Carbo, Sonora, Mexico

29°42′N, 111°35′W; about 500 m

Medium octahedrite, Om. Bandwidth 0.85±0.10 mm. Neumann bands. HV 175±8.

Group IID. 10.15% Ni, 0.62% Co, about 0.5% P, 70 ppm Ga, 87 ppm Ge, 13 ppm Ir.

HISTORY

A mass of about 450 kg was found in 1923 by cowboys riding on the Alamo Ranch which is located northwest of Hermosillo in the state of Sonora. The ranch is 60 km west of Carbo, a station on the Southern Pacific Railway, and 8 km north of the village Bacuache, with the coordinates given above. The meteorite was purchased by Harvard University in 1928 and described by Palache & Gonyer (1930) who presented photographs of the exterior and of an etched section. Nininger reproduced these photographs on various occasions (1933c: figure 27; 1950: plate 3; 1952a: plate 7), but otherwise no structural pictures have appeared in the literature. Marvin (1962) identified cristobalite as a dendritic devitrification product in a glass nodule, associated with troilite. Goldstein (1965) used Carbo in the development of a theory of the Widmanstätten formation, unfortunately, however, accepting Palache & Gonyer's erroneous bulk analysis (8.68%) for nickel. Jaeger & Lipschutz (1967b) found the kamacite phase shocked below the 130 k bar level.

Extensive investigations of the isotopes, particularly of the noble gases, have been performed on Carbo, starting with the helium determinations by Martin (1953) and Paneth (1954). About 1957 the work was intensified after the mass was cut in halves, and a central slice was removed and cut into a number of parallel bars. Fireman (1958) examined the ^{3}He and ^{39}Ar concentrations and found that the absence of ^{39}Ar indicated a terrestrial age above 1,500 years. Hoffman & Nier (1958) examined the ^{3}He and ^{4}He distribution in the slice and plotted contours of constant concentration. The resulting open curves seemed to indicate that the meteorite was either split in half late in its lifetime or corroded away on one side since its fall to Earth. Kohman & Goel (1963) measured ^{14}C and estimated the terrestrial age to be below 6,900 years, but Chang & Wänke (1969) found from their ^{10}Be/^{36}Cl method that the age was rather 130,000 years. The potassium-argon age was found to be 8.4 x 10^{9} years (Stoenner & Zähringer 1958), but the method is not very reliable (Fisher 1965; Rancitelli & Fisher 1968; Kaiser & Zähringer 1968), so the Os/Re value of 4.5 x 10^{9} years is no doubt better (Herr et al. 1961).

The behavior of occluded spallogenic gases (He, Ne, Ar) on reheating of an iron meteorite has been reported and discussed by Nyquist et al. (1972). They found, on samples of Carbo that, although gases were released at an increased temperature, the ratio of the gases remained constant.

The cosmic ray exposure age is 600±150 million years (Signer & Nier 1962), 780-1,480 million years (Goel & Kohman 1963), 720±50 million years (Vilcsek & Wänke 1963), 1370±570 million years (Lämmerzahl & Zähringer 1966), 850±140 million years (Voshage 1967) or 590±70 million years (Chang & Wänke 1969). There are two main reasons for the discrepancies between the data: Estimates of the preatmospheric mass and of the shielding effect vary considerably, and the terrestrial age is bracketed only

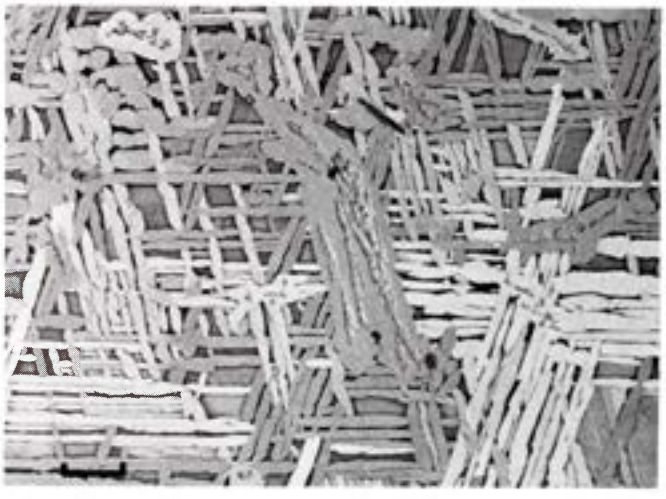

Figure 533. Carbo (U.S.N.M. no. 838). Medium octahedrite with abundant schreibersite inclusions. These are seen in the picture as elongated skeleton crystals, enveloped in swathing kamacite. The bulk phosphorus content of Carbo is more likely 0.4-0.5% than the 0.26% reported in the analysis. Etched. Scale bar 5 mm. S.I. neg. M-1351.

CARBO – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Smales et al. 1967						21	282			94		
Wasson & Kimberlin 1967	10.02								70.0	87.2	13	
Moore et al. 1969	10.29	0.62	0.26	215	155		320					
Rosman 1972								2.7				
Kelly & Moore 1973, pers. comm.								2.9				

Goldstein (1967) determined the distribution of germanium between various phases and found a maximum of 155 ppm in the taenite, 110±20 in the plessite and 70±20 in the kamacite bands.

within wide ranges. To a minor extent the precision of the methods themselves influences the results.

Hintenberger & Wänke (1964) discussed the isotopic compositions of the noble gases ^{3}He, ^{4}He, ^{20}Ne, ^{21}Ne and ^{22}Ne. A rough correlation between the mass of the meteorite and the depth of the sample was found. Hulston & Thode (1965b) identified spallation isotopes of sulfur which had been produced by cosmic rays. References to additional work may be found in the papers quoted; Anders (1962), Voshage (1968) and others have reviewed and discussed the results in a wider context.

COLLECTIONS

Harvard (about 400 kg), Washington (24.3 kg), London (4,057 g), Tempe (4,053 g), New York (642 g), Los Angeles (385 g), Albuquerque (132 g), Chicago (41 g).

DESCRIPTION

According to Palache & Gonyer (1930) the mass was roughly tetrahedral in shape, measuring on the average 80 x 45 x 37 cm and weighing approximately 450 kg. The surface is weathered, but the limonitized fusion crust appears to be preserved in a number of places. Since the microsections prepared in the present study came from other, more weathered, parts of the surface, this observation could unfortunately not be confirmed. The surface is generally covered with 0.1-1 mm thick limonitic crusts, and the original regmaglypts are modified by corrosion. Ten almost parallel cylindrical holes, up to 15 mm in diameter and 70 mm deep, may indicate the previous location of troilite-belemnites; compare Cape York, La Caille and Santa Rosa. Some of the sections support the supposition that the troilite inclusions are elongated, flattened cylinders, roughly parallel in their orientation.

Etched sections display a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 25$) kamacite lamellae with a width of 0.85±0.10 mm. The kamacite has subboundaries decorated with 0.5-2 μ phosphides, and it displays numerous Neumann bands which are equally decorated with 0.5 μ precipitates along both sides. The low kamacite hardness of 175±8 indicates that the metal is well annealed.

Taenite and plessite cover about 40% by area, particularly in the form of dark-etching, dense plessite fields. Comb, net and acicular plessite fields are also present. A complete plessite field exhibits the following structural sequence: an exterior, yellowish to bluish stained taenite rim (HV 260±20) is followed by an acicular, hard martensite (HV 490±20) which is high in nickel and carbon. Then follows a low-nickel, low-carbon martensite (HV 350±50) with the individual platelets parallel to the gross Widmanstätten structure. The central portions of comb or net plessite (HV 190±25) are reached via an acicular plessite with thin, but well defined α-needles.

Frequently the martensitic fields – one out of five – contain carbide roses, 100-800 μ across. These are intricate intergrowths of a cubic carbide, taenite and kamacite; their microhardness ranges from 850 to 1,000, depending upon the exact morphology and thickness of the palmate crystals. They can frequently be spotted on the etched surface with the naked eye due to high relief and contrast to the adjacent dark-etching martensite. The carbide is probably identical to the new mineral, haxonite, identified by Scott (1971) in Toluca.

Schreibersite is common as poorly developed Brezina lamellae; they are typically 20 x 0.5 mm long, branched skeleton crystals segregated in the dodecahedral planes (110) of the parent taenite single crystal. They are monocrystalline and have a hardness of 905±30. Some of the crystals have nucleated and have grown around preexisting chromite crystals. These are euhedral, 10-600 μ across, and have a hardness of 1200±40. Schreibersite is further common as 0.2-0.4 mm wide crystals, located centrally in the kamacite lamellae and as 20-100 μ wide grain boundary precipitates. There are numerous schreibersite blebs, 5-25 μ across, in the net plessite. Rhabdites are common as tetragonal prisms, 1-5 μ thick.

Troilite occurs in scattered nodules and in what appears to be pencil-like inclusions. Cross sections are 5-25 mm in size and indicate some uniform flattening. Small troilite nodules, 0.5-2 mm across, are very common. Schreibersite rims, ranging from 400-15 μ in thickness, are precipitated on all the troilite nodules. At least all the smaller nodules examined by me have been shock melted and have solidified to fine-grained eutectics of sulfide and metal. The schreibersite rims and the chromite inclusions are, however, little affected, so it seems that the shock was barely sufficient to melt the troilite. The green glass in a troilite nodule observed by Marvin (1962) was probably formed by shock melting, too, and the associated cristobalite may then be explained as a later devitrification product of the glass.

All the Brezina lamellae and all the troilite-schreibersite nodules are enveloped in 1-2 mm wide zones of swathing

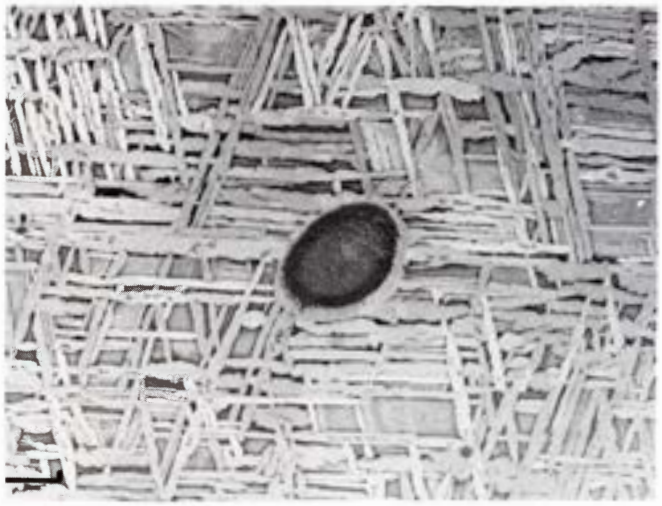

Figure 534. Carbo (U.S.N.M. no. 838). Troilite nodule with a narrow schreibersite rim and a wider, but asymmetric rim of swathing kamacite. Etched. Scale bar 5 mm. S.I. neg. M-1351a.

kamacite. The individual rims are frequently polycrystalline 1 mm kamacite units, indicating that many independent kamacite grains nucleated and grew almost simultaneously upon the schreibersite. The rims stop abruptly against the Widmanstätten structure which formed later by a different process.

Carbo is a medium octahedrite which structurally is related to N'Kandhla, Mount Ouray, Needles and Puquios. Carbo appears to have had its primary structure somewhat annealed, possibly in connection with shock reheating. The annealing has resulted in relatively low hardness of kamacite and taenite, and in the production of dark-etching martensite and fine precipitates along the Neumann bands. These are corroded selectively near the surface due to the local chemical potentials established by the microsegregation.

The terrestrial age is difficult to ascertain. It appears to me that Carbo's state of corrosion resembles that of Odessa, with the fusion crust and heat-affected rim zones removed over large parts of the surface but preserved in other places. The average loss of material by weathering is estimated to be 2 mm, so it is certainly an old fall, possibly over 10,000 years old. The open contour lines for ^{3}He and ^{4}He discussed by Hoffman & Nier (1958) do not appear to be caused by corrosion.

Specimen in the U.S. National Museum in Washington:
24.28 kg polished and etched, full slice (no. 838, 37 x 33 x 2.8 cm)

Carlton, Texas, U.S.A.

31°51′N, 98°9′W; 350 m

Polycrystalline, fine octahedrite, Of. Bandwidth 0.21±0.04 mm. Neumann bands. HV 210±10.

Group IIIC. 13.3% Ni, 0.53% Co, 0.6% P, 0.05% C, 11 ppm Ga, 8.4 ppm Ge, 0.07 ppm Ir.

HISTORY

A mass of about 82 kg was plowed up in 1887 by Frank Kolb about 8 km south of Carlton, Hamilton County. The meteorite passed through several hands before it was acquired for the Ward & Howell Collection in 1889; it was described by Howell (1890), who gave an analysis, a sketch of the mass before cutting and a figure of the Widmanstätten structure printed directly from a deeply etched section. During the following years large and small sections were cut and distributed all over the world; in the 1930's sections were still available from Ward's Establishment (see for example Price List no. 342, 1931).

Because of the thorough cutting, Carlton has been intensively studied; however, only a few publications can be listed here. Cohen (1905) and Farrington (1915) reviewed the literature, and Brezina & Cohen (Atlas 1886-1906: plate 31) presented two photographs. Young (1926) X-rayed the kamacite and taenite, and Vogel (1932) included Carlton in discussions of the Fe-Ni-P diagram. Nininger (1933c: figure 4; 1950: plate 16) presented photomacrographs, and Perry (1944: plates 3 and 13) gave additional structural pictures, as did Buchwald (1966: figure 35). Reed (1965a, b; 1968) measured the composition of the kamacite, taenite and schreibersite with the

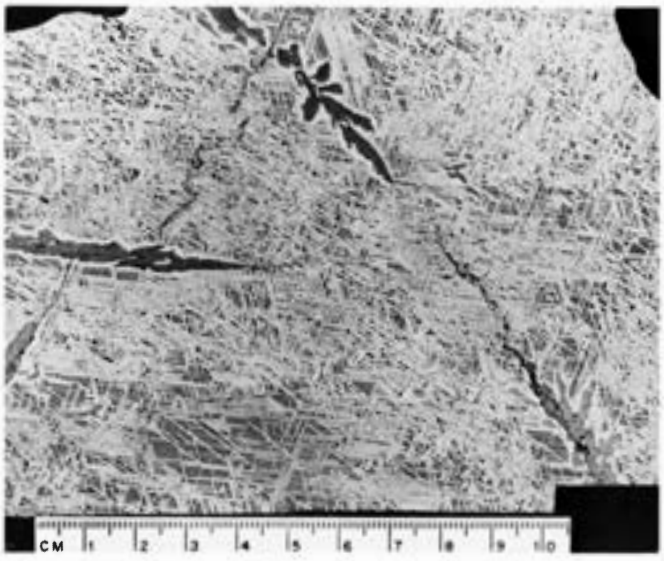

Figure 535. Carlton (Tempe no. 35a). Fine octahedrite with large skeleton crystals of schreibersite, enveloped in swathing kamacite. Etched. Scale bar in cm. (Courtesy C.B. Moore.)

CARLTON – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Eakins in Howell 1890	12.77	0.63	0.16	1100	300							
Goldberg et al. 1951	12.68	0.63							13			
Lovering et al. 1957		0.50				3.8	199		10	19		
Smales et al. 1967						7.3	240	21	10	8.1		
Wasson & Kimberlin 1967	13.20								11.4	8.73	0.072	
Moore & Lewis 1968	13.43	0.53	0.14	480	40		250					

The average composition is calculated from the last three analyses. The carbon content is significant. Reed (1969) found the kamacite to contain 7.0% Ni and 0.052% P.

microprobe, while Goldstein (1965) included Carlton in his discussion of the formation of the Widmanstätten pattern. Voshage (1967) found by the $^{41}K/^{40}K$ method the cosmic ray exposure age to be 615±70 million years.

COLLECTIONS

Chicago (9,350 g), Vienna (6,980 g), London (6,146 g), Ann Arbor (5,570 g), New York (4,966 g), Amherst (3,853 g), Paris (3,770 g), Harvard (3,284 g), Washington (1,486 g), Tempe (1,290 g), Vatican (800 g), Budapest (798 g), Tartu (Dorpat, 634 g), Warsaw (210 g; 284 g), Tübingen (372 g), Los Angeles (341 g), Leningrad (205 g), Yale (172 g), Rome (154 g), Prague (140 g), Göttingen (130 g), Helsinki (117 g), Strasbourg (105 g), University of Illinois, Urbana (105 g), Canberra (54 g), Copenhagen (27 g).

DESCRIPTION

The mass was an irregular angular mass with a flattened "beak"; the maximum dimensions were about 44 x 33 x 25 cm. Some portions of the thinner end had been hammered by the first owners; this explains the bent Widmanstätten lamellae and fractured inclusions on some near-surface specimens, e.g., Prague no. 154. Even though some weathering has produced a coating of 0.1-0.5 mm iron oxides, the original sculpturing from the atmospheric flight is well preserved. Regmaglypts, 10-40 mm in diameter and 5-10 mm deep, are common, and minor amounts of fusion crust may be observed in some of them. At one place the crust is composed of 4-6 layers of dendritic metallic material and increases locally to 0.5 mm thickness. The magnetite crust has mostly disappeared. On the opposite side of the same slice (no. 585) aggregates of small globules, 0.5-1.5 mm in size, are deposited, probably in a part that was temporarily rather protected during the flight of the meteorite; compare Arlington. On other sections too, e.g., the 3.8 kg Amherst slice, small pits, 2-3 mm deep and 5-15 mm wide, are filled with irregular melted aggregates that resemble whirlpools.

A heated rim zone of serrated α_2 occupies the outer 0.1-2 mm of most sections. The schreibersite is melted and resolidified to fine-grained eutectics in the outer 50% of the zone. The traces of Neumann bands are rather well preserved because the bands were beset with small phosphide precipitates, <0.5 μ, which did not completely dissolve during the rapid superficial reheating in the atmosphere. The microhardness of the α_2 zone decreases from a maximum of 225±10 at the surface to 180±10 at the transition to the interior untransformed kamacite. From there the hardness rapidly increases to 210±10 (hardness curve type II).

Etched sections display a beautiful fine Widmanstätten pattern with dominant "flames" and rosettes of schreibers-

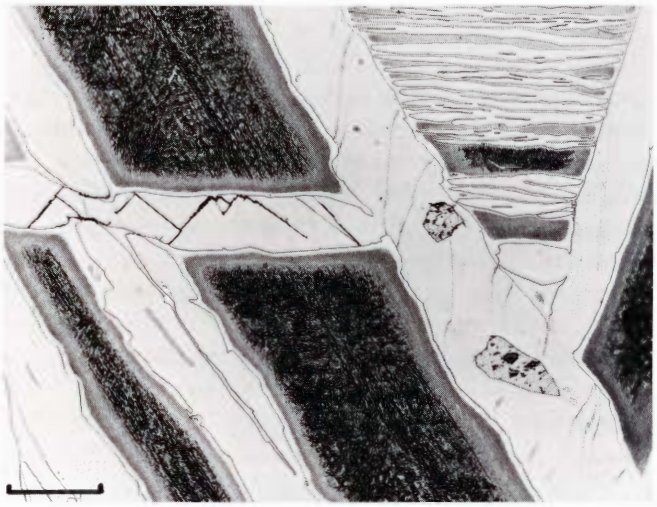

Figure 537. Carlton (Copenhagen no. 1904, 1589). Comb plessite and plessite with dark martensite Neumann bands and fissures that follow cubic cleavage planes of the kamacite. Etched. Scale bar 300 μ.

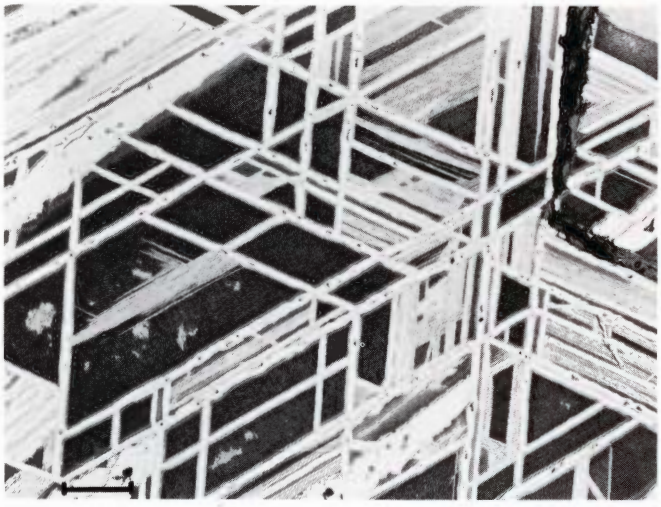

Figure 536. Carlton (Copenhagen no. 1904, 1589). In addition to the large skeleton crystals, schreibersite occurs as smaller angular bodies in the kamacite lamellae. Etched. Scale bar 2 mm.

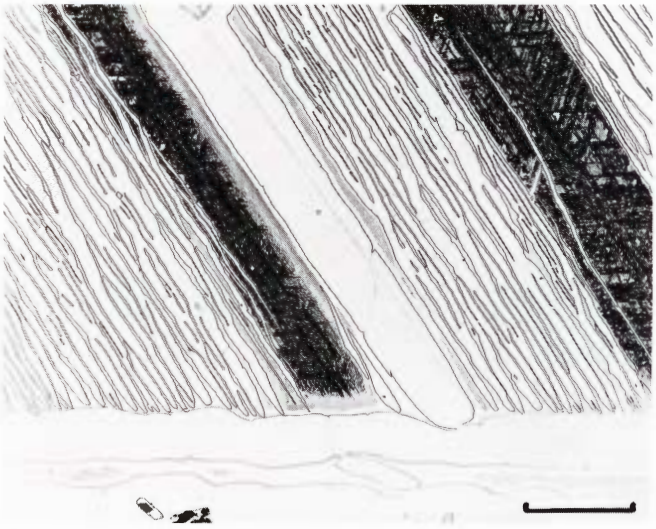

Figure 538. Carlton (Copenhagen no. 1904, 1589). Comb plessite and plessite with dark martensite developed parallel to the bulk Widmanstätten structure. Etched. Scale bar 300 μ.

ite. The kamacite lamellae are long ($\frac{L}{W} \sim 40$) and narrow with a width of 0.21±0.04 mm. Some areas are homogeneously transformed to Widmanstätten structure with few, intercalated plessite fields; other, somewhat smaller areas, only a few centimeters distant, display only a few scattered α-lamellae in a plessitic background. The most reasonable explanation appears to be local differences in the concentration of the austenite stabilizing element carbon.

Neumann bands are common in the ferrite. They have served as nucleation sites for 0.5 μ grains of phosphides. The taenite ribbons between the primary α-lamellae are unusually wide, typically 20-60 μ; such wide taenite ribbons will in most irons display a decomposed interior to some form of $\alpha + \gamma$ or α_2. It is here assumed that a high carbon content (~0.5%?) has prevented decomposition.

The plessite fields may be developed as rather normal comb plessite, but usually they are martensitic. A typical field is 2 x 1 mm bordered by an unusually wide cream-colored zone of 20 μ taenite. The brown-etching interior is decomposed to acicular martensite that repeats the (111) directions of the macroscopic Widmanstätten pattern. In some areas, when examined under high magnification, it is seen that the martensite is decomposing to a fine-grained, duplex $\alpha + \gamma$ structure that follows the Widmanstätten directions. In other areas 100-200 μ patches of high reflectivity turn out to be intricate intergrowths of haxonite and taenite, somewhat similar to those described in Colfax and Santa Rosa, but smaller. Exact duplicates are to be found in Edmonton (Kentucky), Mungindi and Coopertown. These small reflecting blebs in the dark-etching plessite were also observed by Brezina & Cohen (1886-1906: plate 31), who called them "taenite-roses," The microhardness of the haxonite roses varies somewhat according to the exact proportions of haxonite, taenite and kamacite in the intergrowths but is, in general, found to be 850±100. The adjacent martensite and duplex plessite show, in contrast, a hardness of only 290±50. The morphology of the intergrowths suggests that the haxonite is a rather late precipitate which formed after the bulk had transformed to a Widmanstätten structure and after part of the retained taenite had decomposed to pearlitic and spheroidized plessite.

Schreibersite occurs as irregular branched plates and rosettes, typically 50 x 20 x 3 mm in size, but sometimes as long as 14 cm. Point counting of several sections, totaling 900 cm^2, showed the macroscopically visible phosphides to occupy about 3.3% by area, which corresponds to 0.45% P. If we add the 0.14% P found by chemical analysis on material free of visible inclusions, we get about 0.6% P as an estimate of the total phosphorus content. From the Fe-Ni-P equilibrium diagram (Buchwald 1966) it becomes clear that a 13% Ni alloy will be supersaturated with respect to phosphorus of this amount at about 750° C. Assuming then that no undercooling takes place the phosphide will start

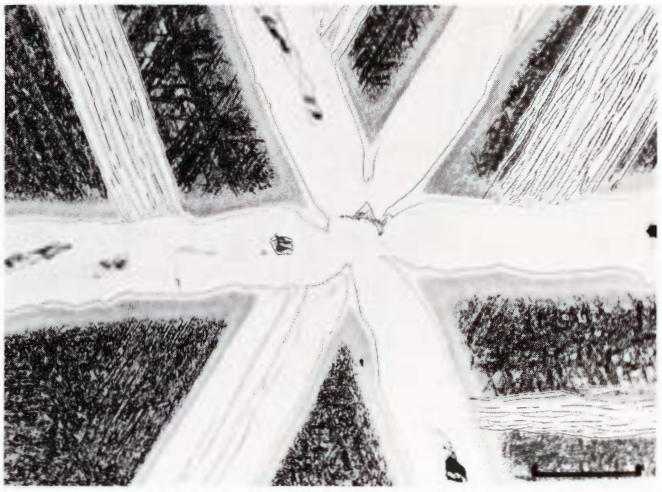

Figure 539. Carlton (Copenhagen no. 1904, 1589). Kamacite lamellae with schreibersite crystals. Because these are fractured due to cosmic events, they usually break open on polishing, thereby leaving holes and causing numerous scratches across the sample. Etched. Scale bar 300 μ.

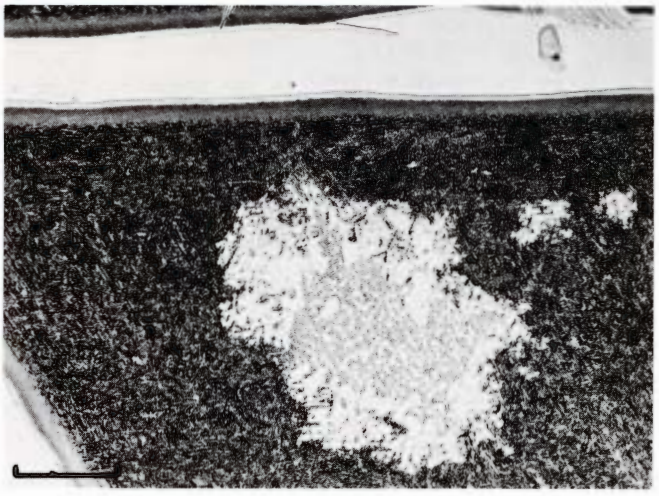

Figure 540. Carlton (Copenhagen no. 1904, 1589). A "taenite rose" in dark-etching plessite. The white rim is a carbide, haxonite, precipitated in the kamacite and enveloping numerous fine taenite beads. Etched. Scale bar 300 μ.

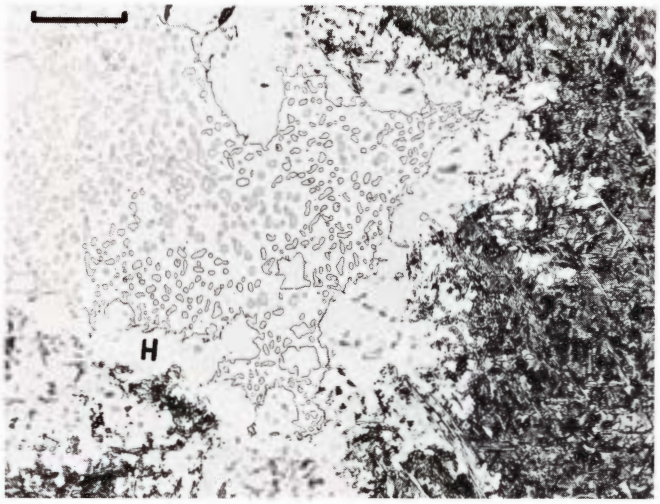

Figure 541. Carlton. Detail of Figure 540, showing the haxonite rim (H) and the taenite beads. Etched. Scale bar 100 μ.

precipitating at this temperature and grow to a considerable size, while other, smaller ones will also precipitate, before the Widmanstätten pattern forms. Ferrite will precipitate on the schreibersite and create the observed 0.5-1 mm wide rims of swathing kamacite. The small branched schreibersite crystals, about 0.1 mm wide and situated in the center of many α-lamellae, presumably also started to grow before the Widmanstätten pattern formed, but they only formed incomplete skeleton crystals, probably because of lack of phosphorus by this time. Lastly, the α-lamellae precipitated, a few nucleated by the schreibersite, but most nucleated homogeneously, thus creating the Widmanstätten structure proper. Indications are that the first precipitating schreibersite followed {110} planes of the austenite as seen in, for instance, Bella Roca. Later growth, however, proceeded along several {110} planes simultaneously, thereby creating the rosette and the swallowtail-like aggregates. The schreibersite units are often brecciated due to some slight, late, plastic deformation. The adjacent kamacite then shows distorted Neumann bands, and the microhardness increases locally to above 250. Schreibersite is further present as 10-30μ grain boundary precipitates. A few 0.5-1μ rhabdites are located in the α-lamellae.

Troilite and graphite have been reported in this meteorite (Brezina 1895: 270-71; Cohen 1905), but it is certainly not evenly distributed as it was not observed on a total of 1100 cm² sections from many collections.

Interesting are two small slices from near the surface (no. 2707) which are of a polycrystalline nature. The original austenite grains, about 1 cm in diameter, are separated by a 0.5 mm wide α-zone, and each grain reveals its own independent Widmanstätten orientation. The fragments are so similar to Pitts, structurally and probably chemically, that it was even thought that they were mislabeled. However, this does not appear to be the case, and it is hence concluded that Carlton locally contains polycrystalline, troilite-rich parts, gradually merging into Pitts-like material. The same conclusion has been reached in examining several slices of Edmonton (Kentucky), page 555.

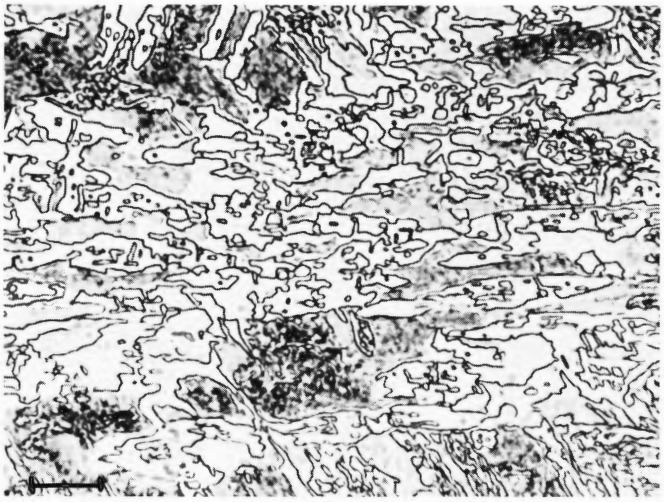

Figure 542. Carlton (Copenhagen no. 1904, 1589). Even in the fine-grained duplex plessite an oriented intergrowth of α and γ in a Widmanstätten pattern can be observed. Etched. Oil immersion. Scale bar 10 μ.

Carlton is an unusual meteorite, which structurally shows a considerable variation, mainly due to uneven carbon, phosphorus and sulfur distribution. It is related to Edmonton (Kentucky) and Mungindi, and possibly also to Soroti and Victoria West.

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

1,305 g slice (no. 585, 25 x 15 x 0.6 cm)
58 g part slice (no. 152, 4 x 3 x 0.6 cm)
51 g part slice (no. 1582, 4.5 x 3 x 0.5 cm)
58 g part slice (no. 2708, 5.5 x 3.5 x 0.5 cm)
13 g part slices (no. 2707; a few cm² sections)

Carrizalillo. See Pan de Azucar (Carrizalillo)

Carsons Well. See Needles

Carthage, Tennessee, U.S.A.

36°15′N, 85°57′W; 150 m

Medium octahedrite, Om. Bandwidth 1.25±0.15mm. Artificially recrystallized. HV 158±7.

Group IIIA. 8.35% Ni, about 0.2% P, 21.5 ppm Ga, 43.7 ppm Ge, 0.56 ppm Ir.

At least a fraction, and possibly all, of the mass was heated to 700 or 800° C and hammered. See also Jackson County which appears to be a still more heated and partly forged fragment of Carthage.

HISTORY

A mass of about 127 kg (280 pounds) was found a few years before 1844 about a mile from Carthage, the county seat of Smith County. Carthage has the coordinates given above. It was believed to be silver by the finders, and was for a time in the possession of a blacksmith. About 18 kg was sawed off for the cabinet of Professor Troost who described it (1846). It was divided further and distributed to a large number of collections and, consequently, many rather brief descriptions appeared in the nineteenth century

CARTHAGE – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Wasson & Kimberlin 1967	8.35								21.5	43.7	0.56	

(Shepard 1847; Clark 1852; Reichenbach 1862a,b; Rose 1864a; Boričky 1866; Brezina 1881; Huntington 1888; Cohen 1894). The only analysis published, however, was that of Boričky, which evidently, with 0.25% Co and 0.4% S, was not too reliable. Modern work includes microprobe analysis of the α, γ and phosphide phases by Reed (1965 a,b) and shock interpretations by Jaeger & Lipschutz (1967b) and Jain & Lipschutz (1968). Paneth (1954) determined the helium content of Carthage, later used by Wänke (1960b). Müller & Zähringer (1966) determined by neutron activation analysis the K-Ar age to be about 6.0 x 10^9 years, but K-Ar datings are apparently doubtful (Rancitelli & Fisher 1968). With an improved method Kaiser & Zähringer (1968) found K-Ar ages ranging from 3.65 to 4.85 x 10^9 years.

COLLECTIONS

Tübingen (44 kg endpiece and 25 kg in numerous slices), London (24.6 kg), Harvard (10 kg plus fragments), Budapest (6 kg), Prague (1.8 kg and 100 g), Paris (1.7 kg), Berlin (0.8 kg), Canberra (520 g). 100-200 g slices are widely distributed.

DESCRIPTION

The mass was oblong and shapeless (Troost 1846); the dimensions must have been approximately 40 x 30 x 25 cm before cutting, judging from the large pieces preserved in Tübingen and London. Due to weathering the surface is covered with thick limonitic crusts, and locally octahedral, weathered fragments are easily detached. All specimens have been exposed to corrosion for a sufficiently long time to remove the melted crust and the α_2 zone from atmospheric penetration. Some specimens (e.g., Harvard no. 144, Yale no. 24 and U.S.N.M. no. 1583), and perhaps the whole mass, show indications of heavy hammering and heating to 700-800° C. On such specimens the structure is often opened to produce gapping fissures and cracks along the (111) planes, and the surface is covered with high temperature oxides. The damage probably took place in the period when the mass was in the blacksmith's shop, which is further indicated by the exterior, hammered, subparallel surfaces.

Etched sections show a Widmanstätten pattern of long straight lamellae ($\frac{L}{W} \sim 25$) with a bandwidth of 1.25±0.15 mm. Taenite and plessite areas occupy roughly 30% by area. No specimens I have seen contain Neumann bands; in fact, the lamellae of all specimens appear to possess a granulated ferrite, variously developed as equiaxial, polygonal aggregates or as serrated, lobed grains, 25-100 μ in diameter. Angular 1 μ precipitates, presumably of phosphides, are frequently found in grain boundaries and corners. The observed variation in grain aggregate morphology resembles what is produced at recrystallization experiments in the laboratory at 600-800° C in a few hours. The hardness is 158±7.

The taenite and plessite are, under higher magnification, rather diffuse, and somewhat spheroidized. The plessite contains 5-50 μ schreibersite blebs substituting for taenite of the same general size and form.

Schreibersite is present locally as 10 x 1 mm rosettes but more ubiquitous as 20-50 μ wide grain boundary precipitates. The longer bodies are often brecciated and displaced a few microns, and some are recrystallized to differently orientated segments. They often show a 2-5 μ wide, creamy rim zone. Rhabdites have been common in the α-phase but are now almost resorbed, leaving only ghost-like etching pits. The amount of phosphides present corresponds to about 0.20% P in the meteorite.

Troilite is present as scattered 1-2 cm nodules with 0.5 mm schreibersite rims. A 3 x 1 mm troilite nodule in no. 2203 was unusual in being an individual that was lightly fractured to many segments and showed significant recrystallization to 25-50 μ anisotropic grains along many of the fracture zones. The unfractured segments were twinned, showing the typical lenticular sparks which indicate compression or other slight deformation. A 70 μ wide daubreelite band was recrystallized or had reacted with troilite at an elevated temperature to produce an intricate lamellar grain pattern on the micron scale.

On the other hand, a 100 μ daubreelite inclusion in schreibersite was untransformed. Locally, the troilite displays opaque black crystals, 3-5 mm across, which, however, were not identified on this occasion.

On all specimens I have seen there are peculiar lace-like, 100 μ wide oxide-sulfide metal intergrowths along the surface and along near-surface cracks and inclusions. From other meteorites known to have been involved in blacksmithing operations (e.g., Burlington, Cacaria) I have concluded that this mineral assemblage is typical of high temperature reactions between the atmosphere, the corrosion products in the meteorite and the meteorite itself. All evidence thus appears to corroborate the view that Carthage – or at least essential parts of it – was heated

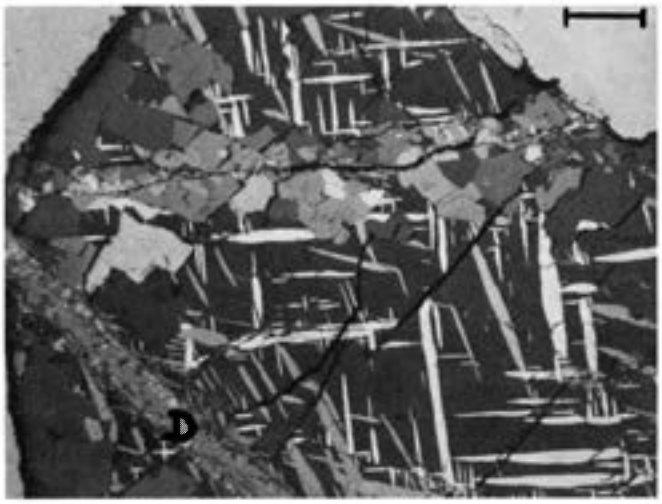

Figure 543. Carthage (U.S.N.M. no. 2203). A troilite nodule showing multiple twinning. Artificial reheating has caused the troilite to recrystallize in shear-zones (horizontal) and a daubreelite lamella (D) to react with the adjacent troilite. Polished. Crossed polars. Scale bar 100 μ.

by the blacksmith who owned it to about 600-800° C for some hours. It was certainly not above 1000° C since the sulphides and phosphides would then have melted, but experiments show that, on the other hand, it must have been above 600° C to create recrystallization in the ferrite, troilite and schreibersite.

From the preserved structural elements it is estimated that, before the artificial reheating, Carthage was a shock-hardened medium octahedrite with ϵ-structure and monocrystalline but twinned troilite. Thus, it corresponds to, e.g., Orange River and Thunda, and is a typical group IIIA iron.

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

65 g part slice (no. 97, 4 x 3.5 x 1 cm)
33 g part slice and fragments (no. 986, 3 x 2.5 x 0.6 cm)
129 g part slice (no. 2203, 5 x 4 x 0.8 cm)
932 g endpiece (no.1583, 10 x 7 x 2.5 cm)
12 g part slice (no. 2709, 23 x 15 x 5 mm)
34 g part slice (no. 2710, 32 x 20 x 12 mm)
193 g corner (no. 3293, 6 x 3 x 2.5 cm)

Casas Grandes, Chihuahua, Mexico
30°24′N, 107°57′W

Medium octahedrite, Om. Bandwidth 1.15±0.15 mm. Deformed Neumann bands. HV 245±15.

Group IIIA. 7.72% Ni, 0.49% Co, 0.15% P, 0.1% S, 19.5 ppm Ga, 38.1 ppm Ge, 5.0 ppm Ir.

HISTORY

Somewhat conflicting and insufficient sources reported the discovery of a large mass, later shown to weigh 1,545 kg, in an Indian temple ruin in Casas Grandes on the western bank of the Rio de las Casas Grandes in northern Chihuahua. The first information to be given was by Tareyre (1867: 343-353) who briefly examined the 160 x 160 m labyrinthine ruin and reported that an earlier excavation of one of the chambers had brought to light a lenticular mass of meteoric iron. The iron, 50 cm in diameter, was carefully wrapped in cloths, similar to those which enshroud the mummies in the graves of the same locality, but Tareyre evidently did not see the iron itself. The tombs were situated outside the temple near the river and took the form of small, elliptical chambers, in each of which a body was seated with raised knees. The enveloping cloths were made of maguey (agave) and normally crumbled rapidly when a grave was opened. A related story was reported in letters to the Smithsonian Institution by Pierson [Annual Report (1873) of the Board of Regents of the Smithsonian Institution, Washington 1874: 419] differing only as to the actual discoverer and to the size of the mass.

As Monnig (1939) has explained, the meteorite was hauled about 1500 km on a wagon via San Antonio, Texas, to Luling from where it was shipped to Philadelphia to be exhibited at the World's Fair, 1876, among the Mexican minerals (U.S. Centennial Commission International Exhibition 1876. Reports and Awards, Philadelphia, 1878: Volume 1: 369). It was bequeathed to the Smithsonian Institution and was described by Tassin (1902b) with several photographs and by Cohen (1903). Farrington (1915) reviewed the literature. Merrill (1916a) reprinted two of Tassin's photographs and gave a new analysis by Whitfield; the photographs reappeared in Merrill (1929 and 1943). Nininger (1933c: figure 10) showed the same plate, while Perry (1944) gave the first photomicrograph. Feller-Kniepmeier & Uhlig (1961) presented microprobe profiles across taenite and plessite with photomicrographs.

Several works on rare gases have been published, e.g., by Hoffman & Nier (1960), Fisher & Schaeffer (1960), Herr et al. (1961), Signer & Nier (1962), Bauer (1963), Vilcsek & Wänke (1963), Hintenberger et al. (1967) and Chang & Wänke (1969). According to the results of the last mentioned pair of authors, the cosmic ray exposure age of Casas Grandes is 290±80 million years, while the terrestrial age is $160{,}000^{+140{,}000}_{-110{,}000}$ years. Although there is a

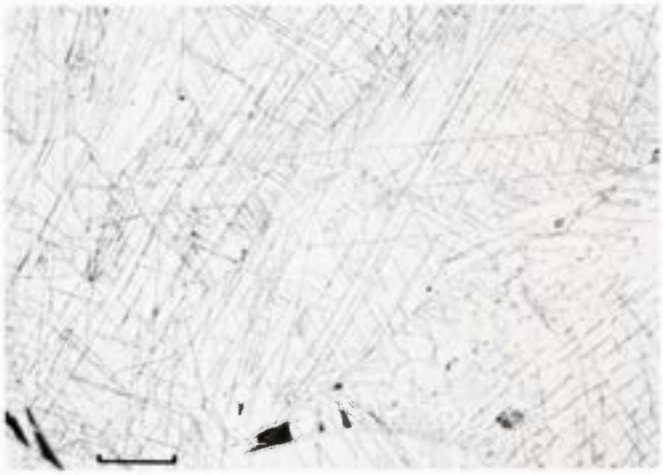

Figure 544. Casas Grandes (U.S.N.M. no. 369). This meteorite resembles Cape York closely in nearly all aspects. The lightly etched section shows the numerous Neumann bands. Scale bar 500 μ. See also Figure 179.

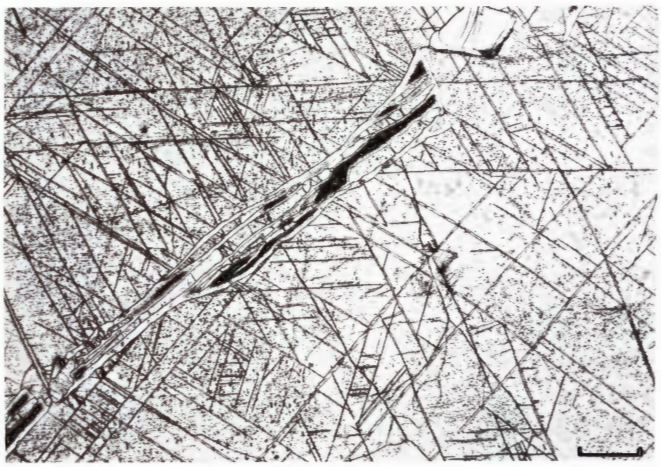

Figure 545. Casas Grandes (U.S.N.M. no. 369). More heavily etched. Neumann bands, comb plessite and dark taenite wedges. Scale bar 200 μ.

considerable amount of uncertainty, the meteorite appears to have fallen before the Indians populated Mexico.

COLLECTIONS

The main mass in Washington is divided into two large pieces (totaling 1,318 kg), and several plates and sections (totaling 8.3 kg). Smaller specimens are in Chicago (9,987 g), Harvard (1,974 g), London (989 g), New York (820 g), Tempe (658 g), Vienna (624 g), Ottawa (601 g), Stockholm (245 g), Berlin (217 g), Moscow (113 g).

DESCRIPTION

The mass is a rounded, massive lump with no significant surface sculpturing, apart from a 40 x 10 cm fin on one side. Its overall dimensions were 97 x 74 x 46 cm before cutting, and it weighed 1,545 kg (Tassin 1902b). The exterior is corroded and covered by 0.5-2 mm thick, adhering oxide crusts, and no signs of fusion crusts can be seen. The flat circular grooves, 2-5 cm in diameter and 1-5 cm deep, are probably mainly a result of terrestrial weathering.

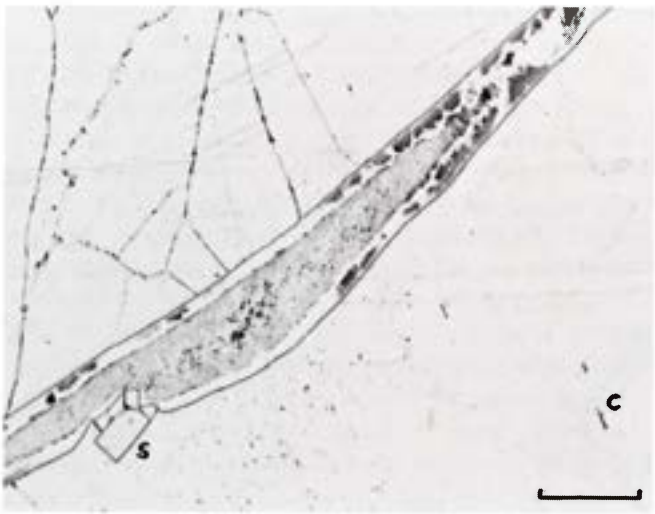

Figure 546. Casas Grandes (U.S.N.M. no. 369). Typical plessite field with a schreibersite crystal (S). Carlsbergite (C) and subboundaries in the kamacite. Etched. Scale bar 100 μ.

Etched sections display a beautiful Widmanstätten pattern of long bundled lamellae ($\frac{L}{W} \sim 40$) with a bandwidth of 1.15±0.15 mm. On several sections, cut almost parallel to $\{111\}$, the fourth Widmanstätten direction shows up as slightly undulating, broad ribbons 3-4 mm wide. Neumann bands exist in profusion but are often heavily faulted and deformed. The Vickers hardness (100 g) of the ferrite is 245±15 and reflects the deformation hardening. Subgrain boundaries, decorated with $< 1\ \mu$ precipitates, are clearly visible in the α-phase. Taenite and plessite cover an estimated 40% by area of the sections, particularly as comb plessite and taenite wedges with the interior transformed to martensite or poorly resolvable duplex structures of $\alpha + \gamma$ ("black taenite"). Schreibersite blebs, 10-50 μ in diameter, are common in the comb plessite.

Schreibersite is further common as 10-50 μ wide grain boundary precipitates. It is monocrystalline but often heavily brecciated and displaced along subparallel shear zones in 10-20 μ steps. The surrounding ferrite exhibits macroscopic deformation bands as well as a microscopically visible flow of hardened kamacite with bent Neumann bands. Rhabdites are common as 1-2 μ thick prisms. Due to the rather low overall phosphorus content of Casas

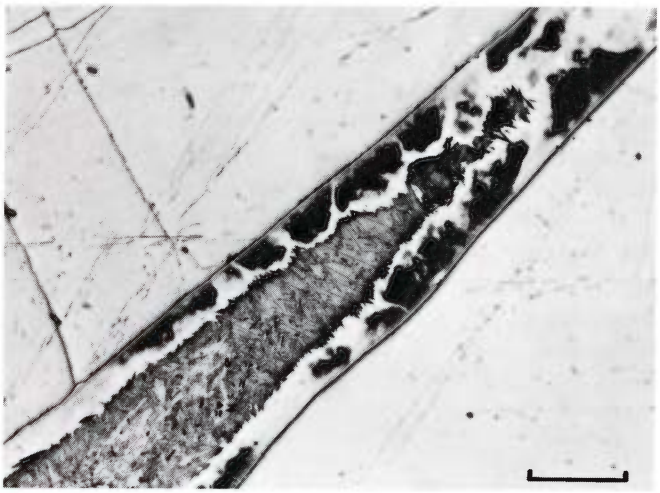

Figure 547. Casas Grandes. Detail of Figure 546. Cloudy taenite rim and transition to acicular martensite. Etched. Scale bar 40 μ.

CASAS GRANDES – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Whitfield in Merrill 1916a	7.74	0.60	0.17	1450	300		120					
Lovering et al. 1957	7.73	0.48				51	157		17	30		
Smales et al. 1967						65	154			47		
Cobb 1967		0.50					173		21.5		4.9	
Moore et al. 1969	7.67	0.50	0.15	75	10		165					
Scott et al. 1973	7.77								19.9	37.4	5.1	

The data of the first line are not used here in calculating the average composition, but they are given for comparison. Judging from the structure, the low value for carbon is the correct one.

Grandes, only thin discontinuous rims of schreibersite have nucleated on the troilite bodies.

Troilite is common as scattered large and small nodules and elongated bodies that have often nucleated a 1 mm rim zone of swathing mamacite. On a total of 9,800 cm^2 sections, 23 nodules larger than 10 mm^2 were counted, 120 in the range 2-10 mm^2, and 470 smaller than 2 mm^2. The corresponding total sulfur content of Casas Grandes is estimated to be 0.1%. The larger troilite bodies are sheared and subdivided into relatively undisturbed fragments embedded in vein material of microcrystalline sulfides with small, angular troilite and daubreelite fragments. The rim zones of large troilites display a dispersed texture of 1 μ sulfide and α-grains suggestive of eutectic remelting. Also characteristic are the detached, rounded 0.1-1.0 mm troilite bodies which are arranged as satellites around a larger, central body of troilite. The smaller troilite bodies are heavily transformed, showing 10-25 μ recrystallized troilite and fringes of the above mentioned troilite-metal eutectic.

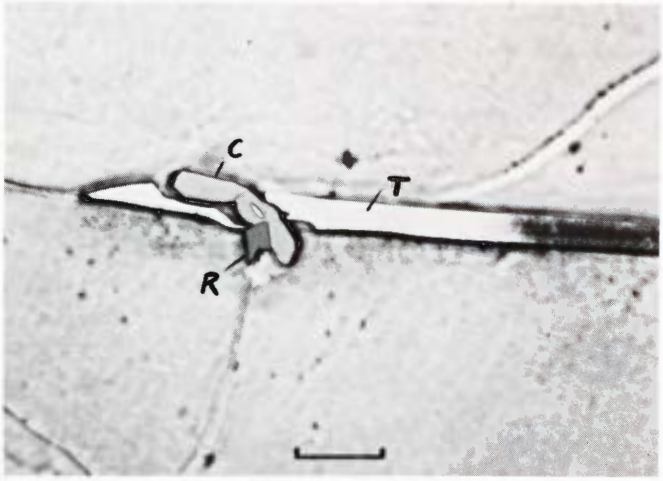

Figure 548. Casas Grandes (U.S.N.M. no. 369). A grain boundary with taenite (T), carlsbergite (C) and rhabdite (R). Etched. Oil immersion. Scale bar 10 μ.

Figure 549. Casas Grandes (U.S.N.M. no. 369). The structure of Casas Grandes is rich in indications of cold working in space. This taenite lamella is shear-displaced along a number of parallel slipplanes, probably as a result of shock-deformation. Etched. Oil immersion. Scale bar 10 μ.

Original daubreelite lamellae are sheared and conspicuously displaced and may even have 20 μ wide, internal fissures filled with metal. Locally the troilite-metal eutectic contains a third, purplish phase of the same morphology and size as the metal phase and substituting for this. It is concluded that the purplish phase is a late terrestrial corrosion product. Scattered in the ferrite are rounded, bluish nodules of daubreelite, 10-50 μ in diameter. Graphite or carbon-bearing minerals were not detected so previous reports are probably in error in this point.

Reichenbach lamellae of troilite appear locally as typically 40 x 20 x 0.05 mm ragged foils. A total of eight such foils are present on 9,800 cm^2, but several other elongated troilite inclusions are apparently intermediate in form between the typical lamellae and the sausage formed troilite bodies. The Widmanstätten structure is developed differently on the two sides of the individual lamellae. It is probable, as Brett & Henderson (1967) have suggested, that the lamellae represent fissures and shear zones which were filled with highly mobile sulfide ("lubricant") at austenitic temperatures. While other fissures healed, the mineral-filled fissures would survive a long cooling period.

Casas Grandes appears to be a normal, medium octahedrite, closely related to, e.g., Cape York. At high temperature it suffered some gentle shearing, creating the Reichenbach lamellae, and at a later stage and low temperature, after the Widmanstätten structure and all major precipitates were formed, it suffered a shock of medium intensity. Neumann bands were then created, minerals were sheared and displaced, and the compressible sulfide provided local heat sinks, recrystallized or melted and partially dissolved the surrounding swathing kamacite.

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

Approximately 1,300 kg { half mass (about 70 x 50 x 50 cm)
corner (about 60 x 30 x 30 cm)

(the above have polished and etched surfaces)

18 kg slice (no. 369, about 64 x 50 x 1.2 cm)
6.8 kg part slice (no. 369, 42 x 28 x 0.9 cm)
0.4 kg slices and sections (no. 369)
28 g knife, forged from a fragment
982 g cube (no. 369, 5 x 5 x 5 cm, polished and etched)

Casey County, Kentucky, U.S.A.

Approximately 37°20′N, 84°55′W

Coarse octahedrite, Og. Bandwidth 2.2±0.4 mm. Neumann bands. HV 205±15.

Group I. 6.96% Ni, about 0.25% P, 81.7 ppm Ga, 317 ppm Ge, 1.1 ppm Ir.

Part of the mass has been heated and forged.

HISTORY

A mass of which the weight and circumstances of find were not given was briefly reported by J.L. Smith (1877). Short catalog descriptions by Brezina (1880a; 1885; 1896), by Huntington (1888) and by Ward (1904a) are practically

all that is known of the iron. Wülfing (1897) was able to identify a total of 732 g in collections then, and Farrington (1915) had no additional information. Casey County is not in Georgia as believed by Brezina and Wülfing, but in Kentucky; the coordinates above are those of Ward's.

COLLECTIONS

Harvard (106 g; 68 g), Washington (91 g), Paris (81 g), Chicago (42 g; 29 g), Vienna (65 g), London (45 g), Stockholm (36 g), New York (22 g). These specimens add up to 584 g. In addition, at Harvard there is a 60 g chisel forged from Casey County material. It is unlikely that much more than 1 kg was ever found.

DESCRIPTION

The specimen no. 2552 in the U.S. National Museum is a small fragment, 3 x 2 x 2 cm in size, heavily corroded and with a 1-2 mm thick, partially adhering, limonitic crust. Other specimens in collections, particularly Harvard's 106 g piece, show the same characteristics; the oxidation penetrates to the interior along grain boundaries and tends to split the specimens into minor fragments. It is probable that it was only such detached fragments that were forged because not all specimens in museum collections have been heated.

The Widmanstätten structure is indistinct in the small sections, the bandwidth being 2.2±0.4 mm. Ferritic grain growth has eliminated many of the former, straight lamella boundaries so that parts of the sections are covered by irregular kamacite grains, e.g., 16 x 8 or 10 x 7 mm in size. Neumann bands are well developed and the microhardness is 205±15. The minor amounts of taenite often have pearlitic interiors, the taenite lamellae being less than 0.5 μ wide. Other taenite ribbons have dark-etching, duplex or martensitic interiors, all structures being typical for group I irons.

Schreibersite occurs as irregular skeleton crystals, e.g., 9 x 0.5 mm in size, and as 10-50 μ wide grain boundary precipitates. The schreibersite is heavily brecciated and often sheared. Rhabdites are very common and may reach 20 μ in cross section. Cohenite occurs as discontinuous 50-150 μ wide rims around some of the larger schreibersite crystals. Troilite and other minerals were not observed on the sections available.

In view of the significant weathering – even the specimens in collections are difficult to preserve – it is interesting to note that the original fusion crust of magnetite and wüsite has been preserved locally, as has also the heat-affected α_2 zone. In one place this is 0.70 mm thick, displays melted rhabdites in its exterior half, and has a microhardness of 195±15. In the recovered transition zone between α_2 and α the hardness reaches a minimum of 160 (hardness curve type II).

Casey County is structurally related to Odessa and unshocked Canyon Diablo specimens, and is a typical group I iron.

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

3.7 g part slice (no. 987, 1 x 1 x 0.5 cm; Shepard no. 89)
52 g cut fragment (no. 2552, 3 x 2 x 2 cm; from University of Kentucky)
36 g slice (no. 3294, 4 x 3 x 0.4 cm; University of Minnesota no. 3354)

Casimiro de Abreu, Rio de Janeiro, Brazil
22°28′S, 42°13′W

Medium octahedrite, Om. Bandwidth 1.30±0.20 mm. Recrystallized. HV 170±15.

Group IIIA. 8.43% Ni, 0.52% Co, 0.23% P, 20.9 ppm Ga, 41.0 ppm Ge, 0.25 ppm Ir.

HISTORY

A mass of 24.2 kg, found on the Andorinhas Estate near Casimiro de Abreu about 100 km east of Rio de Janeiro, was recognized in 1947 by Joaquim Seixas as a

Figure 550. Casimiro de Abreu (Tempe no. 603.1). A normal medium octahedrite which has been exposed to annealing in space and has recrystallized. Deep-etched. Scale bar in cm. (Courtesy of C.B. Moore.)

CASEY COUNTY – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Wasson 1970a	6.96								81.7	317	1.1	

meteorite. It was analyzed and described with several photographs by Curvello (1950c).

COLLECTIONS

Museu Nacional, Rio de Janiero (main mass), Tempe (205 g), Washington (203 g).

DESCRIPTION

The mass is rather smoothly rounded with the average dimensions 26 x 20 x 12 cm. It is covered with corrosion products, and the original crust from atmospheric penetration has disappeared. In several places the surface exfoliates along octahedral lamellae due to the corrosion.

The Widmanstätten structure is well developed with a bandwidth of 1.30±0.20 mm, but there is no oriented sheen from the presence of Neumann bands or ϵ-structure. Instead the lamellae are recrystallized to lobed α-grains, 100-500 μ in diameter. The ferrite phase of the comb plessite is recrystallized to grains generally less than 100 μ in diameter. Neumann bands are only found occasionally in the recrystallized grains; they are created after the recrystallization and are not a remnant structure from the previous α-lamellae. They may have been formed when the meteorite fissured locally along the recrystallized grain boundaries, possibly in the atmosphere. The hardness of the recrystallized kamacite is 170±15.

Figure 551. Casimiro de Abreu (U.S.N.M. no. 1511). Recrystallized kamacite and spheroidized plessite. Etched. Scale bar 100 μ.

Schreibersite is common as subangular bodies centrally in the α-lamellae, typically 2 x 0.5 or 1 x 0.3 mm in size, and with a hardness of 910±25. It also occurs as 25-50 μ wide grain boundary precipitates; the total amount appears to be in harmony with the analytically determined value of 0.23% P. The schreibersite is not recrystallized as the ferrite, but it is surrounded by a 2-5 μ creamcolored reaction zone which indicates some elevated temperature in prolonged time. There are also indications of slight healing of a previous brecciation of the larger schreibersite grains. Rhabdites are not present, but small (1-5 μ), wedge-shaped phosphide precipitates are common in the grain boundaries of the recrystallized ferrite.

The taenite ribbons and the taenite part of the plessite fields are thoroughly spheroidized, often to rows of islands 3-10 microns in diameter. Similarly spheroidized austenite phase is found in, e.g., Maria Elena, Seneca Falls, Hammond

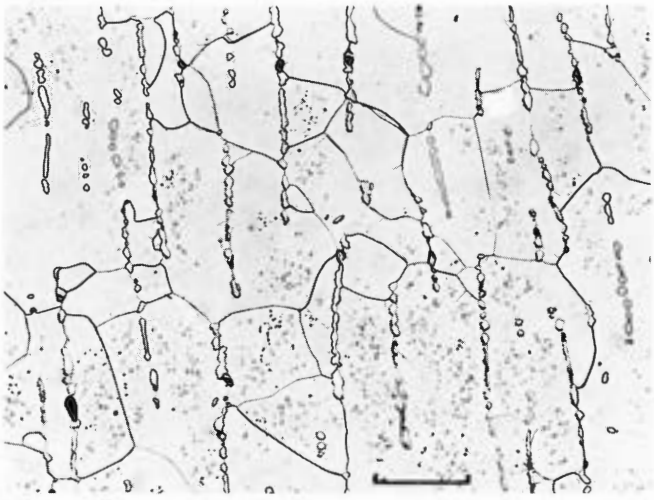

Figure 552. Casimiro de Abreu (U.S.N.M. no. 1511). Comb plessite. On annealing, the kamacite recrystallized, and the taenite lamellae decomposed to beads with rounded contours. Fine black dots are phosphides. Etched. Scale bar 100 μ.

and Willamette. Corrosion along the grain boundaries is common and as usual the nickel-poor phase is transformed to oxides before the nickel-rich. It is highly probable that the grain boundaries of the recrystallized network are depleted in nickel, since they corrode preferentially.

CASIMIRO DE ABREU – SELECTED CHEMICAL ANALYSES

Ferreira (1956) furthermore reported 0.11% Cl, which was ascribed to lawrencite, although not identified in sections. In calculating the average composition of the meteorite here, the value 0.63% Co was considered erroneously high and excluded.

	percentage					ppm						
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Cantição in Curvello 1950c	8.27	0.52	0.20	320	240							
Ferreira 1956	8.57	0.63	0.26		300							
Moore & Lewis 1968	8.49	0.51	0.23	90	15							
Scott et al. 1973	8.40								20.9	41.0	0.25	

No trace of heated α_2 zone from atmospheric penetration is left. No trace of the alleged lawrencite was observed. It is the author's general opinion that lawrencite does not occur as a meteoritic mineral. All reported occurrences are either old or based only upon high analytical chlorine values, which may have a quite different explanation. The high chlorine content reported for Casimiro by Ferreira (1956) could thus very well be terrestrially emplaced chloride present in the unusually large grain boundary area of this meteorite. Whatever the explanation, to the best of my knowledge no report exists which convincingly identifies lawrencite as a cosmic mineral in iron meteorites.

Casimiro was probably originally a normal medium octahedrite similar to, e.g., Thule and Briggsdale, but a cosmic heat source reheated the mass sufficiently to recrystallize the ferrite and spheroidize the taenite. It is difficult to be exact in terms of time and temperature, but I would bracket the temperature between 500° and 750° C. I also believe that the observed recrystallization has required considerable time, possibly days or weeks of cooling after a shock event. The structure and composition are related to Seneca Falls and Willamette.

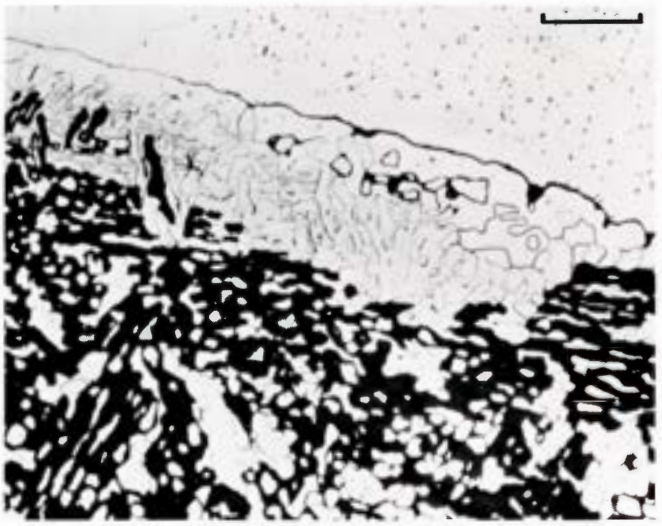

Figure 553. Casimiro de Abreu (U.S.N.M. no. 1511). Near the surface the α-phase is selectively converted to limonitic products by terrestrial weathering. Etched. Scale bar 40 μ.

Specimen in the U.S. National Museum in Washington:
203 g part slice (no. 1511, 8 x 6.5 x 1.1 cm)

Castray River, Russell County, Tasmania

41°30′S, 145°25′E

A piece weighing 51 grains, i.e. 3.3 grams (not 51 grams as believed by Hey 1966: 93) with two others of like size and character, were found by a miner in 1899, when ground sluicing the auriferous drift on the banks of the Castray River. The 3.3 g specimen was a small smoothly rounded mass, 18 mm long and 10 mm maximum width. At one end it was abruptly terminated by angular faces. It was described and figured by Petterd (1901) who assumed that the material was meteoritic. It was, however, not cut, and no analysis was performed. If the specimens are, in fact, meteoritic, they are the smallest individuals of an iron meteorite ever found, excluding tiny fragments of the crater-producing or large meteorites, such as Canyon Diablo, Henbury, and Sikhote-Alin.

According to Hey (1966: 93), the 3.3 g sample is in the Queen Victoria Museum in Launcestown, Tasmania. It is strongly recommended that the material be examined by modern metallographical and chemical methods.

Cedartown, Georgia, U.S.A.

Approximately 34°3′N, 85°18′W; 250 m

Hexahedrite, H. Single crystal larger than 25 cm, with recrystallized portions. HV 145±5.

Figure 554. Cedartown (U.S.N.M. no. 1379). Main mass in the Smithsonian Institution, 9.6 kg. The fissures to the left are partly filled with laminated iron oxides. Scale bar 3 cm. S.I. neg. 32710.

CEDARTOWN – SELECTED CHEMICAL ANALYSES

	percentage							ppm				
References	**Ni**	**Co**	**P**	**C**	**S**	**Cr**	**Cu**	**Zn**	**Ga**	**Ge**	**Ir**	**Pt**
Henderson 1941a	5.48	0.22	0.30		400	200						
Goldberg et al. 1951	5.58	0.53							63			
Wasson 1970, pers. comm.	5.36								61.4	181	8.2	

Group IIA. 5.47% Ni, 0.53% Co, 0.30% P, 61.4 ppm Ga, 181 ppm Ge, 8.2 ppm Ir.

Small samples labeled Aragon are detached from Cedartown, see page 440.

HISTORY

A mass of 11.6 kg was plowed up before 1898 on a farm between Cave Springs and Cedartown, Polk County. For many years it was in the possession of S.W. Mc Callie, state geologist of Georgia. After his house was burned in a violent fire in 1917, the meteorite was recovered from the ashes. The main mass was later donated to the U.S. National Museum, and it was described with photomicrographs by Perry (1946), who showed that the meteorite's structure was undamaged by the fire. Some of the information and photomicrographs had already been presented by Perry (1944). Henderson & Furcron (1957) reviewed the case with several photographs. Bauer (1963) measured the helium isotopes and estimated the exposure age of Cedartown to be 430 million years.

COLLECTIONS

Washington (9.7 kg), New York (271 g), Harvard (245 g), Chicago (213 g), Ann Arbor (102 g).

DESCRIPTION

The flattened, lenticular mass has the average dimensions 27 x 22 x 7.5 cm. Top and underside meet along rather a sharp edge, but flight sculpturing is apparently corroded away. A fissure, 16 cm deep and almost plane, penetrates from one side subparallel with the flattened sides and may represent a cubic cleavage plane. It is conceivable that the fracture originated during the flight through the atmosphere, but it is also evident that it later became an exposed site for corrosion and is now filled with laminated iron oxides. A few other minor fissures are present. Moreover, the surface, in a part many centimeters from the fissures, shows considerable plastic deformation with sheared schreibersite. This, together with the fissures, indicates that Cedartown is only one (the major ?) fragment of a mass that split when decelerating in the atmosphere.

Etched slices display a complex pattern of Neumann bands partly disrupted by patches of recrystallized α-grains. The original hexahedrite had a ferritic grain size of at least 25 cm, and the first generation of Neumann bands crossed the entire section. But two of the Neumann band directions have served as nucleation regions for new ferrite grains that have grown preferentially along these bands. The recrystallized grains are typically 200 x 500 μ, but larger grains occur. The energy source, responsible for the recrystallization and grain growth, disappeared before the whole mass could recrystallize. About 20% by area of the sections display recrystallized regions. The new grains show a second generation of Neumann bands that are narrow and sharp; by contrast, the old Neumann bands are poorly defined,

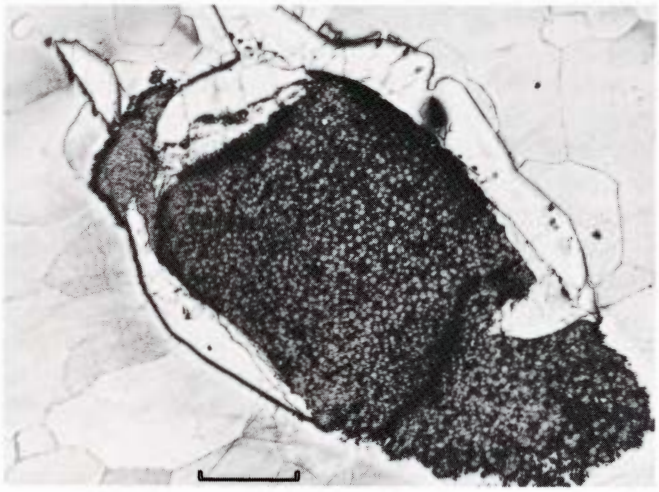

Figure 556. Cedartown (U.S.N.M. no. 1379). A troilite-daubreelite nodule (black) surrounded by a rim of schreibersite (white), in recrystallized kamacite. The shock-melted nodule penetrated the fissured schreibersite and dissolved part of the kamacite. The numerous light dots in the troilite are rounded daubreelite fragments. See Figure 557. Etched. Scale bar 200 μ.

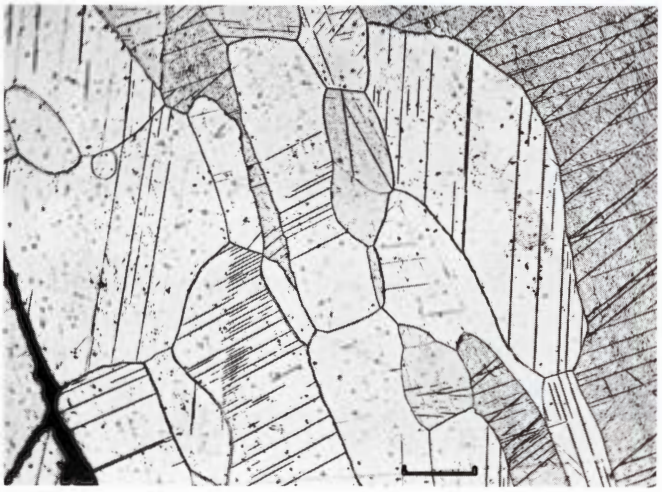

Figure 555. Cedartown (U.S.N.M. no. 1379). Group of elongated recrystallized grains with new Neumann bands. Corroded grain boundary to the left. Etched. Scale bar 100 μ. (Perry 1944: plate 4.)

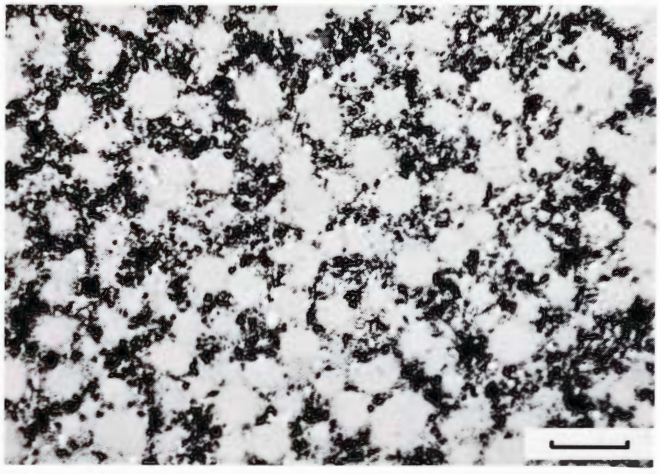

Figure 557. Cedartown. Detail of Figure 556, showing fine-grained iron-nickel-sulfur eutectic through which numerous rounded daubreelite particles (gray) are dispersed. Crossed polars. Scale bar 20 μ.

discontinuous, and subdivided by densely crowded subboundaries. Similar structures were reported from Indian Valley by Buchwald (1966: figures 32-41). The microhardness of the kamacite is 145±5. There is no significant difference between the recrystallized grains and the matrix. Recovery and strain relief evidently occurred everywhere.

Phosphides are common as giant rhabdites or slender plates, typically 2 x 0.5 x 0.05 mm, and as 0.1 mm rims around troilite-daubreelite nodules. The phosphides are monocrystalline but somewhat brecciated. Some of the larger lamellae are branched like a Y. Rhabdites are common as 1-5 μ rounded grains; they lost their sharp edges during the recrystallization of the metallic matrix.

Troilite occurs as scattered, rounded nodules, typically 4 x 1.5 mm, but occasionally increasing to 10 mm size. It is associated with daubreelite and schreibersite and, sometimes, with cohenite and graphite.

The troilite is micromelted and occasionally the former rim zones of schreibersite and cohenite are brecciated and have become dispersed as 5-10 μ fragments in the melt. The same is true of the daubreelite exsolution lamellae. In other nodules the rim zones are well preserved. A 50-150 μ wide cohenite rim was observed under decomposition to 2-5 μ wide graphite veinlets in a matrix of 5-20 μ recrystallized α-grains. Corrosion has removed the heat-affected α_2 zone from atmospheric flight; corrosion also penetrates somewhat along the boundaries of the recrystallized grains and along phosphides.

Cedartown appears to be a normal hexahedrite like Braunau which, upon shocking, acquired its Neumann bands and polycrystalline troilite nodules with entrapped fragments of the surrounding rim zone. While the later cosmic reheating was mild in the related Braunau, in Cedartown it was sufficient to create pronounced recrystallization and partial decomposition of the cohenite to graphite.

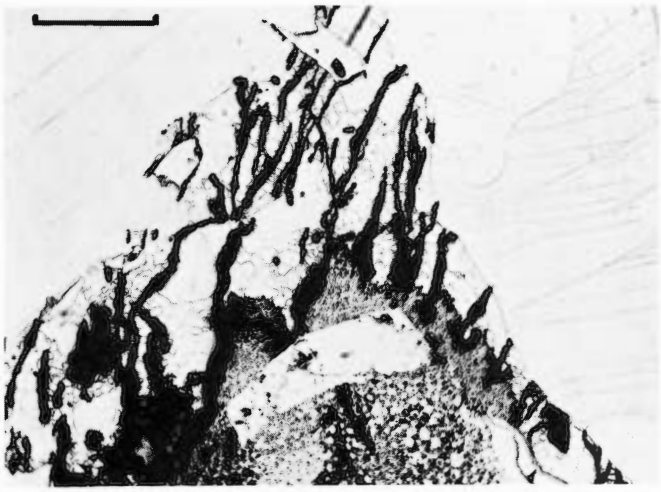

Figure 558. Cedartown (U.S.N.M. no. 1379). Another shock-melted troilite-daubreelite nodule, this one exhibiting both schreibersite and cohenite rims. The cohenite has, however, been decomposed to granulated ferrite and lamellar graphite, and the schreibersite is broken and partly dispersed through the melt. Etched. Scale bar 200 μ. (Perry 1950, Volume 1.)

It is likely that the meteorite split in the atmosphere; however, only one fragment has so far been found and unequivocally identified as Cedartown. The reheating of the mass during the fire appears to have been very gentle (400° C ?), leaving no visible structure alterations. The mass may have been protected by rubble from more intensive heating. The uniform low hardness may be due in part to recovery during this slight reheating, but the hardness would be expected to be slow anyway, considering the cosmically recrystallized structure; compare, e.g., Mayodan.

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

9.58 kg main mass (no. 1379, 20 x 19 x 7.5 cm)
100 g slices and microsections (no. 1379)

Cedartown (Aragon), Georgia, U.S.A.

Two small samples labeled Aragon (Mason 1962: 231; Hey 1966: 24; and elsewhere) are fragments of the Cedartown meteorite.

HISTORY

Two fragments, totaling 5 g, found in 1898 in Aragon, Polk County, were listed by Farrington (1916) as a nickel-poor ataxite. No further information has been published. Henderson & Furcron (1957), however, rightly suspected that Aragon was part of Cedartown.

COLLECTIONS

The two fragments labeled Aragon are preserved in the Field Museum, Chicago, (no. 1962, 5 g) (Horback & Olsen 1965).

ANALYSIS

No analysis has been published.

DESCRIPTION

The two fragments were kindly loaned to me for a metallographic examination by Dr. E. Olsen. One fragment

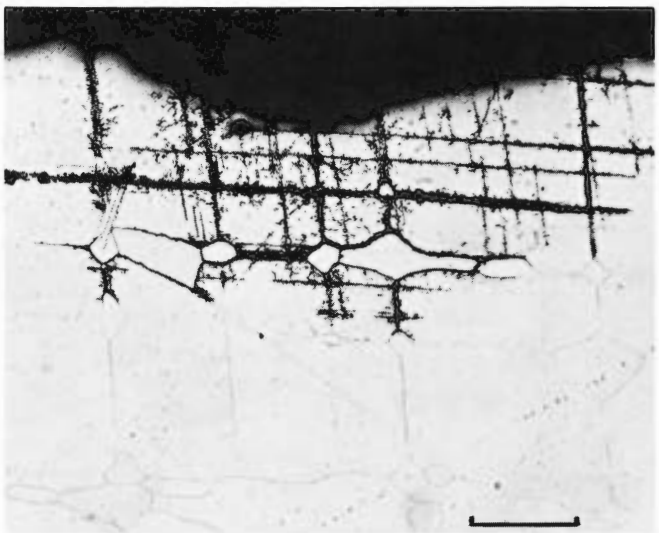

Figure 559. Cedartown. Aragon sample (Chicago no. 1962). Corroded surface. The sensitized Neumann bands are selectively attacked, and corrosion also proceeds along the grain boundaries of the recrystallized grains. Etched. Scale bar 300 μ.

measures 15 x 13 x 1 mm, the other 11 x 10 x 1 mm; both are in the form of thin slices through a somewhat larger fragment, perhaps 15 x 13 x 10 mm in size.

Polished and etched sections show that the unusual macro- and microstructures are identical in every respect to sections through the Cedartown mass. There is no point in giving a full description of the fragments, since it is obvious that they derive from the Cedartown mass: (i) Aragon and Cedartown are both in Polk County, Georgia; (ii) Aragon and Cedartown were both reported as new meteorites in 1898; (iii) the unusual macro- and microstructures and, in addition, the state of corrosion are the same; (iv) the Aragon fragments are somewhat cold-worked; this occurred when they were separated (by hacksaw or chisel) from the Cedartown mass.

A tentative explanation for Aragon's listing as a separate meteorite could then be that the finder detached a sample from the main mass and submitted it to Chicago for identification and possible sale. In the meantime, the Georgia state geologist intervened and secured the main mass for Georgia, so that the sale did not materialize. The state geologist acquired some additional information and was able to give the exact locality as Cedartown. Since nothing was published about the main mass until 1946, and since no one previously has compared sections through the appropriate samples, both Aragon and Cedartown have persisted as individual meteorites in all catalogs and textbooks until now.

Central Missouri. See Ainsworth

Chambord, Quebec, Canada
48°26′N, 72°3′W

Medium octahedrite, Om. Bandwidth 0.95±0.15 mm. ϵ-structure. HV 310±20.

Group IIIA. 7.53% Ni, about 0.1% P, 18.4 ppm Ga, 35.0 ppm Ge, 10 ppm Ir.

HISTORY

A mass of about 6.6 kg was found in 1904 in a field about two miles from the village of Chambord, county of Lake St. John. A preliminary description was presented by Johnston (1906), who gave a set of coordinates which must be erroneous. Dawson (1963) reported the correct set, quoted above. The mass, which has apparently been only little subdivided, has not previously been the object for metallographic examinations.

COLLECTIONS

Ottawa (6,350 g main mass; 52 g slice), Chicago (18 g).

DESCRIPTION

According to Johnston (1906) the block was irregularly shaped, with a length of 19 cm, a thickness of 9 cm, and a width varying from 10 to 15.5 cm. Unfortunately, the surface was marred to a considerable extent by hammer and chisel marks made in an attempt to penetrate and split the iron. The surface was weathered and over a large area a natural etching was visible, in some places as coarse furrowings, and in others as minute ridges.

For the present study, the 18 g sample in Chicago (Me 921, 2 x 1.7 x 0.7 cm) was kindly loaned to me by Dr. E. Olsen. It is a medium octahedrite with slightly deformed, long ($\frac{L}{W} \sim 20$) kamacite lamellae with a width of 0.95±0.15 mm. There are numerous subboundaries in the kamacite, decorated with less than 1 μ phosphide particles and with 5 x 1 μ carlsbergite platelets. Due to a cosmic shock that postdated the formation of the primary structures, all kamacite has been converted to a hatched ϵ-variety of extensive contrast, and the taenite and the carlsbergite lamellae have been bent and distorted. The microhardness of the kamacite is high, 310±20, suggesting significant shock hardening.

Taenite and plessite cover about 35-40% by area, mostly as almost resorbed, degenerate comb and net plessite. The taenite lamellae are cloudy, stained in brown and yellow colors, and hard (HV 365±25), due to plastic deformation. The slightly wider parts of the lamellae are decomposed to indistinct duplex structures of α and γ (HV 310±20). Most common is an acicular plessite type where fine bayonet-like α-spindles, 1 μ wide, occur in an unresolvable matrix.

Schreibersite is rare, occurring only as scattered 2-5 μ wide grain boundary veinlets, and as occasional blebs of the same size inside the plessite fields. Rhabdites are abent. The bulk phosphorus content is estimated to be 0.10±0.02%.

Troilite was reported by Johnston as two small nodules about 13 mm in diameter. They were apparently monocrystalline with distinct cleavage planes.

Carlsbergite is common as 30 x 1 μ oriented platelets in the kamacite and as irregular precipitates on some grain boundaries. Daubreelite occurs as scattered particles in the kamacite, 5-30 μ across. Carbides, graphite and silicates are absent.

Chambord is sufficiently weathered to have lost the fusion crust and the heat-affected α_2 zone. On the section, no hardness gradient could be detected toward the surface so it appears that on the average more than 5 mm has been lost by corrosion. Corrosion also penetrates to a depth of

CHAMBORD – SELECTED CHEMICAL ANALYSES

	percentage					ppm						
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Scott et al. 1973	7.53								18.4	35.0	10	