Troilite does not form typical nodules, but commonly fills the interstices in the silicate-graphite aggregates. The largest troilite observed is 2 x 2 mm in size. It is shock melted along the boundary against the metal, has dissolved some of the metal, and has then solidified to 1-5 μ eutectics. The interior of the troilite is monocrystalline but shows undulatory extinction. Daubreelite is only present in very small amounts. Most of the smaller troilite blebs have

also been shock melted and now form polycrystalline mosaics.

The morphology and the composition of both the metallic and the silicate-troilite-graphite phases are closely related to those of Pine River and Linwood, and farther away to Campo del Cielo, Canyon Diablo and other irons of group I.

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

158 g part slice (no. 3204, 8 x 4 x 0.8 cm)

Corowa, New South Wales

36°S, 146°22'E

Plessitic octahedrite. α -spindles about 0.2 mm wide.

Anomalous. 13.1% Ni, about 0.3% P, 10.1 ppm Ga, 159 ppm Ge, 0.77 ppm Ir.

HISTORY

A mass of about 11.3 kg (25 pounds) was plowed up in a wheat field on the property of D. McGillvray, approximately four miles from Corowa, near the Victoria-New South Wales State boundary. A portion of it was cut with an oxy-acetylene torch and examined by the finder and owner, while another was cut by means of a power hacksaw and examined in great detail by Baker et al. (1964). An electron probe analysis was carried out on various phases, and bulk chemical analysis and hardness tests were reported, together with two photographs of the exterior and ten of etched slices. Corowa was classified as a nickel-rich ataxite, related to Arltunga and Tawallah Valley. The present author disagrees with this classification for the reasons given below.

COLLECTIONS

Melbourne (? grams); the main mass still appears to be in private hands (Baker et al. 1964).

DESCRIPTION

The mass originally measured 23 x 18 cm, with a thickness that varied irregularly from 6 to 9 cm. No fusion crust was detected and limonitic corrosion products covered most of the surface without, however, penetrating more than a few millimeters into the interior (Baker et al. 1964).

COROWA – SELECTED CHEMICAL ANALYSES

The cobalt is anomalously low and probably in error. The phosphorus determination also appears low. Baker et al. (1964) reported lawrencite, but this was only based upon the usual circumstantial evidence: exudation of

colorless liquid from corroded cracks and rapid conversion of the liquid to pustules of rust. It appears that all the chlorine is of terrestrial origin, introduced during long exposure to corroding ground water.

References	percentage			ppm									
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt	

Taenite and plessite occur irregularly, covering 1-5% by area. While comb and net plessite appear to be absent, a very beautiful pearlitic plessite is common. A typical field, 1 x 0.5 mm in size, may be composed of pearlite with 0.5-4 μ wide taenite lamellae that locally merge with spheroidized plessite where the taenite spherules are 2-20 μ across. The hardness of the pearlite is only slightly higher (180 \pm 10) than that of the kamacite. Occasionally a minute haxonite crystal may be detected, intimately intergrown with plessite.

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DESCRIPTION

The mass originally measured 23 x 18 cm, with a thickness that varied irregularly from 6 to 9 cm. No fusion crust was detected and limonitic corrosion products covered most of the surface without, however, penetrating more than a few millimeters into the interior (Baker et al. 1964).

colorless liquid from corroded cracks and rapid conversion of the liquid to pustules of rust. It appears that all the chlorine is of terrestrial origin, introduced during long exposure to corroding ground water.

References	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Baker et al. 1964	13.43	0.16	0.09	200	5800		100					
Wasson 1969	13.13								10.1	159	0.77	

Only a small sample of 26 g was available for this examination. Etched sections show that Corowa is a plessitic octahedrite where scattered, pointed kamacite spindles cover about 20% by area, while taenite and plessite, with more numerous but much finer kamacite spindles, cover 80%. The prominent kamacite spindles are typically 0.2 mm wide and 5 mm long, but larger spindles occur, frequently developed around primary schreibersite crystals. The spindles occupy a multitude of directions, in fact more than can be accounted for by the Widmanstätten laws of precipitation. It appears that the additional directions are conditioned by early precipitates of schreibersite.

The plessitic matrix is a duplex mixture of α and γ on a microscopic scale. The taenite particles are 0.5-1 μ thick, and embedded in a continuous kamacite phase with subboundaries. Numerous fine kamacite spindles, typically 20-40 μ across, occur scattered throughout the plessite. Larger, more irregular kamacite blebs are also present, developed around 10-50 μ schreibersite bodies. Between the kamacite and the plessitic matrix a continuous taenite zone is always found, and this γ -zone can measure up to 20 μ in larger kamacite spindles.

Schreibersite is very common in the kamacite spindles as platelets and irregular bodies, 0.1-0.4 mm across. It also occurs as smaller blebs in the plessite and as discontinuous, 50-150 μ wide rims upon troilite. Baker et al. (1964) reported 0.09% P in a wet chemical analysis. My point counting of an admittedly small section suggested a bulk phosphorus value of $0.30 \pm 0.05\%$.

Troilite occurs as a few large nodules, 5-10 mm across, and as small blebs, widely disseminated in the metallic matrix, according to a sulfur print in Baker et al. (1964). The troilite is shock melted and solidified to fine-grained aggregates from which minute veinlets radiate through adjacent schreibersite and a portion of the metal. Small angular fragments of schreibersite may be found dispersed in the troilite melt.

The meteorite is corroded. The near-surface troilite displays pentlandite veinings, and the α -phase of the plessite is selectively converted to limonite. A few small particles of native copper, up to 8 μ across, reported by Baker et al., can apparently also be explained as the result of weathering.

Corowa is a plessitic octahedrite of a very distinct appearance which immediately singles it out from Tawallah Valley and other IVB irons. Its α -spindles and phosphorus content are the crucial distinctive characteristics. It has little in common with Arltunga, a genuine ataxite with extremely thin spindles, and its resemblance to Wiley and other irons of group IIC is only superficial. Corowa has evidently no known immediate relatives, a fact which is supported by the trace element analysis reported by Wasson.

Corrego de Areado.
See Patos de Minas (Hexahedrite)

Corrizatillo. See Pan de Azucar (Carrizalillo)

Cosby's Creek, Tennessee, U.S.A.

35°47'N, 83°15'W; 450 m

Coarse octahedrite, Og. Bandwidth 2.5±0.8 mm. Neumann bands. HV 170±8.

Group I. 6.67% Ni, 0.53% Co, 0.29% P, 91.5 ppm Ga, 431 ppm Ge, 2.9 ppm Ir.

The greater part was forged, but about 100 kg fragments have survived in collections.

HISTORY

A fragment of a larger mass, found about 1837 near Cosby's Creek in Cocke County, was described by Troost (1840) with an analysis. Further information was provided by Shepard (1842; 1847), and by Huntington (1888; 1894) who discussed the identity of a number of similar irons (Sevier County, Greenbrier County, Jenny's Creek, Wilson County, Waldron's Ridge, Smithville and Cosby's Creek), reportedly coming from different places in the Appalachian Mountains.

At this late date it is difficult to reach a clear-cut conclusion as to the validity of the original claims. Under the heading Cosby's Creek, I will here treat the authentic material from this locality plus the material labeled Sevier County. Several of Huntington's suite of irons certainly do not belong with Cosby's Creek, such as Greenbrier County, Jenny's Creek, Waldron Ridge and Smithville. Black Mountain is probably a transported fragment of Duel Hill (1873), since the detailed structures, the general locality of find and the state of terrestrial corrosion are almost identical.

According to Shepard (1842; 1847) the greatest mass of 700-800 pounds weight (another less reliable estimate: 2,000 lbs) was found on an offset of an eminence about 30 m above the bed of Cosby's Creek. It was an oblong, square block from which it was easy to detach fragments because of the violent, terrestrial corrosion that had taken



Figure 668. Cosby's Creek (Harvard no. 143). In the center, a troilite nodule. To the right cohenite-rich kamacite. Deep-etched. Scale bar in centimeters.

place. The mass was "placed upon what is here called a log-heap, where after roasting for some time, it developed certain natural joints, of which advantage was taken with cold chisels and spikes, for its separation into fragments. These were put into a mountain wagon, and transported 30 or 40 miles" to Lary's forge in Sevier County and Peter Brown's forge in Greene County. The greater part was wrought into "gun scalps,"* horseshoe nails and other articles of common use, but some remnants of the mass fell into the hands of Dr. Troost. Another mass weighing 112 pounds, which was found in the immediate vicinity of the larger mass by a mountaineer, apparently escaped the fate of the larger. It became known under the synonym Sevier County, was divided and went through several hands (Troost, Shepard, Heuland), before it ended up in various collections, the largest part presumably in British Museum (no. 16865-16866).

Many descriptions were given in the nineteenth century, of which, in addition to the above mentioned, those of Reichenbach (1862a), Rose (1864a) and Smith (1876a) are noteworthy. Bergemann (1857) and Cohen (1900b) presented the first reliable analyses, while Farrington (1915) reviewed the literature.

Perry (1944) gave two photomicrographs of the cohenite inclusions, and Brett (1967) used cohenite isolated from Cosby's Creek for his decomposition studies. Marvin (1963) showed that the crust consisted of the terrestrial oxidation products goethite and akaganeite, but Ramdohr (1967) evidently found that also the ablation crust with molten troilite and "porous iron" was preserved. This is, however, doubtful considering the thorough decomposition by weathering that had taken place. Perhaps Dr. Ramdohr worked with material that passed Lary's forge. Reed (1965a, b) determined the composition of the kamacite and the schreibersite. Wänke (1960b) included Cosby's Creek in his discussion of cosmic irradiation ages.

COLLECTIONS

London (50.6 kg), Harvard (19.7 kg), Tübingen (9.4 kg), Chicago (3.2 kg), Oxford (2.9 kg), Paris (1.68 kg), Amherst (1.60 kg), Washington (1.37 kg), Yale (1.18 kg),

*In Tennessee the forged iron bar, before being bored for a gun barrel, is called a "gun-scalp" (Huntington 1894).

Copenhagen (1.12 kg), New York (647 g), Vienna (634 g), Tempe (136 g), Stockholm (110 g).

DESCRIPTION

Most specimens in collections are heavily corroded fragments with weights from a few grams to a few kilograms. The original surface has lost its regmaglypts and atmospheric sculpturing due to terrestrial weathering and is now covered with 1-3 mm thick adhering crusts. Most specimens appear to be broken fragments; concave smooth impressions of now lost troilite-graphite nodules, 2-5 cm in size, are often found in the fracture surfaces. Some specimens have a crust that indicates slight, artificial reheating, since the color and morphology resemble scale on mill products. Such specimens are probably surviving fragments of the larger mass that was heated in order to split it more easily.

Undamaged specimens, (e.g., no. 738) show a coarse Widmanstätten pattern with a bandwidth of 2.50 ± 0.80 nm. The thinner lamellae are invariably associated with cohenite-rich patches. In the cohenite-poor regions grain growth has often wiped out the Widmanstätten array and created almost equiaxial ferrite grains 3-20 nm in diameter. Neuman bands are common. The microhardness of the kamacite is 170 ± 8 on specimens which are believed to have escaped the artificial reheating. Some specimens exhibit significantly lower hardnesses, down to 130, without visible structural changes. This decrease may have been caused by gentle artificial reheating to about 400-450°C whereby recovery occurred. Taenite and plessite occur sparingly, normally as narrow regions adjacent to cohenite, and often with the taenite in direct contact with cohenite. The plessite may have pearlitic (0.5 μ wide γ-lamellae) or acicular interiors, as usual in the carbon-containing irons on the 6-8% Ni level. Locally, almost resorbed comb plessite fields occur; the interiors of these are particularly rich in subboundaries, and they display numerous 2-5 μ rhabdites. The taenite of undamaged specimens have a hardness of 290 ± 30 ; the dark-etching, duplex fields, 330 ± 20 .

Cohenite is the dominant mineral in most sections. It occurs typically as 3 x 0.5 mm oblong, rounded, monocrystalline fingers centrally in the α-lamellae and is occasionally clustered sufficiently to create rosette-like aggregates. Its

COSBY'S CREEK - SELECTED CHEMICAL ANALYSES

Bergemann's analysis is remarkable for those days. Its low-phosphorus and high-carbon content would indicate

that he had analyzed a cohenite-rich specimen.

References	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Bergemann 1857	6.70	0.33	0.09	1700								
Fahrenheit in Cohen 1900b	6.91	0.51	0.37				200					
ibid. on another specimen	6.52	0.74	0.41				200					
Wasson 1970a	6.57								91.5	431	2.9	

microhardness is 1080 ± 40 . The cohenite is somewhat cracked, but its internal decomposition to graphite has not yet begun. Schreibersite bodies, 50-500 μ , are intergrown with the cohenite, and 50 μ windows of kamacite and taenite in the cohenite are also characteristic.

Graphite is common, probably always associated with troilite. Reichenbach (1862b: 57) isolated a graphite nodule weighing about 80 grams, and J.L. Smith (1876a) examined a graphite nodule 6 x 3.5 x 2 cm weighing 92 g. A discontinuous rim of 1 mm troilite covered the surface of the nodule, and in the interior other minor troilite bodies were present. Smaller graphite and troilite nodules are frequently met with. Some appear to have been parallel, elongated cones of finger size that were easily detached from the matrix. In U.S. National Museum no. 738, the remnants of a complex troilite-graphite-schreibersite-cohenite nodule may be seen. The troilite is monocrystalline with veinlets of cream-colored pentlandite. Cliftonite crystals, 100-150 μ in size, are embedded in the cohenite adjacent to the troilite, while the remainder of the graphite is an irregular aggregate with "horsetail" extinction. Daubreelite frequently occupies 5-10% of the troilite nodules.

Schreibersite is present as 10 x 1 mm skeleton crystals with 200 μ cohenite rim zones. It further occurs as 20-50 μ grain boundary precipitates and as inclusions in cohenite. Phosphides are numerous as 1-10 μ rhabdites in the ferrite matrix and on the subgrain boundaries of the ferrite. Submicroscopic precipitates on dislocation lines and subgrain boundaries may be phosphides or carbides.

The heated α_2 rim zone has been completely removed by weathering on all specimens examined. Corrosion penetrates deep into the interior everywhere and splits the material along (111) planes. Selective oxidation of the nickel-poor phases is common, e.g., in the pearlitic plessite and around phosphide inclusions. The pentlandite mentioned above is a terrestrial corrosion product.

Cosby's Creek is a typical inclusion-rich, coarse octahedrite which is closely related to such irons as Seeläsgen, Duel Hill (1873), Cranbourne and Gladstone. It probably burst in the atmosphere and produced a limited shower centered around Cosby's Creek; specimens from this region were later recovered and described under the names: Cosby's Creek, Sevier County and Wilson County.

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

789 g fragment (no. 738, 6 x 6 x 5 cm)
416 g fragment (no. 1589, 4.5 x 4 x 4 cm)
170 g fragments and shales (nos. 70, 495, 816, 1004, 2732, 3302)

Costilla Peak, New Mexico, U.S.A.

Approximately $36^\circ 55'N$, $105^\circ 20'W$; 3000 m

Medium octahedrite, Om. Bandwidth 1.00 ± 0.15 mm. ϵ -structure. HV 260 ± 10 .

Group IIIA. 7.60% Ni, 0.49% Co, 0.09% P, 0.2% S, 19.2 ppm Ga, 33.6 ppm Ge, 15 ppm Ir.

HISTORY

A mass of 35.5 kg was found in 1881 by a shepherd named Ignacio Martin, who believed it was silver ore and, therefore, withheld exact information as to the finding place. The locality was, however, somewhere on the slopes of Costilla Peak in Taos County near the New Mexico-Colorado state line. The meteorite was hidden for some time in a manure pile, until engineer van Diest got hold of it and transferred it to the Colorado Scientific Society where it was described with an analysis and two photographs of the exterior by Hills (1895). It was cut by Ward and widely distributed in the first quarter of the twentieth century.

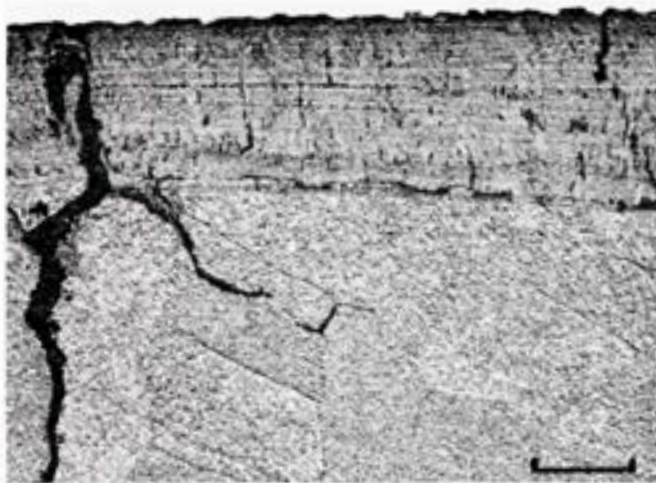


Figure 669. Costilla Peak (U.S.N.M. no. 382). Thick deposits of laminated metallic fusion crusts above a heat-affected α_2 zone. Deep-etched. Scale bar 5 mm. S.I. neg. 1359C.

COSTILLA PEAK – SELECTED CHEMICAL ANALYSES

References	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Eakins in Hills 1895	7.71	0.44	0.10		2600							
Goldberg et al. 1951	7.56	0.54							19.7			
Nichiporuk & Brown 1965												15.3
Wasson & Kimberlin 1967	7.49								18.7	33.6	14	
Moore et al. 1969	7.56	0.49	0.08	400	430		173					

Brezina (1896: 280) commented upon the oriented flight of the mass, and Maringer (1960) gave a photomicrograph of a complete cross section where the ablation deposits on the rear face were plainly seen. The deposits and the hardness variation of the heat-affected zones were further discussed with micrographs by Maringer & Manning (1959; 1962: 131f). Munk (1967) determined the spallation gasses neon, argon, krypton, and xenon.

COLLECTIONS

Chicago (9,627 g), New York (3,645 g), Tempe (2,176 g), Washington (1,849 g), London (1,595 g), Vienna (1,574 g), Harvard (1,551 g), Tübingen (479 g), Rome (473 g), Paris (350 g), Stockholm (294 g), Prague (244 g), Vatican (218 g), Yale (172 g), Bally (164 g), Berlin (147 g). According to a personal communication from Director A.M. Bailey of the Denver Museum of Natural History, Colorado, the main mass is not there, as stated in Hey's Catalog (1966), so it appears that Ward cut and distributed the whole mass.

DESCRIPTION

Before cutting, the mass was turtle-shaped with the overall dimensions 32 x 23 x 11 cm. The convex front surface is smooth with a single deep scar, presumably from a burnt out troilite nodule. The flat or slightly concave rear surface is fluted and pitted and is covered with an unusually thick, laminated, ablation deposit, reaching 1-2 mm in thickness. The meteorite was evidently highly oriented when it penetrated the atmosphere and was severely ablated on the frontal face. The ablation melts poured over the edges to form the "smoke trail," but a minor fraction was deposited in successive layers on the less exposed rear surface. The deposits are found on such surfaces which display the widest visible heat-affected zones, in this case 3-6 mm, while the almost deposit-free leading surfaces have only 1.5-3 mm wide α_2 zones. As Maringer & Manning (1960) pointed out the width of the α_2 zone is "inversely proportional" to the rate of heat

transfer through the surface and, therefore, to the ablation forces on a particular meteorite.

Etched sections display a medium octahedrite pattern of straight, long ($l/w \sim 40$) kamacite lamellae averaging 1.00 mm in width. As most sections were cut by Ward almost parallel to one of the octahedral planes of the original austenite single crystal, the fourth lamella direction becomes clearly visible on sections as parallel ribbons, typically 30 x 3.5 mm in size, with irregular, shiny taenite edges. The kamacite is of the crosshatched ϵ -variety suggesting shocks above 130 k bar. The structure is rather open, resembling that in Ainsworth, e.g., and local recrystallization to 5-25 μ equiaxial ferrite grains has occurred. In accordance with this, the hardness is only 260 ± 10 , indicating a shocked and somewhat annealed ϵ -structure.

Plessite occupies about 40% by area, mostly as degenerated comb and net plessite with discontinuous taenite rims.

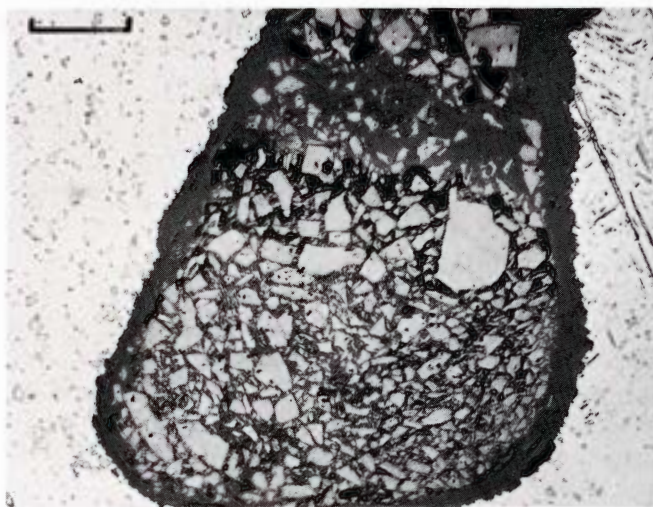


Figure 671. Costilla Peak (Tempe no. 190.1). Brecciated troilite which has become recemented by terrestrial corrosion products (black). Heat-affected α_2 zone to the left, shock-hatched ϵ to the right. Etched. Scale bar 200 μ .



Figure 670. Costilla Peak (Tempe no. 190.1). Open-meshed plessite field with shock-hatched kamacite of various shades. Etched. Scale bar 200 μ .

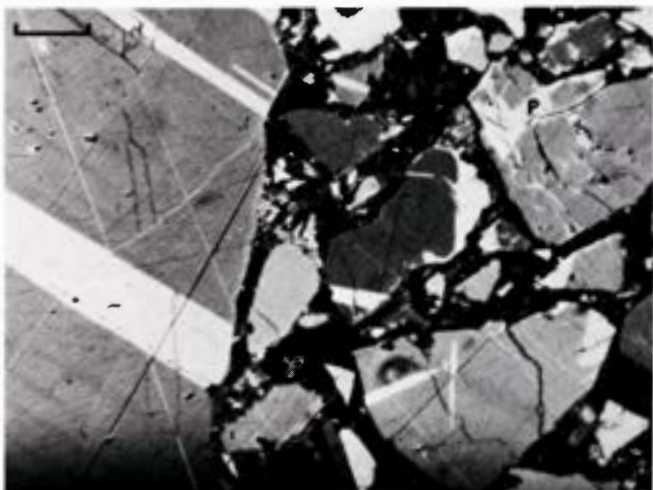


Figure 672. Costilla Peak (Tempe no. 190.1). Troilite showing multiple twinning and brecciation. Recementing by limonite. Veins of yellow pentlandite (P). Crossed polars. Scale bar 20 μ .

Some plessite wedges have martensitic or poorly resolvable $\alpha + \gamma$ interiors. The taenite becomes bluish tinted by etching, but taenite located in the rim zone etches yellowish. The taenite of the rim zone is surrounded by α_2 grains with a distinct bainitic-martensitic appearance. The two features, tinted taenite and bainite, indicate that the small amount of carbon in the meteorite is primarily located in the taenite phase; compare Kayakent.

Schreibersite and rhabdite are practically absent. Only a few 1-2 μ phosphide bodies appear on some of the subgrain boundaries in the ferrite. Almost all of the analytically found phosphorus must, therefore, be in solid solution, primarily in the kamacite.

Troilite is common as 1-15 mm lenticular and spherical bodies. Parallel daubreelite lamellae occupy 10-25% of most of them. The troilite is monocrystalline with numerous lenticular deformation twins, which show up beautifully under crossed Nicols. The troilite is normally enveloped in 0.5-1.5 mm thick layers of swathing kamacite. Point counting of the sulfide inclusions indicated a bulk sulfur content of 0.2%. A copper grain, 300 x 60 μ in size, was discovered in one place in the troilite-kamacite boundary. The location was 25 mm from the surface and no corrosion had occurred here, so it is concluded that the native copper is of cosmic origin.

Smaller sulfide inclusions, 20-300 μ in diameter, are common in the kamacite. They are composed of alternating thin (5-10 μ) lamellae of daubreelite and troilite; the troilite displays deformation twinning. The daubreelite lamellae project into the surrounding α -iron, while the troilite is always protracted. In places a minute, discontinuous schreibersite rim is present. Similar inclusions were described by El Goresy (1965) from Cape York. Chromium nitrides are numerous in the kamacite, mainly in form of hard, oriented platelets, 20 x 1 μ in size. The chromium

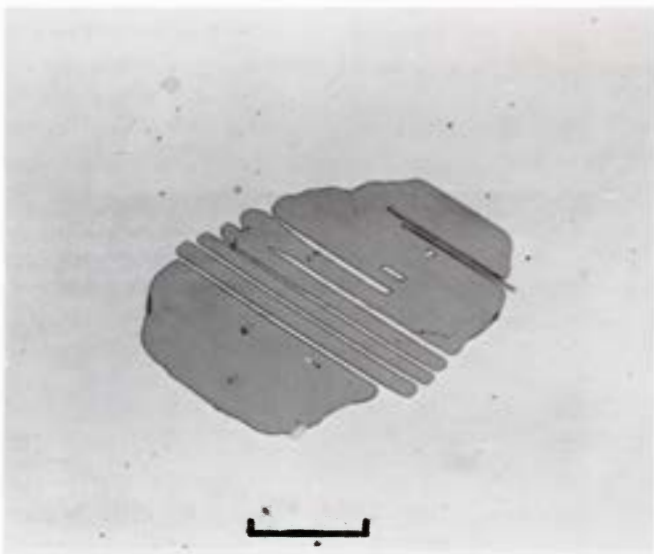


Figure 673. Costilla Peak (U.S.N.M. no. 702). Troilite-daubreelite nodule with kamacite indentations. Polished. Scale bar 50 μ . (Courtesy Battelle Institute.)

nitride is a new mineral, reported by Buchwald & Scott (1971).

The fusion crust is composed of numerous layers of metal with honeycomb solidification structures; the individual cells range in size from 5 μ in the innermost layers to 20 μ in the outermost layers. The hardness is 325 ± 25 , and the structure is fine-grained martensitic. A total of 16

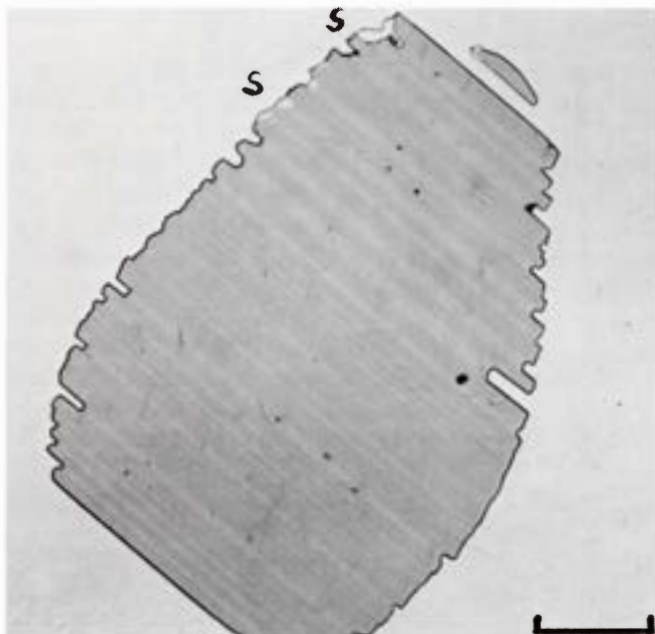


Figure 674. Costilla Peak (U.S.N.M. no. 702). Troilite-daubreelite nodule. Kamacite indents the troilite lamellae. Elsewhere they are sealed by minute schreibersite precipitates (S). Polished. Scale bar 50 μ . (Courtesy Battelle Institute.)

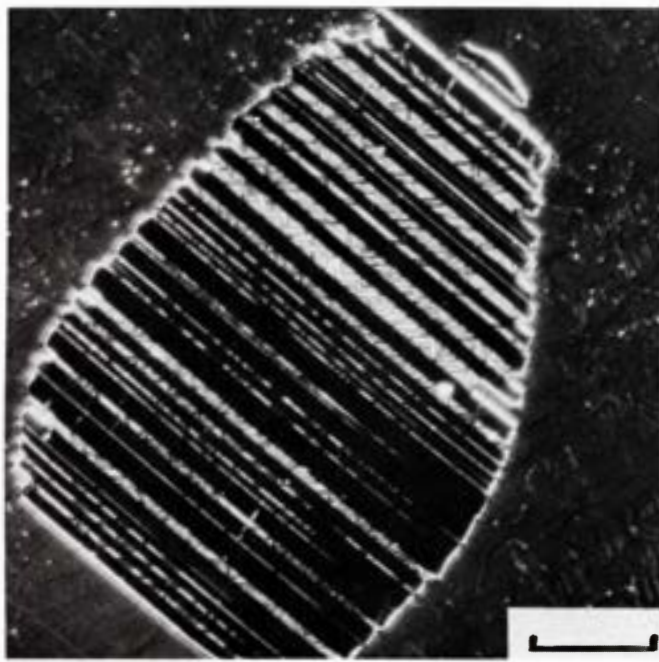


Figure 675. Costilla Peak. Same as Figure 674, but with crossed polars. The hexagonal troilite (bright) shows multiple twinning, while the cubic daubreelite appears dark. Shock-hatched kamacite also appears dark. Scale bar 50 μ . (Courtesy Battelle Institute.)

layers, each 50-200 μ thick, were counted in one place, but an irregular tapering out is common. The outermost layer of fused oxides is lost, due to corrosion. Corrosion also penetrates into and through the fusion crust and generates the false impression of a considerable amount of trapped oxides. In fact, only a few fused oxide globules are included in the fusion crust. Corrosion also penetrates along some octahedral planes to the very center of the mass. In some places troilite nodules have become heavily altered and brecciated, with individual fragments rotated from the original position. It appears that microfissures were present already when the meteorite entered the atmosphere and that some of these fissures had been partially filled with troilite and daubreelite debris. After the landing, such zones were an easy prey to terrestrial corrosion, and the mineral fragments were cemented together by limonite in their random orientations.

Costilla Peak is a shock-hardened medium octahedrite with ϵ -structure and low phosphorus content, very similar to, e.g., Henbury and Kenton County. It displays excellently the results of oriented penetration through the atmosphere.

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

- 1,608 g slice (no. 382, 31 x 11 x 0.8 cm)
- 241 g part slice (no. 702, 8.5 x 3 x 1 cm)

Cowra, New South Wales, Australia
33°51'S, 148°41'E

Plessitic octahedrite, Opl. Spindle-width 70 \pm 15 μ . Neumann bands. HV 185 \pm 10.

Anomalous. 13.3% Ni, 0.70% Co, 0.23% P, 74 ppm Ga, 13 ppm Ge, 14 ppm Ir.

HISTORY

A mass of 5.6 kg was found by the miner J. O'Shaughnessy before 1888 at the top of Battery Mountain in County Bathurst. The locality is near the junction of the rivers Lachlan and Burrowa, a few miles east of Cowra. The meteorite was found firmly embedded in the slates, with only one point projecting above the ground. It was acquired by the Mining Museum, Sydney, and described with photographs by Card (1897a).

Brezina (1895: 267) and Cohen (1905: 289) described the structure, but they first believed that the numerous kamacite spindles were taenite. They did, however, correct

their mistake, when they presented and discussed two photomicrographs (Brezina & Cohen 1886-1906: plate 29). Owen & Burns (1939) determined the lattice parameter of the α - and γ -phases, and Perry (1944) gave five photomicrographs. Reed (1969) examined the composition of the kamacite phase: 7.5% Ni - 0.106% P. Schultz & Hintenberger (1967) determined the amount of noble gases, on the basis of which Voshage (1967) calculated a very approximate cosmic ray exposure age of 710-1400 million years.

COLLECTIONS

Sydney (2,960 g main mass and 178 g slices), New York (677 g), Canberra (263 g), London (180 g), Budapest (99 g), Chicago (87 g), Prague (80 g), Washington (61 g), Copenhagen (48 g), Ottawa (44 g), Vienna (31 g), Calcutta (29 g), Berlin (22 g), Los Angeles (17 g), Vatican (7 g).

DESCRIPTION

The exterior dimensions and the accurate shape of Cowra is uncertain, since there apparently is a discrepancy between the weight of 12¼ lbs and the dimensions as estimated from Plate 7 in Card (1897a). The scale of the figure appears to be inaccurate. The overall dimensions were, very approximately, 30 x 12 x 4 cm. Cowra is probably an example of oriented, stabilized flight through the atmosphere. The fusion crust is preserved in protected, leeward depressions, e.g., on U.S. National Museum no. 733 and Prague no. 302. The crust, which is up to 0.5 mm thick and wedges out irregularly over 10-20 mm, is built of 6-10 consecutive, metallic layers, each of a cellular-dendritic nature. Occasionally the crust fills in empty 0.1-0.2 mm cavities, in which schreibersite crystals previously were located but melted out during flight. The heat-affected α_2 zone is 1.2-1.6 mm thick under the crust and increases elsewhere to 2.0 mm. Micromelted phosphides may be observed in the exterior 40-50% of the α_2 zone. A large schreibersite crystal, exposed at the surface, is partially melted out, but only partially. Below about 2 mm depth it is unaffected.

Corrosion has removed or altered most of the fusion crust and has also started a selective attack upon the α -phase, especially the nickel-poor parts near the schreibersite inclusions. Otherwise the meteorite is very well preserved.

Etched sections show a fine, felt-like disposition of pointed kamacite spindles in a plessitic matrix. The kamacite lamellae, which are arranged in the usual Widmanstätten pattern, are short ($l/w \sim 10$) and have a

COWRA – SELECTED CHEMICAL ANALYSES

References	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Mingaye 1904	13.23	1.02	0.23	250	100		200					
Lovering et al. 1957	13.72	0.70				40	193		82	15		
Wasson & Schaudy 1971	12.94								73.5	12.3	14.0	

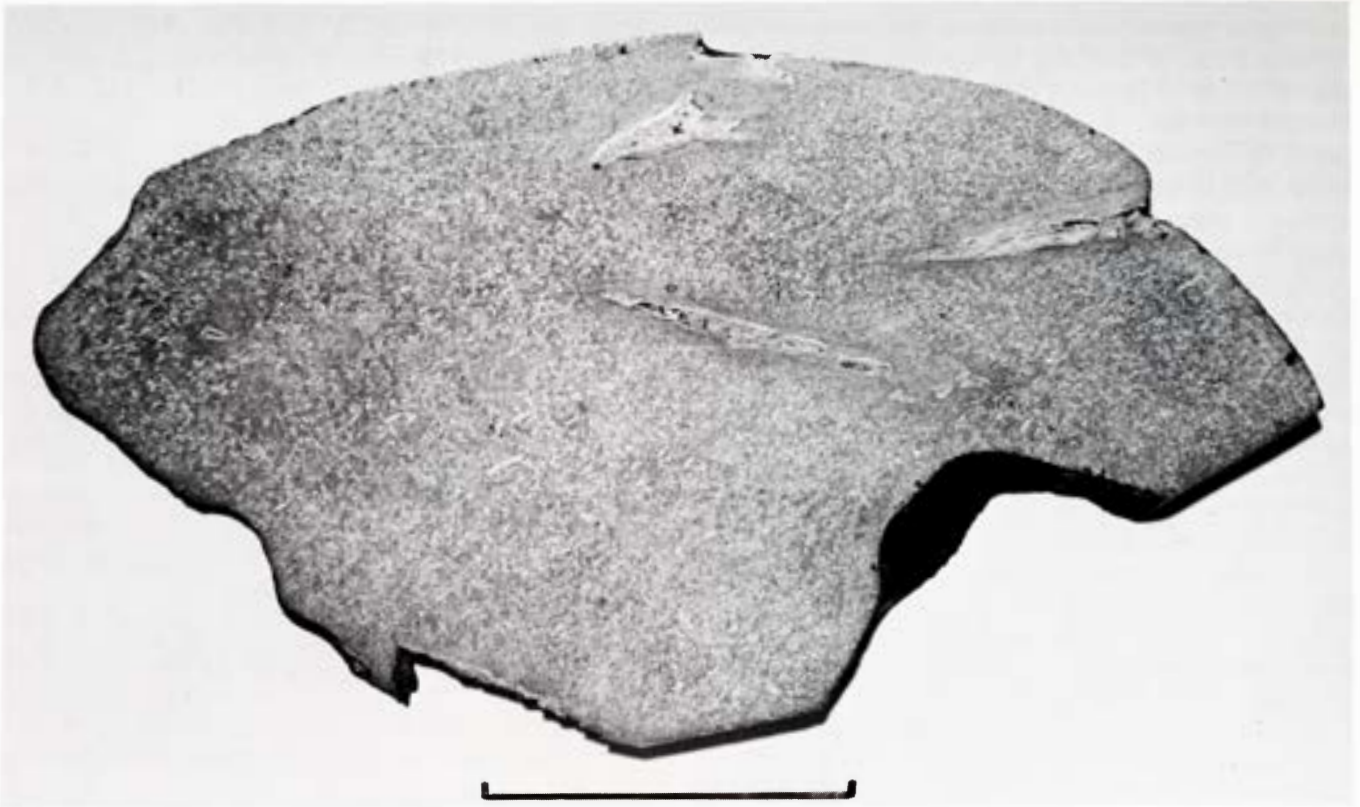


Figure 676. Cowra (Prague no. 302). A slice of 80 g which shows several large schreibersite skeleton crystals in a matrix rich in pointed kamacite spindles. Deep-etched. Scale bar 30 mm.

width of $70 \pm 15 \mu$. In addition, there is an equal number of blunt, irregular kamacite areas, developed around primary schreibersite crystals. The uniformly distributed schreibersite crystals are $50\text{--}100 \mu$ in cross section and enveloped in $50\text{--}100 \mu$ kamacite. On the average there are about four schreibersite crystals of this size per mm^2 . A few larger, platy crystals, typically $20 \times 5 \times 1 \text{ mm}$ and enveloped in 0.5 mm swathing kamacite, occur in some sections. All kamacite has subboundaries without precipitates and displays Neumann bands in varying amounts. The microhardness is 185 ± 10 but increases to 210 ± 10 in the heat-affected α_2 zone (hardness curve type III).

The plessitic matrix covers about 65% by area and is uniformly developed as a rather coarse duplex $\alpha + \gamma$ with individual taenite grains ranging from 0.5 to 2μ width. Only the $10\text{--}20 \mu$ wide rim zones around the kamacite spindles are of an unresolvable duplex nature. It is interesting to note that the various kinds of duplex structures all look martensitic at lower magnification where the individual grains are unresolvable. The microhardness of the duplex matrix is 225 ± 20 .

The schreibersite is monocrystalline. Besides the larger, easily detectable crystals, there are numerous smaller ones, $2\text{--}20 \mu$ in cross section. Even these appear to be the nuclei of small kamacite grains, scattered through the plessitic matrix.

Troilite is rare. Only one 0.1 mm bleb was observed in a kamacite grain. It was shock melted and solidified to a

polycrystalline aggregate of $2\text{--}5 \mu$ troilite in which several daubreelite grains of the same size were embedded.

In Cowra we can distinguish at least four different events during continuous cooling: (i) precipitation of the few large schreibersite plates and development of the swathing kamacite; (ii) precipitation of the numerous 0.1 mm schreibersite crystals and development of their kamacite halos; (iii) homogenous nucleation and growth of

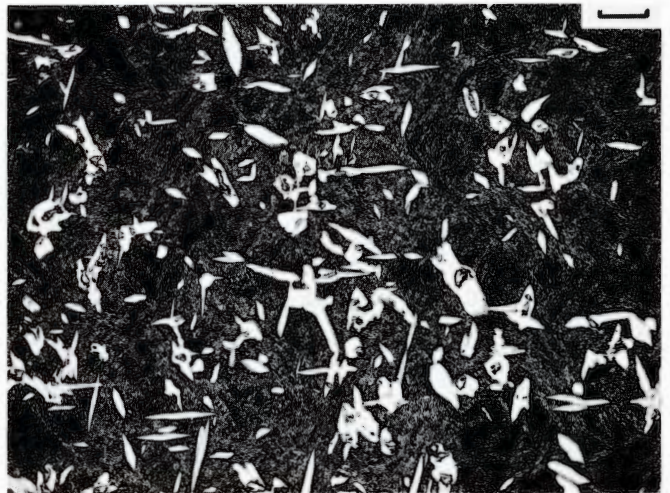


Figure 677. Cowra (U.S.N.M. no. 733). Almost all the bulky kamacite grains show nuclei of schreibersite. The Widmanstätten spindles are usually schreibersite-free. In this particular area all kamacite grains are smaller than the average for Cowra. Deep-etched. Scale bar 200μ .

the genuine Widmanstätten kamacite spindles; and (iv) decomposition of the remaining austenite to a well defined, duplex $\alpha + \gamma$ mixture, probably via an intermediate martensitic stage, as suggested by the appearance of the plessite areas under low magnification. After the full formation of all structural details a shock event created the Neumann bands and micromelted the shock-absorbing, compressible troilite inclusions.

Cowra is a well preserved, plessitic octahedrite which somewhat resembles Ballinoo, Perryville, Wiley, and Corowa. The details of the structure are, however, different, which is in harmony with the fact that the Ni-Ga-Ge determinations of Lovering and Wasson have also placed Cowra apart from the others. As discussed on page 583, Cowra also resembles Gay Gulch but the two irons turn out to have somewhat different chemical composition.

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

61 g slice (no. 733, 6.5 x 5 x 0.3 cm)

Coya Norte, See North Chile

Cranberry Plains, Virginia, U.S.A.

37°13'N, 80°44'W; 550 m

Fine octahedrite, Of. Bandwidth 0.35±0.05 mm. α_2 structure. HV 200±10.

Probably group IVA, related to Duel Hill (1854). About 9.5% Ni and 0.2% P.

All specimens in collections have been artificially reheated to about 1000° C.

HISTORY

Nothing is known of the history and original size of this meteorite. It was briefly listed as Cranberry Plains, Poplar Hill, Virginia by J.L. Smith (1876b: 4), who reported the discovery year as 1852. It was further listed by Meunier (1884: 116) as "Poplar Camp" and by Brezina (1885; 1896) as "Cranberry Plains, Poplar Hill, Virginia." The present "Poplar Hill" in Giles County, which probably is the same locality, has the coordinates given above. Cranberry Plains was a small village of 75 inhabitants, which is marked on Rand McNally's Atlas (1882: 468) in Carroll County about 9 km northwest of Hillsville. The date of find is variously given as 1877 (French catalogs) and 1852 (Smith 1876b; Brezina 1885; Huntington 1886). Only 89 g was known when Wülfing compiled his catalog (1897).

Huntington (1886: 300; 1888: 70 and plate 2) discussed the distorted Widmanstätten structure of the Harvard specimen. He assumed that the kamacite lamellae crystallized from a melt and that the peculiar morphology reflected some original, high temperature stress and flow conditions. Cohen (1905) concluded on the basis of

Huntington's descriptions that Cranberry Plains was a fine octahedrite related to Putnam County and Chupaderos. Farrington (1915) reviewed the literature.

COLLECTIONS

Very little is known. Harvard (29 g), Yale (22 g), Paris (16 g), Washington (7 g), New York (7 g), Amherst (7 g), Chicago (1 g).

ANALYSIS

None is available. Based upon structural observations, the author would estimate the nickel and phosphorus content to be 9.5±0.2% and 0.2±0.02%, respectively, with trace elements placing it in group IVA.

DESCRIPTION

The Washington specimen is a small hammered fragment with no visible fusion crust or regmaglypts. It has suffered so much beating that it is partially split along octahedral, schreibersite-filled lamellae.

The etched section displays a fine Widmanstätten structure with slightly curved long ($\frac{l}{w} \sim 40$) α -lamellae which have a width of 0.35±0.05 mm. It is no longer possible to state whether Neumann bands or ϵ -structure originally were present, since all ferrite is converted to 25-50 μ serrated α_2 grains, due to artificial reheating above 800° C. Original subboundaries in the lamellae are still faintly visible because they were decorated by <1 μ phosphide precipitates.

Plessite occupies 40-50% by area. The taenite is diffuse and has blurred, scalloped edges with thorns protruding into the present α_2 phase. The taenite has evidently been heated to a temperature of about 900-1000° C, whereby it started to dissolve in the matrix. Before complete resorption took place the iron was again cooled.

Schreibersite was originally present as 20-50 μ grain boundary precipitates, as 5-20 μ angular bodies in the plessite interior, and as an occasional 100 x 200 μ crystal. All phosphides have been remelted and partially resorbed, which means that the temperature has been about 1000° C for some time.

Troilite and other meteorite minerals were not observed.

One more indication of artificial reheating is found by examination of the surface zone. Instead of normal corrosion products there are complex pearlitic intergrowths of metal, oxides and sulfides. An oxidation attack, which has penetrated about 50 μ along the high temperature austenite boundaries, can only be interpreted as having taken place while the specimen was in the austenite region (above 800° C) under oxidizing conditions. It appears thus that Huntington's observations may better be interpreted as the result of a blacksmith's work than of some cosmic event.

Cranberry Plains is a fine octahedrite of the Chinautla type. Its structure is severely damaged by man and apparently only little survived the forging, when a black-