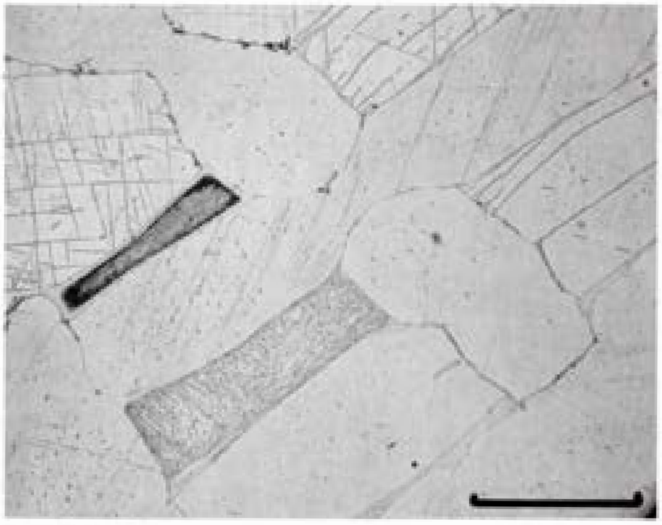

Figure 1199. Murfreesboro (Harvard no. 176F). Medium octahedrite of group IIIA. Kamacite with Neumann bands and normal variety in plessite types. Etched. Scale bar 1 mm.

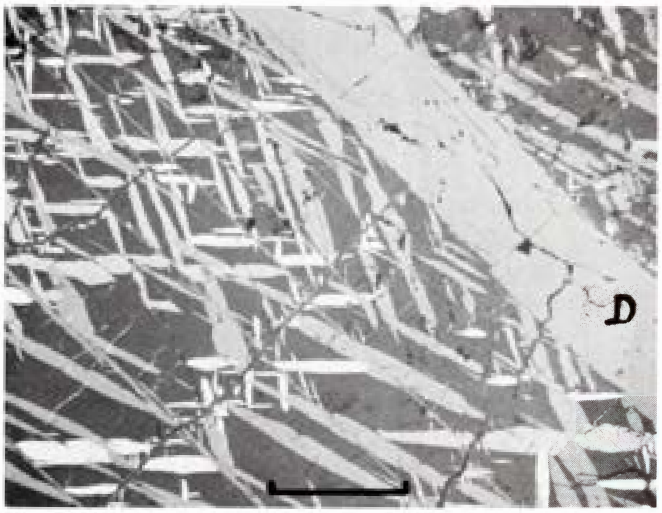

Figure 1200. Murfreesboro (Harvard no. 176F). Troilite with a wide daubreelite lamella (D) and several very narrow daubreelite lamellae parallel to the large one. The troilite shows multiple twinning. Polished. Crossed polars. Scale bar 200 μ.

transition to the heat-affected zone, then increases again to 220±20 in the α_2 zone (hardness curve type I).

Taenite and plessite cover about 40% by area, mostly as open-meshed, comb and net plessite with discontinuous taenite frames. Duplex $\alpha + \gamma$ interiors and martensitic transition zones occur also.

Schreibersite is present as 10-40 μ wide grain boundary precipitates and as 5-50 μ irregular blebs inside the plessite fields. Rhabdites, which range from 1-10 μ in cross section, are common. The bulk phosphorus content lies probably about 0.15%.

Troilite is present as scattered 1-10 mm nodules and lenticular bodies. Daubreelite constitutes 10-20% by area of the troilite bodies, mostly as 5-500 μ wide, parallel bars, which frequently protrude 5-10 μ outside the general outline of the nodules. The troilite is monocrystalline but contains numerous lenticular twins from plastic deformation. Local zones of crushing and brecciation are also present. Daubreelite is further present in the kamacitic matrix as 10-50 μ blebs.

In the kamacite are several oriented, hard platelets, about 20 x 1 μ in size, probably the same chromium nitride, carlsbergite, as observed in Costilla Peak and other irons.

Murfreesboro is a medium octahedrite closely related to, e.g., Cachiyual and Casas Grandes. It somewhat resembles Harriman which was also found in Tennessee, about 170 km farther east, but the two irons are sufficiently different in structural details and in hardness to warrant their listing as two separate falls.

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

57 g part slice (no. 99, 2.5 x 2.5 x 0.7 cm, from J.L. Smith)
6 g part slice (no. 1091, 2.5 x 0.7 x 0.3 cm)
61 g part slice (no. 3344, 4 x 2.5 x 0.8 cm)

Murnpeowie, South Australia

Approximately 29°35′S, 139°54′E; less than 100 m

Anomalous. Recrystallized to 0.1-3 mm kamacite grains. Neumann bands. HV 185±9.

Anomalous. 6.37% Ni, 0.40% Co, 0.2% P, 40 ppm Ga, 85 ppm Ge, 1.8 ppm Ir.

HISTORY

A fine, well-preserved mass of 1,140 kg (2,520 pounds) was found in 1909 by A. Hamblin and others who were repairing some boundary fences on the Murnpeowie Sheep Run of the Beltana Pastoral Company. The locality is 16 miles northeast by east of Mount Hopeless and about five miles west of Lake Callabonna, corresponding to the coordinates given above. The mass was protruding significantly above the sandy plain which otherwise was devoid of stones. It took two men, with a wagon drawn by

MURNPEOWIE – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Hey in Spencer 1935	6.32	0.32			60		20			>70		700
Lovering et al. 1957	6.47	0.47				187	157		42	76		
Smales et al. 1967						198	160	<1	35	93		
Wasson 1969, pers. comm.	6.31								41.8	85.4	1.8	

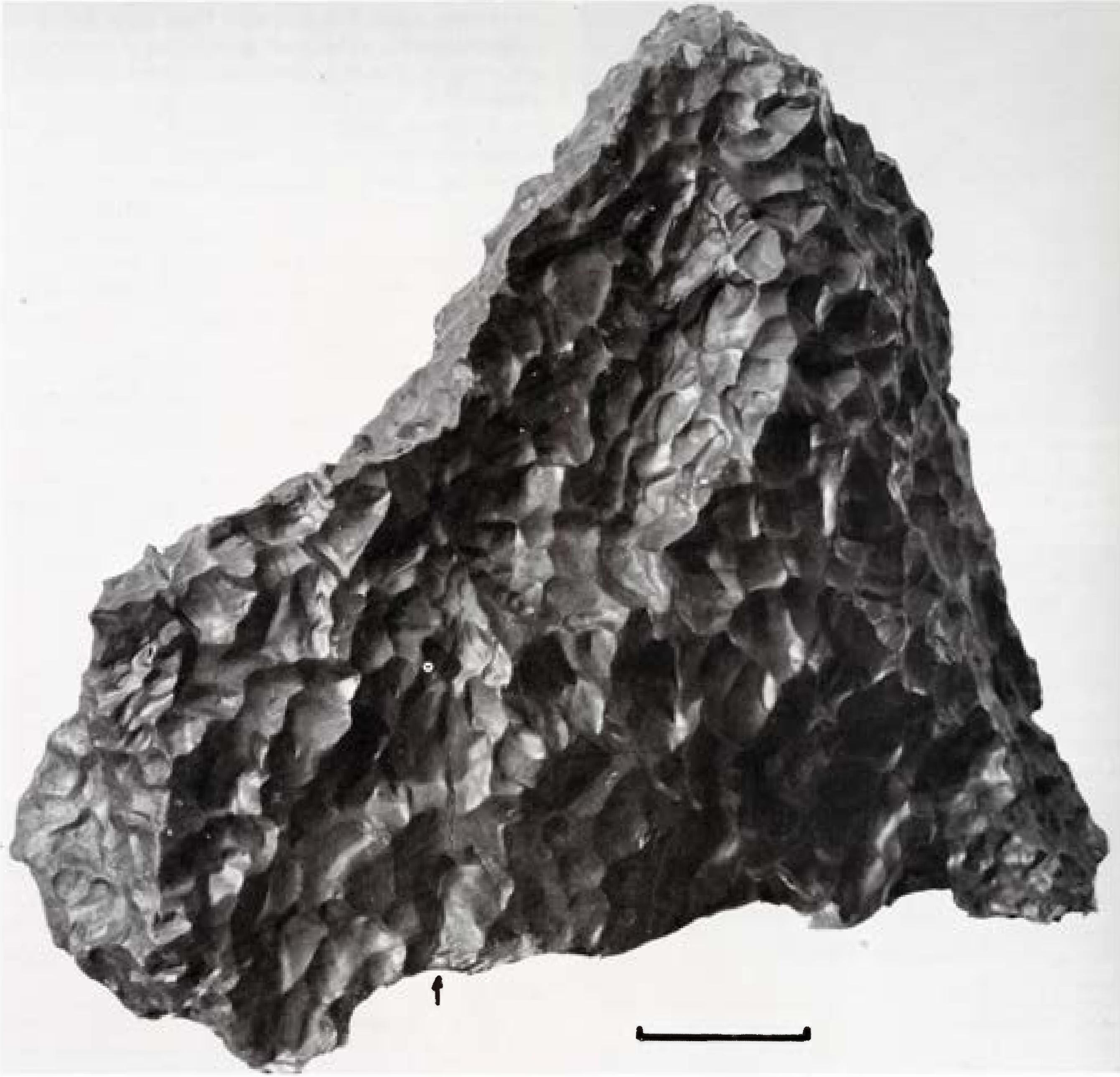

Figure 1201. Murnpeowie. The eminent main mass of 1,140 kg in Adelaide. Regmaglypts, and a fine crack just above the arrow. Scale bar approximately 20 cm.

26 donkeys, 27 days to excavate and transport the large mass to Farina, the nearest railway station. It was deposited in the School of Mines, in Adelaide, where it was described by L.L. Smith (1910). He presented and discussed two photographs that showed the slightly convex front and the slightly concave back of the rather flat mass. He concluded that the well-preserved regmaglypts were remnants from an oriented flight through the atmosphere. Spencer (1935) gave a full description with numerous photographs of the exterior and of etched sections. Owen & Burns (1939) X-rayed the material and found an alpha parameter of 2.8625 Å, albeit with diffuse lines in the diffractogram. Brentnall & Axon (1962) and Axon (1968b) reexamined the specimen in the British Museum and suggested that Murnpeowie is a cosmically reheated and recrystallized meteorite. Reed (1965b; 1969) found a homogeneous kamacite with 6.4-6.6% Ni and 0.18% P in solid solution.

COLLECTIONS

South Australian School of Mines and Industries, Adelaide (about 1,135 kg), Sydney (1.14 kg), London (773 g), Washington (191 g).

DESCRIPTION

From published photographs (Smith 1910; Spencer 1935; Hodge-Smith 1939, plate 6) it appears that the mass is a roughly flat, triangular slab with the average dimensions of 120 x 85 x 30 cm. One of the flat sides is actually slightly concave and covered with very shallow regmaglypts, 8-25 cm in diameter. The opposite side is irregular and slightly convex; it shows a very different surface morphology, being covered with boldly sculptured regmaglypts, 3-10 cm in diameter and 0.5-1.5 cm deep. In their morphology the two faces resemble Cabin Creek and Hraschina very much, and the explanation appears to be the same: Murnpeowie was sculptured differently on its front side (small, deep regmaglypts) and its rear side (large, shallow regmaglypts) during the atmospheric penetration. The flat mass shows several distinct cracks, one of which is 40 cm long and 1 mm wide at the surface. The cracks probably developed during the violent deceleration in the atmosphere. If the mass had been more inclusion-rich it might have produced a shower, with the cracks propagating along the brittle inclusions as seen in, e.g., Sikhote-Alin.

Corrosion has modified the surface very little. The oxidic fusion crust is visible in numerous places, yet its color has changed from black to brown due to slight weathering. Sections perpendicular to the surface reveal that the fusion crust, as usual, is duplex, consisting of an exterior, 100 μ thick magnetite-wüstite crust and an interior, dendritic-cellular metallic crust. The metal may be composed of numerous successive sheets, each 25-50 μ thick, that build up to a total thickness of 200-300 μ and possibly more on other sections. The metal has 1-5 μ oxide globules dispersed in it, and its hardness is 345±20, in accordance with its rapidly chilled, martensitic structure.

The heat-affected α_2 zone ranges from 0.5-3 mm in thickness, being thinnest under the bottom of the regmaglypts where the ablation rate was highest. The hardness is 210±15 and drops to a minimum of 170 at the transition to the unaffected interior which exhibits a hardness of 185±9 (hardness curve type II).

Very characteristic for Murnpeowie's heat-affected rim zone is the presence of numerous martensitic-bainitic nests and ledeburitic melts. They have formed by decomposition of the cohenite precipitates. The original cohenite dissolved and instead of the previous 10-20 μ wide carbide blebs we now observe 50-100 μ wide nests of acicular martensite and bainite with a hardness of 690±30. Immediately under the fusion crust the temperature was high enough for the carbon-rich spots to melt. Similar structures are found in, e.g., Arispe, Morrill and Santa Rosa.

Etched sections display an unusual mixture of large and small, partially oriented, recrystallized kamacite grains. Subboundaries decorated with less than 0.5 μ precipitates are very common. The larger grains which cover approximately 50% of the surface are almost equiaxial and 0.3-3 mm in diameter. The smaller grains fill the "interstices" between the larger grains in an irregular way. They are often lamellar, typically 0.1 x 0.5 mm in size, and a significant number of them are uniformly oriented in five or six directions. Since such a preferred orientation seems to exist, it may indicate that the parent material, before recrystallization, was composed of several single crystals, each some centimeters across, and perhaps with numerous Neumann bands. In other meteorites, not yet fully recrystallized, I have several times noted that the recrystallized grains are elongated along the previous Neumann band directions; see, e.g., Indian Valley and Roebourne. The recrystallized grains have numerous, sharp and narrow Neumann bands; these appear to be of late date and were possibly formed when the mass cracked in the atmosphere.

Taenite is absent in the normally recognized forms, but a small amount occurs with the cohenite. Schreibersite is absent, but phosphides do occur as tiny wedges, 1-3 μ across, in the grain boundaries. It appears that the matrix is loaded with near-submicroscopic particles. Part of these may be fine phosphides, less than 0.5 μ thick. Reed (1969) found 0.18% P in solid solution in the kamacite. This means that it is significantly supersaturated and that the microprobe can not resolve the fine precipitates. In any case, such a condition of an alpha-phase with 0.2% P, but without clearly visible precipitates, suggests an alloy rapidly cooled from about 600° C to temperatures where diffusion practically came to a stop. In an experimental alloy, similar to Murnpeowie, I was able to precipitate 1 μ thick phosphides from a supersaturated α-phase by isothermal heat-treatment at 450° C for 1,500 hours, or 350° C for 2,400 hours. Since Murnpeowie has no visible phosphide precipitates, it must have spent significantly less than 2,000 hours at these temperatures during its secondary cooling period. We may only guess what its initial structure was. Perhaps it was an aggregate of large lamellae and equiaxial grains of kamacite with numerous Neumann bands and rhabdites, somewhat resembling El Burro, Mount Joy, or Nelson County?

Troilite is present as scattered blebs and lamellar bodies, e.g., 2 x 1 and 3 x 0.2 mm in size. Daubreelite constitutes about 15% by area of the troilite in form of parallel, narrow lamellae. The troilite is monocrystalline but beset with many lenticular deformation lamellae. It is not shock-melted in the sections I have seen. Some of the best developed, large, equiaxial kamacite grains are located around the troilite inclusions.

Cohenite is a characteristic accessory for this meteorite. It is mainly precipitated in the grain boundaries of the equiaxial kamacite units and forms 3-25 μ wide, serrated, amoeba-like crystals with minute inclusions of taenite and kamacite. Its hardness is somewhat above 700, but could not be determined accurately due to its small size and the inclusions. The cohenite may be rather nickel-rich.

It is interesting to note that the carbides found time to precipitate in the grain boundaries, while phosphides only formed in insignificant amounts. This is another indication that the cooling was rather rapid, allowing only the agile carbon atoms to diffuse to the grain boundaries.

Murnpeowie is structurally and chemically anomalous. There is no iron meteorite extant with the same structure and composition, and there is no known meteorite type which could be proposed as its immediate predecessor before recrystallization. From arguments given above, and from observations of Spencer (1935) and Axon (1968b), it appears that Murnpeowie represents an example of a mechanically deformed meteorite which is imperfectly recrystallized.

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

56 g part slice (no. 1756, 6 x 3 x 0.5 cm)
135 g part slice (no. 4854, 9 x 3.5 x 0.7 cm)

Murphy, North Carolina, U.S.A.

35°5'N, 84°2'W; above 500 m

Hexahedrite, H. Monocrystal larger than 25 cm. Neumann bands. HV 240±15.

Group IIA. 5.47% Ni, 0.45% Co, 0.34% P, 60 ppm Ga, 186 ppm Ge, 34 ppm Ir.

HISTORY

A mass of 7.75 kg was found by W.B. Lenoir in a field after plowing and heavy rainfall in 1899. The place was 8 km from Murphy in Cherokee County, but the direction is not stated by Ward who acquired and described the mass (1899). The coordinates given above are, therefore, those of Murphy. Ward gave two photographs of the exterior and a print made directly from an etched section through the angular mass. Cohen (1899: 368; 1905: 227) analyzed and described the iron. Jain & Lipschutz (1969) examined the kamacite by X-ray diffraction and found it to be deformed although only Neumann bands appeared on a polished and etched section.

COLLECTIONS

London (1,521 g), Vatican (767 g), Chicago (660 g), Washington (581 g), New York (559 g), Vienna (502 g), Stockholm (292 g), Berlin (217 g), Harvard (212 g), Yale (202 g), Paris (126 g), Tübingen (86 g), Helsinki (46 g), Budapest (43 g), Los Angeles (6 g), Tempe (5 g).

DESCRIPTION

The angular mass was 23 cm long and about 12 x 10 cm in cross section. Ward (1899) cut it in numerous, parallel sections and noted that the exterior shape suggested that the mass was produced by fracturing along cubic planes. The cubic faces are, however, later modified both by atmospheric ablation and by terrestrial corrosion. A similar, but more perfect, cubic shape is preserved by Edmonton (Canada) and Calico Rock. Sections show that the fusion crust and the heat-affected α_2 zone are removed by corrosion; in places there is a 1-2 mm thick crust of terrestrial oxides. A microhardness trace perpendicular to the surface discloses, however, a significant decrease from an interior hardness of 240±15 to a minimum of 220 at the surface, indicating that only about 2-3 mm has been lost by weathering (hardness curve type I, where the left leg has been removed by corrosion).

Etched sections have a mottled appearance which is mainly due to differences in phosphide populations. Both the size and the number of the phosphides vary between bright and matte areas. Murphy is a single kamacite crystal with no traces of recrystallization. Neumann bands are well developed as 5-15 μ wide, serrated ribbons, extending from rim to rim. They decrease significantly in width (to 1-2 μ) where they pass areas of tiny, densely spaced rhabdites. The microhardness (100 g) is 240±15 and not significantly different in matte and bright areas. The hardness is among the highest recorded for a hexahedrite, in accordance with the deformation evidence reported by Jain & Lipschutz (1969).

Schreibersite is apparently rare, except as 50-100 μ wide rims around some of the troilite nodules. Rhabdites do, however, occur in profusion as 5-15 μ thick, sharp prisms. The phosphides are frequently sheared and displaced 2-5 μ along the Neumann bands, another confirmation of the significant cold-deformation of the mass.

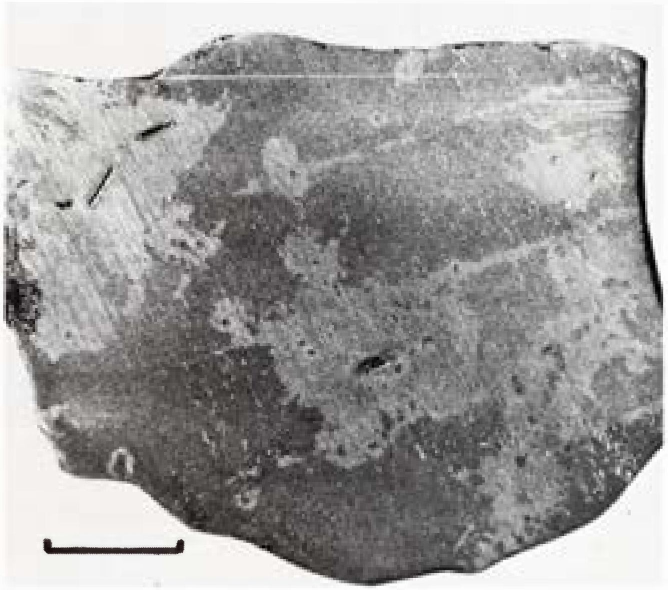

Figure 1202. Murphy (Vienna no. H976). A one centimeter thick full slice. Deep-etching develops the characteristic pattern of light (rhabdite-poor) and dark (rhabdite-rich) patches. Troilite-schreibersite inclusions are located centrally in the light areas. Scale bar 20 mm.

MURPHY – SELECTED CHEMICAL ANALYSES

Cohen (1899) reported 0.06% Cl which was ascribed to lawrencite. The mineral was, however, not seen, and the chlorine was probably mainly introduced by terrestrial, percolating ground water.

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Fahrenhorst in Cohen 1899	5.52	0.61	0.34	400			200					
Lovering et al. 1957		0.45				46	116		40	145		
Wasson 1970, pers. comm.	5.42								60.5	186	34	

Troilite occurs as a few nodules, up to 9 x 13 mm in size, and as numerous angular to lenticular bodies, 0.3-3 mm in size. Several bar-shaped crystals, e.g., 10 x 0.4 mm in size, are also present. Daubreelite constitutes 20-40% of the troilite bodies, and further occurs as separate 10-100 μ blebs in the kamacite, frequently forming a nucleus for schreibersite precipitates. The daubreelite has a hardness of 400±30.

The chromium nitride, carlsbergite, occurs as fine, hard platelets, 10 x 1 μ in size, in the kamacite or embedded in the rhabdites.

Murphy is a monocrystalline hexahedrite which has an unusually high hardness, due to cosmic deformation, and a high daubreelite content. It is apparently particularly related to Negrillos. It belongs chemically to group IIA.

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

572 g slice (no. 557, 9.5 x 8 x 1 cm)
9 g part slice (no. 3345, 20 x 14 x 5 mm)

Muzzaffarpur, Bihar, India
26°8'N, 85°32'E

Plessitic octahedrite, Opl. Spindle width 100±30 μ. Neumann bands. HV 245±10.

Anomalous. 12.9% Ni, 0.65% Co, about 0.4% P, 11.5 ppm Ga, 1.4 ppm Ir.

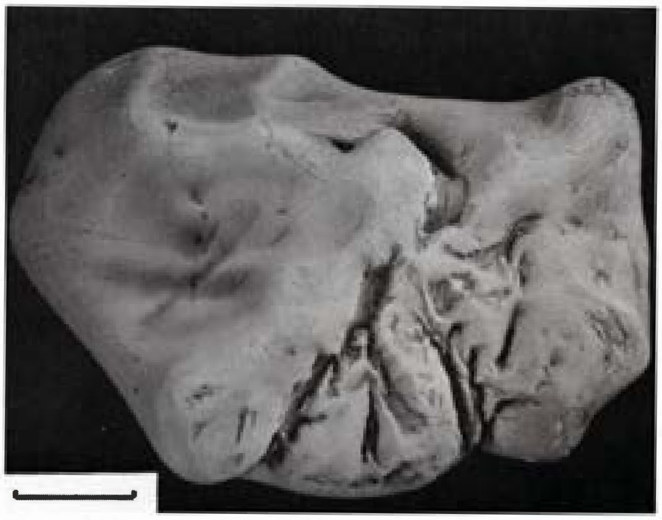

Figure 1203. Muzzaffarpur. The smaller mass, of 153 g, on loan in the Smithsonian Institution. Regmaglypts and grooves from the ablative melting of schreibersite plates. Smoked with NH_4Cl. Scale bar 1 cm. S.I. neg. 1059G.

HISTORY

On April 11, 1964, at 5 p.m. two pieces of 1,092 g and 153 g, respectively, were observed to fall about 13 km east of Muzzaffarpur in the Muzzaffarpur District, Bihar. According to a report by Murthy in the Meteoritical Bulletin, No. 32, 1964, the 1,092 g mass was accompanied by a hissing sound when it hit a cultivated field near Bahrampur (26°8'N, 85°32'E), making a pit 13.5 cm deep and 9 cm in diameter at the surface. The mass was recovered within one minute of its fall and was said to be hot enough to burn the fingers.

The smaller mass fell 3 km southwest of the larger one, near the village of Man Bishunpur (26°7'N, 85°31'15"E), and was also associated with hissing sounds. Three nearly simultaneous, roaring, thunderous sounds were heard in a northeastern direction, and it is implied that the meteorite came from that direction.

The two masses were acquired by the Geological Survey of India, and a preliminary description was given by Murthy et al. (1964). Das Gupta et al. (1969) gave a full description, accompanied by photomicrographs. Further information, with six photographs, was provided by Murthy et al. (1969). The 153 g specimen was kindly lent to the Smithsonian Institution as early as May 1964 in order to have the short-lived, cosmic ray induced radioactivities measured. Fireman (1967) determined ^{39}Ar and ^{3}H and applied the data in an evaluation of the intensity variation of the cosmic rays with distance from the sun.

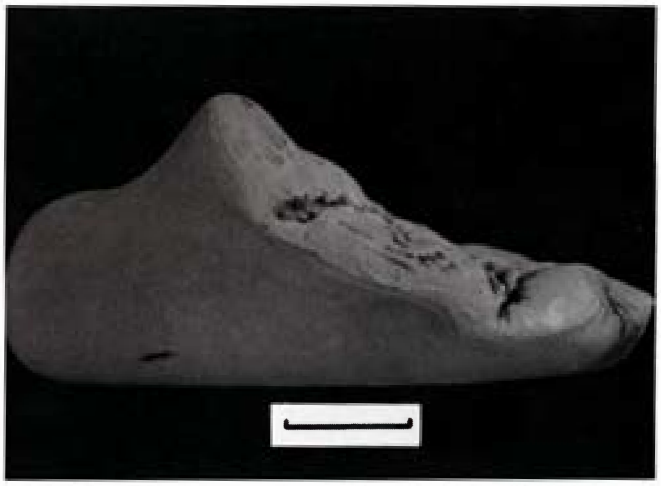

Figure 1204. Muzzaffarpur. The smaller mass from a different angle. Smoked with NH_4Cl. Scale bar 1 cm. S.I. neg. 1059C.

MUZZAFFARPUR – SELECTED CHEMICAL ANALYSES

Das Gupta et al. (1969) also reported 0.31% Si, which is unusually high for an iron meteorite, and comparable to what is present in Tucson and Nedagolla. The phosphorus analysis appears very high; my point counting of the specimens in Washington yielded only 0.3% P, so apparently the phosphides are irregularly distributed.

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Cobb 1967	13.7	0.53					200		11.5		1.4	
Das Gupta et al. 1969	12.0	0.76	0.56		<100	200	100					

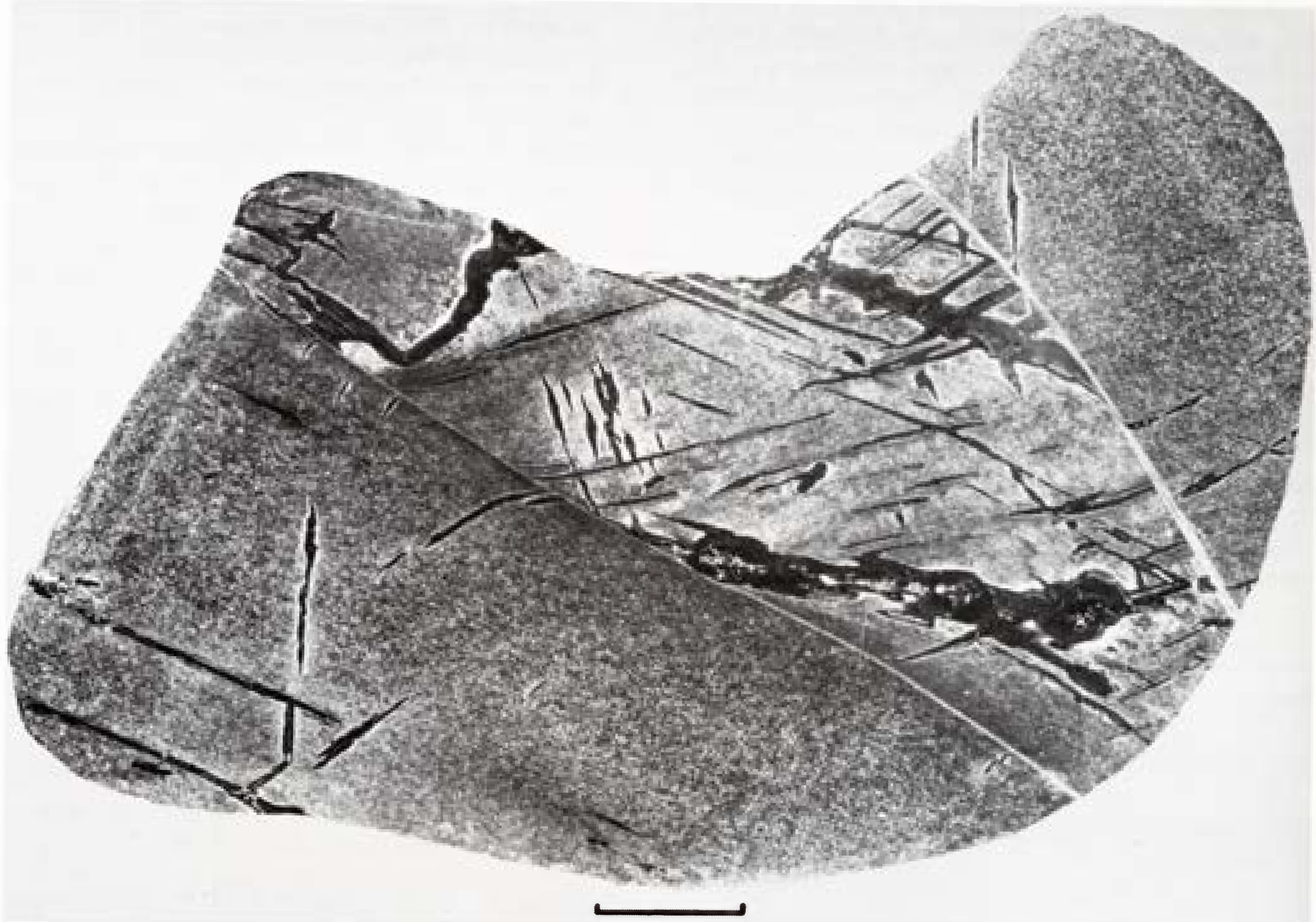

Figure 1205. Muzzaffarpur. Section through the smaller mass. Severe cosmic shear has driven an entire block, of different structure, in between two ataxitic parts. Deep-etched. Scale bar 5 mm. S.I. neg. 1061A.

COLLECTIONS

Calcutta (the two main masses), Washington (three polished sections totaling 5 g).

DESCRIPTION

I have not seen the 1,092 g mass. The 153 g mass had the average dimensions of 5.5 x 3.5 x 1.8 cm and was a smoothly rounded mass with local dents and grooves. They are typically 15 x 1 mm in size and 1-2 mm deep; when the mass is sectioned, it is observed that they are due to selective ablation-melting of schreibersite. The whole surface is covered with fusion crust and late ablation has removed any obvious trace of the fracture surface from bursting in the atmosphere. It appears, however, that one late fracture surface is the 3 x 2.5 cm almost flat part, now heavily indented by grooves; and it is understandable that this should become the fracture surface, since schreibersite bodies were concentrated here.

Etched sections disclose a unique structure, which is difficult to classify. The ataxitic matrix constitutes 70-90%, while irregularly distributed, pointed kamacite lamellae make up the balance. The structure somewhat resembles Butler and Wiley.

The scattered α-lamellae have a width of 100±30 μ and reach lengths of 10 mm. They form an open skeleton Widmanstätten pattern, and their mutual distance is frequently as high as 5-10 mm. The kamacite shows indistinct Neumann bands, and the hardness is 225±15. Subboundaries with 0.5 μ precipitates occur, and microrhabdites, 1-2 μ across, are also present.

The matrix is a micro-Widmanstätten structure in which numerous, short α-spindles, 10±5 μ wide, form an

Figure 1206. Muzzaffarpur. Same as Figure 1205 with the light source in a different position. The kamacite spindles are clearly distinguished. Scale bar 5 mm. S.I. neg 1061.

octahedral felt on a background of plessite, somewhat resembling the matrix of Wiley, but on a finer scale. Irregular α-blebs, 20-50 μ across, are also common and usually nucleated by the abundant phosphides. The plessite is well decomposed to a duplex $\alpha + \gamma$ with vermicular and granular γ about 1 μ thick. A distinct hardness gradient is present across the kamacite-taenite-plessite. From 225 in the α-phase, the hardness increases abruptly to 390 in the taenite rim. It then decreases gradually through the martensitic transition zones and reaches a homogeneous level of 245±10 in the duplex matrix, which constitutes most of the meteorite.

Schreibersite is common as monocrystalline but brecciated bodies. The larger ones are typically 700 x 100 μ or 500 x 25 μ, and they are enveloped in 50-200 μ wide zones of swathing kamacite. They occur locally with a high frequency of 3-4 per mm^2 (Das Gupta et al. 1969). In addition, small phosphide blebs, 3-15 μ across, are very regularly distributed with about 75 per mm^2. Other minerals were not observed.

The 153 g Muzzaffarpur specimen contains a remarkable fault zone. On a 5 x 3 cm section two extremely narrow (100-200 μ) shear zones divide the surface into three almost equal sections. The relative displacements along each of the faults are of the order of 10 mm, and it appears that the middle section has been wedged into position between the two outer parts. The hardness of the cold-worked matrix within the shear zone is 300±15. The schreibersite away from the zone is violently torn and shear-displaced in successive steps of 10-20 μ, and the adjacent swathing kamacite is cold-worked, and locally evenly fissured along cubic cleavage planes. The deformations are clearly preatmospheric, and it is not surprising that a mass with so many internal fissures should fracture

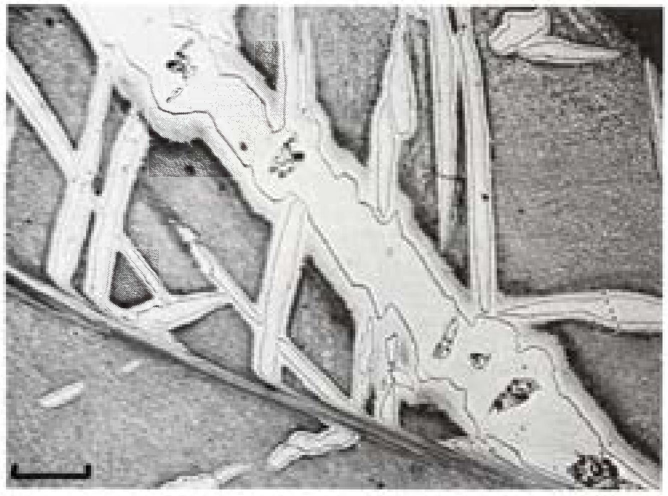

Figure 1207. Muzzaffarpur. Detail of Figure 1205 showing the shear zone with the extensive dragging of the ductile metal. Schreibersite crystals inside the largest kamacite spindle. Etched. Scale bar 1 mm.

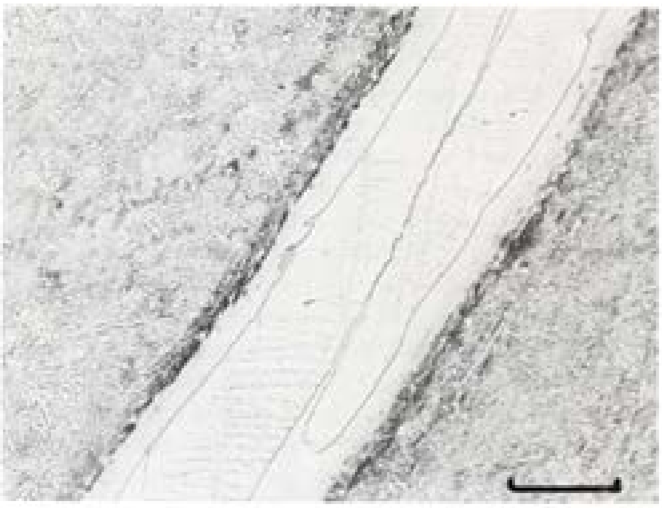

Figure 1208. Muzzaffarpur (U.S.N.M. no. 2484). Two kamacite spindles with deformed Neumann bands. Taenite rims and duplex ataxite matrix on either side. Etched. Scale bar 100 μ.

Figure 1209. Muzzaffarpur. Close-up of the fusion crust. Warty and striated, with fine hair-lines and ridges. Patches where the fused oxides have spalled off, while the fused metal remained. Scale bar 2 mm. S.I. neg. 1059J.

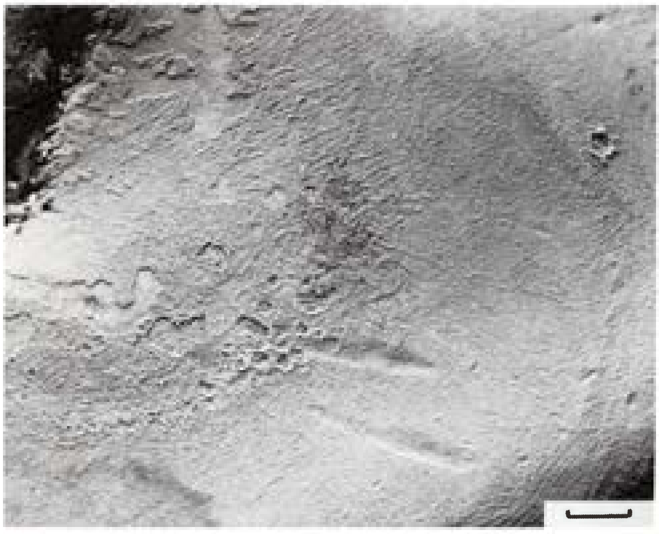

Figure 1210. Muzzaffarpur. Close-up of the oxidic fusion crust which in places has spalled off. Note, in the fusion crust above right, a small crater caused by an impinging particle during flight. Scale bar 2 mm. S.I. neg. 1059L.

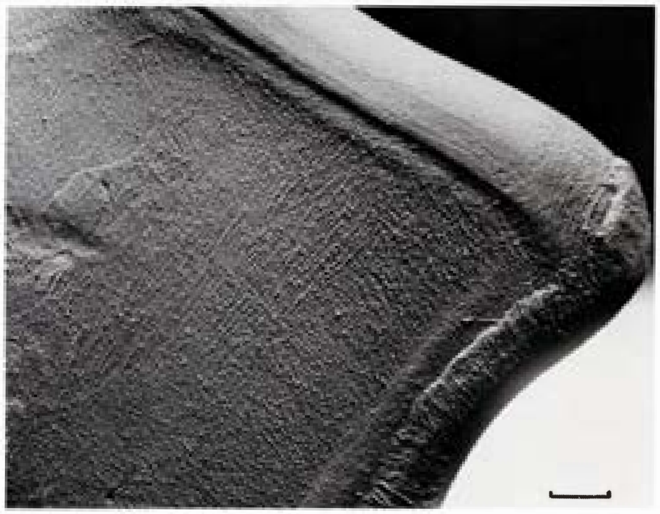

Figure 1211. Muzzaffarpur. Detail of the striated oxidic fusion crust. Note the ablated groove that runs parallel to the edges over a long distance. Scale bar 2 mm. S.I. neg. 1059H.

during the atmospheric deceleration. Similar large scale fault zones are also present in Chinga, and to a minor extent, in New Baltimore, Puquios, Descubridora and others.

The fusion crust is composed of an exterior 30-80 μ thick magnetite plus wüstite layer followed by a 10-100 μ thick, laminated, metallic fusion crust (HV 300±15. There are numerous 1-10 μ gasholes in both the oxides and the metal, and there are metallic islands included in the oxides, and oxidic globules included in the metal. Under the fusion crust the phosphides are micromelted to a depth of 0.6-4 mm and display the usual, fine shrinkage cavities. Heat-affected α_2 is present to double that depth. Das Gupta et al. (1969) saw no evidence of a thermal gradient; nevertheless, it is present. The small 153 g mass thus shows a rather normal, steep temperature gradient from 1500° C to the unaffected interior. The hardness of the matrix in the α_2 zone is 195±8. It decreases to a minimum of 180±5 at the transition α_2 - α and then increases to 245±10 (hardness curve type I). A similar hardness gradient is found when examining only the taenite rims. The hardness in the interior is 360±30 but decreases in the heat-affected zone to 250±10 (hardness curve type V), a result which is quite general for taenite and, e.g., may also be observed in irons, such as Freda and Twin City, which are rich in taenite and its transformation products.

Muzzaffarpur is an anomalous iron with ataxitic and octahedral characters. It somewhat resembles Butler and Wiley, but it is different in many details, both structurally and chemically. The meteorite is widely different from the ataxites Deep Springs (13.4% Ni), Babb's Mill, Blake's Iron (11.9% Ni) and Nordheim (11.7% Ni). Considering its distinct difference from "normal" ataxites and the presence of significant amounts of octahedral elements visible to the naked eye, it is here decided to classify Muzzaffarpur as a plessitic octahedrite. Muzzaffarpur's faulting indicates considerable shearing on its parent body, probably under constrained conditions. The whole matrix is somewhat cold-worked, but the major deformation is concentrated within narrow planes which suggests a violent, shock-resembling event, rather than uniform, slow deformation processes.

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

5 g part slices, three polished sections (no. 2484, each 15 x 10 x 1 mm)

Nagy-Vázsony, Veszprém, Hungary

46°59'N, 17°42'E; 300 m

Coarse octahedrite, Og. Bandwidth 1.40±0.30 mm. Neumann bands. HV 225±25.

Group I. 8.0% Ni and 0.2% P, judging from the structure.

HISTORY

A mass of 1.98 kg was found in 1890 by the miner Johann Koralovsky. The locality was close to the village of Nagy-Vázsony, near Vörös-Bereny in the Veszprém District. The meteorite was discovered in a ditch along a plowed field and appeared to have become exposed by heavy rain. It was briefly described by Brezina (1896: 284) who acquired the whole mass. No later examination results have appeared.

COLLECTIONS

Vienna (1,353 g), New York (218 g), London (107 g), Washington (36 g), Budapest (36 g), Chicago (36 g), Berlin (5 g).

ANALYSES

No analysis has been published.

DESCRIPTION

According to Brezina (1896), the finder believed the mass to be associated with an observed meteor, but Brezina found the iron sufficiently weathered to exclude this possibility. The mass had the size and shape of a hand which was somewhat bent. It was convex on one side and concave on the other, but if regmaglypts had ever been present they were now removed by corrosion.

The small slice in the U.S. National Museum has lost its fusion crust and heat-affected α_2 zone by weathering. The limonitic laminated crust is up to 2 mm thick, and corrosion penetrates several millimeters into the interior, particularly along schreibersite and octahedral grain boundaries. The troilite is veined by pentlandite, and the α phase of the plessite fields is selectively corroded.

Etched sections display a coarse Widmanstätten structure of bulky, short ($\frac{L}{W} \sim 15$) kamacite lamellae with a width of 1.40±0.30 mm. The kamacite has pronounced subboundaries decorated with 1-2 μ thick rhabdites, and Neumann bands are well developed. The microhardness is 225±25, corresponding to a slightly cold-worked kamacite.

Taenite and plessite cover 20-30% by area, both as open-meshed comb plessite and as fine-grained varieties of pearlitic, spheroidized and martensitic fields. The pearlitic fields have beautiful 0.5-2 μ wide subparallel taenite lamellae and are frequently associated with haxonite, as is typical for group I irons.

Schreibersite occurs as monocrystalline skeleton crystals; an H-shaped crystal, 6 x 2 mm in size is enveloped in a 0.2 mm wide cohenite rim. Schreibersite is further common as 20-60 μ wide grain boundary precipitates and as 5-25 μ blebs inside the plessite fields. Rhabdites are ubiquitous as 1-10 μ sharp tetragonal prisms. The bulk phosphorus content is estimated to be about 0.20%.

Cohenite is present in patches as 4 x 0.5 mm rounded, palmate, anisotropic crystals, located along the octahedral α-lamellae. The cohenite has the usual inclusions or "windows" of 10-100 μ kamacite, taenite and schreibersite, and locally it is sheared and displaced 5-10 μ. The microhardness of the cohenite is 1100±50.

Troilite with schreibersite-cohenite rims is present on the specimens in Vienna, while only one tiny weathered troilite bleb was noted on the Washington specimen.

Nagy-Vázsony is in every respect a typical group I iron, closely related to Toluca. A modern chemical examination will probably show its composition to be almost identical to that of Toluca, both with respect to main and trace elements.

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

36 g part slice (no. 865, 6 x 3 x 0.3 cm; no. 139 in Farrington 1895)

Naifa, Arabia

19°56'N, 51°13'E

A small piece of 8 g was found at Naifa, 110 miles south by east of Wabar. It was described by Spencer & Hey (1933a) as a medium octahedrite, and it may be assumed to be a transported specimen from the Wabar crater field. The sample is in the British Museum.

Narraburra, Temora, New South Wales, Australia

34°10'S, 147°43'E

Medium octahedrite, Om. Bandwidth 0.60±0.10 mm. ε-structure. HV 255±25.

Group IIIB. 10.0% Ni, 0.53% Co, 1.0% P, 16.6 ppm Ga, 28.7 ppm Ge, 0.016 ppm Ir.

HISTORY

A mass of 70 lbs 14 oz (32.1 kg) was found in 1855 by O'Brien about 12 miles east of Temora. It was lying on a stony surface near Narraburra Creek in County Bland. It remained in private possession until 1890 when it was donated to the Observatory in Sydney, where it was briefly described by Russell (1890). Brezina (1896: 235, 288) acquired a 52 g specimen and called it Temora, found in 1854; he also stated that it had a rare structure, being a coarsest octahedrite, resembling Seeläsgen. Since that time, two meteorites have been listed in collections as coming from County Bland: Narraburra (Om) and Temora (Ogg). It appears, however, that all material has been cut from the same 32 kg Narraburra specimen.

Liversidge (1904) described the main mass with photographs of the exterior; he cut seven parallel slices and presented photographs of the etched sections. Unfortunately, he was unable in his observations to correctly distinguish between kamacite, taenite, troilite and schreibersite. Brezina (1904a) examined the phosphides and found them to be precipitated in dodecahedral planes of the parent austenite. Cohen (1905: 259) described the

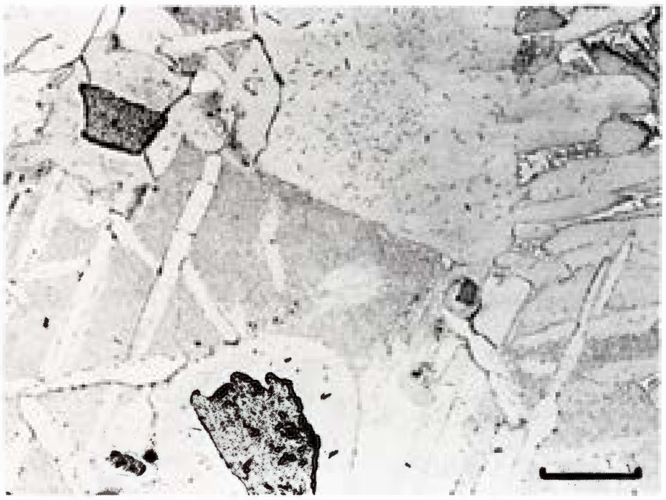

Figure 1212. Narraburra (Copenhagen no. 1905, 1732). Medium octahedrite of group IIIB. Locally, large patches of kamacite occur. They are unexpected on this high nickel level of 10% and they can apparently always be interpreted as swathing kamacite rims. Etched. Scale bar 3 mm.

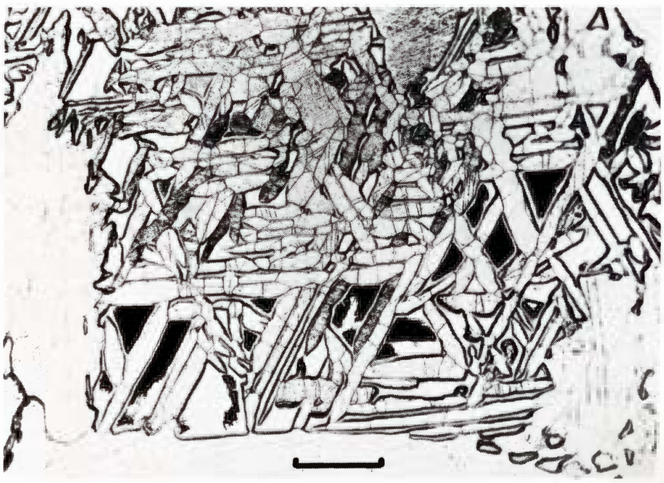

Figure 1213. Narraburra (Copenhagen no. 1905, 1732). Typical plessite field in a group IIIB iron. The kamacite is shock-hatched. Etched. Scale bar 300 μ.

meteorite, and Brezina & Cohen (1886-1906: plate 31) gave two excellent photomacrographs. Owen & Burns (1939) measured the α-lattice parameter, while Spencer (1951) presented a photomacrograph. Axon (1961) reexamined Narraburra and found it remarkably similar to Bear Creek – so much so that he suggested the two masses were part of the same parent mass which in a captured orbit around the Earth dropped material in both Australia and the U.S.A. Buchwald (1966) noted the shocked structure, and Jaeger & Lipschutz (1967a, b) discussed this in more detail, giving a photomicrograph.

Vilcsek & Wänke (1963) found an exposure age of 470±50 million years while Chang & Wänke (1969) with the improved ^{10}Be/^{36}Cl method found 290±60 million years. They also estimated the terrestrial age to be about 200,000 years. Hintenberger et al. (1967) measured the concentration of the helium and the neon isotopes.

COLLECTIONS

Sydney (23.1 kg), London (3.0 kg), Harvard (681 g), Washington (321 g), Chicago (127 g), Paris (119 g), Budapest (69 g), Vienna (52 g), New York (41 g), Calcutta (22 g), Berlin (19 g), Amherst (18 g), Copenhagen (13 g), Bonn (13 g).

DESCRIPTION

According to the photographs given by Liversidge (1904) the mass has the average dimensions of 27 x 22 x 17 cm. It displays several large hemispherical pits, of which at least four are 2-4 cm in aperture and 2-5 cm deep. Otherwise the surface is roughly angular, and covered with 0.1-1 mm thick terrestrial oxides. It is not quite clear whether the hemispherical pits are due to the ablational burning of troilite or to corrosion. I have searched for heat-affected α_2 zones and fusion crust and found none. On the contrary, hardness tracks perpendicular to the corroded surface show no hardness gradient, but a homogeneous level of 255±25, indicating that at least 5 mm of the surface have been removed by corrosion. Plate 19 in Liversidge (1904) shows a spherical troilite crystal, 2 cm in diameter, abutting against the surface. This nodule must have been fully embedded within the metal when the mass penetrated the atmosphere, since it has not burned out. In other words, both the hardness tracks and the troilite nodule suggest that a significant part of the surface, 5-10 mm, has been removed by weathering. Accepting this much corrosion, it, therefore, becomes probable that the large, hemispherical, undercut cavities are corrosion pits developed during the long terrestrial exposure, estimated by Chang & Wänke to be more than 150,000 years.

Etched sections display a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 15$) kamacite lamellae with a width of 0.60±0.10 mm (not 0.16 mm as stated in Hey 1966: 333). The kamacite is of the shock-hardened ϵ-variety, suggestive of shock pressures above 130 k bar, and its microhardness is 255±25. Subboundaries are common, and it appears that both the matrix and the boundaries have many submicroscopic precipitates. Taenite

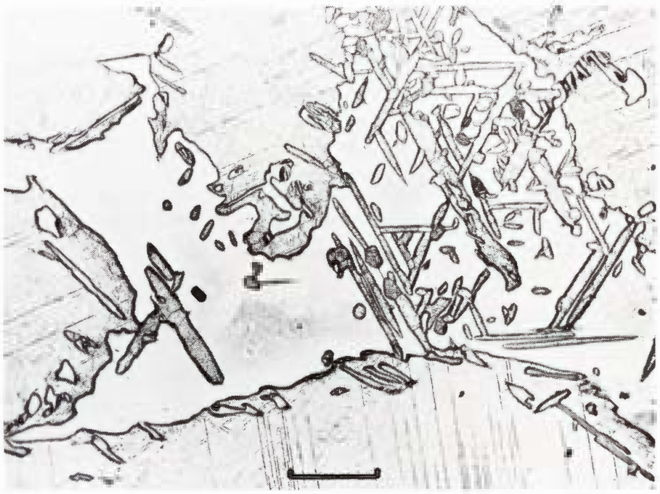

Figure 1214. Narraburra. Detail of Figure 1212. A plessite field with acicular kamacite and island arcs of schreibersite. Etched. Scale bar 300 μ.

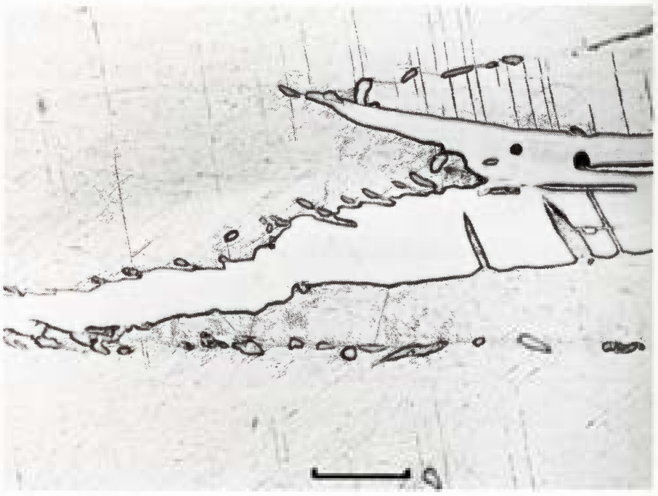

Figure 1215. Narraburra. Detail of Figure 1212. Another plessite field. The interior martensitic platelets are only indistinctly seen. Island arcs of schreibersite. Lightly etched. Scale bar 300 μ.

NARRABURRA – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Liversidge 1904	9.74	0.47	0.43				90					
Lovering et al. 1957	10.22	0.59				<1	157		8.2	29		
Scott et al. 1973	10.13								16.6	28.7	0.016	

Reed (1969) examined the kamacite phase with the electron microprobe and found 7.3% Ni and 0.092% P in solid solution.

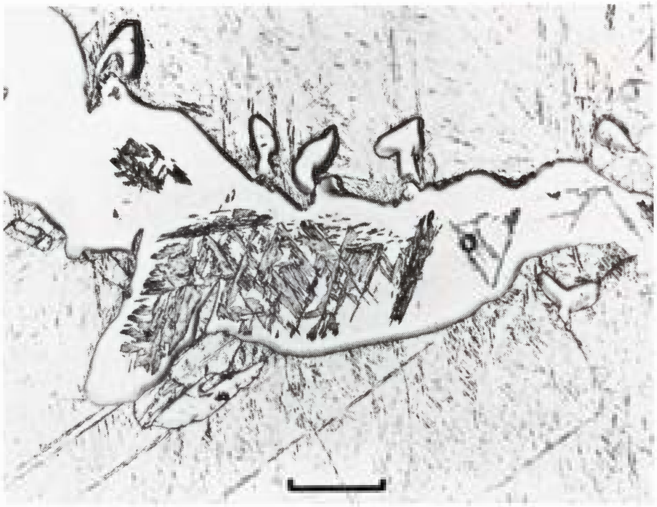

Figure 1216. Narraburra (Copenhagen no. 1905, 1732). Plessite field with martensite platelets parallel to $(111)_\gamma$. Hard schreibersite particles in high relief. Shock-hatched kamacite. Etched. Scale bar 100 μ.

Figure 1217. Narraburra (Copenhagen no. 1905, 1732). A cosmic collision-event shock-hardened the kamacite and taenite and locally caused heavy shear-displacement. Here a faulted plessite field. Etched. Scale bar 100 μ.

and plessite cover about 50% by area. The plessite is of the characteristic acicular type where a basket-weave of pointed α-lamellae, 10-50 μ wide, intersect to form a micro Widmanstätten pattern, leaving numerous, rather homogeneous concave taenite islands in between. The kamacite shows ϵ-structures of various shadings, according to the actual orientation of the lamellae. The larger taenite blebs have yellowish to brownish etching martensitic interiors, the martensite platelets repeating the octahedral directions.

Phosphides are conspicuous and cover about 6% by area in the form of sharply facetted macrorhabdites which are oriented in a dodecahedral pattern, the so-called Brezina lamellae. The individual monocrystalline bodies are typically 10 x 3 x 2 or 4 x 3 x 2 mm, but some crystals reach a size of 40 x 5 mm. They are enveloped in 1-2 mm wide rims of swathing kamacite, in which normal rhabdites 5-15 μ across are numerous. The large crystals are frequently nucleated around 50-200 μ troilite or chromite bodies, or around lenticular, anisotropic blebs, 25-300 μ in size, of an unidentified gray mineral (phosphate?). The phosphides are brecciated and contain numerous troilite veins, only 5-15 μ wide, but often a centimeter long. The troilite is somewhat corroded and partially converted to pentlandite or limonite. Very characteristic is the large number of small schreibersite beads which are located 5-20 μ in front of taenite and plessite. They are typically 20 x 10 μ in size; apparently they nucleated and grew before the kamacite lamellae attained their full size. The bulk phosphorus content of Narraburra is estimated to be 1.0%.

Troilite occurs as a few large nodules, 10-20 mm in diameter, with a surprisingly small amount of rim schreibersite. The schreibersite rims are discontinuous and mostly only 0.1-0.3 mm thick. Small troilite nodules, 0.1-1 mm across, are common. The troilite is monocrystalline but displays numerous lenticular deformation twins. The troilite is often associated with 50-100 μ chromite grains and with the unidentified gray mineral mentioned above. Locally this reaches a size of 5 mm and resembles the sarcopside-graftonite crystals described by Fuchs (1969) from Chupaderos and other irons.

Locally, large irregular kamacite areas up to 2 x 1.5 cm in size occur, which is rather unexpected in a meteorite with 10% Ni. It appears, however, that these fields, which are always rich in small rhabdites, are nothing other than the swathing kamacite rims around some large phosphide crystal which is situated above or below the polished surface.

In addition to the general shock hardening of the meteorite local cold working occurs. The kamacite and plessite are sheared violently and may be displaced 0.1-0.3 mm along a 50 μ wide shear zone. Both effects are certainly preatmospheric.

Terrestrial oxidation has selectively attacked the nickel-depleted kamacite along the phosphide crystals but has also converted the near-surface kamacite phase to limonite, particularly in the acicular plessite fields.

Narraburra is a medium octahedrite which is closely related to Augustinovka, Bear Creek, and Smith's Mountain. Its detailed structure, gross composition and trace element content are, however, sufficiently different to permit the conclusion that all these meteorites are independent falls.

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

186 g endpiece (no. 1754, 8 x 4 x 2.5 cm) } neighbor slices
97 g slice (no. 1754, 8 x 4 x 0.5 cm)

Nashville, North Carolina, U.S.A.

35°58′N, 77°58′W

One main mass and fragments, totaling about 18 kg, were found before 1934 near Nashville, Nash County (Hey 1966: 334).

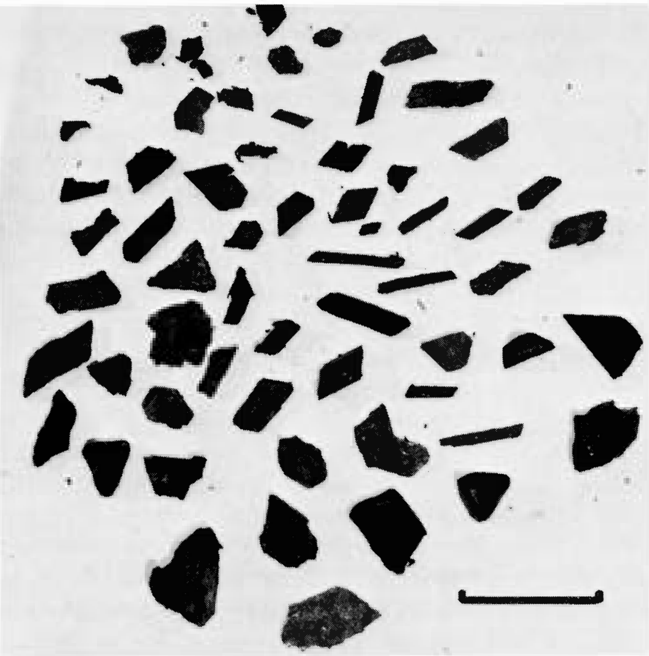

Figure 1218. Nashville (U.S.N.M. no. 894). The disintegrated fragments suggest that the original meteorite was an octahedrite. Scale bar 40 mm.

The samples examined by me (Tempe no. 206a, 266 g; Washington no. 894, 2,555 g) are badly disintegrated fragments; corrosion has attacked along octahedral interfaces and produced numerous octahedral fragments of gram size. Little can be learned about the structure except that it once was an octahedrite.

Nativitas Tlaxcala. See Santa Apolonia

Navajo, Arizona, U.S.A.

35°20′N, 109°30′W; 1,800 m

Coarsest octahedrite, Ogg. Bandwidth 10±5 mm. ε-structure. HV 250±40.

Group IIB. 5.49% Ni, 0.44% Co, 0.3% P, 55 ppm Ga, 180 ppm Ge, 0.46 ppm Ir.

HISTORY

A large mass of 1,500 kg was found in 1921 about 21 km north of Navajo, in Apache County. It was buried in talus at the foot of a ridge of Shinarump sandstone, but the finder, R.K. Thomas, stated that the mass had been covered by rocks to keep the white man or other tribes from finding it. According to him, it had been known to the Navajo Indians since 1600 (?) and was thought sacred. Prior (1927: 32) reported on the basis of a letter from Farrington, that Indian beads were found with the meteorite. Another mass, of 683 kg, was found in 1926 only 48 m northwest of the first mass. It was buried in soil by outwash from the neighboring ridge, but an upright rock standing at the location indicated that this mass had also been known for a long time. Both masses were acquired before 1927 by the Field Museum, but a full description, by Roy & Wyant, first appeared in 1949. However, brief reports had been published by Merrill (1922b) and Prior (1927: 32). Merrill, Farrington, Prior and Roy & Wyant all classified the masses as nickel-poor ataxites. However, as will be shown below, this classification is unfortunate, since the photomacrographs by Roy & Wyant (1949b) indicate that Navajo is an extremely coarse octahedrite related to Mount Joy and El Burro. Berkey & Fisher (1967) reported a range of 10-200 ppm chlorine in a grain separated from the corroded surface. The chlorine content reached a maximum along the grain boundaries which probably mainly reflects terrestrial contamination.

COLLECTIONS

Chicago (1,497 kg, 683 kg, and about 2.8 kg slices), Washington (518 g), Copenhagen (450 g), Tempe (4 g).

DESCRIPTION

The large mass (No. I) is roughly spherical and about 70 cm in diameter, while the small one (No. II) is elongated and measures 85 x 55 x 40 cm. Number I shows a deep fissure that extends half way around it and, locally, reaches a depth of 15 cm and a width of 3 cm. A smaller fissure extends subparallel to the first one. According to the Indians, there were previously many loose fragments of the meteorite in the fissures, but these were detached and kept as souvenirs. At least two of these fragments reached the U.S. National Museum directly from the finder, R.K. Thomas, and an examination shows that they constitute individual, finger-sized kamacite grains enveloped in schreibersite and separated by weathering. Presumably then, the deep fissures originated as fine, intercrystalline cracks

NAVAJO – SELECTED CHEMICAL ANALYSES

References	percentage Ni	Co	P	ppm C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Roy & Wyant 1949b, on No. I	5.37	0.41	0.28		1500	200	200					
Roy & Wyant 1949b, on No. II	5.60	0.47	0.30		800	300	100					
Wasson 1969, pers. comm.	5.50								55.0	180	0.46	

Also other analyses, by Nichols (in Roy & Wyant 1949b), confirm that the masses are identical in composition.

Figure 1219. Navajo (Chicago no. 2099). Shock-hatched kamacite with prismatic rhabdites. Etched. Scale bar 100 μ.

Figure 1220. Navajo (Chicago no. 2099). Fissured schreibersite crystal in a grain boundary. Shock-hatched kamacite on either side. Etched. Scale bar 100 μ.

created when the meteorite split in the atmosphere. Terrestrial corrosion attacked along the schreibersite-filled boundaries and gradually loosened up the texture so that individual grains could be chiseled out. Otherwise the masses are little corroded and still preserve shallow regmaglypts, 4-7 cm in diameter, even displaying, locally, slightly weathered fusion crusts.

The small, detached crystals in the U.S. National Museum show that Navajo is composed of a web of finger-sized kamacite individuals, each typically 1-2 cm across and 2-5 cm long. Thus, Navajo also closely resembles Mount Joy and El Burro in respect to the difficulty of comprehending the Widmanstätten structure on small sections. Taenite and plessite were not observed but will probably be found on larger sections, as is the case with Mount Joy and El Burro; and it is believed that Navajo in most respects will be found similar to these irons.

The kamacite displays a shock-hardened, coarsely-hatched ϵ-structure with a microhardness of 250±40. The hardness range is unusually large; there is an indication that each grain has a maximum along the edge (~ 290) and a minimum in the center (~ 210). The range may reflect a real difference in the disordering of the lattice brought about by shock wave attenuation and reflection along the schreibersite-loaded grain boundaries.

Schreibersite occurs mainly as 50-500 μ wide grain boundary precipitates, but occasionally a millimeter-sized, rhabdite-like inclusion is found. The schreibersite is monocrystalline but somewhat brecciated. The kamacite grains have numerous rhabdites, 3-15 μ across and 10-200 μ long; they are, of course, oriented according to the orientation of the individual kamacite units, and they are somewhat sheared by the ϵ-formation.

Cohenite is present as 40-100 μ wide, continuous rims around some of the schreibersite crystals, It is monocrystalline and has a microhardness (100 g) of 1050±25. Troilite was observed once as a 10 mm nodule with a 1.5 mm wide daubreelite bar.

Navajo is – far from being a homogeneous, ataxitic kamacite mass as assumed by Roy & Wyant – a coarsest octahedrite where the individual kamacite lamellae attain finger size and are separated by schreibersite-filled grain boundaries. It is closely related to Mount Joy and El Burro, but its hardness is larger, due to the shock-hardened ϵ-structure. It is also among the most nickel-poor irons to show a Widmanstätten structure. See also New Mexico.

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

87 g irregular fragments (no. 637, three pieces of 62, 18 and 7 g; gift from R.K. Thomas 1921)
30 g finger-shaped individual (no. 1610, 3 x 2 x 1 cm)
401 g slice (no. 5601)

Nazareth (iron), Texas, U.S.A.

34°31.6′N, 102°6.3′W; 1,100 m

Medium octahedrite, Om. Bandwidth 1.00±0.10 mm. ϵ-structure. HV 285±20.

Group IIIA. 8.90% Ni, 0.53% Co, about 0.35% P, 20.3 ppm Ga, 40.3 ppm Ge, 0.44 ppm Ir.

HISTORY

A mass of 11.3 kg was discovered in 1968 during the breaking out of a new quarter section of sod on the Elmer Shulte farm. The location was 4 1/2 miles northwest of Nazareth, in Castro County. The mass was acquired by the American Meteorite Laboratory and was cut and thoroughly described by Gooley et al. (1971). It was concluded that Nazareth was a moderately shocked medium octahedrite with several internal fissures.

COLLECTIONS

Tempe, Washington (315 g), Copenhagen (230 g).

DESCRIPTION

According to Gooley et al. (1971) the 11.3 kg mass measured 19.5 x 18 x 9 cm. When found, it showed what appeared to be fusion crust, but after some months storage in a vault, the complete exterior had almost peeled off or was in the process of peeling off.

A 14 g specimen which was kindly loaned to me by Dr. C.B. Moore, Tempe, confirms these observations. No fusion crust remains, and the heat-affected α_2 zone has also disappeared. However, a hardness traverse from the interior towards the present surface shows a significant drop from interior values of 285 to about 200 at the edge (hardness curve type I, where the left leg has corroded away). It may, therefore, be concluded that, on the average, 2-3 mm of the surface have been lost by weathering.

Etched sections exhibit a medium Widmanstätten pattern of straight, long ($\frac{L}{W} > 20$) kamacite lamellae with a width of 1.00±0.10 mm. The kamacite is rich in subboundaries decorated with less than 1 μ rhabdites. Due to shock loading above 130 k bar, all kamacite is of the crosshatched variety. It shows a high hardness of 285±20, with no indications of annealing.

Taenite and plessite cover about 30% by area. The taenite is tarnished in yellow-brown colors and exhibits hardnesses of 365±20. The plessite is of the comb and martensite varieties. A complete field will exhibit a tarnished taenite rim (HV 365±20) followed by a light-etching martensite which is developed parallel to the bulk Widmanstätten structure (HV 410±20). Then follows black-etching, unresolvable $\alpha + \gamma$ mixtures (HV 350±30) and finally, easily resolvable $\alpha + \gamma$ mixtures with hardnesses comparable to the adjacent kamacite lamellae.

Schreibersite occurs as scattered Brezina lamellae parallel to $\{110\}$ of the parent austenite phase. The lamellae attain sizes of 30 x 10 x 0.4 mm and are enveloped in 1.2-2.0 mm wide rims of swathing kamacite. Schreibersite is also common as 20-100 μ wide grain boundary veinlets and as 5-30 μ vermicular particles inside plessite where it substitutes for γ-particles of similar sizes. Rhabdites proper are absent. The bulk phosphorus content is estimated to be 0.35%.

Troilite occurs as small lenticular bodies that frequently are enveloped in a 0.2-0.5 mm wide rim of schreibersite. A typical troilite body in the polished section was 1.2 x 0.4 mm in size; it was monocrystalline but showed multiple twinning due to deformation, probably from the same cosmic event that shock-hardened the metallic phases.

Chromite was observed as idiomorphic crystals, for example as a 300 x 150 μ parallelepiped in the kamacite phase.

The mass is cosmically deformed as evidenced by the ϵ-structure and various offsets in the taenite and plessite fields. Several major and minor fissures are also present in the sections. The schreibersite crystals are brecciated and many adjacent α/α and α/γ grain boundaries are opened. After arriving on the surface of the Earth, terrestrial ground water had easy access to the interior of the meteorite along these preexisting fissures which may be cogenetic with the ϵ-formation. Near-surface schreibersite lamellae now occur as a breccia of angular fragments recemented by limonite. The fissured grain boundaries are conspicuous by their fillings of 10-200 μ wide limonitic veins.

Nazareth (iron) is a shock-hardened medium octahedrite which is related to Bartlett, Cleveland, Grant, Bald Eagle and Ilinskaya Stanitsa. It forms a transition member between the resolved chemical group IIIA and IIIB. Its relationship to the little known medium octahedrite, Floydada, allegedly found about 100 km in a southeasterly direction, should be examined on some occasion.

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

315 g slice (no. 5662)

NAZARETH – SELECTED CHEMICAL ANALYSES

Gooley et al. also found 0.3% and 0.8% P from two different pieces. This is what may be expected when schreibersite is irregularly distributed and only small chips of the meteorite are at disposal. From planimetry of 500 mm^2 the phosphorus content is estimated to be 0.35±0.05%.

	percentage			ppm								
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Gooley et al. 1971	8.75	0.53			40							
Wasson 1974, pers. comm.	9.04								20.3	40.3	0.44	

Nedagolla, Andhra Pradesh, India

18°41′20″N, 83°28′30″E; 100 m

Anomalous. Dendritic-cellular on a millimeter scale. HV 200±10.

Anomalous. 6.12% Ni, 0.38% Co, 0.02% P, 0.25% Cr, 0.7 ppm Ga, 0.02 ppm Ge, 4 ppm Ir. Also carbon in significant amount, as graphite, carbides and in solid solution.

HISTORY

A mass of 4.6 kg was observed to fall about 7 p.m. on January 23, 1870, at Nedagolla (or Nidigullam), six miles south of Parvatipuram, in the district of Vizagapatam (or Vishakhapatnam). The bolide traveled from north to south and was accompanied by a violent noise, compared to that of a collapsing house, followed by a series of rumbling sounds. The mass buried itself in a field in a hole, 50 cm deep. A man near whom it fell was stunned, and some other people received violent shocks. The meteorite was carried to the village temple, but it was recovered by the authorities; and about 1876 it was transferred to the British Museum. The circumstances of fall were described by Saxton (1870) and quoted by Flight (1887). Silberrad (1932) verified the place of fall, since various inaccurate coordinates had appeared in the works of Berwerth (1902: 6) and Ward (1904a: 1). Brezina (1885: 204 and figure 3) observed the heat-affected rim zone and established later (1896: 296) a "Nedagolla group" of ataxitic meteorites. Cohen (1897d; 1905: 67) gave a review of the literature and a full description. Berwerth (1905: 355) accepted Nedagolla's peculiar structure as genuinely cosmic, in contrast to the many ataxitic-metabolitic structures produced artificially by man's reheating. Later (1914: 1078) he changed his opinion and concluded that the structure was, after all, artificially altered. Owen & Burns (1939) found a well defined α-lattice parameter of 2.8625 Å. Axon (1962b) reexamined the meteorite and presented a photomacrograph which clearly showed that the mass was dendritically solidified before it entered the Earth's atmosphere. Axon (1968a: 598) reproduced the same photograph and extended the interpretation as showing the effects of a rapid, complete melting due to extraterrestrial shock. Nedgaolla thus presents an extreme case of shock alteration. Wai & Wasson (1970) showed Nedagolla to belong to those very few iron meteorites that have significant amounts of silicon (0.14%) in solid solution. It also had the lowest germanium concentration of any iron examined. Murthy et al. (1969) reviewed the older literature and gave two photographs.

COLLECTIONS

London (4,198 g main mass and 52 g fragments), Calcutta (215 g), Vienna (39 g), Washington (28 g), Copenhagen (26 g), Harvard (18 g), Chicago (9 g), Canberra (7 g), Paris (6 g).

DESCRIPTION

The mass is shaped like an oversized tongue and measures 16 x 11 x 6 cm. It is rather blunt at one end and pointed, or wedge-shaped, at the opposite end. The surface is covered with a thin, black crust which is rhythmically striated more or less perpendicular to the long direction. Only two very shallow grooves, about 2 cm in diameter, are present near the blunt end; otherwise the surface was smoothly ablated in the atmosphere. All material examined comes from the only cut performed, a 9 x 4 x 2 cm section taken from one of the long edges.

The meteorite could be termed an ataxite, which only means that no coarse structural elements are visible to the naked eye. Here, it will be designated anomalous. Careful preparation reveals a dendritic structure. The dendrites are 2-5 mm long, 0.2-1 mm wide and have armspacings of 0.1-0.4 mm, comparable to what is found in sand-cast iron-nickel-chromium alloys. The dendrites are apparently not oriented; no unambiguous orientation was found, at least on the sections examined, so the direction of cooling could not be established. The interstices between the primary austenite dendrites appear to be enriched in chromium and carbon. The concentration of microscopic, hard particles, 0.5-1 μ across, which may be chromium

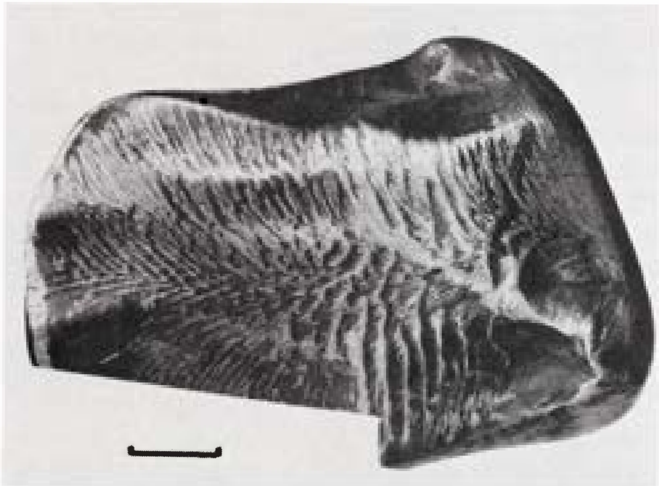

Figure 1221. Nedagolla (Brit. Mus. no. 51184). The main mass is tongue-shaped. The black fusion crust is rhythmically striated due to the eddies around the ablating body when it penetrated the atmosphere. A rectangular cut indicates where material has been removed for examination. Scale bar approximately 2 cm.

NEDAGOLLA – SELECTED CHEMICAL ANALYSES

Sjöström, in addition, reported 0.25% SiO_2, but silicate-bearing minerals were not observed. This analysis was recently confirmed by Wai & Wasson (1970). Reed (1969) examined the mass with the microprobe and found the matrix to have 6.0% Ni and 0.027% P in solid solution. No carbon analysis has been performed, but since free graphite is present and many structural elements are due to carbon, the content must be significant, perhaps 0.1%.

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Sjöström in Cohen 1897d	6.20	0.49	0.02		500							
Moss in Hey 1966	6.10	0.35				2580			1	2		
Cobb 1967	6.19	0.31					<1.5		<2.5		5.9	
Smales et al. 1967						2441	1.5	<1	0.73	0.03		
Wai & Wasson 1970	6.0					2600			0.65	0.005	3.4	
Crocket 1972											5.2	9.9

carbides, is significantly higher here than in the dendrite interior. There are many small, interdendritic pockets of daubreelite, 2-10 μ across, and graphite (e.g., 100 x 10 μ fillings), but silicates were not observed. There are also a few interdendritic shrinkage cavities of the same general size. It is interesting to note that a significant number of tiny graphite spherules are irregularly scattered with about one per mm^2 and are apparently a primary crystallization product. They often consist of a 10 μ perfect spheroidal nucleus composed of radiating graphite sheaves which have nucleated a 10 μ thick, outer fringe of unoriented, 0.5-1 μ graphite particles.

The structure leaves no doubt that Nedagolla at one time was completely melted and homogenized and then solidified and cooled, probably slightly covered by debris, at a rate comparable to the cooling of a 5 kg sand casting. Nedagolla, therefore, shows coring and is probably the one meteorite which most easily could be mistaken for a technological product. It is further remarkable by the absence of troilite. Perhaps a rapid separation of metal and sulfide occurred at the melting point.

The primary dendrites, which were composed of 40-100 μ equiaxial austenite grains, transformed to martensitic-bainitic structures, but the range in structure and microhardness indicates that homogenization was never completed and suggests that the rather rapid cooling continued to low temperatures where all diffusion stopped. The microhardness (100 g) is 200±10, but spotwise it increases to 260. No Neumann bands are found. Phosphides are not present, in harmony with the low analytical values quoted above.

The heat-affected rim zone is also conspicuous; it is mostly 2-2.5 mm thick, but at the pointed end increases to 8 mm due to the multisided heat influx during atmospheric flight. In this zone it may be observed how the carbides become gradually resorbed until they disappear completely in the exterior part. Simultaneously the austenite becomes better homogenized and, upon cooling, produces a nickel-chromium martensite with proeutectoid Widmanstätten ferrite growing from the austenite grain boundaries. The microhardness is 600±50. No wonder that Cohen (1897d: 120) found the meteorite difficult to cut, since it has such a high rim hardness and numerous carbides in the interior. The graphite nodules and the graphite in the interdendritic boundaries are also dissolved – the higher the temperature attained, the more thoroughly dissolved. In many places the graphite has disappeared completely but has left a carbon-stabilized austenite, which remained at low temperature as 20-40 μ white blebs surrounded by acicular martensite.

A hardness track perpendicular to the surface starts at 600±50, gives rather erratic values between 300 and 600 in the heterogeneous rim zone, and then drops abruptly to 200±10 at the macroscopically visible border between the dark-etching rim and the light-etching interior. The border corresponds to an isotherm during atmospheric flight of about 700° C.

The thin fusion crust consists of numerous layers of metal overlain by a 50-100 μ thick oxide film. The metal is deposited as 10-25 μ thick layers that discordantly swell and taper out and include 1-5 μ thick oxide films and globules which appear to be wüstite. The outermost oxide layer is two-phased, composed of wüstite and magnetite. The magnetite is precipitated along the wüstite grain boundaries and as 1-5 μ cubic skeleton crystals in the wüstite interior. It also constitutes the outermost 20-40 μ thick covering, presumably because atmospheric oxygen was able to fully oxidize the surface during the final flight stage.

Nedagolla is a unique meteorite. So far, it is the only iron which shows unambiguous evidence of rapid solidification from a melt, followed by rapid cooling to low temperature. It is difficult to reconstruct the original body, but it is almost certain that it was not a normal hexahedrite or a coarsest octahedrite, because the trace element concentration is significantly different. Nedagolla rather appears to be related to Santiago Papasquiaro which has also been cosmically reheated and shows somewhat similar Ga-Ge-Ir ratios. Still, there are large differences.

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

22.5 g part slice (no. 745, 4 x 1.2 x 0.5 cm)
5.5 g part slice (no. 2396, 15 x 13 x 4 mm)

Needles, California, U.S.A.

34°26.65′N, 114°49.95′W; 550 m

Fine octahedrite, Of. Bandwidth 0.47±0.06 mm. Neumann bands. Partly recrystallized. HV 220±15.

Group IID. 10.3% Ni, about 0.85% P, 77 ppm Ga, 93 ppm Ge, 4.8 ppm Ir.

Carsons Well is a synonym for Needles.

HISTORY

A mass of 45.3 kg was found in 1962 by Carroll and Nora Cantrell while on a rock hunting expedition 50 km southwest of Needles, in San Bernardino County. A sample of the mass was taken to the University of Arizona where the meteoritic nature was confirmed. It was briefly mentioned under the name Carsons Well by Anthony & DuBois (1963) and passed under this name into Hey's Catalog (1966: 91). After the meteorite had been acquired by the University of California in 1967, it was analyzed and described under the name Needles by Wasson & Kimberlin (1969) who did not realize that the other name had already been used. The authors gave photographs of the exterior and of etched slices and further provided a map, stating the exact coordinates. They discussed the striking similarity to Wallapai, the two fragments of which had been found in 1926 about 150 km further northeast, but they hesitatingly concluded that the masses were different. I bring here further observations to support that conclusion.

COLLECTIONS

Los Angeles (33 kg), Washington (10.7 kg).