dense, corroded areas, that are apparently kept in place by a grid of still uncorroded taenite.

Etched sections show a characteristic medium octahedrite structure of long ($\frac{L}{W} \sim 25$) kamacite lamellae with a width of 0.95±0.15 mm. Not all lamellae are straight, because a late grain growth on part of the α-phase has locally pushed the grain boundaries outward. The oriented sheen is silky, or like the sheen on a ripe field of barley, agitated by the wind. Such a macroscopic appearance is typical of the shock-produced hatched ε-structure, and examination under higher magnification confirms this conclusion. The subgrain boundaries of the kamacite are not marked and only decorated by a few 1-2 μ rhabdites. The ε-matrix appears to be loaded with a cloud of submicroscopic particles. A few, hard, thin plates of carlsbergite, typically 5 x 1 x 0.5 μ, occur as oriented precipitates in the kamacite. The microhardness of the shocked kamacite is 300±25.

Plessite covers about 30% by area, mostly in the form of very open meshed, almost resorbed comb and net plessite fields. The framing taenite rim is usually discontinuous. In the few larger wedges of plessite, the interior shows martensite and duplex $\alpha + \gamma$ mixtures with 1-2 μ individual taenite grains. The taenite rim frequently etches bluish-gray in irregular blotches. A few of the larger plessite fields are subdivided into irregular differently oriented cells, where the kamacite of each cell corresponds to the kamacite of the adjacent lamella.

Schreibersite is not visible to the naked eye but does occur as 5-10 μ wide and 50-100 μ long grain boundary precipitates. It is further present as 1-5 μ vermicular bodies, substituting for taenite in the plessite interiors.

Troilite was only seen as a few scattered 1-2 mm grains.

The heat-affected rim zone has long since been removed by corrosion, and grain boundary oxidation and selective attacks on the nickel-poorest part of the α-phase have occurred several centimeters below the present surface.

Harriman (Om) is a medium octahedrite which is related to such well known irons as Norfolk and Henbury. It is a normal member of group IIIA.

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

11.6 kg main mass (no. 1439, 20 x 13 x 10 cm)
376 g part slice (no. 1439, 11 x 10 x 0.7 cm)
276 g endpiece (no. 1439, 8 x 7 x 1.5 cm)

Hart Range, Northern Territory, Australia
23°S, 131°E

A 608 g fragment of a medium octahedrite was reported by McCall & De Laeter (1965: 65) as being in the Western Australian Museum.

Hassi-Jekna, Oued Meguiden, Algeria
28°57′N, 0°49′W

Fine octahedrite, Of. Bandwidth 0.47±0.07 mm. Neumann bands. HV 200±20.

Group IIIC. 10.5% Ni, about 0.25% P, 27 ppm Ga, 70 ppm Ge, 0.18 ppm Ir.

HISTORY

A mass of 1,250 g was purchased from Arab nomads by Captain Hélo, a French officer serving in southern Algeria, in 1890. The meteorite was donated to the Museum d'Histoire Naturelle in Paris and was briefly described by Meunier (1892; 1893a: 40). According to Hélo, the meteorite was observed to fall a few years earlier near an Arab tent camp which had been put up a few kilometers east of the Hassi-Jekna well. This well was

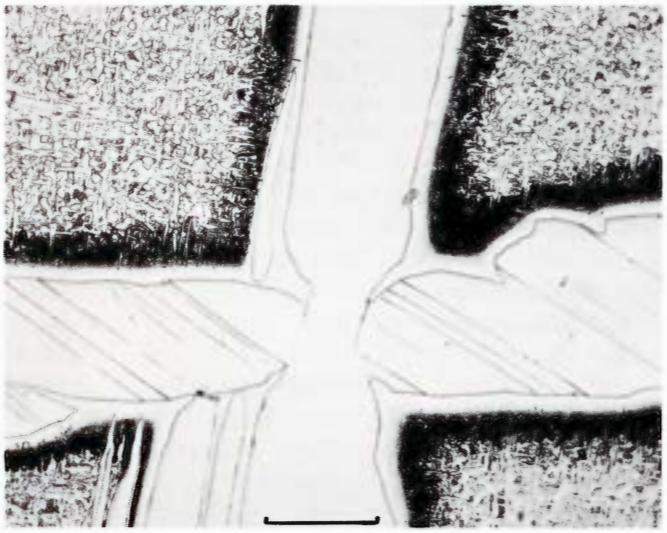

Figure 846B. Hassi-Jekna (Paris no. 2818). A fine octahedrite of group IIIC, related to Mungindi and Carlton. Four plessite fields with duplex interiors, and kamacite lamellae with Neumann bands. Etched. Scale bar 300 μ.

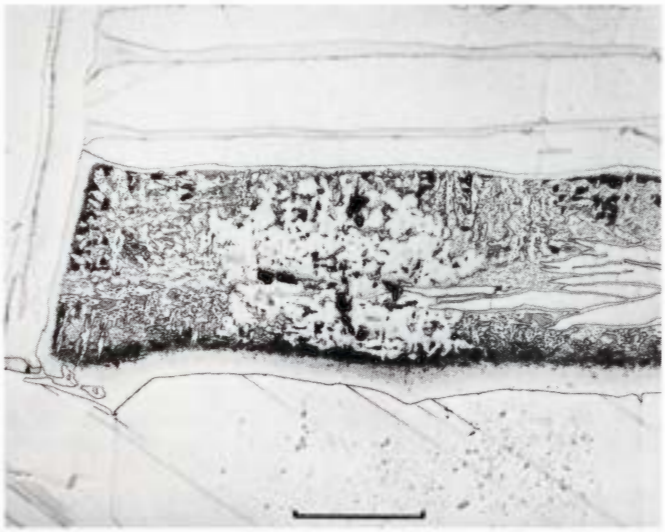

Figure 846C. Hassi-Jekna (Paris no. 2818). Plessite field with a haxonite rose, i.e., an intricate intergrowth of haxonite with fine particles of kamacite, taenite and schreibersite. Etched. Scale bar 200 μ.

situated in the Oued Meguiden valley, on the route between El Golea and Gourara, and had the coordinates given above.

"While the men (of the Chaanbas Mouadhi tribe) were away hunting, the women occupied in the camp heard a violent noise and saw an object hit the ground only 400 m away. The impact scattered the sand widely in all directions. On hearing the noise, the hunting party soon returned to camp and were told what had happened. At the indicated spot they found a funnel-shaped hole in the sand gravel and, excavating this, they found a black mass at a depth of about 80 cm. The discoverer, however, burned his fingers on the mass so he threw it away and they all disappeared, frightened. Next morning when they returned, they recovered from the sand the small aerolite, now completely cold." (Translation of a letter from Captain Hélo, in Meunier 1892).

Meunier described the small mass as irregularly pear-shaped, one half being smoothly hemispherical, the opposite being somewhat flattened and provided with small regmaglypts. A black fusion crust, about 0.5 mm thick, was noted, so it appeared to be a rather fresh fall as maintained by the Arabs.

A polished and etched section yielded Widmanstätten figures, which were compared to those of Schwetz, or rather Butler. Schreibersite and troilite were also present, and the specific gravity was found to be 7.67. Silicates were not observed. An unsatisfactory analysis gave 5.88% Ni.

This analysis was rightly criticized by Cohen (1905: 384), who reviewed the Hassi-Jekna case. Lacroix (1927c: 451) could add nothing, and the mass has unfortunately never been reexamined, but a modern analysis has given the results shown below.

COLLECTIONS

The whole mass of 1,250 g is in Paris. Apparently, a maximum of 50 g has been cut for inspection and analyses.

DESCRIPTION

The main mass is spherical, or slightly pear-shaped, with the dimensions 7 x 6 x 6 cm. It is smooth and covered with a black fusion crust. Near the pointed end a small area, measuring 35 x 20 mm and of 10 mm depth, shows irregular depressions. These are apparently regmaglypts, which were almost eliminated during the later part of the flight. In eight places the surface is scarred by characteristic small grooves (e.g., 10 x 1 mm and 2 mm deep) resembling irregular chisel marks and rosettes. The scars indicate where millimeter-sized schreibersite crystals were removed by preferential ablation in the atmosphere. The black fusion crust is partly worn off due to excessive handling by the original owners.

Sections through the pointed end disclose that Hassi-Jekna is a fine octahedrite. The kamacite lamellae are straight and long ($\frac{L}{W} > 20$) and have a width of 0.47±0.07 mm. The kamacite shows normal subboundaries and many Neumann bands. Its hardness is higher than 170, probably 200±20, but a final result could not be reached because the examined material came from a part of the mass that had been somewhat annealed during atmospheric flight.

Taenite and plessite cover about 50% by area. Comb and net plessite fields occur, but relatively large fields, e.g., 4 x 3 mm, of a duplex nature are more common. They have wide cloudy edges (H ~ 300±20), dark martensitic transition zones and easily resolvable duplex $\alpha + \gamma$ interiors. In

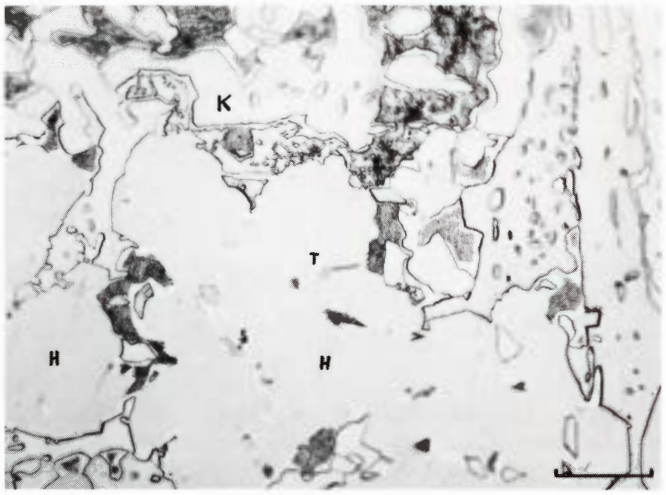

Figure 846D. Hassi-Jekna. Detail of Figure 846C. Haxonite (H), taenite (T), schreibersite (S), kamacite (K) and unresolvable plessite (gray). Etched. Oil immersion. Scale bar 20 μ.

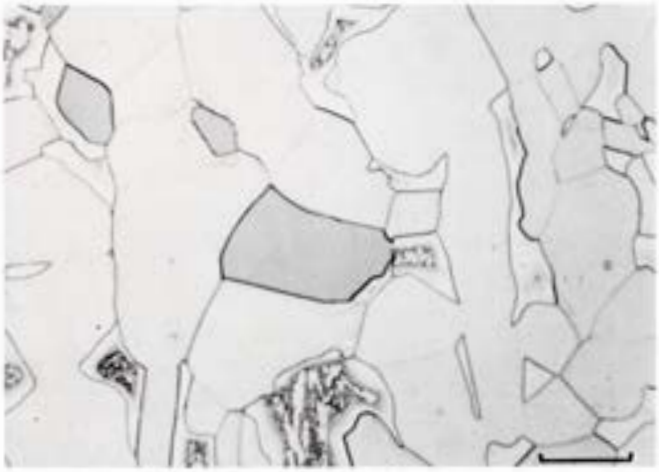

Figure 846E. Hassi-Jekna (Paris no. 2818). Open-meshed duplex plessite with four schreibersite particles (gray). These are often in contact with concave taenite islands, exhibiting unequilibrated interiors. Etched. Oil immersion. Scale bar 20 μ.

HASSI-JEKNA – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Scott et al. 1973	10.50								27.4	69.6	0.18	

about one out of four fields, the carbon concentration was so high that haxonite could precipitate late during the initial cooling period. The haxonite is intergrown with small taenite and schreibersite particles and exhibits hardnesses of 800±50. The haxonite roses sometimes occupy large areas, e.g., 400 x 300 μ, and may then be spotted with the naked eye because they are glossy and stand in high relief on a polished section.

Schreibersite is common as skeleton crystals and rosettes that reach sizes of 12 x 2 mm. Furthermore, it also occurs as 50-200 μ wide angular blebs located centrally in some kamacite lamellae and as 10-30 μ wide veins and irregular particles in grain boundaries and inside duplex plessite fields. The bulk phosphorus content may be estimated to be 0.25±0.05%.

Troilite, graphite and silicates were not observed.

Under the oxidic fusion crust, which shows magnetite and wüstite as usual, there is a thin fusion crust of dendritic metal. Occasional inclusions of fused dendritic oxides are also present. The heat-affected α_2 zone is 2-2.5 mm wide and has a hardness of 190±10. The recovered transition zone shows a minimum of 153±5; from there the hardness increases towards interior values that may be estimated to be 200±20, but could not be measured (hardness curve type II).

In the heat-affected rim zone the haxonite has decomposed. On polished, but unetched sections, the haxonite appears fine-grained under crossed polars. On etched sections the haxonite appears mottled gray, but optical microscopy was insufficient to identify the decomposition products that are probably graphite and unequilibrated ferrite. The adjacent kamacite etches dark due to the presence of martensitic-bainitic transformation products. The adjacent or included taenite particles show high-nickel, high-carbon acicular martensite plates.

Corrosion has superficially attacked the fusion crust and some of the cracked grain boundaries, but the general appearance is not inconsistent with the report that the meteorite was observed to fall in the 1880s.

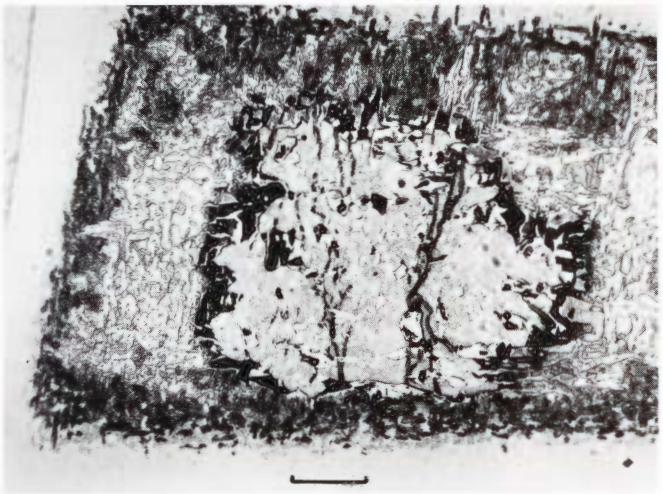

Figure 846F. Hassi-Jekna (Paris no. 2818). An altered plessite field in the heat-affected α_2 zone. The central haxonite rose is decomposed and enveloped by dark martensitic-bainitic rims. Etched. Scale bar 50 μ.

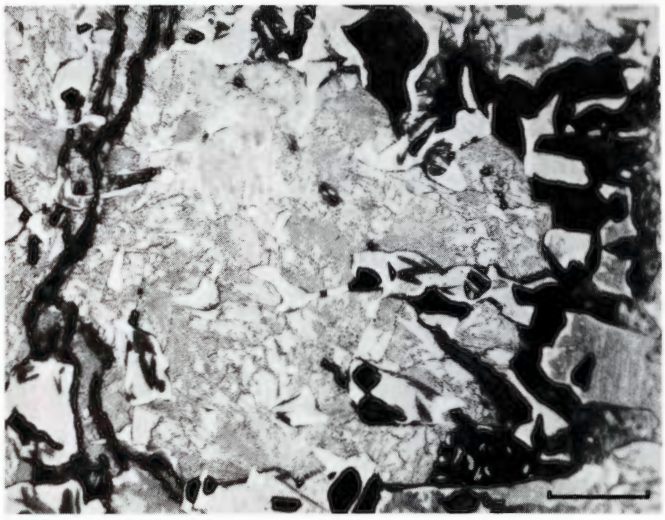

Figure 846G. Hassi-Jekna. Detail of Figure 846F. Decomposed haxonite with mottled appearance. Included taenite particles have, upon rapid cooling, developed acicular martensite plates (dark). Etched. Oil immersion. Scale bar 20 μ.

Hassi-Jekna is a well-preserved fine octahedrite which structurally is very closely related to Mungindi, Carlton and Edmonton (Kentucky). Also chemically it can be related to this group (IIIC), extending it to lower nickel levels than hitherto reported.

Hatfield, Arkansas, U.S.A.

34°29′N, 94°27′W

The only known specimen is a 21 g sample, said to come from near Hatfield in Polk County (Nininger & Nininger 1950: 57). The sample is now in Tempe (no. 488.1) where I compiled a few notes.

It is a 45 x 25 x 2 mm slice through a mass of unknown weight. Fusion crust and heat-affected α_2 zones are entirely lost by weathering, and the surface is slightly marred by hammering. Hatfield is a medium octahedrite with straight, long ($\frac{L}{W} \sim 20$) kamacite lamellae, displaying a width of 1.15±0.15 mm. Neumann

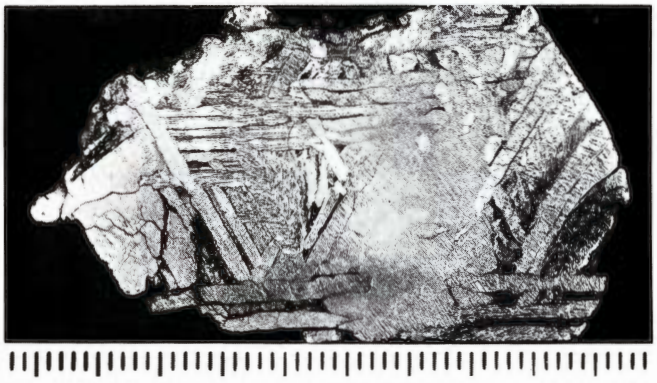

Figure 847. Hatfield (Tempe no. 488.1). The only known specimen of this meteorite. Since the cut is almost parallel to $(111)_\gamma$ the fourth set of Widmanstätten lamellae occupy an unusually large fraction of the surface. Deep-etched. Scale bar in millimeters. (Courtesy C.B. Moore.)

bands are well developed. Taenite and plessite cover about 1/3 by area. The bulk nickel content is estimated to be 8.5±0.5%.

Schreibersite is common as cuneiform skeleton crystals, e.g., 7 x 1.5 mm and 10 x 1 mm in size, enveloped in 1-3 mm wide rims of swathing kamacite. Schreibersite also occurs as 0.5 mm wide blebs centrally in some kamacite lamellae, and as about 50 μ wide grain boundary veinlets. The bulk phosphorus content is estimated to be 0.30±0.05%.

No other meteoritic minerals were observed during the cursory examination. It appears, however, that Hatfield belongs to the common medium octahedrites, exemplified by such well known irons as Bartlett, Cleveland, and Orange River.

Havana, Illinois, U.S.A.

40°20′N, 90°3′W

Fine octahedrite, Of. Bandwidth about 0.35 mm. Annealed kamacite. HV 240±25.

Group IIIC. 11.4% Ni, above 0.2% P, 20.5 ppm Ga, 21.6 ppm Ge, 0.3 ppm Ir.

Artificially annealed and cold-worked.

HISTORY

"In the summer of 1945, members of the Illinois State Museum under the direction of Thorne Deuel, Director of the Museum, excavated a group of Indian burial mounds in the Havana, Mason County area. Burial No. 10 in Mound No. 9 of this group yielded 22 rounded bead-like objects, composed of strongly oxidized iron, together with slightly more than 1000 ground shell and pearl or pearl slug beads. As the burial was evidently prehistoric and of Hopewellian age, it was at once conjectured that the iron might be of meteoric origin" (Grogan 1948).

Two complete rounded specimens and two fragments were thoroughly examined by Grogan who presented an exhaustive description and concluded that the beads were actually worked meteoritic material. Arnold & Libby (1951), who examined wood from the same Mound No. 9, found a C-14 age of 2,336±250 years, which confirmed the Hopewellian age. The Illinois burials are thus of approximately the same age as the burials discussed under Hopewell Mounds, situated 600 km farther east in Ohio, see page 656. Wasson & Schaudy (1971) analyzed the material and found it similar to Mungindi, belonging to group IIIC.

COLLECTIONS

Washington (12 g); Illinois State Museum.

DESCRIPTION

The small iron-bearing masses had cylindrical to flattened globular shapes and maximum transverse diameters of approximately 3/16 to 5/8 of an inch. Dr. Deuel and his associates first advanced the hypothesis that they were beads after observing that in the burial the metallic objects alternated with one or two disc-shaped, cut and ground shell beads and that their sizes varied in a manner indicating that all had been graded to size on a string.

Figure 848. Havana (U.S.N.M. no. 1466). Indian bead from a Hopewellian burial mound in Illinois. The meteoritic iron is hammered flat, then rolled to a cylinder through which the cord could be threaded. Deep-etched. Scale bar 3 mm.

Figure 849. Havana (U.S.N.M. no. 1466). A cut perpendicular to the one in Figure 848, but not extending through the center. The deformed kamacite lamellae suggest thorough working at elevated temperatures. Deep-etched. Scale bar 3 mm.

HAVANA – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Wasson & Schaudy 1971	11.37								20.5	21.6	0.3	

Laboratory study substantiated this hypothesis by disclosing a hole remaining part way through one specimen and central cores of porous limonite marking the probable sites of central holes in two others (Grogan 1948).

The sample examined here, a 12 x 10 mm section through approximately the center of a 15 x 12 x 8 mm ellipsoidal bead, fully supports the above conclusions by Grogan. The original hole was about 1.5 mm wide but is now filled with porous limonite. The exterior shape of the bead is only slightly altered since most of the 0.1-0.5 mm thick corrosion products have luckily remained in place. This is probably due to taenite lamellae which are only slightly altered and have locked the weathered kamacite in position.

Etched sections immediately reveal the meteoritic nature. Kamacite and taenite alternate and, although artificially altered, are easily recognized. The widest kamacite lamellae observed have widths of 0.25±0.05 mm. Since the material has been worked, this is a lower limit of the original kamacite bandwidth. From the deformations present it is estimated that the original bandwidth was 0.35±0.05 mm.

The original regular Widmanstätten structure is severely distorted due to the working. Most kamacite lamellae have been brought into a subparallel, concentric arrangement around the central hole of the bead. At one place there is a discontinuity, filled with limonite, suggesting that two edges of the metallic strip were brought together here in a lap joint.

The material has been both worked and reheated. The kamacite is an unequilibrated two-phase mixture of cold-worked and recrystallized α-iron with a grain size of about 20 μ and with finely dispersed 0.5-2 μ γ-particles. The typical α_2 transformation products are not present, indicating temperatures below 750-800° C. The microhardness varies appreciably but may generally be expressed as 240±25. The high hardness – if annealed or recrystallized alone this material would have shown a hardness below 170 – and the slightly distorted shape of the α-grains indicate that significant cold-work followed the last annealing. This would suggest that the Indians during the fabrication were not depending entirely upon cold-work but also applied intermediate annealing treatments.

The observations of the taenite and schreibersite phases support this idea. The taenite forms 10-50 μ wide ribbons and wedges. Original duplex plessite and plessite with carbide precipitates – compare, e.g., Edmonton (Kentucky) and Carlton – have disappeared and become homogenized by annealing. Some very wide plessite fields, 200 μ or more in cross section, still show slight heterogeneity, while most others appear yellow and structureless on an etched section. The microhardness of the taenite varies very much, from 220 to 360, mainly due to imperfect annealing and inhomogenous cold-work. The kamacite-taenite boundaries are serrated and diffuse, again suggesting significant annealing.

Schreibersite is present in limited amounts. The crystals were apparently originally 10-50 μ wide and up to 300 μ long. In the parent material larger schreibersite crystals were probably present, but such material may have been rejected by the Indians as too brittle, or alternatively, the surviving beads have been produced by the schreibersite-poor material between the primary schreibersite crystals. From structural observations it may be estimated that the bulk phosphorus content is at least 0.2%.

The schreibersite inclusions are all heavily brecciated due to cold-work. There are 2-5 μ wide reaction zones between schreibersite and kamacite, but melting is nowhere observed. We can, therefore, conclude that 1000° C was the absolute upper limit to the temperature applied during fabrication.

Troilite and other meteoritic minerals were not detected.

Although there is a very limited amount of the material, a surprising lot of information may be deduced from it. It is of meteoritic origin, and the parent material

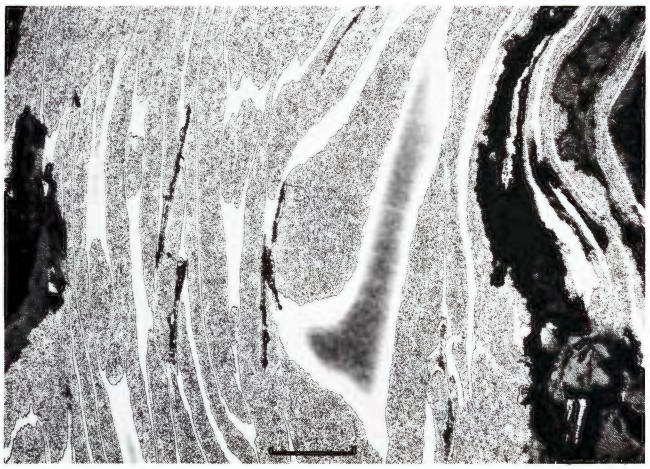

Figure 850. Havana (U.S.N.M. no. 1466). Deformed taenite and plessite, and late terrestrial corrosion products (black). Artificial reheating has annealed the taenite and transformed the kamacite to granulated α_2. Etched. Scale bar 400 μ.

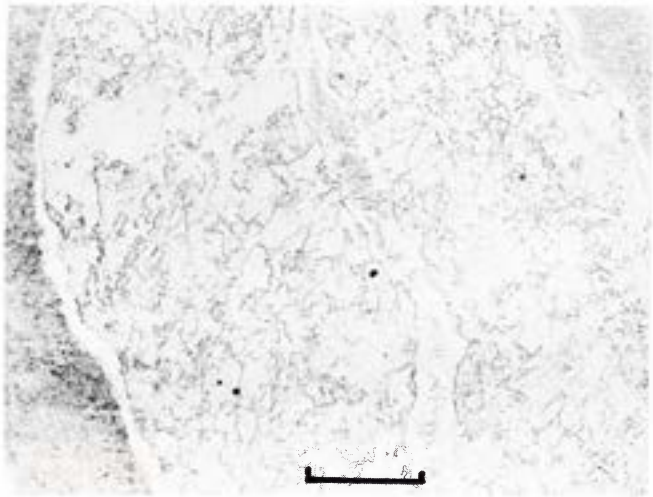

Figure 851. Havana (U.S.N.M. no. 1466). Indistinct unequilibrated α_2 structure in the kamacite lamellae. Vertically, taenite-plessite areas which are annealed. Etched. Scale bar 200 μ.

must have had a structure and chemical composition closely resembling Anoka, Mungindi, Carlton and Edmonton (Kentucky). About 300 B.C. the meteorite was worked by Indians of the Hopewellian culture into a number of ornamental beads. During fabrication they must have cold-hammered the material into sheets and bent it into cylindrical shape. In order to facilitate shaping, heat was applied once or more, before the final shape was attained. The microstructure suggests that the applied annealing temperatures may be bracketed between 500° C and 800° C, and most likely have been about 650° C. This is a temperature which we today know to be well suited for the annealing of cold-worked iron-nickel alloys. Surprisingly, no tools or weapons of worked meteorites seem to have been reported from the Hopewellian culture.

Specimens in the U.S. National Museum in Washington:
2 beads, totaling 12 g (no. 1466)

Hayden Creek, Idaho, U.S.A.

Approximately 45°N, 113°45′W; 2000 m

Medium octahedrite, Om. Bandwidth 1.00±0.15 mm. ϵ-structure. HV 300±20.

Judging from the structure a typical group IIIA iron. About 7.5% Ni, 0.5% Co, 0.1% P. Perhaps a fragment of Livingston (Montana).

HISTORY

A mass of 270 g was found by a prospector at the bottom of a 3.6 m deep shaft before the year 1895, possibly in 1891 (Hidden 1900; Ward 1900: 12; Berwerth 1903: 18). Hidden acquired a portion of the meteorite and quoted a letter from his informer, dated October 3rd, 1895: "The piece of supposed meteoric iron, when first found, was just twice the size of the part I send you. It was kidney-shaped, and in that condition would have been much more valuable, but the prospector who found it in the bottom of a 12-foot shaft on Hayden Creek, Lemhi County, Idaho, just above the United States agency ground, while prospecting for placer gold, wondered what he had found and went to work on it with a 4-pound hammer. This he kept up at odd times for weeks while in camp, and the first time he came down to the Agency shop, he laid it upon the lap of the anvil and with a 14-pound hammer succeeded in bending it one way, then turned it over and bent it the other way; this he kept up until he broke it in two. Finding it was not a nugget of gold, he had no further use for it, and I got it from him for a trifle."

Hidden made a considerable effort to secure also the other half, which eventually was acquired from a private collector. He noted that further enquiries among the miners did not bring additional material to light. Except for a brief description by Hidden (1900) and for various catalog entries, the meteorite is not described. Berwerth (1903) classified it as a medium octahedrite, which classification has been correctly adopted in later catalogs (Farrington 1915; Horback & Olsen 1965; Hey 1966). The meteorite was divided into a few samples and distributed between 1900 and 1903. Ward (1904a: plate 1) gave a photomacrograph of an etched section.

COLLECTIONS

London (77 g), Chicago (68 g), Vienna (61 g), New York (15 g).

ANALYSES

The meteorite is not analyzed. From the structural examinations below, I would estimate the mass to be composed of 7.5±0.2% Ni, 0.5% Co, and 0.10±0.02% P.

DESCRIPTION

Hidden (1900) restored the meteorite to a kidney-shaped mass with the maximum dimensions 78 x 33 x 20 mm. He noted that the silvery-white fracture surfaces rapidly became oxidized, so he supposed that the meteorite was rich in lawrencite. This appears, however, to be just another case of a weathered find, where the majority of the chlorine present is due to terrestrial contamination.

The specimen in the Field Museum, Chicago (Me489 of 45 g) was loaned to me for examination by Dr. E. Olsen. It is an endpiece measuring 50 x 40 x 8 mm. Its polished surface of 12 cm^2 is almost parallel to an octahedral plane of the Widmanstätten structure and probably represents the plane along which the finder forced the meteorite apart. It provided the easiest way of cleavage because it was beset with numerous limonitic corrosion products. The limonite may be observed to follow the α/α and α/γ grain boundaries of the Widmanstätten structure and often forms 0.1 mm wide veinlets. On the surface, only a discontinuous 0.1 mm thick oxide-shale is preserved; the rest presumably spalled off when the meteorite was worked by the finder. No fusion crust and no heat-affected α_2 zone is preserved, which is not surprising when the discovery place in the shaft is taken into consideration. No hardness drop was found during a traverse perpendicular to the surface. Consequently more than 4-5 mm on the average must have disappeared by corrosion.

The etched section displays a medium Widmanstätten structure of long ($\frac{L}{W} \sim 20$) kamacite lamellae with a width of 1.00±0.15 mm. The lamellae are straight except where the obvious hammering has bent them slightly. The kamacite etches to a hatched, contrastless ϵ-structure, indicative of a cosmic shock-intensity above 130 k bar. In harmony with this supposition, the kamacite is shock-hardened to 300±20. The kamacite is rich in subboundaries, decorated with $< 1\ \mu$ rhabdites. In one place there is an anomalously large kamacite grain, 10 x 5 mm, produced by late grain growth and resorption of taenite.

Taenite and plessite cover about 35% by area, mainly as comb and net plessite fields. The fields are very open-meshed, the taenite being almost resorbed. Dense networks of α/α grain boundaries with only a few scattered taenite blebs (1-5 μ across) still mark the interior of the

fields. The taenite lamellae etch yellow with a brownish stain and have hardnesses of 370±20.

Schreibersite occurs as 1-20 μ wide grain boundary precipitates and as 1-10 μ irregular blebs inside the degenerated plessite fields. Rhabdites are present in modest quantities as 1-4 μ prisms. The bulk phosphorus content is estimated to be 0.10±0.02%.

Troilite was only observed in minute quantities associated with daubreelite, e.g., as a 200 x 80 μ inclusion which was composed of thin (< 1 μ) parallel lamellae of alternating troilite and daubreelite. Daubreelite alone is somewhat more common, mainly as subangular particles ranging in size from 40 μ to 200 x 100 μ. Carlsbergite, the chromium nitride, occurs as hard rose colored platelets that measure up to 100 x 2 μ in the section. They are precipitated in a few distinct crystallographic directions in the kamacite phase.

The way in which the finder treated the meteorite, as noted on page 637, is easily revealed in the microstructure. Upon the hatched ε-structure, there is locally superimposed a plastic deformation with lenticular deformation bands. Likewise, 50 μ wide shear zones extend across the specimen and in many places displace taenite and plessite abruptly with 50-200 μ.

Hayden Creek is a shock-hardened medium octahedrite which belongs to group IIIA and is closely related to, e.g., Livingston (Montana), Davis Mountains, Morito and Wabar. It is interesting because of its considerable terrestrial age, since it was discovered by gold placer diggings at the bottom of a twelve-foot shaft.

In one more respect it may arouse some interest. While it is unrelated to other iron meteorites of Idaho, it is structurally so closely related to Livingston from the adjacent state, Montana, that it is impossible to tell individual samples apart. The Livingston mass was discovered in an Indian grave and had, therefore, presumably been transported some distance. Consider then, the interesting possibility that Livingston and Hayden Creek are fragments of the same parent body that landed in eastern Idaho in the remote past. While the smaller part was buried under gravel, the larger mass (1.6 kg) was found by Indians and transported about 200 km eastwards to Livingston.

Helt Township.

See Canyon Diablo (Helt Township)

Henbury, Finke River, Northern Territory, Australia

24°35′S, 133°10′E; 450 m

Medium octahedrite, Om. Bandwidth 0.95±0.10 mm. Neumann bands or reheated. Hardness range 170-290.

Group IIIA. 7.51% Ni, 0.45% Co, 0.09% P, 18 ppm Ga, 34 ppm Ge, 13 ppm Ir.

HISTORY

The Henbury meteorite and crater field is situated 11 km west-southwest of Henbury Cattle Station in the heart of arid Central Australia. The meteorites and the craters had been known for some time by the local residents, when in 1931 Alderman (1932) and Bedford (ibid.: 30) organized small parties in order to examine the craters and recover the meteorites. Alderman published a full report with maps of the crater field and photographs and sections of some of the craters. He recovered about 800 fragments, ranging from a few grams to 24 kg, and totaling 225 kg.

Much of Bedford's material was sent to the British Museum where it was fully described by Spencer (1933) with photographs of the exterior and of etched sections. The collection consisted of 647 pieces, ranging from 0.9 g to 132 kg, and totaling 424 kg. Spencer also described the

Figure 852. Henbury (Tempe. From left to right: no. S193x of 444g; no. 193.310 of 44g; no. S193 V of 173g). Three heavily deformed explosion fragments. The left one is almost divided in two but still adheres along a one cm wide metallic bridge. The two others show – on polished and etched surfaces – the diffused and sheared structures that are usually present in these small slugs. Scale bar 3 cm.

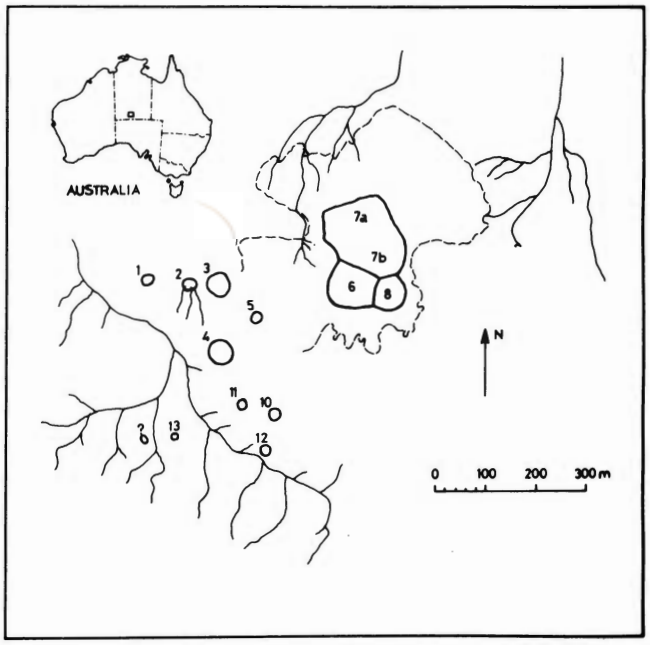

Figure 853. Henbury. A sketch of the crater field in Central Australia. Dashed line indicates approximate outer limit of ejecta from the larger craters. (From Milton 1968.)

shale-balls, formed by weathering of the iron meteorites, and the silicate-glass which was created at the moment of impact with the terrestrial rocks. He maintained that no fusion crust and no regmaglypts were present on the irons, although Bedford (1934) pointed out at an early stage that they were abundant on some specimens. They are thus clearly seen on Figure 10, Plate 15 in Spencer's original paper (1933). Nininger (1950b; 1952a: 182) also noted regmaglypts and fusion crusts when cutting a considerable number of Henbury irons.

The craters have been well examined. Alderman drilled crater No. 5 to a depth of 2.5 m, but found no meteoritic fragments. Bedford partly excavated craters Nos. 10, 11 and 13; and in the last mentioned he recovered four large masses of 132, 54, 11 and 2 kg at a depth of 2.1 m. About 20 kg of flaky iron shale was found surrounding and in between the masses with a thickness of 0.5-5 cm, demonstrating the fact that the four solid irons were clearly remnants of a single larger mass that had decomposed by corrosion (Spencer 1933: 391).

Rayner (1939) conducted a magnetic survey and concluded that, since no large magnetic anomalies were found, it was unlikely that significant masses should be buried. Small anomalies were found to be due to small iron fragments; an 18 kg mass was thus found in crater No. 5. Extensive geologic field work has been carried out by Milton & Michel (1965) and Milton (1968), who also produced a geologic map of the scale 1:360. According to Milton the bedrock consists of late Precambrian shale and siltstone, moderately indurated, and dipping homoclinally about 35°. The impact created anticlinal folds in the lower wall of the main crater and synclinal folds nearer the rim, but a large number of disturbances is present within the crater field. The smaller craters, e.g., Nos. 5, 11 and 13 are probably impact holes rather than explosion craters. Hodge (1965) has produced a collection of photographs, showing the craters from the air and in close-ups. Krinov (1966a:

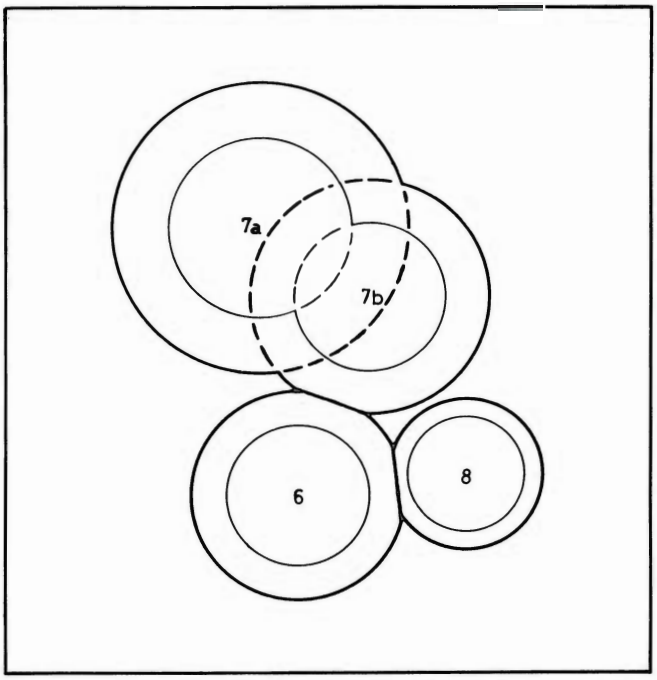

Figure 854. Henbury. Diagram showing relationship of the larger craters. Heavy lines indicate rim crests; light lines, base of walls. Dashed lines complete craters 7a and 7b as either would have been had the other not formed. (From Milton 1968.)

Crater	Average Diameter	Height of Rim	Depth of Crater	Remarks
		meters		
1	20	0	0	Nearly obliterated by erosion, but size indicated
2	24	0	0	by the extent of clay pans
3	69 x 50	0.5-1.2	3-5	Notable for the ray pattern of debris
4	66 x 57	0.4-1.5	3.5-6	One ray extends radially for 70 m
5	17	0-0.3	0-0.9	Nearly eroded away. Bored by Alderman. 18 kg mass found by Rayner
6	96 x 84	1.5-3	6	"Water Crater." The wall breached by a "wadi"
7a-7b	180 x 130	4-6	10-15	"Main Crater." Composed of two overlapping craters
8	69	1-3	1.5-6	Nos. 6, 7a, 7b and 8 form a cluster
9	?	0	0	Noted by Alderman, but doubtful
10	30 x 24	0.1-0.2	0.9-2.1	Partially excavated by Bedford
11	14	ab.0.1	ab.0.1	Partially excavated by Bedford
12	28 x 24	0.2-0.9	ab.2	Located on the south slope of a sandstone ridge
13	9 x 6	0	0.9	Excavated by Bedford, who recovered 200 kg iron fragments

The Henbury Crater Field. Data from Alderman (1932), Rayner (1939), Hodge (1965) and Milton (1968). Probably only Nos. 3, 4, 6, 7a, 7b and 8 are true explosion craters while the others are large impact holes.

11) discussed the crater field and reproduced several of the earlier pictures. He concluded that probably only Nos. 6, 7a, 7b, and 8 were true explosion craters. The Water Crater and some of the others show a sparse growth of mulgas (Acacia aneura) and saltbush (Atriplex species), while the surroundings are rather barren. The annual rainfall is about 200 mm, concentrated in the summer storms.

Buddhue (1957: 112) analyzed various portions of the oxides. The hard and compact, platy, blackish-brown oxide was found to be depleted in nickel. Perry (1944) gave a photomicrograph, and other macro- and micrographs have appeared in Nininger & Nininger (1950: plates 6, 7, 9), Spencer (1951) and Heide (1957: figures 20-23). Lovering & Parry (1962) included Henbury in their thermomagnetic analysis of iron meteorites. Wood (1964) took a nickel profile through a shock-reheated specimen; the plessite has lost its characteristic M-profile due to diffusion of nickel, and the specimen could not, of course, be used for an estimate of the primordial cooling rate. Reed (1965a, b; 1969) measured the composition of the various phases, evidently working with an insignificantly reheated specimen since he found a rather normal, high Ni-concentration (43%) in the taenite rims. The kamacite was found to have 6.7-7.2% Ni and 0.084% P in solid solution. Nichiporuk & Chodos (1959) studied the composition of the troilite nodules. Taylor & Kolbe (1965) and Taylor (1967) examined in great detail the glasses formed by impact and gave figures of the impactites and of the craters. Taylor concluded that most impactites were derived from a subgraywacke located in the double crater No. 7. Hodge & Wright (1971) examined the microscopic spherules separated from the soil around the craters. They found the spherules to be made up of a mixture of elements from the soil and the impacting meteorite. Comparing the spherules with those of other crater fields, they found the Henbury spherules to be unique in this respect.

Herr et al. (1961) measured the osmium and rhenium isotopes and found a solidification age of about 4×10^9 years. Gentner & Zähringer (1957) estimated the cosmic ray exposure age to be 1,200 million years, but the value was reduced to 780±320 million years by Lämmerzahl & Zähringer (1966). The concentration of ^{36}Cl, ^{10}Be and various noble-gas isotopes has been measured by Vilcsek & Wänke (1963) and Chang & Wänke (1969), while Voshage (1967) found too low a $^{40}K/^{41}K$ for a meaningful estimate of the cosmic age. Goel & Kohman (1963) and Kohman & Goel (1963) measured the ^{14}C and ^{36}Cl activities and estimated the terrestrial age to be less than 5,000 years. The natives have a legend that the craters were formed during a fiery explosion; they call the place "Chindu chinna waru chingi yabu" which means "Sun walk fire devil rock" (Alderman 1932: 31). Under the circumstances it is quite possible that Henbury is a witnessed fall.

COLLECTIONS

London (408 kg, maximum about 225 kg subdivided), Washington (230 kg, maximum 181 kg), Tempe (175 kg, maximum 26.2 kg), Adelaide (130 kg, maximum 26.7 kg), Sydney (57 kg, maximum 47.6 kg), Idar-Oberstein Heimatmuseum (36 kg individual), Tübingen (24 kg, maximum 23 kg), Chicago (19 kg, maximum 13.7 kg), New York (15 kg), Paris (7.5 kg), Budapest (7.35 kg), Calcutta (5.7 kg), Oslo (4.8 kg), Dorpat (4.6 kg), Canberra (2.6 kg), Los Angeles (2.45 kg), Perth (2.1 kg), Yale (2.1 kg), Harvard (2.0 kg), Ann Arbor (1.58 kg), Ottawa (1.37 kg), Amherst (1.10 kg), Moscow (950 g), Stockholm (530 g), Prague (500 g), Copenhagen (440 g), Belgrade (200 g). In 1967, Mason & Henderson saw several specimens, up to 50 kg in weight, in the possession of local residents (personal communication).

DESCRIPTION

It may be estimated that by now at least 1,200 kg iron meteorite fragments have been recovered from the crater field, most of the material having been collected from sites outside the craters. Alderman (1932: figure 2) gave a sketch map, indicating where the major part of his specimens were collected. From this and other reports, it appears that the fragments are narrowly concentrated within a few hundred meters of the craters. Individuals of 0.1-3 kg weight have,

HENBURY – SELECTED CHEMICAL ANALYSES

An analysis published by Lovering et al. (1957) and again used by Nichiporuk (1958), was apparently performed upon mislabeled material, since the Ga-Ge values are much too high to be explained by analytical errors.

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Alderman 1932	7.54	0.37	0.08	130	100							
Cobb 1967		0.50					180		18		14	
Smales et al. 1967						58	156	<1	15	36		
Wasson & Kimberlin 1967	7.41								17.4	34.2	13.8	
Lewis & Moore 1971	7.62	0.47	0.09	70								
De Laeter 1972									18.8			
Rosman 1972								2.0				
Scott et al. 1973	7.47								17.7	33.7	13	

Figure 855. Henbury (U.S.N.M. no. 1492). A perfect oriented sample with regmaglypts and fusion crusts. This type of material cannot have been involved in the cratering explosion but must have separated from the incoming main mass at high altitude. Smoked with NH_4Cl. Scale bar 5 cm. S.I. neg. M-22D. See also Figures 33 and 130.

Figure 856. Henbury (Prague no. 314). An irregular fragment of 349 g with regmaglypts. Terrestrial corrosion has formed the millimeter-sized pits. Scale bar 30 mm.

however, been discovered 800-1,500 m away, both north and south of the crater field (Mason, personal communication).

In the following description I have selected a number of typical specimens which together should cover the wide range of morphologies, sizes and structures.

The largest, unbroken individual known is the shield-shaped mass of 181 kg in Washington (no. 933). It measures 60 x 40 x 22 cm and is an oriented individual, very similar to Oakley, Cabin Creek and Hraschina. Unfortunately, there is no record of where it was found, but it must have had a long flight as an individual before it made its own impact hole. Its convex front surface is covered with beautifully sculptured regmaglypts, typically 4 x 1.5 or 3 x 2 cm in size and 0.5-1.5 cm deep and with rounded ridges in between. Along the edge are several ablation grooves, oriented parallel to the flight direction and typically 7 x 2 cm in size and 0.5 cm deep. The rear surface is relatively flat with little sculpturing. The mass is well-preserved and 0.1 mm thick fusion crusts are still present at the bottom of numerous regmaglypts. The mass is uncut but will probably exhibit an undistorted, unaltered Widmanstätten structure, similar to No. 2489A below. The much smaller monolith, No. 1492 of 3.85 kg, measures 17 x 10 x 6 cm and provides an almost perfect miniature of the 181 kg mass. Here, the front surface regmaglypts are 1-2 cm across and 0.5-1 cm deep, while the regmaglypts on the concave rear surface are

1.5-2.5 cm across and shallow, less than 0.5 cm deep. The two masses are virtually uncorroded, covered only with the characteristic, glossy, dark red-brown patina of little weathered desert finds. Other large monoliths, such as the 23 kg mass in Tübingen and the 15 kg and 11 kg masses in London (no. 1932, 1424; no. 1934, 135), also show numerous regmaglypts with some preserved fusion crust. However, depending upon the degree and character of soil covering, the morphology has been altered by later subsoil corrosion. The Tübingen and London specimens provide good illustrations of this process. The parts exposed to the air are virtually unaltered (less than 0.5 mm lost in 5,000 years), while the buried parts show large, shallow depressions with sharp ridges in between.

The U.S.N.M. specimens Nos. 882C (1.8 kg) and 2489B (1.4 kg) also show regmaglypts on the exposed parts and large shallow depressions on the buried parts. Specimen No. 2489A of 2.6 kg is somewhat more altered by weathering. The regmaglypts are partly rendered unrecognizable by a superimposed pattern of closely spaced pockmarks, each being 1-3 mm across and 0.5-1 mm deep. The deeply attacked underside meets the less attacked top side along an edge which in places is knife-sharp. Sections disclose, however, local remnants of heat-altered α_2 zones from an independent atmospheric flight. The specimen has on the average lost perhaps 3 mm by weathering. Its structure is typical for the unaltered Henbury specimens. The kamacite forms straight long ($\frac{L}{W} \sim 30$) lamellae with a width of 0.95±0.10 mm. There are numerous subboundaries with less than 1 μ phosphide precipitates. The Neumann bands are rather normal but may be somewhat decorated or discontinuous due to slight reheating. The hardness is 187±7 but increases in the heat-affected α_2 rim to 200±10 (hardness curve type II).

Taenite and plessite occupy 20-30% by area, mostly as very open-meshed comb and net plessite fields. The net plessite may exhibit large α-cells of various orientations. The taenite is tarnished and its interior may be martensitic or dark-etching, duplex. The taenite is relatively soft, HV 225±15, and the martensitic transition zones (HV 275±20) and the duplex, unresolvable interiors (HV 275±25) are also rather soft, indicating some annealing.

Schreibersite is present as 5-10 μ wide grain boundary precipitates and as a few 5-20 μ blebs in the plessite interiors. Some kamacite lamellae are quite crowded with 1 μ rhabdites, but since the bulk phosphorus content is only 0.09%, few phosphides are to be expected.

Quite a few chromium nitrides, i.e., carlsbergite, are present in the kamacite. They form oriented platelets, 50 x 1 μ in size, or up to 15 x 6 μ irregular pink precipitates in some grain boundaries.

Troilite occurs as 0.1-5 mm nodules and lenses. They have 10-400 μ wide parallel daubreelite lamellae, or they may be composed of a stack of parallel troilite and daubreelite lamellae, each only 1 μ thick. The troilite is, however, shock-melted and has partially destroyed the daubreelite. Various stages may be distinguished, from partially melted troilite with passive 0.1-0.4 mm troilite blocks with undulatory extinction, to completely melted troilite which has dissolved the surrounding metal and created iron-sulfur eutectics of 1 μ grain size. In these cases the troilite may be injected up to 0.4 mm out into adjacent grain boundaries which are split open for a still wider distance.

Some specimens, e.g., No. 882B, show recrystallized kamacite around the shock-melted troilite and polygonization in the kamacite farther away. The recrystallized grains are 0.1-0.3 mm across and contain new generations of Neumann bands, independently oriented with respect to the previously existing ones. There is a distinct hardness gradient in the kamacite, from 170 near the troilite to 187 about 4 mm away, showing that the amount of energy available for recrystallization and recovery was at a peak in the vicinity of the point-melted troilite.

The schreibersite is surrounded by 1-2 μ wide reaction zones, and the rhabdites are partially resorbed. Several cracks are present along the Widmanstätten planes; they

Figure 857. Henbury (U.S.N.M. no. 943). A heavily deformed and sheared fragment of 3.4 kg from the cratering explosion. The surface shows gouging and tearing as a result. Scale bar 35 mm. S.I. neg. 1629A.

Figure 858. Henbury (U.S.N.M. no. 882). Typically distorted and annealed structure of the small explosion fragments. Etched. Scale bar 200 μ. (Perry 1944: plate 8.)

are, of course, now partly filled with terrestrial corrosion products.

The discussed structures appear to be the basic structures of Henbury before its entering the atmosphere. They correspond closely to what is present in a number of other octahedrites, and it is believed that they represent a very old event, possibly the shock and associated heating when Henbury was dislodged from its parent body. The large number of internal cracks created at this event in the large body may have contributed significantly to an early breakup in our atmosphere whereby many large and small specimens, during a long independent flight acquired the characteristic sculpturing of regmaglypts and flutings. The Neumann bands in the recrystallized regions may date from the atmospheric breakup.

The following modifications appear to be due to the cratering impact. Specimen No. 882A of about 1 kg is a distorted fragment with no visible α_2 zone. It is deeply corroded into the interior along the marked, branched shear zones which almost divide the specimen in two. The Widmanstätten structure is violently deformed. The kamacite shows lenticular deformation bands and the Neumann bands are twisted. The shear zones are 50-200 μ wide, and where the shear energy reached a maximum, the kamacite was able to recrystallize to 1-10 μ irregular grains. The taenite shows incipient decomposition, with tiny 1 μ windows. Due to cold-working the kamacite shows a hardness range of 225-290. In the narrow, recrystallized zones it drops to 185±10.

Several other specimens show violent deformations like those of No. 882A, e.g., No. 943 of 3.4 kg, which is a flat explosion fragment with razor-sharp edges, locally overturned. This particular specimen has a slickensided surface from shear-rupturing, and it is covered by a thin fusion crust formed when it was hurled away from the impact site. The whole specimen is unique but corresponds closely to the numerous Imilac specimens with slickensided surfaces; see page 1398.

The numerous common small slugs (no. 3218-24) represent the ultimate stage in solid state alteration during cratering impact. Many of the fragments have ragged edges and protruding spikes. A small slug, 5 x 3 x 2 cm in size and weighing 100 g (marked "2"), is typical. The exterior shows bent and twisted ears, indicating a violent rupturing from the impacting main body. On sections, the Widmanstätten structure is seen to be distorted and partially resorbed. A tapering fissure almost divides the mass in two smaller fragments. The kamacite is completely recrystallized, or alternatively, has been through an $\alpha \rightarrow \gamma \rightarrow \alpha_2$ transformation. The hardness is as low as 170±5. The taenite is decomposing, being cavernous with 1-2 μ angular windows of kamacite. Shear of the order of 0.1-0.2 mm occurs everywhere, and the windows are frequently – and surprisingly – deformed with the taenite, which evidently formed before the shear took place.

The schreibersite and the rhabdites are almost fully resorbed. The chromium nitrides are little affected but do show faulting and bending. The troilite is smeared out in 100 μ wide and very long plates along the shear zones. It is micromelted and solidified with iron to spongy eutectics which are now rather sensitive to weathering. As a result of the cratering impact, a substantial part of the main masses melted and vaporized. Some of this material may now be identified as minute iron-nickel globules embedded in the impactite glasses. Full descriptions of the impactites have been given by Spencer (1933) and Taylor (1967).

A few shale-balls, similar to those of Canyon Diablo, Boxhole and Wolf Creek, have been found. They have been recovered from some depth under the present surface and represent a late stage in weathering. Little, if any, unoxidized iron is still present. A typical shale ball (no. 885) of 338 g measures 9 x 7 x 4 cm and exhibits a bread crust structure with centimeter-deep fissures and grooves.

Henbury is a rather normal medium octahedrite, related to Boxhole, Kenton County, Cape York, Haig, and Wabar. The structural details and those of the chemical composition are sufficient to justify treating Henbury and Boxhole as independent meteorites, despite the fact that both impacts happened in Central Australia about 5,000 years ago (Kohman & Goel 1963). Essential differences are the gallium-germanium-iridium values, particularly the last mentioned, the phosphide content and the ϵ-structure (HV 310) of Boxhole versus the somewhat annealed Neumann bands (HV 187) of Henbury. Henbury, like Wabar, is interesting because of the complex breakup which produced a few large crater forming bodies and a shower of independently falling fragments which had time to develop regmaglypts fully and only made impact holes. Such fragments would be expected to be present at a considerable distance from the crater field.

Henbury is interesting, too, because it displays various degrees of weathering, which over about 5,000 years, ranges from virtually no removal of iron to complete disintegration to shale-balls. The major factor in producing this range

Figure 859. Henbury (U.S.N.M. no. 882 – three pieces – and no. 943, below). Typically distorted explosion fragments. Twisted, with ears and razor-sharp edges. The one below is a cross section of Figure 857 and shows the indistinct distorted and annealed structure. Scale bar 50 mm. S.I. neg. 1630 and 1629B.

does not appear to be structure or reheating phenomena, but mainly depth of burial and access of water.

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

14.1 kg (no. 862)
7.0 kg on 9 individuals (no. 882)
180.9 kg shield-shaped individual (no. 933, 60 x 40 x 22 cm; from Bedford 1935)
3.4 kg flat fragment (no. 943, 22 x 8 x 5 cm)
3.85 kg monolith (no. 1492, 17 x 10 x 10 cm)
1.43 kg monolith (no. 2489B, 10 x 8 x 6 cm)
2.62 kg monolith, now cut (no. 2489A, 20 x 6 x 4 cm)
1.83 kg 6 pieces (nos. 2134, 2271, 2809, 2810, 2811, 5300)
1.97 kg 144 pieces (nos. 3218-3221, mainly explosion fragments)
9.02 kg 253 pieces (nos. 3222-3224, 3226, mainly explosion fragments)
3.58 kg 300 pieces of impactite (no. 3225). Nos. 3218-3226 were collected by E.P. Henderson and Brian Mason in 1963.
900 g shale-balls and some meteoritic glass (nos. 883-885)

Henbury (Basedow Range), Northern Territory, Australia

25°6′S, 132°33′E

Medium octahedrite, Om. Bandwidth 1.00±0.20 mm. Neumann bands. HV 185±10.

Group IIIA. 7.44% Ni, 0.48% Co, < 0.1% P, 19 ppm Ga, 34 ppm Ge, 11 ppm Ir.

HISTORY

A mass of probably only a few kilograms weight was found four miles from Willbia Wells along the south side of Basedow Range, Central Australia, and was considered years ago by Hodge-Smith to be one of the Henbury masses that had been transported by human agency, most likely aboriginal (letter in the Smithsonian Institution of April 1, 1958, from Dr. R.O. Chalmers, Australian Museum, Sydney). Weight and date of find were not given. Lovering et al. (1957), who presented an analysis, considered it an independent fall, and it is now listed separately in, e.g., Hey's Catalog (1966).

COLLECTION

Washington (246 g).

DESCRIPTION

The specimen in the U.S. National Museum is weathered. The fusion crust and the heat-affected α_2 zone have disappeared, and the surface is covered by a 0.5-1 mm thick limonitic crust.

Etched sections display a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 20$) kamacite lamellae with a width of 1.00±0.20 mm. Neumann bands are present, and the microhardness is 185±10. The taenite and plessite fields are of the open-meshed comb and net types, and very degenerated, with discontinuous taenite rims.

Schreibersite only occurs as rare, 2-5 μ wide veinlets in the grain boundaries or as tiny grains in the plessite interiors. The bulk phosphorus content is estimated to be below 0.1%. A few elongated troilite nodules, typically 2 x 0.5 mm, are present locally, and minute inclusions, 20-50 μ across, of rounded, bluish grains may be daubreelite.

A peculiar feature, which is best observed on a polished section, is the profusion of hard platelets, typically 15 x 3 x 0.5 μ, which occur in the subboundaries or as oriented precipitates in the kamacite matrix. They were shown to consist of a chromium nitride, carlsbergite (Buchwald & Scott 1971), and are particularly common in the phosphorus-poor group IIIA irons, like Henbury, Denton County, Madoc, and Rancho de la Pila, although they are also found in other groups.

Henbury specimens vary somewhat in structure as seen from its description. The typical Henbury corresponds, however, in all details to Basedow Range. Since, furthermore, Basedow Range has, within analytical error, the same main and trace element composition as Henbury, it is difficult to escape the conclusion that Basedow Range, as already assumed by Hodge-Smith, is a transported specimen from the Henbury shower. Basedow Range is about 85 km southwest of the Henbury craters.

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

246 g endpiece (no. 1751, 6 x 5 x 2 cm)

Hex River, Cape Province, South Africa

33°19′S, 19°37′E

Hexahedrite, H. Single crystal larger than 40 cm, partly recrystallized. HV 164±6.

Group IIA. 5.64% Ni, 0.46% Co, 0.25% P, 60.7 ppm Ga, 181 ppm Ge, 4.4 ppm Ir.

HISTORY

A mass of about 61 kg was found in 1882 in the Hexrivierberge about 125 km northeast of Cape Town. It was acquired for the Vienna Museum and described by Brezina (1885: 218; 1887: 289; 1896: 291), who also gave several figures of the exterior and of etched sections. Cohen (1905: 222) gave a thorough description of the structure, accompanied by analyses of the matrix and of phosphides isolated from the matrix. He observed scattered green

HENBURY (BASEDOW RANGE) – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Lovering et al. 1957	7.42	0.48				88	187		15	30		
Scott et al. 1973	7.45								19.1	34.5	11.0	

pleochroic augite resembling prisms, also bluish somewhat stained grains, as well as colorless grains with high birefringence. Perry (1944) gave two photomicrographs of the rhabdites and of allegedly troilite-daubreelite inclusions.

The oxidized crust was found to consist of magnetite with a small amount of wüstite (Marvin 1963). Ureyite, $NaCrSi_2O_6$, was reported as a new pyroxene mineral by Frondel & Klein (1965), who found polycrystalline, emerald-green aggregates, 0.1-0.5 mm in size, associated with daubreelite; this is probably the green mineral previously reported by Cohen. Reed (1969) determined the Ni and P concentrations in the kamacite and found 5.3% and 0.066%, respectively.

COLLECTIONS

Vienna (main mass of about 31.2 kg, and 6.6 kg slices), New York (2,515 g), Budapest (2,500 g), Chicago (694 g), Washington (582 g), London (530 g), Dorpat (337 g), Cape Town (300 g), Helsinki (296 g), Paris (289 g), Amherst (238 g), Tempe (182 g), Prague (182 g), Stockholm (175 g), Bonn (169 g), Strasbourg (121 g), Vatican (108 g), Harvard (94 g), Breslau (89 g), Berlin (80 g), Rome (66 g), Sarajevo (62 g), Yale (46 g), Ottawa (44 g), Leningrad (29 g), Hamburg (27 g), Dresden (25 g).

DESCRIPTION

The average dimensions of the irregular "jawlike" mass were approximately 45 x 20 x 20 cm. The mass was cut lengthwise into two halves; one part was further subdivided, while the other half was polished and etched. It is now on display in Vienna. The surface is boldly sculptured with sharp edged cavities, ranging from 1 to 8 cm in diameter, assumed to be atmospheric regmaglypts by Brezina and Cohen. This is, however, very doubtful; it appears that they are rather the result of prolonged terrestrial weathering. The fusion crust and the heat-affected α_2 zone are corroded away and a centimeter thick skin is estimated to have been removed from most of the meteorite by weathering, possibly at a different rate on the top and the underside of the mass.

Etched sections display a hexahedrite structure. Conspicuous, parallel rows of phosphide plates, easily visible to the naked eye run across the sections. The matrix is relatively bright-etching around the larger phosphides in the rows, while it rapidly attains a dull appearance between the rows due to the large number of small rhabdites here. The rows are actually parallel planes which are densely populated with plate-shaped rhabdites, 0.5-4 mm long and 0.05-0.2 mm thick. Over a length of 40 cm, 25 planes were counted with irregular intervals of 5-30 mm. It appears that another set of parallel planes, cutting the prominent ones obliquely, is also present. The rhabdites have sharp facets, are frequently branched, and then polycrystalline, each branch being an independent unit. They are sometimes "hollow," that is, enclosing a long nucleus of kamacite. The smaller rhabdites between the parallel planes are normal prismatic rhabdites, 5-20 μ thick, and rather evenly dispersed.

The kamacitic matrix is loaded with subboundaries in irregular, intricate networks that are often decorated with 0.5 μ precipitates of phosphides. The original Neumann bands have been modified by annealing and precipitation of 0.5-1 μ phosphides along both sides. They are subdivided in short cells and occasionally recrystallized. Well defined recrystallized ferrite units, 10-50 μ across, occur particularly at Neumann band junctions and around some of the larger rhabdites. The hardness of the kamacite is uniformly low, 164±6.

In several places cohenite ghosts were observed: Rhabdite crystals enveloped in recrystallized ferrite with

Figure 860. Hex River (U.S.N.M. no. 311). Typical hexahedrite with rhabdite platelets in parallel zones. Troilite shock-melts (black) are also present. Deep-etched. Scale bar 20 mm. S.I. neg. M-1444.

HEX RIVER – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Lovering et al. 1957		0.47				30	105		45	143		
Moore et al. 1969	5.69	0.46	0.25	65	25		150					
Wasson 1969	5.59								60.7	181	4.4	

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

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

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

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

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

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

Hill City, Kansas, U.S.A.

39°28′N, 99°58′W; 750 m

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

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

HISTORY

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

COLLECTIONS

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

DESCRIPTION

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

HILL CITY – SELECTED CHEMICAL ANALYSES

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