Schreibersite is present as $10-50 \mu$ wide grain boundary precipitates and as $5-50 \mu$ irregular blebs inside the plessite. Rhabdites occur as $14 \mu$ thick tetragonal prisms.

Hard oriented platelets of the chromium nitride, carlsbergite, mentioned under Schwetz and Cape York, are quite common and $10 \times 1 \mu$ in size.

Troilite occurs as $0.5-15 \mathrm{~mm}$ nodules and as lenticular bodies, typically $5 \times 4 \times 0.8 \mathrm{~mm}$ in size. Daubreelite constitutes $10-20 \%$ of the inclusions; and $10-20 \mu$ thick, discontinuous schreibersite precipitates may also be found. The troilite is monocrystalline with a few lenticular twins from slight plastic deformation.

In the following I shall point out the facts from which it is possible to conclude that the mass has been artificially reheated.

The metallic matrix shows both by its hardness range and its optical appearance that an incomplete homogenization has occurred. The rhabdites are dissolved to varying degrees, and recrystallization and $\alpha_{2}$ formation have occurred in various specimens. The taenite has lost its high hardness ( $\sim 350$ ), a loss which will occur during reheating for as brief a period as 15 minutes at $550^{\circ} \mathrm{C}$; compare page 94. The specimen No. 191 in Prague is rather informative in this connection. It is a full slice of $13 \times 10 \times 0.15 \mathrm{~cm}$ through the mass, and it shows a thermal gradient. It exhibits recrystallized material at one end - but Neumann bands at the other end - in a fashion much related to Kingston.

A close examination of polished sections reveals that the hydrated corrosion products have reacted with the meteoritic minerals. Laceworks, $5-50 \mu$ wide, are present along the interface between limonite and kamacite, and in the limonite itself there are numerous metallic beads, $0.5-1 \mu$ across. The interface between schreibersite and limonite now forms a $2-5 \mu$ wide, creamcolored zone, but the phosphides are unmelted. The troilite is partially recrystallized to angular blocks, $10-100 \mu$ across, that follow the previous corrosion fissures. A similar structure was shown in Rodeo, Figure 1455.

It is impossible to escape the conclusion that the mass was reheated - perhaps in a primitive fireplace - and attained a thermal gradient from perhaps $850-500^{\circ} \mathrm{C}$ across the mass. Equilibrium conditions were not reached before the mass was again cooled.

Verkhne Udinsk is a medium octahedrite which, except for its reheating, is closely related to Cape York, Casas Grandes, Schwetz and Augusta County, and, as these, belongs to the chemical group IIIA.

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

36 g part slice (no. $1179,4.5 \times 2.5 \times 0.7 \mathrm{~cm}$ )

Vicenice, South Moravia, Czechoslovakia
$49^{\circ} 13^{\prime} \mathrm{N}, 15^{\circ} 48^{\prime} \mathrm{E}$

A mass of 4.37 kg , buried 0.8 m deep in clay, was found in 1911 near the village of Vicenice (Meteoritical Bulletin 1964, No. 31). A preliminary examination indicated that it was a medium octahedrite. The material is apparently in the University in Brno.

Victoria West, Cape Province, South Africa $31^{\circ} 42^{\prime} \mathrm{S}, 23^{\circ} 45^{\prime} \mathrm{E}$

Fine octahedrite, Of. Bandwidth $0.22 \pm 0.05 \mathrm{~mm}$. Decorated Neumann bands. HV $170 \pm 10$.
Anomalous. $12.0 \% \mathrm{Ni}$, about $0.6 \% \mathrm{P}, 15.3 \mathrm{ppm} \mathrm{Ga}, 31.4 \mathrm{ppm} \mathrm{Ge}$, 0.02 ppm Ir.

The whole mass has been artificially reheated to about $900^{\circ} \mathrm{C}$.

## HISTORY

A small mass of 6-7 pounds was briefly mentioned by Gregory (1868). It was said to have fallen in 1862 at Victoria West and had later been acquired by the South African Museum in Cape Town. According to a letter in the British Museum (Hey 1966: 507), the mass was allegedly observed to fall in 1860 by a Hottentot on a farm 30 miles southwest of Victoria West. Similar information was obtained by Smith (1873) and Cohen (1905: 293) who gave the locality as Treurfontein. Numerous sets of different coordinates have been presented by Cohen (ibid.), Ward (1904a) and Brezina (1896). The coordinates above are those of Hey (1966), but I have not been able to confirm them on available maps.

As will be shown below, the meteorite is so corroded that it is out of the question that it could have fallen in 1860 or 1862 . A similar conclusion was already reached by Brezina (1893: 164). However, most authors, e.g. Hey (1966), Frondel (1965) and Horback \& Olsen (1965) still accept that the meteorite was an observed fall.

Tschermak (1871) and Smith (1873) gave brief descriptions, and Cohen (1905) gave further details. Brezina \& Cohen (1886-1906, plates $12-14$ ) presented eight photomacrographs of the specimen in Vienna; in their description


Figure 1851. Victoria West (Copenhagen no. 1905, 1731). An anomalous fine octahedrite. Artificial reheating has granulated all kamacite. Etched. Scale bar $400 \mu$.
the iron is called "äusserst eigenthümlich," which is quite correct. Buchwald (quoted in Hey 1966: 507) pointed out that the "extreme anomality" was at least partly the result of an artificial reheating.

## COLLECTIONS

Cape Town (about 1 kg ), Museum of Practical Geology, London ( 227 g ), Calcutta ( 224 g ), Harvard ( 181 g ), Vienna ( 172 g ), London ( 142 g ), Stockholm ( 83 g ), Berlin $(46 \mathrm{~g})$, Washington ( 33 g ), Chicago ( 17 g ), Copenhagen $(4 \mathrm{~g})$. Small fragments in Budapest, Bonn, New York and Paris.

## DESCRIPTION

According to Smith (1873), the mass was pear-shaped and weighed about 6 lbs 8 oz (about 2.95 kg ). One end was smooth and rounded; the opposite end was "jagged as if torn from a larger meteorite." Smith presented a cut of a polished section and noted an oval cavity about 4 cm in its longest and $21 / 2 \mathrm{~cm}$ in its shortest diameter; the cavity was filled with pyrite (i.e., troilite) and lined with schreibersite.

The following is based on examination of specimens in Cape Town, Washington, Copenhagen, Chicago, Harvard and London. Common to all is the extensive weathering. The fusion crust and heat-affected $\alpha_{2}$ zone are lost and numerous fissures $0.1-1 \mathrm{~mm}$ wide extend deep into the sections along Widmanstätten directions and along phosphides. In places the surface is spalling off in octahedral flakes. Massive, laminated oxides cover the surface and many fissures as $0.1-1 \mathrm{~mm}$ thick layers. The corrosion is extensive and must have required countless years to develop, so it is obvious that the mass cannot be an observed fall from 1860.


Figure 1852. Victoria West (Copenhagen no. 1905, 1731). Two crossing kamacite lamellae and coarse-grained plessitic matrix. The kamacite is granulated and the taenite is homogenized due to artificial reheating. Etched. Scale bar $250 \mu$.

Etched sections display a fine Widmanstätten structure with straight, long ( $\frac{1}{W} \sim 40$ ) kamacite lamellae with a width of $0.22 \pm 0.05 \mathrm{~mm}$. The kamacite was once rich in Neumann bands and these had been decorated by $0.5 \mu$ phosphides along both sides by a slight cosmic reheating. However, due to a later artificial reheating to about $900^{\circ} \mathrm{C}$, all kamacite now appears as serrated, unequilibrated $\alpha_{2}$ units, $25-100 \mu$ in size. The hardness is $170 \pm 10$, corresponding to $\alpha_{2}$, air-cooled from about $900^{\circ} \mathrm{C}$.

Taenite and plessite cover about $80 \%$ by area. Comb and net plessite occupy most of the area, but the wide individual taenite ribbons and blebs frequently have martensitic-bainitic, duplex-unresolvable, or easilyresolvable $\alpha+\gamma$ interiors. The taenite is yellow-etching and rather soft (HV 240 $\pm 15$ ), because it has been artificially annealed. The martensitic and duplex areas are clearly diffuse, as a result of the same late imperfect reheating (HV 250 $\pm 30$ ).

Schreibersite is conspicuous as lamellar and rosette-like crystals, typically $10 \times 1,12 \times 3$ or $3 \times 2 \mathrm{~mm}$ in size, and apparently dodecahedrally arranged. They are enveloped in 1 mm swathing kamacite, and the distribution resembles what is known from, e.g. Carlton, Augustinovka and Bear Creek. Phosphides are also very common as $0.1-0.4 \mathrm{~mm}$ blebs and as $5-50 \mu$ subangular substitutes for taenite in the open plessite fields. On some specimens, notably on one in Vienna, the schreibersite crystals have partially disappeared and have left gaping fissures. Where present, the phosphides have been visibly altered by high temperature reaction: $1-5 \mu$ wide creamcolored zones separate the phosphides from adjacent terrestrial corrosion products, and in other places the phosphides have jagged edges with thorns and


Figure 1853. Victoria West (U.S.N.M. no. 3136). On sections that are polished only, an intergranular dark network is noted. The main component is fused sulfides that have penetrated from preexisting troilite nodules. Polished. Scale bar $200 \mu$.

VICTORIA WEST - SELECTED CHEMICAL ANSLYSES

| Reference | $\mathbf{N i}$percentage <br> Co | $\mathbf{P}$ | $\mathbf{C}$ | $\mathbf{S}$ | $\mathbf{C r}$ | $\mathbf{C u}$ | $\mathbf{P p m}$ | $\mathbf{Z a}$ | $\mathbf{G e}$ | $\mathbf{I r}$ | $\mathbf{P t}$ |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | ---: |
| Wasson \& Kimberlin <br> 1967 | 11.98 |  |  |  |  |  |  |  |  |  |  |



Figure 1854. Victoria West (U.S.N.M. no. 3136). A fused troilite nodule that has reacted with terrestrial corrosion products and created bizarre eutectic structures of iron, nickel, sulfur and oxygen. Polished. Scale bar $40 \mu$.
spikes projecting into the $\alpha_{2}$ matrix. The morphology of the phosphides thus also indicates artificial reheating to above $800^{\circ} \mathrm{C}$, but with the possible exception of the Vienna specimen, they have not been melted. The bulk phosphorus content is estimated to be $0.6 \pm 0.1 \%$.

Troilite occurs as $0.5-20 \mathrm{~mm}$ nodules which were originally monocrystalline. They are reasonably pure and enveloped in $0.5-1.0 \mathrm{~mm}$ wide rims of schreibersite, followed by $0.5-1.0 \mathrm{~mm}$ rims of swathing kamacite. In some specimens, e.g., Washington No.3136, the troilite has reacted with oxygen from the air and has melted. The resulting liquid has penetrated 5 mm or more away from the parent nodule along the high temperature austenite boundaries. It has even sweated into net plessite fields and created bizarre structures of $\alpha_{2}$, taenite, phosphide and iron-sulfur-oxygen eutectics. In other specimens, the troilite has partially recrystallized to equiaxial 10-100 $\mu$ grains.

The only other meteoritic mineral observed was small ( $20-60 \mu$ ) elliptic inclusions, around which some of the larger schreibersite crystals had grown. The inclusions were grayish-blue, nonopaque and anisotropic and were probably silicates or phosphates.

The crucial proof for the artificial reheating lies in the state of the corrosion products. They have all suffered by the reheating, indicating that this occurred after considerable corrosion had taken place. The external surfaces exhibit (in microsection) high temperature intercrystalline oxidation. The limonitic corrosion products are decomposed to oxides with numerous, tiny ( $1-2 \mu$ ) beads of metal. The interfaces between kamacite and limonite are developed as $20-50 \mu$ wide zones of laceworks. Finally, the schreibersite and the troilite have reacted with the corrosion products and with the air, as mentioned above.

Victoria West is an anomalous meteorite, which may have Carlton as its nearest relative, considering both structure and composition. Victoria West is an old fall, which was found or recorded in 1860-62. Since so many


Figure 1855. Victoria West (U.S.N.M. no. 3136). Altered plessite field. Two schreibersite crystals (S) with wide yellow reaction halos. Iron-sulfur-oxygen melts penetrate along all grain boundaries. Polished. Scale bar $40 \mu$.
specimens exhibit reheated structures, it must be concluded that the whole mass was reheated and not just the examined pieces. The observations already made by Smith (1873), i.e., the torn and jagged end, strongly indicates that some violent activity occurred at an early date. It must be concluded that a reheating, for an hour to about $900^{\circ} \mathrm{C}$, but presumably with a temperature gradient, must have occurred before Gregory and Smith learned of the mass. It was possibly inflicted by the curious finder, either in order to divide it or to examine its true nature.

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

2 g fragment (no. 1174)
17 g part slice (no. 1563)
14 g part slice (no. $3136,2.5 \times 1 \times 0.4 \mathrm{~cm}$ )

# View Hill, North Canterbury, New Zealand $43^{\circ} 19^{\prime} 12^{\prime \prime} \mathrm{S}, 172^{\circ} 3^{\prime} 48^{\prime \prime} \mathrm{E}$ 

Medium octahedrite, Om. Bandwidth $0.80 \pm 0.12 \mathrm{~mm} . \epsilon$-structure. HV $310 \pm 15$.
Group IIIA-IIIB. $8.87 \% \mathrm{Ni}$, about $0.45 \% \mathrm{P}, 21.0 \mathrm{ppm} \mathrm{Ga}, 42.6 \mathrm{ppm}$ $\mathrm{Ge}, 0.27 \mathrm{ppm}$ Ir.

## HISTORY

A mass of 33.7 kg was plowed up by C.C. Anderson of View Hill, Oxford, about 1952. In 1954 the meteorite was donated to the Canterbury Museum. It was later cut and described by Frost (1967b) who gave the exact locality and presented several photographs of the exterior and of polished and etched slices. The presence of lawrencite in small quantities was deduced from the exudation of drops of ferrous chloride from the cut surface. This appears, however, to be a misinterpretation of chlorine, introduced with circulating ground water from the soil.


Figure 1856. View Hill (U.S.N.M. no. 3196). A medium octahedrite of group IIIB. Two large troilite nodules with rims of swathing kamacite. Deep-etched. Scale bar 10 cm .

## COLLECTIONS

Canterbury Museum, Christchurch, New Zealand (main mass of about 30 kg ), Washington ( 1.88 kg ), Chicago ( 56 g ), Canberra ( 53 g ).

## DESCRIPTION

According to Frost (1967b), the meteorite has one rounded but elongated surface and comes to a rough acute point opposite to this. The maximum dimensions are 29 x 28 x 19 cm . Some surfaces show concave marks, but considerable rusting has occurred. An X-ray powder photograph of the rust gave lines, the most of which could be indexed on the assumption that lepidocrocite, goethite and nickel-iron were present.

The specimen in Washington is a full slice through the mass. It is somewhat corroded on the surface and the fusion crust has disappeared. Selective oxidation has attacked the $\alpha$-phase of near-surface plessite fields and filled schreibersite fissures with terrestrial corrosion products. A little pentlandite veining is visible in the troilite. However, the
heat-affected $\alpha_{2}$ zone is still preserved in thicknesses ranging from $0.1-2.5 \mathrm{~mm}$, and micromelted phosphides and recrystallized troilite are present in the exterior part of the


Figure 1857. View Hill (U.S.N.M. no. 3196). An oval phosphate inclusion (black) in a sheared Brezina lamella of schreibersite. Shock-hatched kamacite on either side. Etched. Scale bar $100 \mu$.

VIEW HILL - SELECTED CHEMICAL ANALYSES

|  | percentage |  |  |  |  |  |  | ppm |  |  |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Reference | $\mathbf{N i}$ | $\mathbf{C o}$ | $\mathbf{P}$ | $\mathbf{C}$ | $\mathbf{S}$ | $\mathbf{C r}$ | $\mathbf{C u}$ | $\mathbf{Z n}$ | $\mathbf{G a}$ | $\mathbf{G e}$ | $\mathbf{I r}$ |
| Pt |  |  |  |  |  |  |  |  |  |  |  |
| Scott et al. 1973 | 8.87 |  |  |  |  |  |  |  | 21.0 | 42.6 | 0.27 |

$\alpha_{2}$ zone. It is, therefore, estimated that, on the average, only 1 mm of the surface is lost by terrestrial weathering.

View Hill is a medium octahedrite with straight, long $(\mathrm{L} \sim 20)$ kamacite lamellae with a width of $0.80 \pm 0.12 \mathrm{~mm}$. The kamacite shows lightly decorated subboundaries, but because of a severe shock, above 130 k bar, the primary structure is superimposed and somewhat obscured by a hatched $\epsilon$-structure, rich in contrast. The intensity of the event was sufficient to shock-harden the kamacite to $310 \pm 15$. Along the edge of the meteorite, the atmospheric ablational heating recovered the kamacite to a minimum of $195 \pm 15$, while the $\alpha_{2}$ transformation zone shows $200 \pm 10$ (hardness curve type I). The grain size of the $\alpha_{2}$ phase is small, $5-25 \mu$, because it was formed from a preexisting shock-hardened $\epsilon$-structure.

Taenite and plessite cover $35-40 \%$ by area, as comb, net, martensitic-bainitic and duplex fields. A fully developed millimeter-sized field will display a tarnished taenite rim (HV $305 \pm 15$ ) followed by a light-etching yellow martensite (HV 390 $\pm 15$ ). Then follows brown, marked mar-tensite-bainite developed parallel to the bulk Widmanstätten structure and frequently occupying large areas (HV $450 \pm 40$ ). Finally come duplex, unresolvable $\alpha+\gamma$ zones (HV 300 $\pm 15$ ) and duplex, coarse $\alpha+\gamma$ zones (HV 310 $\pm 15$ ).

Schreibersite is common as dodecahedral Brezina lamellae, attaining sizes of $12 \times 1.2,8 \times 1.0$ or $30 \times 0.2 \mathrm{~mm}$ in cross section. They are enveloped in asymmetric, $0.2-1.0 \mathrm{~mm}$ wide rims of swathing kamacite. Also 2,1 and 0.5 mm schreibersite blebs are common. Grain boundary schreibersite, $20-100 \mu$ wide, and $2-20 \mu$ blebs inside the coarser fields are also present. No "island arcs" of phosphides were detected, and large rhabdites are absent. Small rhabdites $0.5-1 \mu$ across, are common, however. The bulk phosphorus content is estimated to be $0.45 \pm 0.05 \%$. The phosphides are brecciated and often shear-displaced in $10-50 \mu$ steps. The adjacent kamacite then shows distorted $\epsilon$.


Figure 1858. View Hill (U.S.N.M. no. 3196). Edge of a troilite nodule. Areas with recrystallized grains (left) alternate with areas of monocrystalline material or material displaying undulatory extinction. Polished. Crossed polars. Scale bar $200 \mu$. See also Figure 224.

Many of the Brezina lamellae have nuclei of $50-200 \mu$ oval, bluish-black, anisotropic grains that appear to be phosphates (sarcopside, graftonite). Also a few white, 1.2 mm phosphate grains were detected in the troilite of the hand specimen.

Troilite occurs as prominent nodules $15-30 \mathrm{~mm}$ in diameter. They have only discontinuous and narrow ( $<100 \mu$ thick) schreibersite rims. The swathing kamacite is asymmetrically developed, $0.1-1.5 \mathrm{~mm}$ wide and divided into several segments of different orientation, corresponding to as many growing nuclei of kamacite. The troilite is monocrystalline but, as the result of shock, is severely twinned and recrystallized. And $90 \%$ of the troilite is composed of subparallel bundles of pointed twins with undulatory extinction, while the remaining $10 \%$, particularly situated along the phase boundaries, is recrystallized to irregular patches of $5-10 \mu$ grains. A deformed troilite nodule that happened to extend into the reheated $\alpha_{2}$ zone recrystallized partially to $50-150 \mu$ grains when the temperature briefly exceeded about $950^{\circ} \mathrm{C}$ during the atmospheric passage.

In the troilite, small islands of metal are sometimes present. Such isolated iron-nickel blebs, $1-2 \mathrm{~mm}$ across, have decomposed to a Widmanstätten pattern, oriented in the same way as the bulk of the meteorite. Many of the blebs are apparently islands while they are, in fact, connected to the bulk metal above or below the section. The blebs display $50-150 \mu$ wide rims of swathing kamacite (now $\epsilon$ ) adjacent to the troilite, while the interior may be developed as rather uniform martensite-bainite. Similar blebs are present in Chupaderos and Cape York, e.g.

View Hill is a medium octahedrite which is related to Nazareth, Grant, and Ilinskaya Stanitsa. Like these, it shows a marked, shock-hardened $\epsilon$-structure. The mass is in a good state of preservation, and the present exterior is almost identical to the shape it had after having penetrated the atmosphere, since the weathering is insignificant.

Specimen in the U.S. National Museum in Washington: $1,880 \mathrm{~g}$ full slice (no. $3196,26 \times 12 \times 1 \mathrm{~cm}$ )

> Wabar, Rub' al Khali, Saudi Arabia
> $21^{\circ} 29^{\prime} 59^{\prime \prime} \mathrm{N}, 50^{\circ} 28^{\prime} 20^{\prime \prime \mathrm{E} ; 230 \mathrm{~m}}$

Medium octahedrite, Om. Bandwidth $0.95 \pm 0.15 \mathrm{~mm}$. Neumann bands. HV $205 \pm 15$.
Group IIIA. $7.51 \% \mathrm{Ni}, 0.1 \% \mathrm{P}, 20.6 \mathrm{ppm} \mathrm{Ga}, 38.3 \mathrm{ppm} \mathrm{Ge}$, 7.4 ppm Ir.

Nejed I-II are, no doubt, transported individuals of Wabar.

## HISTORY

In semiclassical Arabic poems Wabar or Ubar is the site of a legendary city, which was destroyed by fire from heaven because of the wickedness of its king. The exact place was never known but was expected to be somewhere southeast of Riyadh in Rub'al Khali, one of the largest sand
deserts in the world. When Philby (1933a, b), on his third journey of exploration through the "Empty Quarter," was eventually guided to the spot of the unfortunate city, he first believed he had discovered a volcano; but the subsequent finding of an 11 kg iron meteorite and six small iron fragments, totaling 114 g , convinced him that the craters were produced by impacting meteorites. The Arabic legend became understandable when it was observed that cinder-like masses were thickly strewn around the two craters; Philby's Arab followers firmly believed that the numerous black beads with a glazed skin were black pearls which had been used by the harem of the king. Philby also searched for Al-Hadida, literally the "piece of iron," which allegedly was to be found in the region, but without success. He presented a map of his travels, and sketch map of the crater field.

Recently a large mass, of $2,170 \mathrm{~kg}$ weight, was reported by Abercrombie (1966), who gave a photograph of it in situ. It was located 400 m south-southwest of the main crater. The Arabian American Oil Company, Aramco,


Figure 1859. Wabar. The $2,170 \mathrm{~kg}$ shield-shaped mass was discovered 400 m south-southwest of the main crater. Mrs. Abercrombie and an Arab guide at the site of excavation.


Figure 1860. Wabar. The $2,170 \mathrm{~kg}$ mass is a low cone, or shield, with regmaglypts radiating from the apex. Photographed 1968 by Erling Bondesen on the Riyadh University Campus.
brought a bulldozer to the site and recovered the meteorite. Another mass of 210 kg , found on this occasion 575 m south of the crater, was also hauled away to Dhahran. The two masses are presently exhibited in front of the Faculty of Science, Riyadh University.

Spencer \& Hey (1933a) gave an excellent description of the 11 kg specimen and of a distorted fragment, and they further described and analyzed the associated silica glass and sandstone. The Wabar craters are unique by their high concentration of nearly pure silica-glass, one reason presumably being the abundance of raw material provided by the sand desert and the underlying (tertiary ?) friable, white sandstone. They also suggested that the two Nejed irons were, in fact, transported fragments of Wabar. In support of this, they maintained that there were identical structures and chemistry; furthermore, Philby (1933a: 178) recognized the name of the Shaykh, who submitted the first Nejed iron, as having been head of the tribe that dug the well of Umm al Hadid, 22 km from Wabar. The present author, having examined the two Nejed irons, and four Wabar irons, can fully support the identification.

Nichols (1939) reported the recovery of two small iron individuals, totaling 62 g , and a piece of silica glass. Holm (1962) reported the recovery of several small fragments which, unfortunately, remained in private possession. Holm also changed the coordinates of Philby to a more exact set which is given above. Barnes and Holm collected about 20 kg of glass slags, much of it from the rim of the main crater and the immediate surroundings. Chao et al. (1961) identified coesite, the high pressure polymorph of silica, in this material. Park \& Reid (1964) examined the metallic spherules from the crater glass. Short (1968a) and Short \& Bunch (1968) discussed the shock lithification responsible for the formation of sandstone lumps from the desert


Figure 1861. Wabar. A vesiculated impactite glass, which is glossy black, and was greatly esteemed by the Arabs who used it for black pearls. Here it appears white, because it has been smoked with $\mathrm{NH}_{4} \mathrm{Cl}$ to bring out the morphological details. Scale bar 5 mm . S.I. neg. 1476.
sands; and they also compared Wabar to other known impact craters. El Goresy et al. (1968) described the metallic spherules and identified baddeleyite, $\mathrm{ZrO}_{2}$, as a decomposition product of zircon in impactite glasses. A few inclusions of chromespinel were also discovered, and verified by microprobe analyses. Magnetite skeleton crystals of a type similar to those found in the fusion crusts of iron meteorites were found to occur in vesiculated areas of the silica bombs. Kullerud \& El Goresy (1967) noted that the nodules in the massive iron demonstrated extensive reactions between daubreelite and troilite. They assumed this to be the result of the cratering impact, but this is not certain, since these structures are also very common in small irons that never produced craters. The shock reactions are rather the result of preatmospheric shock events. Reed (1969) examined the kamacite phase of the 11 kg specimen in London and reported $7.1 \% \mathrm{Ni}$ and $0.088 \% \mathrm{P}$ in solid solution.

Short summaries and historical background information may be found in Philby's book "The Empty Quarter" London, 1933a, in Spencer (1933), Heide (1957: 39-41), Krinov (1966a: 19-26) and in Hey's Catalog (1966: 336, 510,560 ), where further references may be found. The desert geomorphology has been treated by Holm (1960; 1962). He reported that the smaller crater, about $54 \times 40 \mathrm{~m}$ across and 9 m deep when Philby visited it, was almost filled with drifting sand in 1961. The larger crater, originally 100 m in diameter and 12 m deep, was estimated to be only 5 m deep in 1961. Occasional gales with wind


Figure 1862. Wabar (U.S.N.M. no. 4516). Two open-meshed comb plessite fields. Kamacite with subboundaries, fine rhabdite precipitates and Neumann bands. Etched. Scale bar $400 \mu$.
velocities up to 120 km per hour apparently are the main reason for the rapid mass movement of Aeolian sand. It is not completely clear whether the craters are excavated only in loose, Aeolian sand, consolidated by the impact-fusion, or whether the impacts penetrated to the bedrock. Outcrops of sandstone do occur at several places in the vicinity, but geologic reports about the crater structures have apparently not been published.

## COLLECTIONS

University of Riyadh, Saudi Arabia (the two largest individuals of about 2.2 tons and 210 kg ), London ( 10.7 kg ), Moscow ( 224 g slice of 11.4 kg mass), Washington ( 138 g ), Tempe (three individuals, 120 g ), Chicago (two individuals, 62 g ).

## DESCRIPTION

For descriptions and analyses of the crater and the associated impactites, the reader is referred to the literature quoted above.

So far the following irons have been collected: $2,170 \mathrm{~kg}, 210 \mathrm{~kg}, 62 \mathrm{~kg}$ (Nejed II), 59.4 kg (Nejed I), 11.4 kg and numerous small, twisted fragments, generally weighing from 10 to 80 g each. The large irons display undistorted Widmanstätten lamellae and appear to be complete individuals which have penetrated most of the atmosphere independently in oriented, stabilized flight. This is particularly well seen on the largest, shield-shaped mass which measures $120 \times 90 \times 60 \mathrm{~cm}$ and closely


Figure 1863. Wabar (U.S.N.M. no. 4516). Acicular plessite and open-meshed net plessite (left). Kamacite with subboundaries, fine rhabdite precipitates and Neumann bands. Etched. Scale bar $400 \mu$.

## WABAR - SELECTED CHEMICAL ANALYSES

The first analysis was performed upon a Nejed sample, the second upon a Wabar sample. Since these meteorites are
here shown to be identical, the average will be used as the analysis of Wabar.

| References | percentage |  |  | ppm |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Ni | Co | P | C | S | Cr | Cu | Zn | Ga | Ge | Ir | Pt |
| Wasson 1968, pers. comm. | 7.40 |  |  |  |  |  |  |  | 19.9 | 38.1 | 8.7 |  |
| Scott et al. 1973 | 7.62 |  |  |  |  |  |  |  | 21.3 | 38.4 | 6.0 |  |

resembles the largest Sikhote-Alin individual. It is a beautiful, low cone with heavy furrows and ridges radiating from the apex, and it is covered with little-corroded fusion crusts. This mass is not a fragment from a cratering explosion, and neither is Nejed (I). In other words, the incoming meteorite must have split into several masses in the high atmosphere. While the largest exploded, fragmented and vaporized upon impact and created craters proper with fused silica-glass and coesite, the smaller ones survived and only made impact holes, which were rapidly covered by the blowing sands.

The following is a description of an edge specimen from the $2,200 \mathrm{~kg}$ mass and of a slice of the 11.4 kg mass. Etched sections reveal a medium Widmanstätten structure of straight, long ( $\frac{L}{W} \sim 30$ ) kamacite lamellae with a width of $0.95 \pm 0.15 \mathrm{~mm}$. Only near the edge are there bunches of distorted, cold-worked lamellae which indicate where the mass separated from other masses during atmospheric breakup. The kamacite has subboundaries which are decorated with $0.5-2 \mu$ rhabdites and Neumann bands which are faintly decorated with $0.5 \mu$ phosphides. Therefore, the location of the Neumann bands is still visible in the heat-affected rim zone where Neumann bands normally disappear completely. The rim zone on the large mass is about 2.5 mm thick at the edge where the specimen was taken, and micromelted phosphides are present in the exterior half of this zone. The kamacite microhardness varies from $200 \pm 10$ at the edge through a minimum of $175 \pm 10$ in 3 mm depth to an interior value of $205 \pm 15$ (hardness curve type II).

Taenite and plessite cover about $30 \%$ by area, mostly in form of open-meshed, comb and net plessite with discontinuous taenite borders. The nickel-rich plessite wedges display zones of transition from taenite at the exterior via Ni -C-martensite with acicular morphology, through martensite platelets parallel to the octahedral structure, to a duplex interior of fine-grained $\alpha+\gamma$.

Schreibersite occurs as scattered $5-25 \mu$ wide grain boundary precipitates and as $5-10 \mu$ blebs inside the plessite. Rhabdites are numerous as $1-2 \mu$ sharp prisms. The bulk phosphorus content is estimated to be $0.10 \% \pm 0.02 \%$.

Troilite is common as $0.1-5 \mathrm{~mm}$ lenticular and rhomboidal nodules which have inclusions of daubreelite covering $5-15 \%$ by area. The troilite is shock-melted, and the adjacent $15 \mu$ thick rims of schreibersite are partially dispersed in the melt. The daubreelite is partially melted, partially brecciated, and troilite has been injected into the fissures. The present grain size of the sulfide is $2-10 \mu$; incorporated metallic droplets, $1-2 \mu$ in size, are selectively corroded. Since these structures are present in the coneshaped individual as well as in the $10-60 \mathrm{~kg}$ masses, it must be concluded that they are preatmospheric and not the result of cratering impact.

Daubreelite is present as scattered $10-50 \mu$ blebs in the kamacite phase. The $20 \times 1 \mu$ hard, oriented platelets of carlsbergite reported in Cape York, Nejed and others, are also present in Wabar.

Corrosion has attacked the surroundings of phosphides and sulfides, but is not violent on the shield-shaped main mass. The 11 kg mass is somewhat more corroded.

The small fragments originally had the structure described above but are now altered due to reheating. A typical fragment, of 38 g , measures $3 \times 2 \times 1.5 \mathrm{~cm}$. Its exterior suggests a violent fragmentation and bending of the edges. It has a unique, glazed, smooth surface, evidently because it is coated by silica glass which was deposited by evaporated desert sand. Sections through such explosion fragments confirm the distorted nature. The Widmanstätten structure is bent, and the phosphides are micromelted. The taenite displays numerous thorns and spikes projecting into the kamacite and indicating incipient resolution. The kamacite is converted to serrated $\alpha_{2}$ grains with a microhardness ( 100 g Vickers) of $170 \pm 10$. The same hardness was found in experimental series of alloys with $7 \% \mathrm{Ni}$ and $0.1 \% \mathrm{P}$, quenched from $1100^{\circ} \mathrm{C}$. (Buchwald 1966). The structure may thus be explained as the result of rapid heating to about $1000^{\circ} \mathrm{C}$, followed by rapid cooling. The specimens were certainly only a few minutes at the maximum temperature, since the 1-2 $\mu$ rhabdites melted but found no time to dissolve and disappear completely. The structure closely corresponds to that of shock-reheated Canyon Diablo, Gibeon, Boxhole and Henbury specimens. However, the glazed crust appears to be preserved better upon Wabar than upon the other meteorites. It contains numerous metallic droplets, $1-5 \mu$ in diameter, and numerous vacuoles, $2-20 \mu$ in diameter. Magnetite skeleton crystals are also present.

Wabar is a medium octahedrite closely related to Cape York, Casas Grandes and other group IIIA irons. Nejed I and II are, no doubt, early recovered individuals of Wabar. The fall is extremely interesting by providing an example of the simultaneous impact of large and small bodies. The large bodies ( $\sim 4 \mathrm{~m}$ in diameter? ) produced the craters and spattered the surroundings with impactite glass and glazed iron fragments, but the major part of these masses probably disappeared by evaporation. The smaller bodies (e.g., the


Figure 1864. Wabar (U.S.N.M. no. 4516). Detail of an open-meshed net plessite field. Black dots are taenite particles. Grain boundaries and subboundaries are visible in the kamacite. Neumann bands show direction shifts at grain boundaries only. Etched. Scale bar $200 \mu$.
2.2 ton-cone) generated only impact holes and survived the general devastation and reheating, having landed 400 m from the main crater. The distance to which explosion fragments were hurled is not known. Philby (1933a: 369) discovered an 8 g bean-shaped individual 180 km south of the crater field. Spencer found that it had the same granulated structure as the other small fragments and assumed that it had been transported. The name of the well 22 km northeast of the crater field, Umm al Hadid, may come from iron actually having been found there or in the vicinity (Philby 1933a: 160). It appears, therefore, that Wabar is an extensive crater field strewn with large and small blocks of which we, as yet, have only recovered a small fraction. Most likely, fragments are only to be found out to a distance of a few kilometers from the crater, while the others must be considered to have been transported.

```
Specimens in the U.S. National Museum in Washington:
161 g slice of the 11.4 kg mass (no. 1564, 9 < 6 x 0.4 cm)
    25 & 28 g two small, reheated individuals (no. 2317, 3.5 x 1.5 x
        1.5 cm)
    52g part slice of 2.2 ton mass (no. 4516, 4 < 3 x 0.8 cm)
    38g}g\mathrm{ glazed individual ( }3\times2\times1.5\textrm{cm}\mathrm{ )
Impactites
```

Wabar (Nejed fragments),<br>"Empty Quarter," Saudi Arabia<br>$$
21^{\circ} 30^{\prime} \mathrm{N}, 50^{\circ} 28^{\prime} \mathrm{E}
$$

Medium octahedrite, Om. Bandwidth $0.95 \pm 0.15 \mathrm{~mm}$. Neumann bands. HV $205 \pm 15$.
Group IIIA. $7.40 \% \mathrm{Ni}, 0.10 \% \mathrm{P}, 19.9 \mathrm{ppm} \mathrm{Ga}, 38.1 \mathrm{ppm} \mathrm{Ge}$, 8.7 ppm Ir.

## HISTORY

Two masses of 59.4 and 62 kg , respectively, are in collections under the name of Nejed, but the exact circumstances and locations of find are unknown for both of them. The first mass was acquired in 1885 by the British Museum and was briefly described with an analysis by Fletcher (1887a). According to Fletcher's informer, an Arab shaykh, the mass was observed to fall in 1863, near Wadi Bani Khaled, and since Fletcher found the iron to have a fresh fusion crust, he believed the information to be
correct. However, Brezina (1896: 278) raised doubt as to the authenticity of the report, since he found the specimen in Vienna to be significantly weathered.

The second mass was also offered to the British Museum, in 1893, and came allegedly from the same general area (Spencer \& Hey 1933a: 402; Hey 1966: 336). However, it was acquired by H.A. Ward who mentions it in his 1901 Catalog as weighing $61,715 \mathrm{~g}$. In the following years he cut about 13 kg from it for exchange, and specimens could be purchased from Ward's Establishment as late as 1940, according to various price lists. The main mass, of 48 kg , came to the Field Museum in Chicago (No. 1100).

Spencer \& Hey (1933a) suggested that the two masses could come from Wabar, or Al-Hadidah, where Philby (1933a, b) had reported craters and recovered about 12 kg metallic fragments besides silica-glass. Chemical and structural comparisons corroborated their suggestion. Prior (1953) and Hey (1966) evidently accepted this conclusion, since they gave Wabar and Nejed the same coordinates. Holm (1962) apparently was not aware of the existence of the Nejed masses when he discussed Arabian meteorite locations. Photomacrographs of Nejed have been presented by Mauroy (1913: plate 1), Sickels (1917: figure 14), Spencer \& Hey (1933a) and Henderson \& Furcron (1958). The figure given by Nininger \& Nininger (1950: plate 95) is of Tempe No. 86b, a mislabeled specimen, probably of Gibeon, and certainly not of Nejed.


Figure 1865. Wabar. Sample from Nejed No. 2 (U.S.N.M. no. 576; 1472 g , gift from C.S. Bement 1917) Typical medium octahedrite of group IIIA. The large troilite nodule has been removed for examination. Deepe tched. Scale bar 20 mm . S.I. neg. 151.

## WABAR (NEJED FRAGMENTS) - SELECTED CHEMICAL ANALYSES

An analysis, presented by Moore et al. (1969) as Nejed, was performed upon a specimen, Tempe No. 86b, which the present author, upon structural examination, could prove to be a mislabeled specimen. Number 86 b is a
shocked fine octahedrite with a bandwidth of 0.3 mm and closely related to the phosphorus-free end of the group IVA meteorites. It might be a mislabeled Gibeon specimen.

| References | $\mathbf{N i}$ | percentage | $\mathbf{C o}$ | $\mathbf{P}$ | $\mathbf{C}$ | $\mathbf{S}$ | $\mathbf{C r}$ | $\mathbf{C u}$ | $\mathbf{p p m}$ |  |  |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathbf{Z n}$ | $\mathbf{G a}$ | $\mathbf{G e}$ | $\mathbf{I r}$ | $\mathbf{P t}$ |  |  |  |  |  |  |  |  |
| Fletcher 1887a <br> Wasson 1968, <br> pers. comm. | 7.40 | 0.66 | 0.10 |  | tr. |  | tr. |  |  |  |  |  |

## COLLECTIONS

London (main mass of No. 1: $58,160 \mathrm{~g}$, and 628 g ), Chicago (main mass of No. 2: $48,080 \mathrm{~g}$, and 203 g ), Washington ( $2,400 \mathrm{~g}$ ), New York ( $1,819 \mathrm{~g}$ ), City College of New York ( 825 g ), Vatican ( 433 g ), Helsinki ( 230 g ), Calcutta ( 154 g ), Ann Arbor ( 147 g ), Vienna (No. 1, 126 g ), Prague ( 122 g ), Paris ( 77 g ), Leningrad ( 57 g ), Yale (30 g), Tempe (No. 86a, 30 g ), Berlin (No. 1, 29 g ), Stockholm ( 14 g ).

## DESCRIPTION

Nejed (I). This mass is of roughly tetrahedral shape with the overall dimensions of $30 \times 25 \times 20 \mathrm{~cm}$. It is cut in only one place, exposing a $10 \times 10 \mathrm{~cm}$ section. It is only slightly weathered and is covered with numerous shallow pits. On sections the atmospheric fusion crust may be found in several places as a composite of 0.1 mm oxide laminae and 0.1 mm , metallic, dendritic melts. The metallic layers are, as usual, discordantly overlapping and are frequently composed of numerous individual layers, each $20-30 \mu$ thick. The metal is solidified in columnar cells, $1-3 \mu$ wide, perpendicular to the meteorite substrate. Under the fusion crust there is a $0.2-1 \mathrm{~mm}$ thick heat-affected $\alpha_{2}$ zone. In places a cold-deformed Widmanstätten structure may be seen close to the surface. The linear elements are bent and stretched as if a tensile fracture had occurred in the surface. The phosphide bodies, which were too brittle to yield to the plastic deformation, fragmented and formed boudinage structures. Moreover, the deformation zone is completely covered with fusion crust, and some of the fragmented phosphides are micromelted. The best interpretation appears to be that the mass broke from another mass in the high atmosphere, thereby creating local necking, followed by ablation melting of the new surface. That the deformation and melting are not due to man's activity is clear from one observation: corrosion has attacked the fusion crust and the melted phosphides and has created the typical meteoritic-weathering replacement structures. The exterior morphology and the state of


Figure 1866. Wabar. A Nejed fragment (Tempe no. 86a). Degenerated comb and net plessite fields. Kamacite with subboundaries, fine rhabdite precipitates and Neumann bands. Etched. Scale bar $400 \mu$.
preservation thus indicate (i) that the fall is of relatively recent date, although, no doubt, much older than 1863, and (ii) that the mass separated from its main mass high in the atmosphere and developed its own fusion crust and regmaglypts with a thin heat-affected $\alpha_{2}$ zone. The mass was, in other words, hardly produced as a fragment of a large meteorite that exploded upon cratering impact.

Etched sections display a medium Widmanstätten structure of straight, long ( $\stackrel{L}{\mathbb{W}} \sim 30$ ) kamacite lamellae with a width of $0.95 \pm 0.15 \mathrm{~mm}$. Locally a trifle of grain growth has scalloped the straight lamellae edges and even created $1.5-2 \mathrm{~mm}$ equiaxial ferrite grains here and there. Neumann bands are common, as are subgrain boundaries in the kamacite which are frequently decorated with $0.5-1 \mu$ phosphides. The microhardness ranges from $205 \pm 15$ in the interior through a minimum of $160 \pm 10$ in the recovered transition zone to $190 \pm 20$ in the reheated rim (hardness curve type II).

Plessite covers about $25 \%$ by area, particularly as open-meshed, comb and net plessite, and as black taenite. The framing taenite around the plessite fields is frequently discontinuous, in harmony with the relatively low overall nickel content of the octahedrite. Neumann bands propagate in various directions through the individual ferrite grains of the net plessite. In some places the ferritic matrix is loaded with slip lines that are decorated with ultrafine precipitates. The slip lines are caused by strain from transformation of austenite to martensite, and the precipitates on the slip lines are probably formed during a slight reheating (to about $300^{\circ} \mathrm{C}$ ?).

Schreibersite is present as $5-15 \mu$ wide grain boundary precipitates and as $1-15 \mu$ blebs in the plessite fields. Rhabdites are numerous as $1-2 \mu$ thick prisms, both in the $\alpha$-lamellae and inside the open-meshed, plessite fields.


Figure 1867. Wabar. In 1924 the Smithsonian blacksmith forged a knife blade from a piece of Nejed No. 2. The damascened pattern produced by the distorted Widmanstätten structure is clearly seen. Etched. Scale bar 50 mm . S.I. neg. 43545E.


Figure 1868. Wabar. Detail of Figure 1867 showing the damascened pattern. Etched. Scale bar 10 mm . S.I. neg. 43545D.


Figure 1869. Jalandhar. In 1621 an iron meteorite of about 2 kg fell near Jalandhar, Punjab, India. It was forged into sword and knife blades. The knife shown was allegedly made from this meteorite. The eminent damascened pattern is clearly seen. Etched. The knife is in the Freer Gallery of Art, Washing ton. S.I. neg. 43432C.

Troilite occurs as $0.3-5 \mathrm{~mm}$ grains which are usually enveloped in $1-2 \mathrm{~mm}$ wide, cellular rims of swathing kamacite. They are shock-melted and solidified to eutectic sulfide-metal mixtures with a grain size of $1-10 \mu$. The daubreelite, which occupies $5-15 \%$ by area of the troilite, is shattered and invaded by the troilite melts but is not melted itself. Daubreelite is also present as scattered $10-50 \mu$ blebs in the alpha phase.

The hard chromium nitride platelets, carlsbergite, typically $50 \times 2 \times 1 \mu$, observed in Cape York and other irons, are also present in Nejed. Fletcher (1887a) reported graphite, but this could not be confirmed and appears unlikely.

Nejed (II) now measures about $32 \times 25 \times 18 \mathrm{~cm}$ and weighs 48 kg after one-fourth has been cut from it. It was only examined in macroetched sections but appears to be identical to Nejed (I). No fusion crust and heat-affected $\alpha_{2}$ zone were observed, however, but this may be due to the sections having been taken from weathered portions of the surface. A large troilite nodule, 2 cm in diameter - or rather the cavity after its artificial removal - was present in one of the sections.

In 1924 the museum blacksmith, Samuel McDowell, forged a 356 mm long and 30 mm wide knife from a piece of Nejed (II). It was ground to a sharp edge and etched to show the damask produced by the distorted Widmanstätten structure. An iron like Nejed will be relatively easy to forge because the phosphorus and sulfur contents are tolerably low.

Nejed (I) and Nejed (II) are normal medium octahedrites which are closely related to Cape York, Red River and Casas Grandes. It is almost certain that they belong to the shower of meteorites that produced the Wabar craters since their detailed metallography is identical to that of the Wabar specimens. The coordinates given above are, therefore, given as the Wabar coordinates. See also the discussion under Wabar.

Specimens in the U.S. National Museum in Washington:
Nejed No. 1:
6 g fragment (no. $670,3.5 \times 2.2 \times 0.15 \mathrm{~cm}$ )
37 g part slice (no. $1093,4 \times 3 \times 0.4 \mathrm{~cm}$; Shepard Collection no. 73)
Nejed No. 2:
309 g part slice (no. $241,9 \times 5.5 \times 0.7 \mathrm{~cm}$ )
$1,472 \mathrm{~g}$ endpiece (no. $576,13 \times 7.5 \times 2.5 \mathrm{~cm}$ )
478 g corner (no. $669,7.5 \times 4.5 \times 2.5 \mathrm{~cm}$; neighbor to no. 576)
107 g part slice (no. $2949,6 \times 4 \times 0.6 \mathrm{~cm}$ )
154 g forged knife (no. $739,36 \times 3 \times 0.25 \mathrm{~cm}$ ) See Figure 1867.

Waingaromia, Auckland, New Zealand

$$
178^{\circ} 5^{\prime} \mathrm{E}, 38^{\circ} 15^{\prime} \mathrm{S}
$$

A mass of $9,204 \mathrm{~g}$ was found in 1915 on a farm near Waingaromia, 14 miles northwest of Tolaga Bay. It was acquired by the Gisborne Museum but was transferred in 1970 to D.R. Gregg, Canterbury Museum, Christchurch. It measures $216 \times 159 \times 112 \mathrm{~mm}$ and displays a severely corroded exterior. A preliminary examination of a small section indicates that Waingaromia is a medium octahedrite with a bandwidth of about 0.9 mm (letter from R.S. Clarke of December 9, 1970).

Waldron Ridge, Tennessee ?, U.S.A.

$$
36^{\circ} 33^{\prime} \mathrm{N}, 83^{\circ} 45^{\prime} \mathrm{W}
$$

Coarse octahedrite, Og. Bandwidth $1.60 \pm 0.20 \mathrm{~mm}$. Neumann bands. HV 130-210.
Group I. $7.55 \% \mathrm{Ni}$, about $0.2 \% \mathrm{P}, 74.6 \mathrm{ppm} \mathrm{Ga}, 282 \mathrm{ppm} \mathrm{Ge}$, 2 ppm Ir.
Some samples - and perhaps the entire mass - have been artificially reheated to about $600^{\circ} \mathrm{C}$.

## HISTORY

The original weight and the place of discovery of Waldron Ridge are somewhat obscure. The following is an attempt to reconstruct its history from what is known from
the reports by Kunz (1887d), Ledoux (1889) and Brezina (1896: 234, 287): a mass of about 14 kg was discovered by a prospector in 1887 in the Appalachian Mountains near Cumberland Gap. The prospector split the weathered mass into several fragments, of which the largest ( 15 pounds $=$ 6.8 kg ) passed through several hands before it was described by Kunz ( 1887 d ). Another fragment of 12 pounds ( 5.4 kg ) came to New York and was described by Ledoux (1889) who stated that it was found on "Waldron Ridge, 10 miles NE of Cumberland Gap, Tennessee." Farrington (1915: 475) noted, however, that no such locality was marked on the U.S. topographic maps of the region. He suggested that the locality instead was Wallens Ridge, 10 miles southeast of Cumberland Gap, and he changed the name of the meteorite accordingly. This suggestion has not been followed up by later authors.

Kunz (1887d) and Huntington (1894) suggested that Waldron Ridge and several other irons from the Appalachian Mountains were paired falls with Cosby's Creek. This is out of the question, however, considering the details of the structure and the composition, as discussed below.

Brezina (1896: 234, 287) acquired Kunz's collection of 91 meteorites, and among these was the 6.8 kg main mass of Waldron Ridge. He gave a brief description, while Ward (1904a: plate 2) gave a photomacrograph of an etched section. Wasson (1970a) showed that Waldron's Ridge, on the basis of $\mathrm{Ga}-\mathrm{Ge}-\mathrm{Ir}$ data alone, could not be a paired fall with Greenbrier County or Cosby's Creek.

The coordinates above are for Cumberland Gap, since no decision as to the precise location could be reached. It should also be noted that three states meet at this point so it is, in fact, unknown whether the mass was found in Tennessee, Virginia or Kentucky.

## COLLECTIONS

Vienna ( 3.32 kg and 350 g slices), London ( 3.04 kg corner piece and 158 g slices), Chicago ( 427 g endpiece), New York ( 372 g ), Berlin ( 343 g ), Budapest ( 256 g ), Bonn $(78 \mathrm{~g})$, Washington ( 70 g ), Paris ( 68 g ), Vatican $(38 \mathrm{~g})$, Strasbourg ( 28 g ), Harvard ( 12 g ). Farrington (1915: 475) believed that only a total of 8 kg was known. From the original reports and the cumulative weight of preserved specimens, i.e., 8.56 kg , it is clear that more must have existed - probably about 30 pounds or 14 kg - as also suggested by Hey (1966: 512).

## DESCRIPTION

According to Kunz (1887d) and Brezina (1896: 287), the 6.8 kg mass was the more massive nucleus of a somewhat larger mass. The exterior had spalled off by the combined action of weathering and a sledge hammer, so the
remaining mass was essentially bordered by octahedral cleavage planes.

Accordingly, etched sections through the mass show neither fusion crusts nor heat-affected $\alpha_{2}$ zones. There is a coarse Widmanstätten structure composed of straight, somewhat swollen $\left(\frac{L}{W} \sim 10\right)$ kamacite lamellae with a width of $1.60 \pm 0.20 \mathrm{~mm}$. - The bandwidth of 1.3 mm given in Hey (1966) appears to be determined on an atypical specimen. - The kamacite is rich in subboundaries decorated with $1 \mu$ phosphides, and Neumann bands are common. They are, however, somewhat altered by annealing; they now display straight parallel edges, or they are discontinuous. The hardness of the kamacite phase is highly erratic, ranging from 130 to 190 from original values of $180 \pm 10$ as if the kamacite has been partially annealed. Also, in near-surface regions the hardness increases to above 210; but the reason here is clear since several hammer marks can be detected, and the structural elements are distorted.

Taenite and plessite cover about $10 \%$ by area, often as up to $4 \times 3 \mathrm{~mm}$ comb plessite fields. Pearlitic plessite with $1 \mu \gamma$-veinlets and spheroidized plessite with $5-20 \mu \gamma$-spherules are prominent. Even taenite lamellae as thin as $20 \mu$ show interiors which are decomposed to eminent pearlite.

Schreibersite occurs as cuneiform or branching skeleton crystals, generally $1-2 \mathrm{~mm}$ thick but often several centimeters long. It is also common as $20-100 \mu$ thick grain boundary precipitates and as $5-50 \mu$ particles substituting for taenite in the plessite fields. Rhabdites are common; their cross sections are generally $1-10 \mu$. The bulk phosphorus content is estimated to be $0.20 \pm 0.05 \%$.

Troilite-graphite nodules are present in some sections as complex aggregates surrounded by rims of 0.3 mm schreibersite, 0.2 mm cohenite and 1.2 mm swathing kamacite. Silicates were not detected but would probably be found during a systematic examination.

As usual in group I, cohenite occurs in some sections but not in others. It forms elongated rounded bodies aligned in the Widmanstätten kamacite lamellae. They are typically $3 \times 0.5 \mathrm{~mm}$ in size and show $10-50 \mu$ inclusions of kamacite, taenite and schreibersite. The decomposition to graphite has not started. Most cohenite bodies are situated in the kamacite lamellae; occasionally, however, a large massive cohenite crystal may be detected inside an openmeshed plessite field. Almost all taenite in contact with cohenite is of the pearlitic variety.

The meteorite has been gently reheated by the finder possibly in order to facilitate the splitting or to reveal the true nature of the material. The finder was a prospector who, for a while, believed he had found an iron ore (Kunz 1887d; Ledoux 1889). Evidence of the reheating, which seems to have been carried to about $600^{\circ} \mathrm{C}$, is the straight

WALDRON RIDGE - SELECTED CHEMICAL ANALYSES

| Reference | percentage |  |  | ppm |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Ni | Co | P | C | S | Cr | Cu | Zn | Ga | Ge | Ir | Pt |
| Wasson 1970a | 7.55 |  |  |  |  |  |  |  | 74.6 | 282 | 2.0 |  |

and stippled Neumann bands, the erratic microhardness, the presence of minute ( $0.5-1 \mu$ ) metal particles in the terrestrial limonite, and development of $2-5 \mu$ wide zones with laceworks of oxides and metal along corroded grain boundaries.

Waldron Ridge is a typical inclusion-rich coarse octahedrite which has as its nearest relative Ogallala, Mount Ayliff and Bohumilitz.

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

70 g part slice (no. $1565,6 \times 3.5 \times 0.4 \mathrm{~cm}$ ) from British Museum No. 67589.

Walker County, Alabama, U.S.A.
Approximately $34^{\circ} \mathrm{N}, 87^{\circ} 10^{\prime} \mathrm{W} ; 300 \mathrm{~m}$
Hexahedrite, H. Single crystal larger than 25 cm . Neumann bands. HV $172 \pm 10$.
Group IIA. $5.46 \% \mathrm{Ni}, 0.28 \% \mathrm{P}, 59 \mathrm{ppm} \mathrm{Ga}, 189 \mathrm{ppm} \mathrm{Ge}, 3.0 \mathrm{ppm}$ Ir.

## HISTORY

A mass of 165 pounds ( 75 kg ) was found in 1832 in the uncultivated and rather unfrequented northeast corner of Walker County. The finder, Wiley Speaks, while on a deer hunting excursion, placed his foot to rest on the pointed end which projected above the ground.
"Believing it to be some precious metal, he took especial pains to have it safely and secretly conveyed to his house, some 15 miles off [in the adjacent Morgan County], where it remained till February 1843, when it came into the possession of Dr. Sowell, and shortly after I received it in Nashville. The original weight was 165 pounds; this weight was somewhat diminished when it came into my possession, some small pieces having been chiselled off. This must of course be expected, as these masses fall mostly in the hands of ignorant persons, who are generally on the look-out for some of the precious metals (as silver and gold are usually called), and consequently every thing that is uncommon is very often considered as such. It is therefore necessary, in order to convince themselves of its true nature, that some small parts of it should be sent to a silversmith" (Troost 1845).


Figure 1870. Walker County (Brit. Mus. no. 16867). A typical hexahedrite with numerous rhabdite plates. Troilite crystals with schreibersite rims at T, and schreibersite skeleton crystals at S . Etched. Scale bar approximately 5 mm . B.M. neg. 6257.

The existence of the meteorite was known to Dr. Sowell in 1840, but negotiations stretched over a period of two or three years before he was able to obtain possession of it, probably pending the finder's queries into the actual content of noble metals (Shepard 1847). The small specimens which were chiseled off on that occasion were later traded to various collections under the name "Morgan County." Buchner (1863: 181) and Brezina (1896: 290) rightly concluded that these specimens were nothing other than separated pieces of Walker County which had been traded independently.

According to Cohen (1905: 167), "the main mass ( $653 / 4 \mathrm{~kg}$ ) of this iron was offered for sale in 1843 , under the name Alabama, by Troost, through the dealer Heuland, to the British Museum, which acquired 22.5 kg ." The remainder of the mass was purchased by Reichenbach (1861: 119; 1862a: 630), who unfortunately used the name "Claiborne" for his material. Specimens exchanged


Figure 1871. Walker County (Chicago no. 938). Prismatic rhabdites and Neumann bands. Etched. Scale bar $200 \mu$. (Perry 1944: plate 52.)


Figure 1872. Walker County (Harvard no. 116C). Troilite (white) with several daubreelite bars parallel to ( 0001 ) of the hexagonal troilite. Envelope of schreibersite (S). Neumann bands in the kamacite. Etched. Crossed polars. Scale bar $200 \mu$.
from him in the 1850s and 1860s are labeled thus. This has brought about considerable confusion, since Claiborne was also the name of an ataxite found in Alabama in 1834 and described by Jackson in 1838 (Lime Creek). Due to the imperfect stage of the techniques for structural and chemical examinations a hundred years ago, it proved difficult to separate hexahedrite and ataxite specimens, and the confusion has, in part, remained to this day. The 40 kg main mass (now 38 kg ) of Walker County in Tübingen is still erroneously labeled "Lime Creek, Claiborne" in the catalog of the collection (Machatschki 1940: 14).

Walker County was preliminarily described by Troost (1845). Shepard (1847) gave a woodcut of the exterior shape. His analytical results, giving $99.9 \% \mathrm{Fe}$, were obtained from pseudeometeorite material, as noted by Cohen (1905: 168). Reichenbach had several observations published in a rather unsystematic way. Pertinent references will be found in Wülfing $(1897: 206)$ who listed the meteorite under "Lime Creek." Cohen (1905) gave an excellent description, accompanied by bulk chemical analyses and by an analysis of rhabdite-isolates, remarkable for its day: $51.10 \% \mathrm{Fe}, 32.99 \%$ Ni, $0.42 \%$ Co, $15.49 \%$ P. He also reported chromite, daubreelite and at least two different, unidentified silicates. A summary is given by Farrington (1915).

Perry (1944) presented nine photomicrographs of typical structural elements. One of these, allegedly of an anomalous plessite variety, was reinterpreted by Axon (1960) as a weathered "striated" troilite. Reed (1969), examining the kamacite with the electron microprobe, found it to contain $5.3 \% \mathrm{Ni}$ and $0.082 \% \mathrm{P}$, with a very high abundance of small rhabdites.

Spencer (1951), when discussing the occurrence of Reichenbach lamellae in octahedrites, erroneously assumed that Walker County showed "a complex pattern of troilite bands in at least a dozen directions, suggesting an orientation on (211) and inviting further study."

## COLLECTIONS

Tübingen ( 38.2 kg , mislabeled Lime Creek), London ( 22 kg ), Harvard ( 2.3 kg ), Yale ( 371 g ), Washington ( 290 g ), Ann Arbor (187 g), Berlin ( 157 g ), Chicago (111 g), Canberra ( 106 g), Stockholm (79 g), Amherst (77 g), New York $(71 \mathrm{~g})$, Vienna ( 65 g ), Paris ( 63 g ), Budapest $1956(33 \mathrm{~g})$, Calcutta ( 17 g ), Tempe ( 12 g ), Ottawa ( 6 g ).

## DESCRIPTION

No direct information as to the original size of the
mass has been preserved. From a sketch in Shepard (1847) and from various remarks by Reichenbach (1859: 119; 1862b: 584) it may be deduced that the meteorite was smoothly rounded, of pear-shape and with the average dimensions of $32 \times 25 \times 25 \mathrm{~cm}$.

The mass is covered with $1-5 \mathrm{~mm}$ thick crusts of terrestrial oxides, fusion crust and heat-affected $\alpha_{2}$ rim zones cannot be detected. In the limonitic surface layers, the rhabdites are often relatively well-preserved. Corrosion penetrates into the mass along the extensive rhabdite plates and, in places, the metal is separating along these corroded planes, leaving a hackly, jagged surface. Along part of the surface the meteorite is indented by heavy hammer and chisel marks.

Etched sections show that Walker County is a single kamacite crystal, larger than 25 cm in diameter, with Neumann bands extending from edge to edge. The Neumann bands are conspicuous, clear and serrated; only one direction seems to be modestly decorated by phosphides, $1-5 \mu$ across. Where Neumann bands pass the inclusion-free kamacite around the larger sulfides and phosphides, they are broad ( $\sim 10 \mu$ ), but in zones rich in small rhabdites ( $1-2 \mu$ ) the same bands are narrow ( $1-4 \mu$ ). The phosphides are bent due to deformation and they are often sheardisplaced their own thickness. The hardness of the kamacite is $172 \pm 10$, in agreement with the structure which presents signs of slight cold-deformation.

Walker County is remarkable by the large number of plate-shaped rhabdites. While the concentration varies from section to section, it was found that a density of 8-10 plates per $\mathrm{cm}^{2}$ was typical for those rhabdite plates that were visible to the naked eye. Their dimensions are typically $10 \times 10 \times 0.01 \mathrm{~mm}$, but larger plates, up to at least $30 \times$ $30 \times 0.02 \mathrm{~mm}$, exist. The plates are randomly distributed and not arranged in parallel planes. Some of the larger rhabdites are imperfectly developed, exhibiting irregular cavities and internal, tubelike channels. Between the primary plates there are numerous finer plates, typically 3 x $1 \times 0.003 \mathrm{~mm}$ in size. All rhabdites are uniformly oriented, apparently parallel to $\{221\}$ and $\{100\}$ of the kamacite. Between the plate-shaped rhabdites there are a large number of prismatic rhabdites, ranging from $15 \mu$ and downwards in cross section.

Troilite is common as lenticular or globular nodules, $0.3-15 \mathrm{~mm}$ in size. The larger nodules were not available for examination, but the smaller ones, $1-2 \mathrm{~mm}$ in size, are normally regular intergrowths of troilite and daubreelite. As

WALKER COUNTY - SELECTED CHEMICAL ANALYSES

| References | percentage |  |  | ppm |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Ni | Co | P | C | S | Cr | Cu | Zn | Ga | Ge | Ir | Pt |
| Hildebrand in Cohen 1905 | 5.30 | 0.64 | 0.28 | 100 | 1900 | 500 | 600 |  |  |  |  |  |
| Smales et al. 1967 |  |  |  |  |  | 44 | 120 | <1 | 59 | 170 |  |  |
| Wasson 1972, pers. comm. | 5.46 |  |  |  |  |  |  |  | 58.2 | 189 | 3.0 |  |
| Crocket 1972 |  |  |  |  |  |  |  |  |  |  | 1.2 | 5.6 |

a result of slight plastic deformation, the monocrystalline troilite is penetrated by several sharply delineated twins, and sometimes the whole lamella-stack is gently bent and sheared. The daubreelite forms $1-100 \mu$ wide lamellae, exsolved parallel to (0001) of the troilite. The smaller the nodules, the more the daubreelite. In $0.2-0.4 \mathrm{~mm}$ nodules, daubreelite constitutes about $50 \%$, often as exceedingly fine repetition lamellae. Such were the units pictured by Perry (1944: plate 6) and which were further discussed by Axon (1960). The texture may be somewhat obscured near the surface where troilite is partially converted to pentlandite by weathering while the adjacent kamacite is converted to limonite.

The troilite nodules are frequently enveloped by narrow, discontinuous layers of schreibersite and cohenite. The aggregates are situated in a pure kamacite, depleted in phospho-


Figure 1873. Walker County (Harvard no. 116C). A crescent-shaped chromite crystal surrounded by three schreibersite crystals. Lightly etched. Scale bar $100 \mu$.


Figure 1874. Walker County (U.S.N.M. no. 379). Near-surface section showing extensive corrision of the kamacite adjacent to rhabdites. The rhabdites themselves survive for a long time. Polished. Scale bar $50 \mu$.
rus, carbon and nickel; this kamacite is macroscopically visible as a $0.5-1 \mathrm{~mm}$ wide, bright zone around the inclusions.

In one section a 1 mm graphite nest was encountered. It was a loose aggregate of $1 \mu$ graphite grains, apparently with no distinct crystallographic relationship. Upon routine polishing, most of the graphite disappeared, leaving only irregular cakes along the periphery of the nodule. Locally, a few cliftonite crystals, $10.50 \mu$ across, were preserved. Between the graphite and the kamacite there is a highly irregular, $0.1-0.2 \mathrm{~mm}$ thick layer of an isotropic carbide, probably haxonite, with a microhardness of $940 \pm 25$. In the haxonite there are numerous $1-5 \mu$ rhabdites. The haxonite must, therefore, be of rather late origin, having segregated at a temperature below that necessary for rhabdite precipitation


Figure 1875. Walker County (U.S.N.M. no. 379). A troilitedaubreelite nodule. It is entirely decomposed to a fine stack of alternating troilite (light) and daubreelite (dark) lamellae. Compare Figure 171. Polished. Scale bar $40 \mu$.


Figure 1876. Walker County (U.S.N.M. no. 379). An unusual aggregate, mainly consisting of loosely packed graphite that was torn out during polishing. Along most of the periphery is an irregular carbide rim, probably of haxonite (H). Rhabdites and distorted Neumann bands are also seen. Etched. Scale bar $300 \mu$.
( $\sim 400^{\circ} \mathrm{C}$ ). The kamacite around the graphite-haxonite aggregate is highly anomalous to a distance of 1 mm , with numerous undulating subboundaries decorated with rhabdites.

The aggregate described above is unusual, but related to other poorly preserved aggregates in the North Chilean hexahedrites. It probably started at a high temperature with the precipitation from solid solution of a few cliftonite crystals. These later served as nucleation sites for more graphite, now of a microcrystalline nature. Finally, in a last attempt to get rid of dissolved carbon, the kamacite rejected carbon to form haxonite at a time when rhabdites had already precipitated.

Besides the minerals mentioned above, Walker County also contains a modest amount of the chromium nitride, carlsbergite, as $5 \times 1 \mu$ platelets. Chromite occurs as $50-200 \mu$ euhedral crystals which are intergrown with troilite and daubreelite. Cohen (1905: 172) observed at least two different types of silicate grains; they were detected in the residue from dissolving a 43 g specimen for analysis.

There are indistinct, $5-10 \mu$ wide reaction zones of a lacework type between the corrosion products and the kamacite. There also seem to be $0.5-1 \mu$ metallic beads in the limonite. This, in connection with the rather low hardness for a hexahedrite which shows no signs of cosmic annealing, indicates that the finder reheated the meteorite slightly, probably for a short time to about $400^{\circ} \mathrm{C}$. The evidence is circumstantial and far from so decisive as, e.g., is the case for Rodeo, Ruff's Mountain and Victoria West.

Walker County is a normal hexahedrite with a large number of rather evenly distributed rhabdite plates. Structurally and chemically, it is closely related to the North Chilean hexahedrites even as far as the occurrence of graphite nodules is concerned.

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

13 g part slice (no. 120)


Figure 1877. Walker County (U.S.N.M. no. 379). Detail of the edge of another graphite nest similar to that in Figure 1876. A cluster of fine cliftonitic graphite crystals (black) are located in kamacite (K) with Neumann bands, and in haxonite (H) with small phosphide inclusion (S). Etched. Scale bar $50 \mu$.

259 and 10 g endpiece (no. $379,8 \times 4.5 \times 1.5 \mathrm{~cm}$ and mounted fragment)
8 g fragment (no. 3144)

## Wallapai, Arizona, U.S.A.

Approximately $35^{\circ} 48^{\prime} \mathrm{N}, 113^{\circ} 42^{\prime} \mathrm{W} ; 2000 \mathrm{~m}$
Fine octahedrite, Of. Bandwidth $0.43 \pm 0.06 \mathrm{~mm}$. Neumann bands $/ \epsilon$. HV $255 \pm 15$.
Group IID. $11.4 \% \mathrm{Ni}, 0.69 \%$ Co, about $0.9 \% \mathrm{P}, 82 \mathrm{ppm} \mathrm{Ga}, 98 \mathrm{ppm}$ $\mathrm{Ge}, 3.5 \mathrm{ppm}$ Ir.

## HISTORY

In 1927 two masses of 306 and about 124 kg were reported to the U.S. National Museum from the Wallapai Indian Reservation in Mohave County. They were lying on the slope of a limestone mountain, only about 1.5 m apart, and protruded with about one-fourth of their mass above the ground. The meteorites had been discovered by an Indian, Dick Grover, and the location was given as 10-12 miles southeast of the Music Mountain mine and six miles from the rim of the Grand Canyon of the Colorado River. It appears, however, that the exact locality is no longer known. The smaller mass was acquired by the University of


Figure 1878. Wallapai (U.S.N.M. no. 788). The 306 kg mass is in the Smithsonian Institution. It is covered by corrosion products that indicate that its terrestrial age is high. Wallapai cannot be an observed fall as believed by previous writers. S.I. neg. 6154B.

