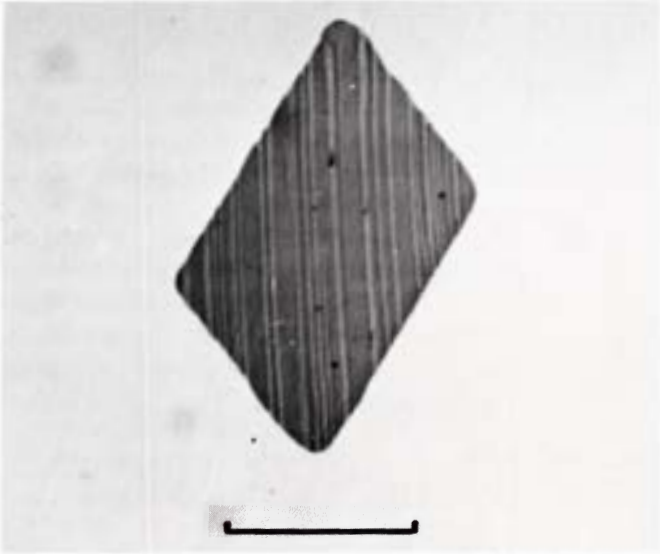

Figure 1439. Rhine Villa (Copenhagen no. 1902, 1060). A rhomboid sulfide inclusion composed of alternating troilite (light) and daubreelite lamellae. Slightly bent. Polished. Oil immersion. Scale bar 20 μ.

Rhine Villa is an unusual coarse octahedrite. It is unrelated to Toluca and other group I irons of this bandwidth (1.4 mm), but related to Willow Creek, Paneth's Iron, Staunton, Coopertown and similar group IIIE meteorites. A particular noteworthy feature which Staunton, Coopertown, and Rhine Villa have in common is the carbide constituent of the plessite fields, and the short, spindle-shaped kamacite lamellae.

Specimen in the U.S. National Museum in Washington:
114 g slice (no. 272, 8 x 4 x 0.5 cm)

Richa, Nigeria

Approximately 10°N, 9°E

Medium octahedrite, Om. Bandwidth 0.55±0.08 mm. Neumann bands. HV 200±25.

Anomalous. 9.4% Ni, 0.66% Co, about 0.3% P, 78 ppm Ga, 82 ppm Ge, 17 ppm Ir.

HISTORY

According to Hey (1966: 406), this mass of approximately 1.5 kg was found before 1960 near the Daudy mining camp. This was situated between Bargesh and Richa in the southwestern corner of the Jos plateau, but the coordinates could not be given with more precision than quoted above. The mass was acquired by the Geological Survey of Nigeria, and a 390 g endpiece was presented to the British Museum in 1966. This was briefly described and analyzed by Easton, who classified it as a medium octahedrite, anomalous with respect to the Ni-Ga-Ge ratios (Hey 1966).

COLLECTIONS

Geological Survey of Nigeria, Kaduna (about 1 kg), London (390 g).

DESCRIPTION

The mass appears to have been of an ovoidal shape with the approximate dimensions of 10 x 7.5 x 5 cm and a weight of 1.5 kg. The sample in London is a 36 mm high endpiece with a cut section of 72 x 46 mm. It has undergone a peculiar oxidative weathering, resulting in the prominent standing out of the kamacite plates of the structure – surprisingly enough not the taenite – over the whole surface. Fusion crust and heat-affected α_2 zones are not preserved.

Etched sections reveal a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 20$) kamacite lamellae with a width of 0.55±0.08 mm. There are numerous subboundaries decorated with 0.5 μ phosphides, and Neumann bands are common. The kamacite has a rather variable hardness, 200±25, evidently due to small variations in the degree of cosmic deformation of the metal.

Taenite and plessite cover about 40% by area. The larger fields show comb and net plessitic development of the interiors, while the smaller, massive wedges display martensitic-bainitic and unresolvable duplex interiors. A typical field will show a tarnished taenite rim (HV 310±20) followed by a transition zone, etching indistinctly martensitic (HV 370±30). Next comes a brown-etching martensitic-bainitic zone, with individual platelets parallel to the bulk Widmanstätten structure (HV 340±30), followed by duplex, unresolvable $\alpha + \gamma$ structures (HV 290±20). The central portions are easily resolvable $\alpha + \gamma$ structures with 2-10 μ γ-particles and hardnesses only slightly above those of the adjacent kamacite lamellae. Annealing effects are not present.

Schreibersite occurs as cuneiform skeleton crystals in sizes up to 6 x 0.5 mm. More typical are the 1.5 x 0.5 mm bodies, normally aligned centrally in some of the kamacite lamellae. The schreibersite is monocrystalline but brecciated, and individual segments may be shear-displaced 5-10 μ. Schreibersite is also common as 10-30 μ grain boundary precipitates and as 2-20 μ particles substituting

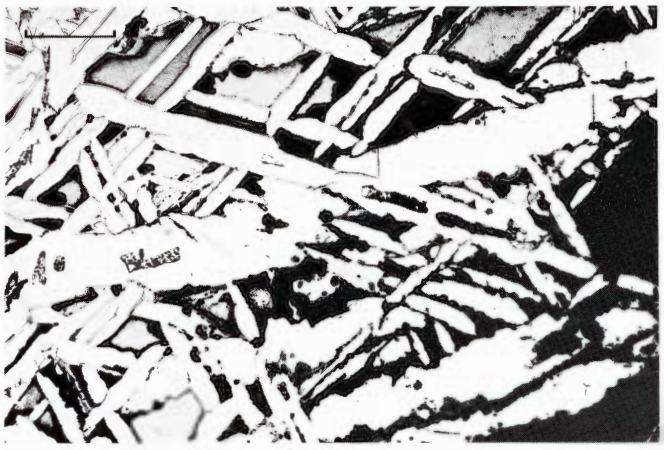

Figure 1440. Richa (Brit. Mus. no. 1966, 55). Medium octahedrite of group IID. The mass is severely weathered, and the duplex plessite fields and grain boundaries are particularly attacked (black). The kamacite lamellae, therefore, protrude above the general surface in a most peculiar way. Etched. Scale bar 3 mm.

for taenite inside the coarser plessite varieties. Rhabdites are common but generally only form small prisms with a cross section of 0.5-4 μ. The bulk phosphorus content is estimated to be 0.30±0.05%.

Sulfides occur as small scattered nodules, 0.2-0.5 mm across. They are situated in the kamacite or sometimes in direct contact with taenite and plessite in a rather unusual way. The sulfides are intergrowths of troilite and daubreelite, normally with the daubreelite forming massive bars, constituting 10-40% of the whole aggregate. The troilite is monocrystalline but shows multiple twinning due to plastic deformation. The various sulfide nodules are independently oriented as witnessed by the variable orientation of the daubreelite bars. The sulfide nodules have served as substrates for the precipitation of 10-50 μ thick schreibersite rims, which again may be surrounded by 0.5-0.8 mm wide rims of swathing kamacite.

Carbides, graphite and silicates were not detected.

As previously mentioned, Richa is corroded in a rather peculiar way. Sections through the mass show an exterior rim zone (A), where the plessite fields are dissolved, leaving 0.5-0.7 mm thick kamacite lamellae in high relief; next comes a 10-15 mm wide zone (B) where the plessite fields are visibly altered to cavernous limonitic pockets by replacement; and, finally, the massive nucleus of the mass where corrosion is only beginning to attack along α - γ and α-phosphide grain boundaries.

A detailed examination of the B-zone reveals that the plessite fields are attacked in the usual way, i.e., the fine-grained α-phase of the duplex fields is selectively transformed before the γ-phase which in numerous places is well-preserved. The small schreibersite particles also are late to corrode in the plessite fields.

Figure 1441. Richa. Detail of a corroded plessite field in Figure 1440. The high-nickel taenite rims survive for a while and provide a marked contrast to the limonite. Etched. Scale bar 30 μ.

Corrosion has developed along the α - γ phase boundary and also inside the plessite field along a line subparallel to this phase boundary and only 1-10 μ away. In the best developed examples of zone B a former plessite field will, therefore, be separated from the adjacent kamacite lamella twice along its periphery, leaving an almost continuous, unattacked γ-shell only 1-10 μ thick as an envelope around the limonitic-plessitic interior. It appears that this 1-10 μ unattacked envelope is the only truly homogeneous single-phase taenite material, while everything else in the plessite field is decomposed to $\alpha + \gamma$, either on a submicroscopic or on a microscopic scale. And it is these two-phase $\alpha + \gamma$ structures that are very sensitive to corrosion. They are also rapidly attacked by the 2% Nital reagent used in preparation of the etched sections. As a rule, the metallic phase which is most rapidly attacked upon etching with Nital is also the phase which will be found to be least resistent to corrosive attack in a terrestrial environment.

The most conspicuous difference between Richa and other corroded meteorites is that Richa's kamacite lamellae live much longer than its duplex plessite fields. It appears that a high relative humidity and a high average temperature in the local Nigerian environment have contributed to a relatively rapid removal of the plessitic material; and, further, that the electrochemical contact between the kamacite lamellae and the taenite part of the plessite was interrupted at an early stage so that the kamacite lamellae would corrode with a lower velocity than the duplex, intimately coupled $\alpha + \gamma$ interior of the plessite fields.

Richa is a medium octahedrite of a rather unusual bandwidth. Its combination of 9.4% Ni and 0.55 mm bandwidth places it outside the major octahedrite groups.

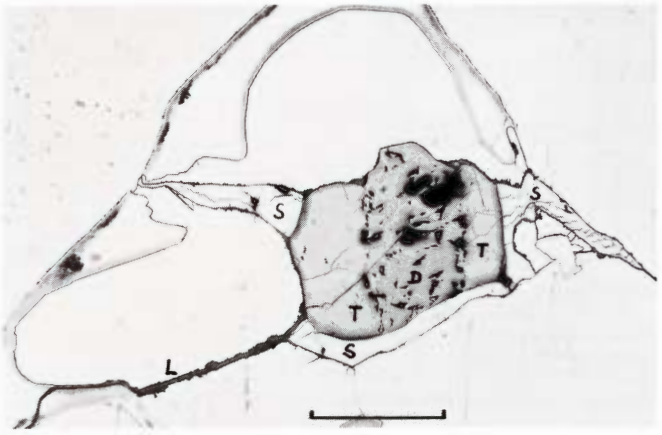

Figure 1442. Richa (Brit. Mus. no. 1966, 55). Troilite (T) and daubreelite (D) with fissured schreibersite crystals (S) and cloudy taenite. Grain boundary corrosion (L). Neumann bands in the kamacite. Etched. Scale bar 200 μ.

RICHA – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	**Ni**	**Co**	**P**	**C**	**S**	**Cr**	**Cu**	**Zn**	**Ga**	**Ge**	**Ir**	**Pt**
Easton in Hey 1966	8.71	0.66				56	208		78	72		
Wasson 1974, pers. comm.	10.0								78	92	17	

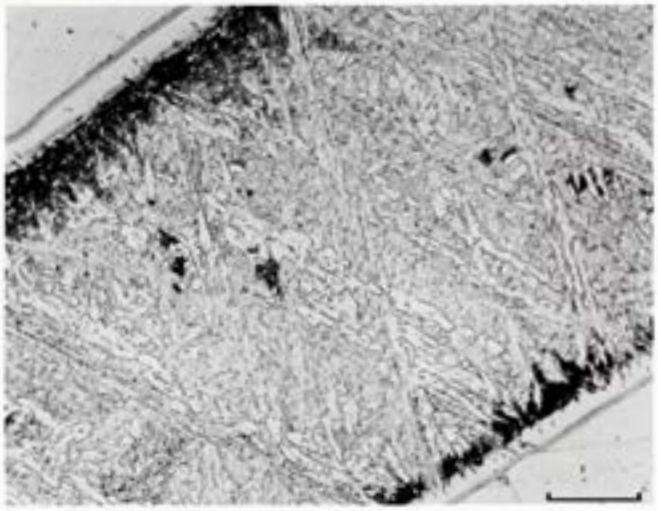

Figure 1443. Richa (Brit. Mus. no. 1966, 55). Plessite field. Cloudy edges, martensitic transition zones and duplex $\alpha + \gamma$ interior. Etched. Scale bar 100 μ.

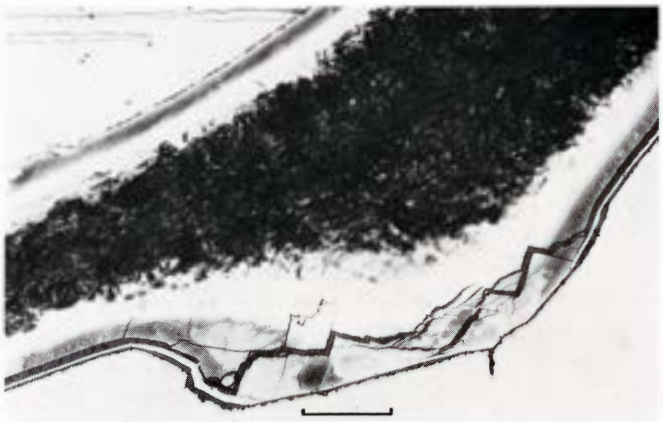

Figure 1444. Richa (Brit. Mus. no. 1966, 55). Plessite field with unresolvable martensitic interior, Corrosion penetrates along the $\alpha - \gamma$ boundary and inside the taenite rim. The very thin, homogeneous high-nickel taenite edge is thereby isolated as a strip. Etched. Scale bar 40 μ.

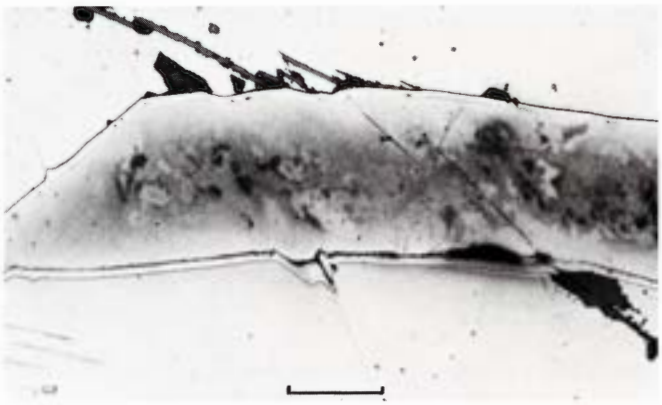

Figure 1445. Richa (Brit. Mus. no. 1966, 55). Another example of the progress of corrosion. The high-nickel strips are almost detached from the plessite field. Ultra-fine fissures inside taenite and kamacite are recemented by limonite. Etched. Scale bar 40 μ.

The anomaly is confirmed by the Ga-Ge analyses which indicate that Richa falls outside the resolved chemical groups, or possibly is slightly related to such irons as Needles and Wallapai of group IID.

Richland, Texas, U.S.A.

Approximately 31°55′N, 96°26′W; 100 m

Hexahedrite, H. Single crystal larger than 22 cm across. Neumann bands. HV 156±8.

Group IIA. 5.48% Ni, 0.21% P, 60.6 ppm Ga, 180 ppm Ge, 8.2 ppm Ir.

HISTORY

A mass of 34 pounds (15.4 kg) was found in 1951 by Edgar L. Arnold at Richland, Navarro County. While cleaning out an old water well, he found the meteorite among the debris at the bottom. The depth was reported to be 5.5-6 m, but the mass may originally have been located in the wall at a higher level. The discoverer kept the iron for a while, drilling several holes in it and hammering it superficially. In 1955 it was sold, and a slice was acquired by the U.S. National Museum where it was described in detail by Henderson & Monnig (1956). They presented photographs of the exterior and of etched sections and suggested that the mass was a transported Coahuila fragment. As the present reexamination shows, this is an unwarranted assumption.

COLLECTIONS

Dept. of Geology, Southern Methodist University, Dallas (main mass of about 12 kg), O.E. Monnig, Fort Worth (about 1 kg), Washington (1 kg).

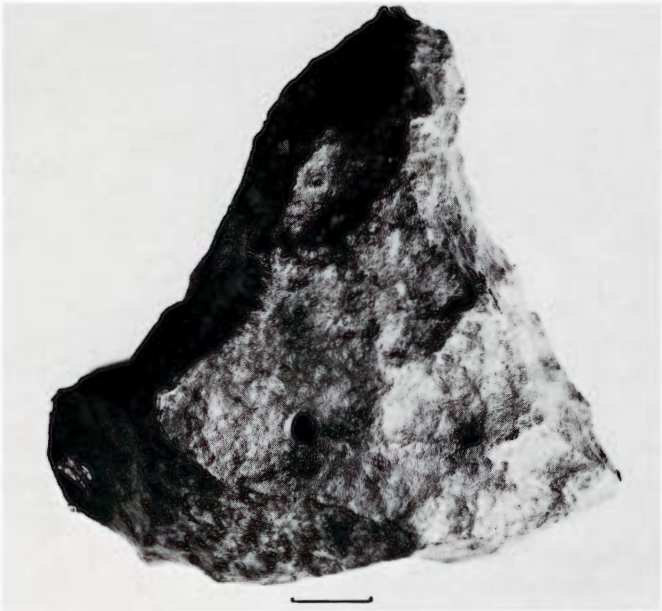

Figure 1446. Richland. Main mass in Dallas. The meteorite is weathered and fusion crusts are not expected to be preserved. A drill hole near the center. Scale bar approximately 3 cm. S.I. neg. 43758E.

DESCRIPTION

The average dimensions of the rather flat triangular slab are about 22 x 22 x 8 cm (the magnification of Figure 1 in Henderson & Monnig is 0.45, and not 0.67, as stated). It is weathered, and no indications of fusion crust or α_2 zone are present, except at one place where both a 0.6 mm thick crust of fused, dendritic metal and a 4 mm thick α_2 zone were identified. The fused metal appears very fresh and uncorroded; it is rather coarse-grained, and no layering could be found. It appears to be deposited among corroded parts of the surface, so I am inclined to conclude that it represents the activity of the discoverer who may have attempted to cut the material with a blow torch, although no such event is recorded in the literature. The general state of Richland is that of a terrestrially old meteorite.

Etched sections show Richland to be a monocrystalline hexahedrite with conspicuous parallel rows of rhabdites. The kamacite has Neumann bands which extend across the full sections, and it has subboundaries which are best visible near the inclusions where they are decorated with 0.5-1.0 μ rhabdites. The hardness is rather low, 156±8, suggesting some recovery of the kamacite at 400-500° C. It may or may not be associated with the supposed heating by an acetylene torch.

Schreibersite is present as 30-60 μ wide rims around the troilite nodules but otherwise is very scarce. Most of the precipitated phosphorus is bound in three generations of rhabdites, one plate-shaped and the two others prismatic. The plates are arranged in parallel planes which penetrate the whole mass; the average distance between the rhabdite-

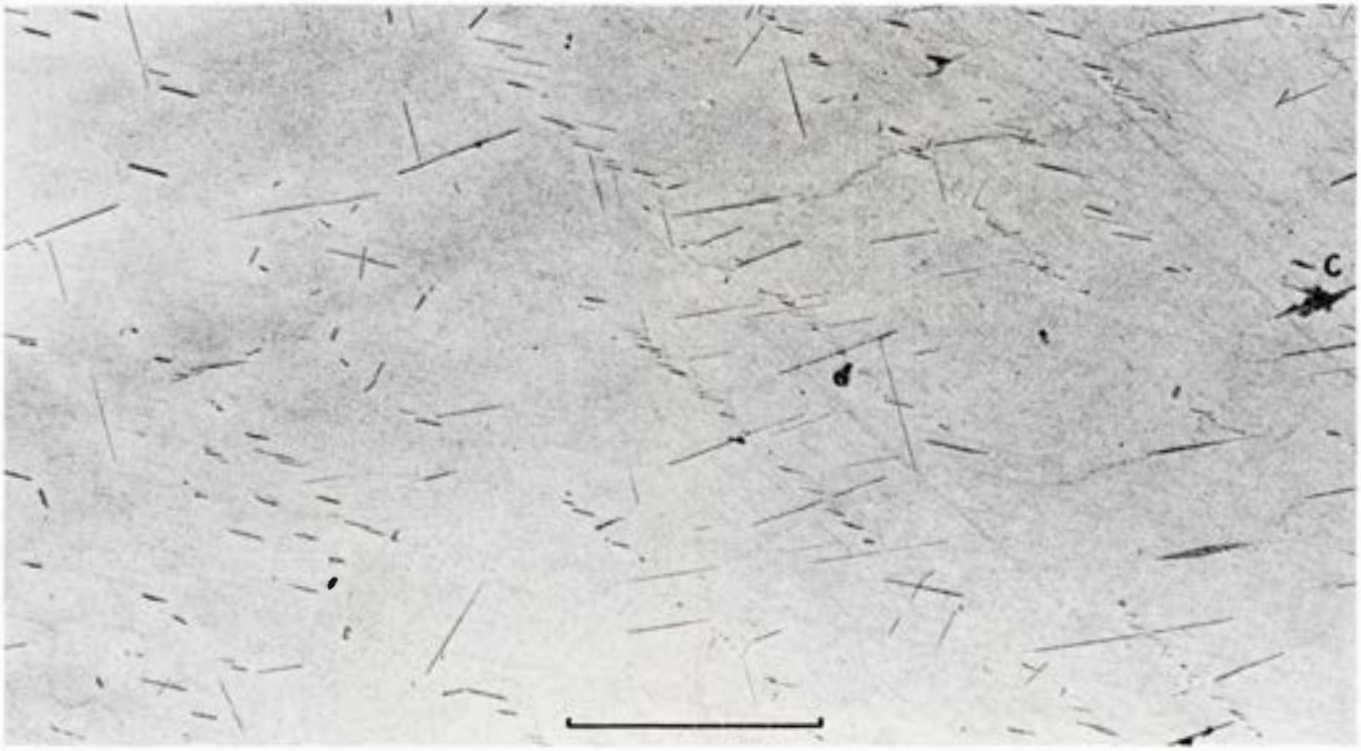

Figure 1447. Richland (U.S.N.M. no. 1735). Hexahedrite with parallel planes of rhabdite platelets. To the extreme right, at C, an original cohenite precipitate around a rhabdite platelet is decomposed to granulated ferrite and lamellar graphite. Deep-etched. Scale bar 10 mm. S.I. neg. 41390B.

RICHLAND – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	**Ni**	**Co**	**P**	**C**	**S**	**Cr**	**Cu**	**Zn**	**Ga**	**Ge**	**Ir**	**Pt**
Henderson & Monnig 1956	5.56	0.84	0.21									
Wasson 1970, pers. comm.	5.40								60.6	180	8.2	

The cobalt determination appears to be 100% too high, (i.e., should be 0.40-0.45%).

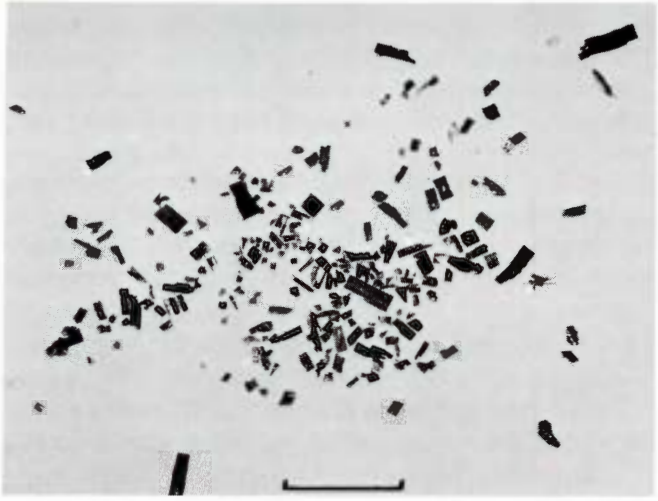

Figure 1448. Richland (U.S.N.M. no. 1735). Plate-shaped rhabdites isolated by dissolution of the metallic matrix in acid. Note the interior cavities in some of them. Scale bar 20 mm. (Henderson & Monnig 1956.) See also Figure 156.

rich planes is 5-10 mm, while the rhabdites themselves are typically 2 x 2 x 0.04 mm in size. Henderson & Monnig (1956) reported them to contain 26% Ni on the average. The larger rhabdite prisms are 5-10 μ across and several hundred microns long; the same authors found 33% Ni in them. The smaller rhabdite prisms are 0.5-2 μ across and were not analyzed. The prisms are located in the matrix between the planes. All the phosphides, but particularly the plate-shaped ones, are visibly shear displaced, frequently along a series of successive steps, each 2-10 μ wide.

Troilite is common as nodules and blebs that range from 20 to 0.5 mm in diameter. All contain 10-20% by area of daubreelite, often as 1 mm thick bars. The troilite is, however, shock-melted, and the daubreelite is brecciated and invaded by 2-20 μ wide veins of melted troilite. The rimming schreibersite is also scattered and invaded by melts. Fragments of both daubreelite and schreibersite are dispersed in the troilite, but the melting must have been of very brief duration since the fragments are not scattered homogeneously but to some extent still delineate the original positions of the minerals. The troilite appears as an aggregate of grains ranging in size from 1 to 100 μ. The smallest grains are found where solution of the surrounding kamacite has created iron-sulfide eutectics. The hardness is 255±10.

Corrosion penetrates locally to a depth of several centimeters, especially converting the nickel-depleted zones around the phosphides to limonite. Some veining of pentlandite is present in the troilite.

Richland is a normal hexahedrite that resembles Braunau, Calico Rock, Hex River, Lombard and Uwet. It differs from Coahuila in various small ways, which together are of significance, such as pronounced rhabdite rows, pronounced Neumann bands and shock-melted troilite. The chemical composition is also slightly different.

Specimens in the U.S. National Museum in Washington:
961 g endpiece (no. 1735, 22 x 7 x 1 cm)
40 g part slice, in plastic (no. 1735, 4 x 2 x 1 cm)

Rifle. See Canyon Diablo (Rifle)

Rio Loa. See North Chile (Rio Loa)

Rodeo, Durango, Mexico

25°20′N, 104°40′W; 1500 m

Medium octahedrite, Om. Bandwidth 0.65±0.10 mm. Artificial α_2 structure. HV 177±10.

Group IID. 10.6% Ni, 0.66% Co, 0.75% P, 83 ppm Ga, 95 ppm Ge, 8 ppm Ir.

The whole mass has been artificially reheated to 800-900° C.

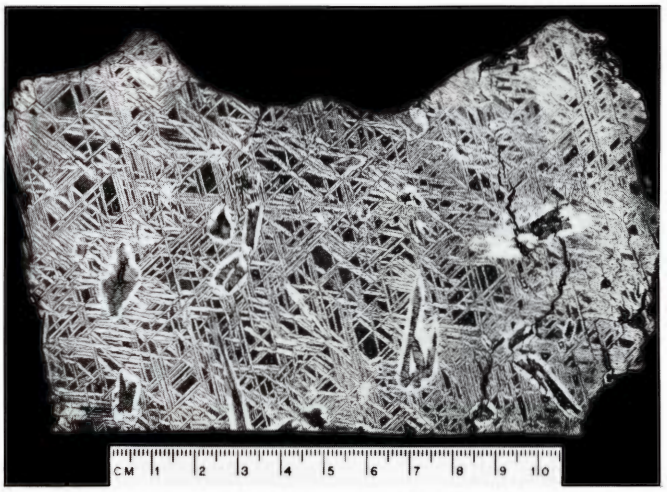

Figure 1449. Rodeo (Tempe no. 101ax). A medium octahedrite of group IID. Large skeleton crystals of schreibersite are enveloped by swathing kamacite. Deep-etched. Scale in centimeters. (Courtesy C.B. Moore.)

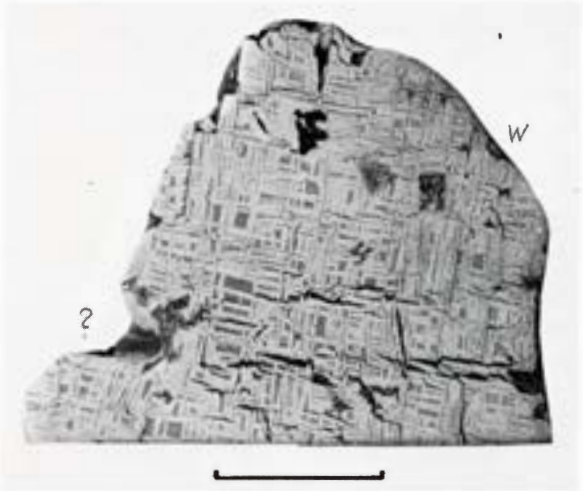

Figure 1450. Rodeo (Vienna no. H2620). Although fusion crust is preserved, e.g., at W, the structure is severely altered by artificial reheating and hammering. The numerous cracks date from this action. To the left, the blunt end of a tool (?) has deformed the Widmanstätten structure. Deep-etched. Scale bar 30 mm.

HISTORY

A mass of 44 kg (97 lbs) was found about 1852 by a goatherd in an arroyo north of the Nazas River, 12 km northwest of the hamlet of Rodeo. The approximate coordinates are given above, while those given in Hey (1966: 409) place the find 130 km too far south. The mass served for many years as an anvil at a forge before it was acquired about 1904 by the Field Museum where it was fully described with photographs of the exterior and of an etched slice by Farrington (1905). Ward (1904a) briefly mentioned the iron as being represented in his collection, and Cohen (1905: 297) examined a slice. Brezina & Cohen (1886-1906: plate 39) gave two photomacrographs and discussed the microstructure, while Berwerth (1914: 1081) attributed the granulated matrix to the artificial reheating while doing duty as an anvil. Schultz & Hintenberger (1967) examined the concentrations of the noble gases; it is interesting to note that the reheating evidently did not influence the absolute or relative amounts of gases present, since they correspond well to values obtained upon other irons, particularly upon the related Carbo, as determined by Hintenberger & Wänke (1964).

COLLECTIONS

Chicago (25.8 kg main mass, and 2.90 kg slices), Washington (2.00 kg), Harvard (1,732 g), London (1,177 g), Tempe (805 g), Budapest (653 g), Vienna (about 400 g), Ottawa (379 g), Prague (319 g), Berlin (287 g), Mexico (176 g), Bonn (125 g), New York (77 g), Strasbourg (64 g), Rome (53 g), Copenhagen (28 g).

DESCRIPTION

According to the photographs reproduced by Farrington (1905) and Haro (1931: plates 16 and 17 and plate 1; plate 1 and 15 have been exchanged in the printer's office), the overall dimensions of the mass were 30 x 20 x 18 cm.

The main mass now in Chicago (No. 590, 25.8 kg) measures 21 x 17 x 17 cm and displays a 21 x 17 cm deep-etched section. Regmaglypts, 2-4 cm across, are common, and slightly weathered fusion crusts are indistinctly visible at the bottom of the regmaglypts. Straight grooves and cylindrical pits from schreibersite lamellae and troilite nodules that were removed by ablational melting in the atmosphere may be distinguished in a few places.

One side, measuring about 22 x 12 cm evidently served as the anvil face; it is smooth and there are several overturned edges and marks of plastic flow from the use of heavy tools. Cut and etched sections through the mass, as, e.g., U.S.N.M. No. 357, Harvard No. 528, and Prague No. 287, clearly show how the working has bent the kamacite lamellae to a depth of 3-5 mm, while the lamellae of the interior are straight. Several specimens, e.g., U.S.N.M. No. 3016, Vienna No. H2620, and Mexico No. 37, show, in addition, partial fissuring along corroded zones of phosphides and Widmanstätten lamellae. The Vienna specimen has a dent, 12 mm deep and 7 mm wide, evidently from a tool which has been forced into the mass and broken. The blunt end of the tool is still embedded in the fissure and the violently deformed octahedral lamellae under the tool's edge are clearly seen on the etched section.

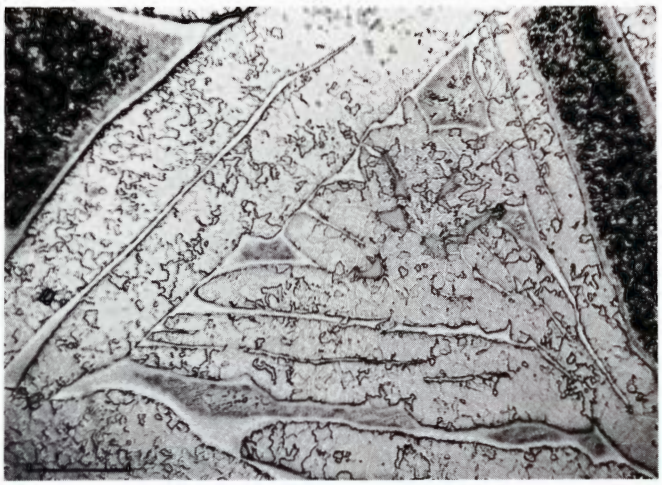

Figure 1451. Rodeo (Tempe no. 101ax). Artificial reheating above 800° C has transformed kamacite to unequilibrated α_2 and started resorption of the taenite-plessite fields. Etched. Scale bar 400 μ.

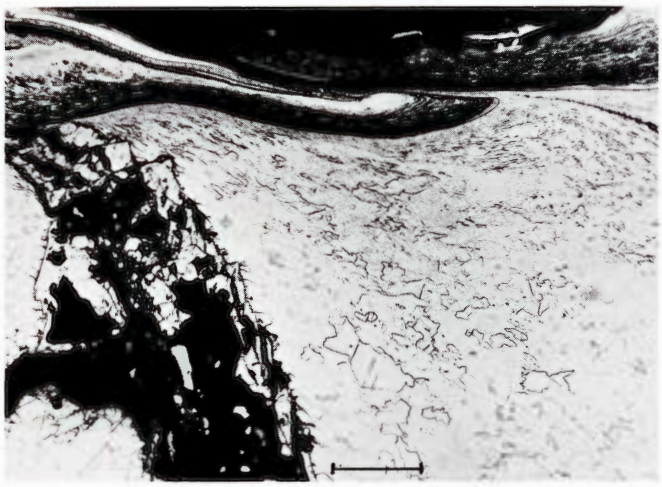

Figure 1452. Rodeo (Tempe no. 101ax). Hammered and overfolded kamacite and taenite. Brecciated schreibersite partially torn out (left). Matrix of unequilibrated α_2. Etched. Scale bar 200 μ. See also Figure 29.

RODEO – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Wasson & Kimberlin 1967									83.6	95.4	8.0	
Moore et al. 1969	10.57	0.66	0.75	460	130		260					

Considering these observations, it can not come as a surprise that the microstructure of the mass indicates that it has been artificially heated to 800-900° C. The kamacite is converted to serrated α_2 units, 25-100 μ in diameter; and the taenite has diffuse borders with thorns protruding into the α_2 matrix. Various types of martensite-bainite are present in the plessite fields, according to the local nickel and carbon concentrations. High temperature reaction zones, typically 2-5 μ wide and creamcolored, separate the schreibersite from the hydrated terrestrial corrosion products, and intergranular oxidation occurs in several places, producing 50 μ wide, lacelike zones around fissures and near the surface. The troilite is recrystallized to angular, 25-100 μ units, the size of which are more or less determined by the previously existing brecciation and corrosion. Even the schreibersite appears to have recrystallized partially. The artificial alterations of the various elements of the structure are of particular interest, because Rodeo provides us with an authentic example of having been preserved in a forge. In many other cases only circumstantial structural evidence indicates when a meteorite was artificially reheated. The microhardness of Rodeo's α_2 phase is 177±10.

Etched sections display a medium Widmanstätten structure of straight kamacite lamellae with a width of 0.65±0.10 mm. The previous subboundaries may be seen as ghost-lines, but otherwise the kamacite is completely transformed to α_2, leaving no trace of the original development. Taenite and plessite cover about 50% by area; both comb plessite and duplex $\alpha + \gamma$ fields were originally present. The martensitic fields were previously monocrystalline and oriented homogeneously according to the orientation of the original austenite single crystal. They are now, however, transformed to polycrystalline aggregates of 50 μ grains in much the same way as martensitic plessite fields located in the natural heat-affected rim zone on other meteorites, as, e.g., Föllinge, are transformed.

Schreibersite is an abundant mineral. It occurs as H-, Y- and L-shaped skeleton crystals that range from 1 mm to 40 x 5 mm in size. Rosettes of schreibersite, developed around a 0.5-1 mm nucleus of troilite, are also common. Zones of swathing kamacite, 1-2 mm wide, envelop the aggregates. Schreibersite further occurs as 50 μ wide grain boundary precipitates and as 5-50 μ inclusions in the comb plessite. Point counting of sections, totaling 600 cm^2, led to an estimate of 0.8% P as a bulk value for the whole meteorite, in good agreement with the value given by Moore & Lewis (1968) and earlier by Nichols (in Farrington

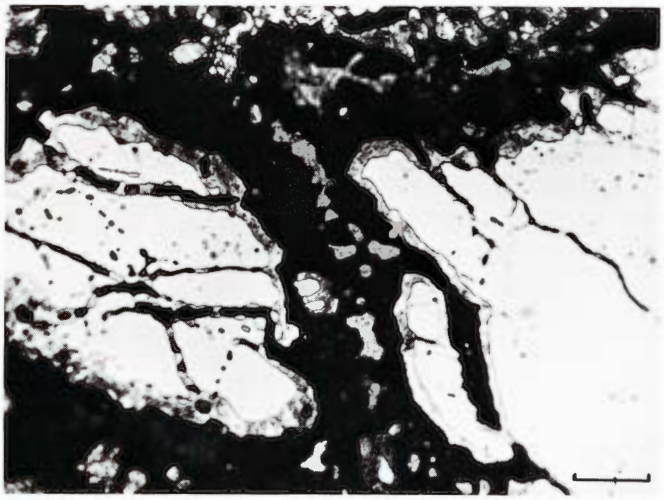

Figure 1454. Rodeo (Tempe no. 101ax). Altered schreibersite in terrestrial corrosion products (black). A reaction zone a few micron wide developed between the schreibersite fragments and the hydrated iron oxides when the meteorite was artificially reheated above 800° C. Etched. Scale bar 20 μ.

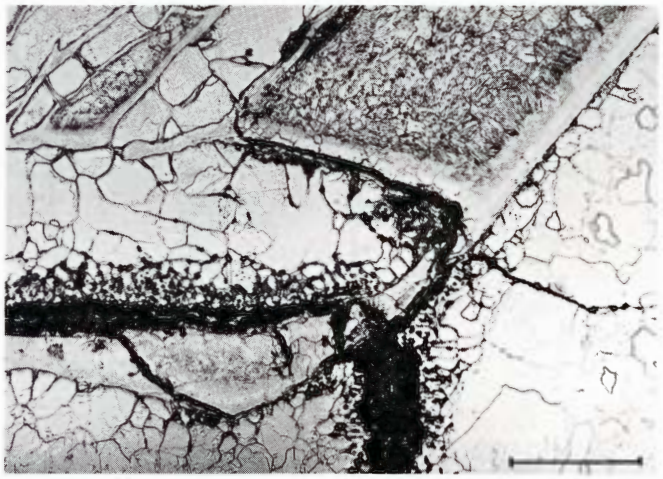

Figure 1453. Rodeo (Tempe no. 101ax). Altered plessite fields. The terrestrial corrosion products, which filled part of the grain boundaries, have upon artificial reheating, reacted and formed lace-like networks of metal and oxides. Etched. Scale bar 100 μ.

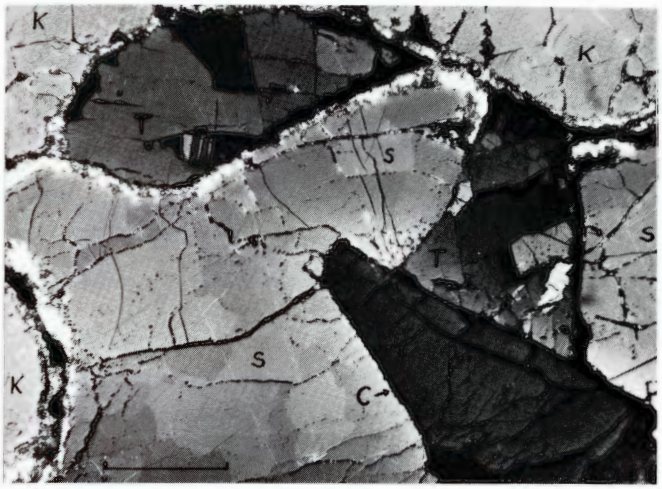

Figure 1455. Rodeo (Tempe no. 101ax). A complex chromite (C), troilite (T), schreibersite (S) aggregate in kamacite (K). Artificial reheating recrystallized troilite, schreibersite and kamacite but did not alter chromite. Etched. Crossed polars. Scale bar 100 μ.

Figure 1456. Rodeo (Tempe no. 101ax). The interior of a nickel-rich (15-20% Ni) plessite field. The plessite is homogenized and decomposed to numerous austenite grains, each 10-50 μ across. Upon cooling, each of these transformed to unequilibrated α_2. Etched. Scale bar 40 μ.

1905). The large schreibersite crystals are apparently oriented as Brezina lamellae, parallel to the dodecahedral planes of the original austenite single crystal; they precipitated from solid solution before the Widmanstätten structure was formed.

Troilite, although reported as lacking by Farrington (1905) who cut and examined eight slices, is present but as smaller units and certainly at a much lower level than in Bella Roca and other group IIIB irons. The troilite is 0.5-2 mm across and frequently completely embedded in schreibersite. It is artificially recrystallized to angular units, 25-100 μ across. A few chromite crystals, 50-200 μ across, are present within the troilite nodules or isolated in the kamacite. Graphite was reported by Farrington, but this observation could not be confirmed.

Rodeo was slightly corroded before it reached the forge. It was covered with 0.1-1 mm thick terrestrial oxides, and 0.5 mm wide veinlets penetrated many centimeters into the mass. It appears, on the other hand, that the exterior was little influenced by the corrosion, having preserved several marked regmaglypts, 2-4 cm in diameter, and a large, hemispherical pit, 10 x 8 cm in aperture and 4 cm deep. At the surface of U.S.N.M. No. 3016 a whirlpool melt from the atmospheric ablation is preserved. A pit, 7 mm in diameter and 4 mm deep, is filled with concentric layers of dendritically solidified metal.

Rodeo is a phosphide-rich, medium octahedrite, which (before reheating) resembled Carbo, Mount Ouray, and Wallapai. Chemically, it is a typical group IID iron, as shown by Wasson (1969).

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

1,768 g slice (no. 357, 21 x 17 x 0.8 cm)
130 g part slice (no. 3016, 7 x 4 x 0.7 cm) (Brezina & Cohen 1886-1906: plate 39, Figures 2 and 3)
100 g part slice (no. 3017, 4 x 3 x 0.8 cm)

Roebourne, Hamersley Range, Western Australia
22°20′S, 118°0′E

Medium octahedrite, Om. Bandwidth 1.10±0.10 mm. Recrystallized. HV 180±12.

Group IIIA. 8.12% Ni, 0.55% Co, 0.17% P, 21 ppm Ga, 42 ppm Ge, 0.65 ppm Ir.

HISTORY

A mass of 86.8 kg (191 1/2 pounds) was found in 1894 by H.R. Hester on an alluvial plain 200 miles southeast of Roebourne (the nearest town) and 20 miles from Hamersley Range in northwest Australia. This information does not exactly pinpoint the locality, but the coordinates given by Ward (1904a: 21) are quoted above. It was deposited in

Figure 1457. Roebourne (Chicago no. 874). The 12 kg endpiece showing some fusion crust. Scale bar 2 cm. S.I. neg. 102.

the Public Museum at Perth from which the whole mass was obtained by Ward in 1896. Several casts had been made already, and Ward now proceeded to cut the mass, as it happened, almost parallel to an octahedral plane. He described it (1898) and gave a cut of the exterior shape. Another view of the exterior was given by Hodge-Smith (1939: plate 6). Photomacrographs of etched sections were presented by Ward (1904a: plate 3) and Mauroy (1913: plate 2). Perry (1944: plate 40) and Buchwald (1966: figure 30) gave photomicrographs of the recrystallized structure. Schultz (1967) discussed the $^3He/^4He$ ratios of Roebourne and Ruff's Mountain; he concluded that the deficiency in ^3He could be explained by assuming that its parent nuclide, tritium ^3H, was partially lost in space when the meteorite recrystallized.

COLLECTIONS

Chicago (12.11 kg endpiece, 19.33 kg section, 2.40 kg slice), Washington (4,018 g), Paris (3,274 g), Bonn (2,502 g), Denver (about 2.5 kg), New York (2,371 g), Vienna (1,779 g), Amherst (1,617 g), Tempe (1,460 g), London (1,183 g), Sydney (1,140 g), Leningrad (619 g), Oslo (611 g), Calcutta (587 g), Harvard (559 g), Tübingen (445 g), Budapest (338 g), Prague (296 g), Berlin (265 g), Uppsala (263 g), Copenhagen (225 g), Perth (184 g), Dresden (173 g), Ann Arbor (145 g), Bally (143 g), Stockholm (108 g), Sarajevo (66 g), Ottawa (34 g), Yale (33 g). Roebourne is among the best distributed iron meteorites.

DISCRIPTION

The shape of the mass may be compared to a turtle, except that heavy ablation has carved reentrant portions at opposite sides of the edge. The maximum dimensions are 57 x 34 x 7 cm, according to Ward (1898). The surface is rather smoothly rounded, except at the reentrant portions where normal regmaglypts, 2.5-4 cm in diameter are common. The exterior shape suggests that the meteorite was

Figure 1458. Roebourne (Tempe no. 353.1). A full slice of 1,466 g showing the anomalously wide heat-affected α_2 zone. It is superimposed upon a cosmically recrystallized structure. Along the lower side there are several intrusive whirlpool melts from the atmospheric flight (W). Deep-etched. Scale bar 20 mm. S.I. neg. 103.

ROEBOURNE – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Mariner & Hoskins in Ward 1898	8.33	0.59	0.16	+	+							
Lovering et al. 1957	8.04	0.56				44	190		15	49		
Buchwald 1966, unpubl.	8.11	0.51	0.18		40		220			41		
Scott et al. 1973	8.01								21.2	42.4	0.65	

Figure 1459. Roebourne (Copenhagen no. 1905, 1740). To the right, the heat-affected α_2 zone; to the left, the unaffected recrystallized interior with annealed plessite fields. Etched. Scale bar 4 mm.

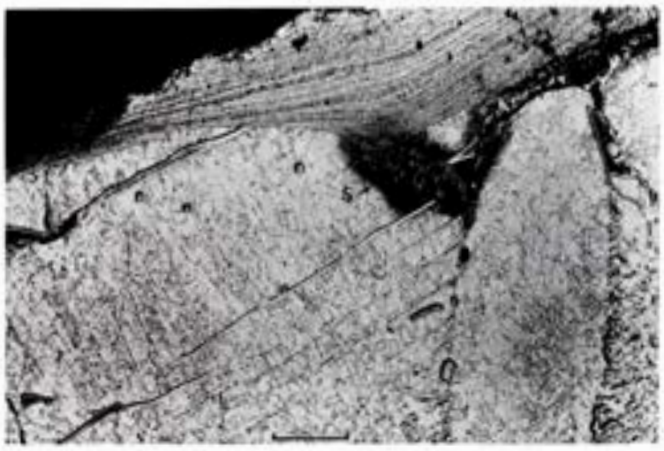

Figure 1460. Roebourne (Copenhagen no. 1905, 1740). Multilayered dendritic fusion crust of metal with a few intercalated oxidic lamina and globules and with spherical gasholes. Terrestrial corrosion, particularly of the fused schreibersite at S. All kamacite is now α_2. Etched. Scale bar 500 μ.

oriented during its flight, and this impression is confirmed by examination of the etched sections. The heat-affected α_2 rim zone is 3-6 mm thick under the slightly convex leading edge but increases to 6-12 mm under the protected, rather flat rear side. Numerous whirlpools of fused metal are found only on this rear side. The whirlpools are typically 2-5 mm in diameter and penetrate irregularly 2-5 mm under the otherwise evenly ablated surface. Locally, near the middle (?) of the rear side they increase to 15 mm in diameter and penetrate at least 10 mm under the surface. The pools apparently represent fused metal from

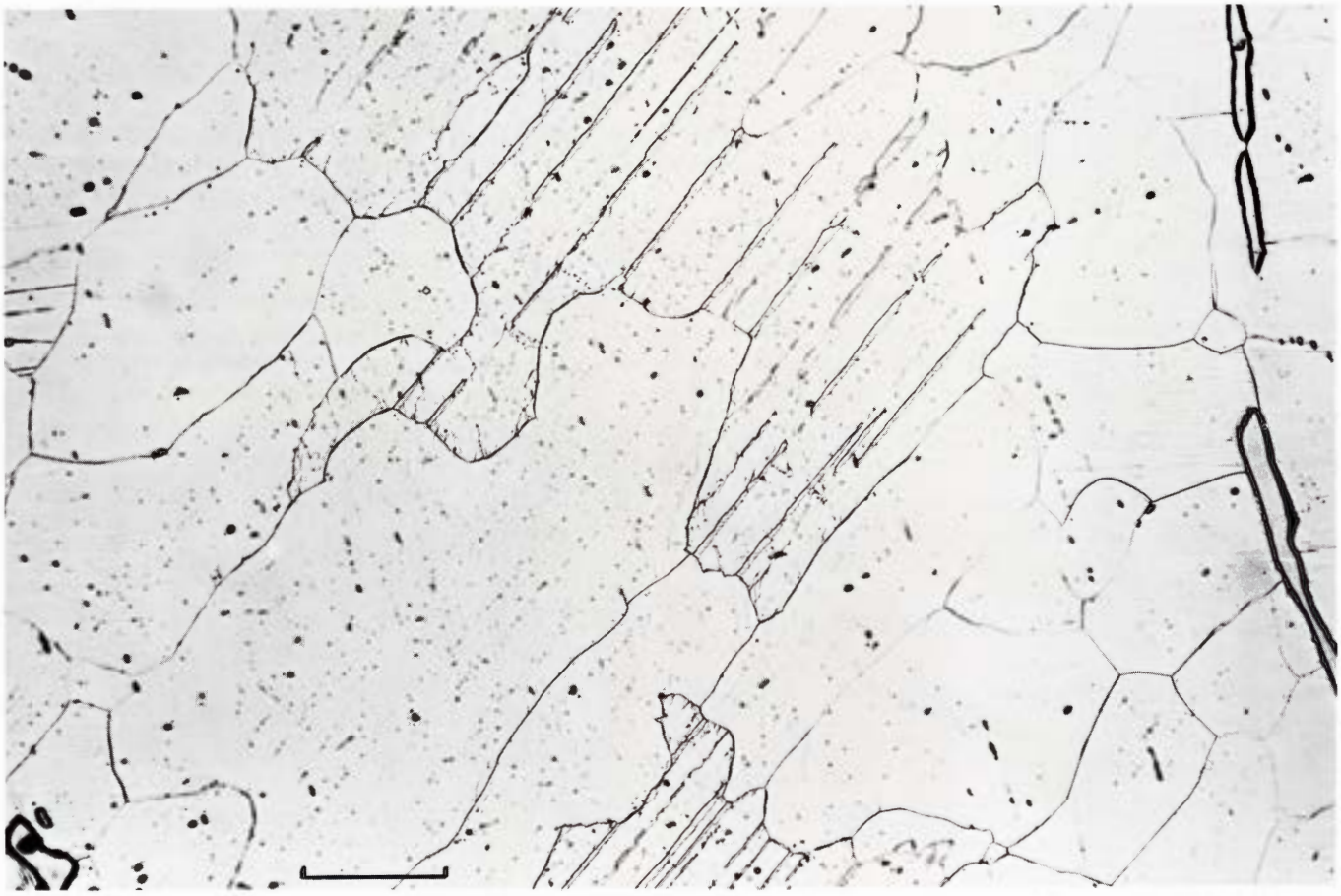

Figure 1461. Roebourne (Copenhagen no. 1905, 1740). The interior is a mixture of equiaxial recrystallized kamacite grains and areas which have resisted recrystallization and still show Neumann bands. Etched. Scale bar 200 μ.

the ablating front side that were redeposited on the rear during a complex play of air vortices. The solidification pattern shows intricate, concentric textures with dendritic-columnar growth of the metal. The armspacing of the dendrites is 3-10 μ, and the cell size is anywhere from 10-200 μ. Within each cell the metal is transformed to uniformly oriented α_2, the microhardness of which is 265±20. Since the heat-affected α_2 zones are unusually wide, it was checked whether some artificial reheating had taken place. This appears not to be the case, so Roebourne must have had an exceptionally long, coasting flight through the atmosphere with a rather low ablation rate. The α_2 phase has a hardness of 190±10; the location of the original Neumann bands may still be seen because the bands were decorated by double rows of small phosphides, and these were not obliterated – neither during recrystallization nor during the $\gamma \rightarrow \alpha_2$ transformation.

Etched sections display a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 25$) kamacite lamellae with a width of 1.10±0.10 mm. Taenite and plessite constitute about 35% by volume. The primary structure from continuous cooling is identical to that of, e.g., Thule, Cape York, Norfork and Casas Grandes. Neumann bands were originally present in Roebourne, as may be inferred both from the presence of minute phosphide beads, 0.5-1 μ in diameter, precipitated along both sides of the bands, and from the scattered patches of unrecrystallized material that still display the original Neumann bands; see Figure 30 in Buchwald (1966).

What immediately catches the eye is the shimmery appearance of the etched surface. This is due to recrystallization of the kamacite phase leading to a multitude of almost randomly oriented ferrite grains. The grains are equiaxed or slightly elongated after the old Neumann band directions, and they are in a reasonably good state of equilibrium as witnessed by the frequent occurrence of 110-120° grain boundary angles in contrast to the serrated α_2 grains of the heat-affected rim zone. The recrystallized grains of the kamacite lamellae are typically 0.5 mm in diameter, while those inside the plessite fields range from 25-150 μ in diameter. The hardness is 180±12.

The prolonged annealing that resulted in recrystallization of the kamacite partly spheroidized the taenite and decomposed the duplex plessite fields to easily resolvable $\alpha + \gamma$ mixtures. The normal transitional structures of martensite between taenite rims and plessitic interiors are almost absent, the taenite being remarkably homogeneous in its nickel composition. The taenite is soft, 185±15, also very anomalous and a result of annealing.

Schreibersite is not present as large crystals but is common as 20-80 μ grain boundary precipitates and as 2-30 μ blebs inside the plessite fields. The schreibersite is monocrystalline. It is surrounded by minor amounts of 1-2 μ blebs of taenite, forming islands or discontinuous rims which are evidently a result of the cosmic annealing. Rhabdites were not observed, but fine spheroidized phosphides, 1-3 μ across, are common in the recrystallized grain boundaries; and still smaller phosphides originally decorated the Neumann bands before they were eliminated by recrystallization. Many phosphides display internal fissures that have been healed by comprehensive diffusion processes.

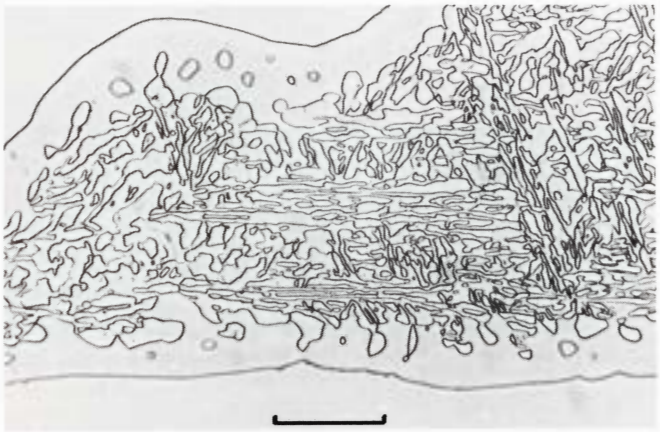

Figure 1463. Roebourne (Copenhagen no. 1905, 1740). Annealed and partly spheroidized plessite field. Etched. Scale bar 20 μ.

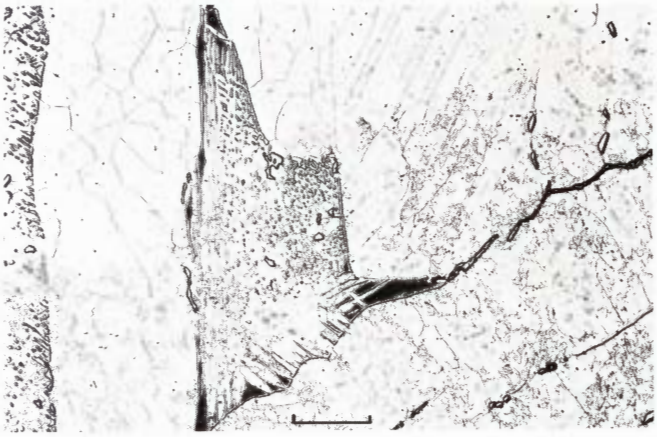

Figure 1462. Roebourne. Detail of Figure 1459. Recrystallized kamacite (left) and annealed plessite with phosphide particles (in relief). Heat-affected α_2 zone to the right. Etched. Scale bar 500 μ.

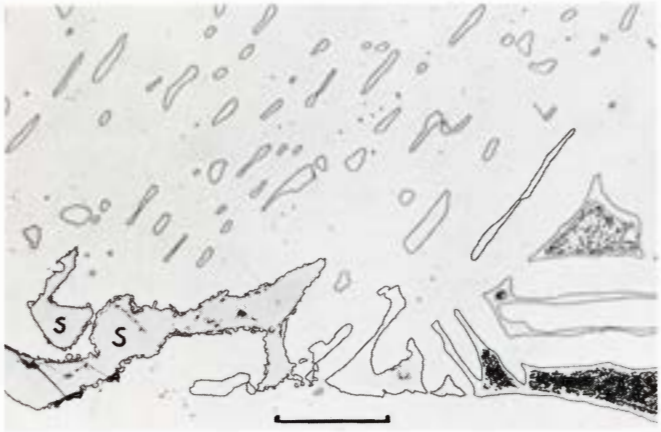

Figure 1464. Roebourne (U.S.N.M. no. 459A). Spheroidized plessite field. The schreibersite crystals (S) have adjusted their composition by the segregation of fine γ-particles. Etched. Scale bar 100 μ.

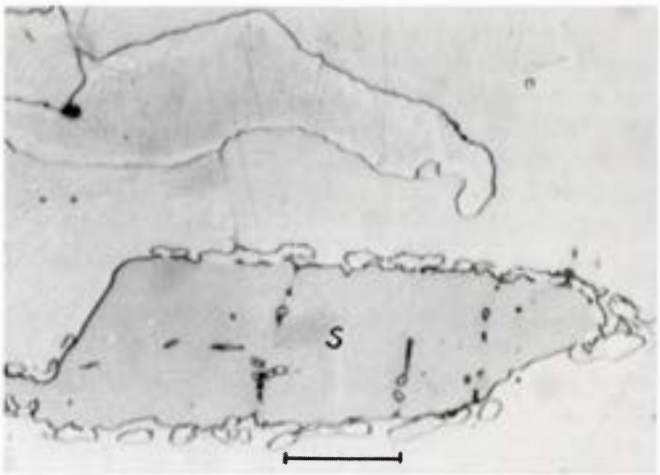

Figure 1465. Roebourne (Copenhagen no. 1905, 1740). Taenite (above) and schreibersite (S) that upon cosmic annealing has segregated numerous taenite particles. Etched. Scale bar 20 μ.

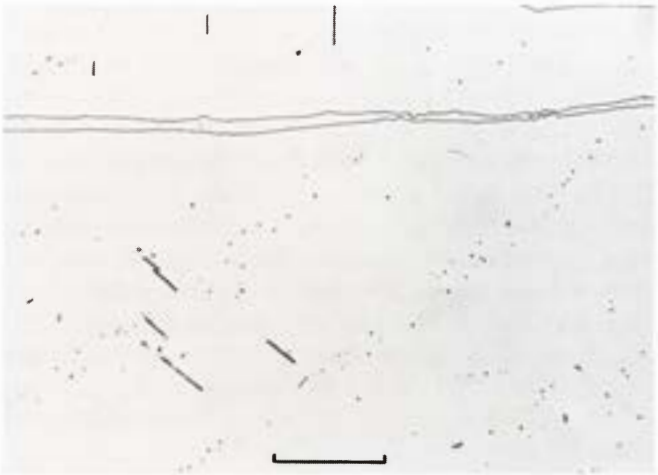

Figure 1466. Roebourne (Copenhagen no. 1905, 1740). Two kamacite lamellae separated by a taenite lamella. The match-like carlsbergite platelets are differently oriented in the two kamacite lamellae. Lightly etched. Scale bar 100 μ.

Troilite occurs as scattered, irregular nodules, ranging from 50 μ to at least 12 mm in diameter. They are all shock-melted and display frayed edges against the surrounding metal. The nodules are microcrystalline eutectics of 1-2 μ troilite and metal, and daubreelite and schreibersite are dispersed through the eutectics as 1-3 μ subangular grains. The microhardness is 290±30. Daubreelite appears to constitute 10-20% of the nodules, while schreibersite is an accessory mineral, probably coming from shattered schreibersite rims originally located around the nodules in minor amounts. Some fine cracks radiating out from the troilite into the metal are filled with injected sulfide melts.

In the kamacite matrix there are numerous, oriented, hard platelets of the same chromium nitride, carlsbergite, described under Schwetz, Cape York and other irons. The nitride is spheroidized to a large extent.

Terrestrial weathering has formed limonitic crusts, 0.1-1 mm thick, but the general state of preservation is good. The whirlpool melts, the microcracks that follow many of the phosphides, and the recrystallized grain boundaries are particularly sensitive to corrosion.

Roebourne is an interesting example of a medium octahedrite of group IIIA that cooled and formed a primary structure similar to, e.g., Norfolk and Casas Grandes. It was later shocked and – possibly as a result of the relaxation heat following the shock – the kamacite recrystallized, while taenite and plessite spheroidized and segregated to clear, duplex structures. The phosphides regulated their nickel content downwards by the precipitation of taenite beads, and the nitride spheroidized. Lastly, a tertiary structure consisting of the α_2 transformation product, was superimposed on the former structures along the rim when the meteorite penetrated the atmosphere. The structural evolution of the octahedrite Roebourne appears to correspond wholly to that of the hexahedrite Bingera and of the fine octahedrite Social Circle. Chemically, it is closely related to Casimiro de Abreu and Durango, and it has extensive similarities to Durango in structural aspects too.

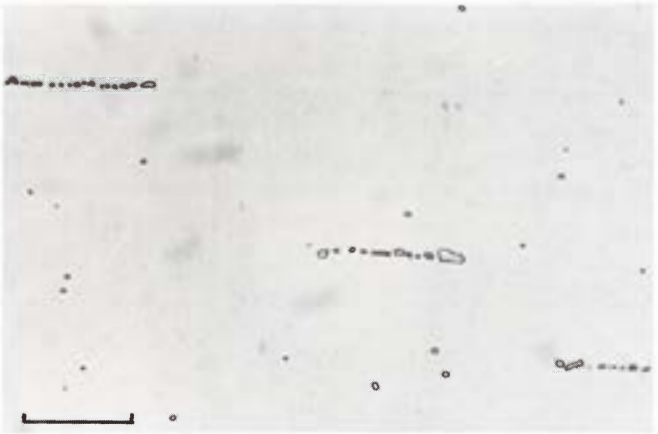

Figure 1467. Roebourne (Copenhagen no. 1905, 1740). Three carlsbergite platelets which spheroidized during cosmic annealing. Lightly etched. Scale bar 20 μ. See also Figure 149A.

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

234 g part slice (no. 453 5 x 5 x 1.1 cm)
1,190 g part slice (no. 459A, 16 x 12 x 1 cm)
157 g part slice (no. 1126, 6 x 4 x 1 cm)
282 g part slice (no. 1933, 7 x 5.5 x 1 cm)
315 g part slice (no. 3018, 7 x 6 x 1 cm)
266 g part slice (no. 3019, 7 x 5 x 1.1 cm)
220 g part slice (no. 3364, 7.5 x 6 x 0.7 cm)
1,354 g endpiece (no. 3429, 16 x 9 x 3.5 cm)

Roper River, Northern Territory, Australia

About 15°S, 135°E

Medium octahedrite, Om. Bandwidth 0.65±0.10 mm.

Group IIIB. 9.86% Ni, about 0.6% P, 18 ppm Ga, 34 ppm Ge, 0.04 ppm Ir.

HISTORY

A mass of 6.4 kg was found before 1953 near Roper River (Prior 1953: 318). It is undescribed.

COLLECTIONS

Melbourne, National Museum (main mass), Canberra (175 g).

DESCRIPTION

A brief examination of a small deep-etched section showed that Roper River is a medium octahedrite with straight, long ($\frac{L}{W} \sim 20$) kamacite lamellae displaying a width of 0.65±0.10 mm. The Widmanstätten structure appears messy due to the numerous Brezina lamellae that have developed 0.5-1.0 mm wide rims of swathing kamacite. The Brezina lamellae consist of schreibersite and are typically 10 x 1.5 and 4 x 2 mm in size. The bulk phosphorus content is estimated to be 0.6±0.2%. No troilite or other meteoritic minerals occur in the section.

The meteorite is well-preserved, apparently showing a heat-affected α_2 zone and indistinct remnants of fusion crust. It is different from the other iron meteorites of Australia's Northern Territory. Structurally, it is closely related to Chupaderos, Sam's Valley and Mount Edith, and, chemically, it is a typical member of group IIIB.

Rosario, Honduras

14°36′N, 88°41′W

Coarse octahedrite, Og. Bandwidth 1.70±0.30 mm. Neumann bands. HV 200±15.

Group I judging from the structure. Approximately 7.1% Ni and 0.25% P.

HISTORY

Rosario was a small iron of about 2.7 kg (see below) which was acquired by Ward about 1897 and put in circulation the following year. No description was published, but brief notes occurred in the catalogs of Ward in 1900, 1901a and 1904a. According to information from Mr. E. Schernikov in 1922 (Hey 1966: 412), the mass was found in 1896 by a native on a ranch called Rosario about 50 miles from the Rosario mine. The coordinates above are taken from Hey (1966); they differ only slightly from Ward's (1904a: 21).

COLLECTIONS

New York (1,540 g half mass), Chicago (450 g full slice), Washington (190 g), London (118 g), Stockholm (61 g), Berlin (40 g), Vatican (30 g), Vienna (24 g), Bonn (18 g), Yale (8 g). These specimens add up to 2.5 kg; if we allow for loss in cutting and for specimens not in public collections, it is safe to assume that the original weight must have been about 2.7 kg (6 pounds), and not four pounds as suggested by Hey (1966).

ANALYSIS

No analysis is available, but estimating from the structure, I would expect 6.9-7.3% Ni and 0.20-0.30% P with significant amounts of carbon (~ 0.3%).

DESCRIPTION

The half-mass in New York measures 11 x 8 x 4.5 cm and weighs 1,540 g. It is irregularly rounded and covered with a crust of terrestrial oxides, 0.5-2 mm thick. No fusion crust and no heat-affected α_2 zone are preserved. Corrosion penetrates deep into the interior and forms 0.1-0.4 mm wide, limonitic grain boundary veins. Schreibersite and cohenite are brecciated and cemented together by terrestrial corrosion products. Selective oxidation has converted the α-phase of the plessite to limonite, giving rise to complex duplex structures. The deeper interior is well-preserved.

The slice in Washington shows Rosario to be a coarse octahedrite with irregular, short ($\frac{L}{W} \sim 10$) kamacite lamellae with a width of 1.70±0.30 mm. The kamacite has Neumann bands and numerous subboundaries decorated with 1-2 μ phosphides. Locally, some equiaxial kamacite grains 5-10 mm in diameter occur. The microhardness is 200±15, with a tendency towards lower values close to the present surface; this is perhaps an annealing effect from the atmospheric heating, indicating that only 2-5 mm of the meteorite has weathered away (hardness curve type I, where the left leg has disappeared).

Taenite and plessite cover about 5% by area. Comb plessite is present, but taenite ribbons and wedges, the interior of which is decomposed to martensitic or pearlitic structures, are more common. The martensite is either of the low-nickel low-carbon variety, or of the high-nickel high-carbon, acicular variety. The taenite is blotched by irregular, brownish to blackish stains and displays various transition textures to the martensitic parts. The microhardness ranges from 330 to 400 in the various parts. The pearlitic plessite has 0.5-1 μ wide taenite lamellae where it is best developed; its hardness is 275±25.

Schreibersite occurs as 10 x 1.5 mm skeleton crystals enveloped in 3-5 mm swathing kamacite. Its hardness is 875±25. It further occurs as 50-150 μ thick grain boundary precipitates and as similar blebs overgrown by cohenite, or forming a discontinuous rim around cohenite. Rhabdites are not common, but a profusion of submicroscopic

ROPER RIVER – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Lovering et al. 1957	9.91	0.58				4.9	168		15	32		
Wasson & Kimberlin 1967	9.81								18.1	33.9	0.04	

particles in the matrix may be phosphides. They are apparently mostly situated upon slip lines and upon short dislocation lines.

Cohenite is conspicuous as oriented, elongated crystals, precipitated centrally in the kamacite lamellae. Their dimensions are typically 5 x 3 x 0.8 mm, and they are abundant on the sections to be found in New York and Washington, covering about 5% by area. The individual crystals are closely associated with carbon-saturated taenite and plessite. They possess the normal 50-100 μ wide windows of kamacite, taenite and schreibersite, and exhibit a hardness of 1090±25.

Troilite, graphite and silicates were not present in the sections studied but may be present in other sections.

Rosario is a coarse octahedrite which, structurally, closely resembles Bahjoi, Bohumilitz, and Odessa. Chemically, it is, no doubt, a typical group I.

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

134 g part slice (no. 626, 8 x 5 x 0.6 cm)
56 g polished sections (no. 626)

Roswell, Chaves County, New Mexico

The 30 g slice in Tempe is apparently a normal Canyon Diablo fragment. The size of the original mass is unknown but possibly several kilograms. There is little doubt that it is a transported Canyon Diablo mass.

Rousoumouski. See Agricultural College

Rowton, Shropshire, England

52°46′N, 2°34′W; 60 m

Medium octahedrite, Om. Bandwidth 1.15±0.15 mm. Recovered ϵ-structure. HV 215±10.

Group IIIA. 7.79% Ni, about 0.15% P, 20.5 ppm Ga, 38.1 ppm Ge, 2.8 ppm Ir.

HISTORY

This is the only iron meteorite observed to fall in England and one of the very few iron meteorite falls of Europe. According to Flight (1882), the mass fell on April 20th, 1876, at 3:40 p.m. at Rowton near Wellington. A strange rumbling noise was heard in the air, followed almost instantaneously by a startling explosion resembling a discharge of heavy artillery. About one hour later the mass was discovered by George Brooks in a field belonging to the Duke of Cleveland. The 3.5 kg meteorite had evidently fallen vertically in the last part of its flight, since it had formed a vertical hole penetrating 10 cm of soil and 35 cm of clay. The mass was donated to the British Museum, where it was described by Flight (ibid.) who also presented two lithographs of the exterior and of an etched slice. Brezina (1885: 203 and plate 2) discussed the heat-affected rim zone and gave a photomacrograph, and Flight (1887) reproduced a new photograph of the exterior. Marvin (1963) identified magnetite and wüstite in the fusion crust; the latter gave only diffuse lines by X-ray diffraction.

COLLECTIONS

London (3,109 g main mass and 45 g slices), Vienna (39 g), Washington (32 g), Copenhagen (29 g), Harvard (17 g), Chicago (13 g), Stockholm (10 g), Berlin (2.5 g), Paris (2 g).

DESCRIPTION

The mass is an irregular low pyramid with the average dimensions of 13 x 11 x 7 cm. There is a 7 x 7 cm cut section at one end. The regmaglypts are soft flutings except in a few places where sharp pits indicate how troilite burned out in the atmosphere. A black magnetite-wüstite crust covers the mass, but it is often very thin, 10-50 μ. In

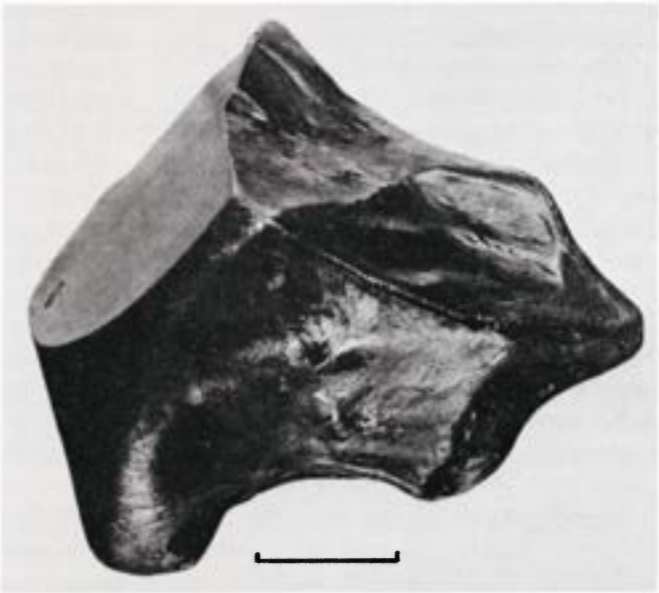

Figure 1468. Rowton (Brit. Mus. no. 50062). The meteorite is an irregular low pyramid covered with oxidic and metallic fusion crusts. To the left, a polished section with a troilite nodule. Scale approximately 3 cm.

ROWTON – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Cobb 1967		0.48					174		23		3.9	
Scott et al. 1973	7.79								20.5	38.1	2.81	

Reed (1969) found the kamacite to have 7.0% Ni and 0.083% P in solid solution.

numerous places it is completely worn off, probably due to human handling. A little metallic fusion crust is seen here and there, up to 300 μ thick and layered. The metal is solidified to dendritic aggregates with an armspacing of 6-10 μ; the hardness is 290±20.

Under the fusion crusts is a heat-affected α_2 zone ranging from 1.5 to 5 mm in thickness. The α_2 is composed of fine-grained, frayed units, 5-25 μ in size – fine-grained as is usually the case when the α_2 forms from shock-hardened ϵ-structures. The α_2 has a hardness of 180±10, except immediately under the fusion crust where it increases to 335±25. This is partly due to the almost complete solution of phosphides in the outer region and partly due to carburization from the melt; the zone extends 10-50 μ inwards. Hard zones (HV 275±25) are also found as 20-50 μ wide borders around taenite and plessite, where the structure is visibly altered to bainitic-martensitic structures. This must be due to carbon enrichment, the carbon having diffused away from the adjacent taenite in the very brief time available.

The schreibersite crystals and the rhabdites are micromelted in the exterior 50% of the heat-affected α_2 zone. It is common to see intercrystalline, zigzagging veinlets of melted phosphides in this zone. They are 1-2 μ wide and mark the grain boundaries of the short-lived austenite, formed by the atmospheric reheating. The austenite grains may thus be estimated to have been 15-25 μ in diameter. The phenomenon is perfectly common in the iron meteorites but often obscured by terrestrial corrosion.

Etched sections reveal a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 25$) kamacite lamellae with a width of 1.15±0.15 mm. The kamacite has subboundaries decorated with 0.5-2 μ phosphides, but this structure is superimposed by a hatched shock-hardened ϵ-structure. The hardness increases from a minimum of 175 at the inner α_2 boundary to 215±10 10 mm below the surface. This is low for a hatched structure and suggests that some cosmic annealing (300-400° C) has occurred.

Taenite and plessite cover about 40% by area. Comb and net plessite fields are common, and the wider taenite wedges (HV 270±15) have acicular kamacite needles only 1-5 μ thick. Numerous fields have marked martensite, developed parallel to the bulk Widmanstätten structure (HV 290±20). The yellowish taenite rims and ribbons have hardnesses of 235±20. All hardness values are low – probably due to some cosmic annealing.

Schreibersite occurs as 20-80 μ wide grain boundary veinlets and as 2-50 μ wide blebs in the plessite. Rhabdites are common but mostly as small, 1-3 μ thick prisms. They occasionally reach a size of 10 μ in cross sections. The bulk phosphorus content is estimated to be 0.15±0.02%.

Troilite occurs as scattered nodules, 0.5-8 mm across, but was not present in any of the microsections prepared. The troilite nodules will probably turn out to be polycrystalline, shock-melted aggregates like those present in, e.g., Uwet. Daubreelite is disseminated as bluish blebs in the kamacite, generally 10-50 μ in diameter. Schreibersite sometimes has nucleated and grown upon them.

Rowton is a medium octahedrite which is related to Kayakent, Puente del Zacate, Kyancutta, Bagdad and Merceditas. Chemically, it is a normal group IIIA.

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

19 g part slice (no. 86, 4 x 2 x 0.5 cm)
13 g part slice (no. 2395, 2 x 1.5 x 0.9 cm)

Ruff's Mountain, South Carolina, U.S.A.

34°10′N, 81°21′W; 125 m

Medium octahedrite, Om. Bandwidth 1.25±0.15 mm. Recrystallized. HV 150-225.

Group IIIA. 8.59% Ni, 0.53% Co, 0.26% P, 21.5 ppm Ga, 46.5 ppm Ge, 0.47 ppm Ir.

The meteorite appears to have been reheated twice, both preterrestrially and artificially.

HISTORY

A mass of 53.1 kg (117 pounds) was found in 1844 on the surface of Ruff's Mountain, Lexington County. It went through several hands and was forgotten for a while until it was acquired by Shepard who published several brief accounts of it, with sketches of the exterior appearance (1850; 1851; 1853). He believed it to be a recent fall and presented an alleged eyewitness report; all later investigators agree, however, that it is a weathered find. Brezina (1880b) gave two prints of etched sections showing poorly developed Reichenbach lamellae, and he later (1885: 213; 1896: 277) briefly discussed the metallic matrix and gave a photomacrograph. References to numerous other, older papers and comments will be found in Wülfing (1897: 298) and Farrington (1915: 387). Wherry (1917) determined the angles of the schreibersite inclusions with a two-circle goniometer and found the phosphide to be tetragonal.

Figure 1469. Ruff's Mountain (Tempe no. 99b). A recrystallized medium octahedrite transitional between group IIIA and IIIB. Deep-etched. Scale in centimeters. (Courtesy C.B. Moore.)