Cohenite was not positively identified, but it appears that the figure given by Spencer (1938: plate 3) does exhibit several branching, millimeter-sized cohenite crystals and not schreibersite as believed by Spencer. Graphite, troilite and silicate were not detected in this study but will undoubtedly be identified if more material should become available.

The plastic deformation is concentrated within narrow shear zones that frequently continue in internal fissures. Shear-displacements of 10-100 \( \mu \) m are very frequent, and a 500 \( \mu \) m fault through a plessite field was also observed. Ultimately the shear led to fragmentation, and most of the present specimen surfaces are such shear-surfaces, somewhat altered by later corrosion. Many Imilac fragments have a similar appearance. No fusion crust and no heat-affected \( \alpha_2 \) zone from the atmospheric flight were detected in this study.

Corrosion mainly attacks along the explosion-induced fissures and is usually well developed along the phosphides. The kamacite of the pearlitic, acicular and duplex fields is selectively corroded and gives rise to beautiful, contrast-rich structures of dark limonite in light unattacked taenite.

Kaalijärvi is a coarse octahedrite which is related to Campo del Cielo, Cranbourne, Seelásen and Yardymly. Although no trace element analysis has been performed and the examined sections are small, Kaalijärvi is, no doubt, a normal member of the chemical group I, with somewhat less nickel than Canyon Diablo, another prominent crater-producing meteorite. The preserved fragments have primary structures (bandwidth, pearlitic, spheroidized and acicular plessite, possibly cohenite) which closely correspond to the group I meteorites mentioned above. The secondary structures of the fragments, such as e, deformation bands, shear zones and recrystallization, date from the impact and are similar to what is present in Canyon Diablo, Henbury, Wabar and other crater-producing meteorites. There is, thus, no reason at all to maintain the classification by Spencer (1938) and Hey (1966): “Metabolitic ataxite to medium octahedrite.”

Specimens in the U.S. National Museum in Washington:
4.3 g individual (no. 1293, 15 x 10 x 5 mm)
3/4 kg Silurian dolomite (no. 1290) and 3 snail shells (no. 1292) from the crater field

Kalkaska, Michigan, U.S.A.
44°38'49"N, 85°8'12"W; 300 m

Medium octahedrite, Om., Bandwidth 1.00±0.15 mm. e-structure. HV 290±12.
Group IIIA. 7.4% Ni, about 0.1% P, 18.1 ppm Ga, 33.5 ppm Ge, 11 ppm Ir.

HISTORY
A mass of 9.4 kg (20.7 pounds) was plowed up in 1947 or 1948 by A. R. Sieting, about 10 km south-southwest of Kalkaska, in Kalkaska County. The field had been cultivated for over 30 years, so the sound of the cultivator blades striking metal was quite unexpected. The mass was shown to various peoples and to schools, before it was presented, in 1964, to Michigan State University where it was described with a photograph of the exterior and a photomacrophotograph by Chamberlain (1965) who also gave further details of the find. Schultz & Hintenberger (1967) measured the amount of various noble gases while Voshage (1967), from these values, estimated the exposure age to lie between 420 and 800 million years.

COLLECTIONS
Abrams Planetarium, Michigan State University, East Lansing (main mass), Washington (759 g).

DESCRIPTION
The irregular mass has the approximate overall dimensions 18 x 15 x 9 cm, and it shows numerous well developed regmaglypts 10-20 mm in size. Locally, deeper holes are carved out, as for instance, 10 mm deep with an

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Figure 959. Kaalijärvi (Brit. Mus. no. 1938, 135). Pearlitic plessite with cloudy taenite rims. This structure is almost exclusively found in group I irons with significant carbon content. Etched. Scale bar 50 \( \mu \).
Kalkaska

aperture of 20 x 15 mm. The mass is covered by a brown oxide crust from terrestrial corrosion, but the fusion crust may still be observed in various places as a composite of 0.1-0.2 mm oxides and 0.5-2 mm laminated metal-melts. A section through the crust revealed that the outer oxide layer is two-phased, probably consisting of wüstit and magnetite, while the inner, metallic layer is subdivided in 5-10 single layers of cellular-dendritic material with a hardness of 335±20. Below this is a 1.8-3.0 mm wide rim zone of heat-affected $\alpha_2$. Micromelted phosphides occur in the outer 40-50% of this zone. They are, as usually in the rim zone, asymmetrically solidified with the primary dendrites attached to the cavity wall facing the cool interior of the meteorite, clearly indicating that the melts solidified by conduction of heat into the cool interior rather than to the surface. The hardness of the $\alpha_2$ rim zone is 200±10. It increases inwards to 290±12, a level which is reached at a depth of 10 mm (hardness curve type 1).

Etched sections display a medium Widmanstätten structure of straight, long ($\sim30$) kamacite lamellae with a width of 1.00±0.15 mm. The oriented sheen is rather subdued, partly because the kamacite is of the shock-hardened $\varepsilon$-type (HV 290±12), and partly because the plessite fields are degenerated and contain only little taenite.

Plessite covers about 30% by area. The comb plessite has discontinuous taenite rims, and the individual taenite ribbons and grains are few and small. Also present are duplex, poorly resolvable $\alpha+\gamma$ fields.

Schreibersite is not common. It occurs as 2-10 $\mu$ wide grain boundary precipitates and as 2-10 $\mu$ vermicular bodies inside many of the comb and net plessite fields and, finally, as 0.5 $\mu$ blebs on the subgrain boundaries of the kamacite. Rhabdites are present in many kamacite lamellae, but they are small, generally less than 1 $\mu$ thick. The bulk phosphorus content of the meteorite may be estimated to be near 0.1%.

Troilite occurs as angular and lenticular bodies, e.g., 5 x 1, 2 x 2 or 1 x 0.5 mm in size, frequently enveloped in 0.5-1 mm swathing kamacite. A total of eight bodies were observed on 86 cm². They are monocrystalline, but the lenticular deformation twins indicate a certain plastic deformation, as does the frequent brecciation. The troilite contains daubreelite as 50-200 $\mu$ wide bars that are often

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Kalkaska - Selected Chemical Analyses

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breciated together with the troilite itself. Isolated daubreciated, or possibly brezinned, grains occur as angular crystals, 10-40 μm in size, in the kamacite. From a typical 1 mm troilite grain centimeter-long, branched veinlets of troilite extend into the metallic matrix, mainly following the α-α and α-γ grain boundaries. The veinlets are 5-50 μm wide and contain breccias of troilite with minor amounts of daubreciated that are set in a matrix of terrestrial corrosion products. The breccia-filled fissures mainly follow schreibersite-filled (111) grain boundaries; it appears that the cracks were created at a remote shock event and that shattered debris from the troilite nodules partly filled them up. Open as they were, they became an easy prey for percolating, terrestrial ground water. The troilite shows a little pentlandite along the cracks.

Numerous, tiny, hard platelets, typically 20 x 1 x 0.5 μm, are present in the kamacite, no doubt the same chromium nitride, carlsbergite, as reported from, e.g., Costilla Peak, Schwetz and Cape York.

Kalkaska is a shocked medium octahedrite which appears to be related to Costilla Peak and Boxhole. It is a low-nickel low-phosphorus member of group IIIA.

Specimen in the U.S. National Museum in Washington:
759 g slice (no. 3217, 10 x 5 x 2.4 cm)

Karasburg, South West Africa
27°40'S, 18°58'E

Medium octahedrite, Om. Bandwidth 1.20±0.20 mm. Duplex kamacite. HV 193±7.

Probably group IIIAB. About 8.7 Ni, 0.23% P.

The examined sample — and probably the whole mass — has been artificially reheated.

HISTORY
A small mass (5-15 kg) was found before 1964 on the farm Duurdrift Nord, No. 26, District of Warmbad, which is about 45 km north-northeast of Karasburg. It passed through several hands and was for a while in the possession of the plumber, Andy Morris of Karasburg. About 1964 it was donated to the Geological Museum, Johannesburg, where Robert Citron noted it during his extensive search for Gibeon meteorites in South West Africa. A small sample was forwarded to the Smithsonian Institution for verification as a Gibeon sample. However, it turned out to be an independent meteorite which was briefly described by Buchwald (1969a). Further attempts to locate the main mass for description have so far been unsuccessful.

COLLECTIONS
4.6 g polished section in the Smithsonian Institution, Washington.

ANALYSIS
In a partial analysis Roy S. Clarke, Jr., found 8.68% Ni (1968, personal communication).

DESCRIPTION
The only available section indicates that Karasburg is a medium octahedrite. It shows straight kamacite lamellae with a bandwidth of 1.20±0.20 mm. No Neumann bands or c-structures are present.

Taenite and plessite cover 40-50% by area, both as varieties of comb and net plessite and as more massive fields with acicular interiors. Schreibersite often occurs centrally in the kamacite lamellae as 0.5-1 mm skeleton crystals. It is also present as 20-60 μm wide grain boundary veinlets. Locally, 5-10 μm blebs are situated as island arcs about 20-60 μm. No Neumann bands or taenite units.

"Isothermal taenite" shows straight kamacite lamellae and the taenite edges are frayed as if partially redissolved in the kamacite. All kamacite, both of the lamellae and of the taenite itself, are decomposed to a most open meshed plessite varieties, is decomposed to a most corroded grain boundary veinlets. The veinlets are 1.20±0.20 mm. Duplex kamacite. HV 193±7.

High temperature in tercrystalline oxidation occurs along 5-10 μm grain boundaries. The veinlets are 1.20±0.20 mm. Duplex kamacite. HV 193±7.

Proof that the reheating is terrestrial is shown by the fact that all corrosion products are also heat-treated. Creamcolored reaction zones, 3-5 μm wide, are common between schreibersite and terrestrial limonite. High temperature intercrystalline oxidation occurs along the whole of the surface to a depth of 0.1-0.3 mm. Around corroded grain boundary fissures 50-100 μm wide laceworks of decomposed oxides and metal are present. The heat treatment seems to have lasted for several hours at temperatures up to 700° or 800° C.

Considering that only a very minor fragment has been examined, it is suggested that an attempt should be made to locate and thoroughly describe the main mass, and that a full analysis be carried out. See also the Supplement.

Specimen in the U.S. National Museum in Washington:
4.6 g polished section (no. 2513)
Karee Kloof, Cape Province, South Africa
31°36'S, 25°48'E

Coarse octahedrite, Og. Bandwidth 1.6±0.4 mm. Neumann bands. HV 180±5.
Anomalous member of group I. 8.26% Ni, 0.44% Co, 0.22% P, 80 ppm Ga, 355 ppm Ge, 1.5 ppm Ir.

HISTORY
A mass of 92 kg (203 pounds) was found near Karee Kloof, Hofmeyer, about 1914 (Port Elizabeth Museum, Director's Report for 1914: 4 and figure). The meteorite was described by Prior (1923b) who found it similar to Annaheim and gave a photograph of the exterior. Comerford et al. (1968) recently reinvestigated the iron to find out whether it could be a paired fall with Deelfontein. This possibility was ruled out.

COLLECTIONS
Port Elizabeth Museum (about 85 kg), London (419 g), Washington (27 g).

DESCRIPTION
The relatively flat mass is irregularly shield-shaped with the average dimensions 43 x 33 x 20 cm. It is pitted on both a small and a large scale. The largest depression, which has an aperture of 20 x 15 cm and is 7.5 cm deep, is subdivided into smaller bowls. Since concretionary calcite was identified on the surface Prior (1923b) concluded that the meteorite was of considerable terrestrial age. The present author, having examined the main mass, comes to the same conclusion.

The specimen in the U.S. National Museum is small and only allows for few observations. Sections through the rim zone fail to disclose fusion crust and heat-affected \( \alpha_2 \) zones, and there is no hardness gradient in the kamacite phase towards the surface. It is estimated that at least 3 mm has been lost by corrosion. The surface is locally violently deformed, displaying recurving taenite lamellae, brecciated schreibersite and distorted Neumann bands in the outermost one or two millimeters. Lenticular deformation bands and boudinage of the schreibersite may also be found, and even incipient recrystallization of the most severely deformed kamacite is present. Corrosion penetrates the deformed rim zone and also attacks deeper into the mass along grain boundaries. The surface deformation appears to be of the type which is associated with shattering of a larger mass during entry through the atmosphere. It resembles, on a minor scale, the deformation which is present in many specimens of Campo del Cielo and Gibeon. If this interpretation is correct, one would expect more material to be found if the vicinity of Karee Kloof were subjected to an intensive search.

Etched sections display an irregular, coarse Widmanstätten structure of bulky, short (\( \sim 10 \)) kamacite lamellae with a width of 1.6±0.4 mm. Local grain growth has created 5-10 mm irregular kamacite grains. The kamacite has Neumann bands and shows subboundaries, marked by numerous, rod-like precipitates, 0.5-5 \( \mu \) thick, which are

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Figure 964. Karee Kloof (Los Angeles). Net plessite field with cloudy taenite rims and a schreibersite crystal (S). Etched. Scale bar 100 \( \mu \).

Figure 965. Karee Kloof (Los Angeles). Typical plessite field with cloudy taenite rim, indistinct transition zones, and interior of tempered martensite developed as platelets parallel to \( (111)_{\gamma} \). Etched. Scale bar 50 \( \mu \).
mainly phosphides. The hardness of the kamacite is 180±5, but it increases in the distorted areas to above 260.

Plessite is present as comb and net plessite but hardly covers 1% by area. The taenite blebs of the plessite are normally concave; the larger wedges of taenite are frequently decomposed to a contrast-rich martensite, (HV 300±20), with individual platelets parallel to the gross Widmanstätten pattern. The interior of other taenite fields is decomposed to a more or less fine-grained, almost unresolvable, duplex α + γ, which is very dark-etching. The taenite frames stain blue or brown upon etching (HV 250±10). The total impression is that of carbon having influenced the structure considerably; although no cohenite or graphite were present in the sections studied, they may well be present in other parts of the meteorite.

Schreibersite is present as 20 x 1, 5 x 1 mm or smaller monocrystalline units in the kamacite and common as 30-100 μ wide grain boundary precipitates. The matrix is rich in rhabdites, 5-10 μ in cross section, but also contains numerous particles less than 1 μ across.

Troilitc was not observed, but 15-50 μ daubreelite grains occur sporadically in the kamacite. Prior (1923b) reported minute quantities of an orthorhombic pyroxene and of feldspar.

Karee Kloof is a coarse octahedrite of a somewhat unusual character. The normal plessite development — compare, e.g., Deport and Toluca — was nowhere observed, the bandwidth was relatively high for the nickel content, and the typical troilitc-graphite and cohenite minerals were not detected. In many respects Karee Kloof resembles medium octahedrites like Thule or Kayakent, but, chemically, the meteorite is more closely related to the group I meteorites, as shown by the Ga-Ge-Ir-values of Wasson. Perhaps the structural anomalies will be understood better when larger sections of the meteorite become available.

Specimen in the U.S. National Museum in Washington:
27 g part slice (no. 1550, 3.5 x 1.5 x 1 cm) divided into two polished sections

Figure 966. Karee Kloof (Los Angeles). Another martensitic plessite field. Schreibersite (S). Indistinct Neumann bands in the kamacite. Etched. Scale bar 100 μ.

Figure 967. Karee Kloof (Los Angeles). Close-up of the transitional zone between untempered and tempered (dark) martensitic platelets, in a field similar to Figure 966. Etched. Scale bar 20 μ.

Kayakent, Eskisehir Province, Turkey

39°15.8′N, 31°46.8′E; 1,000 m

Medium octahedrite, Om. Bandwidth 1.20±0.15 mm. ε-structure. HV 310±15.
Group IIIA. 8.20% Ni, 0.51% Co, 0.21% P, 19.9 ppm Ga, 44.0 ppm Ge, 1.1 ppm Ir.

HISTORY
A mass of 85 kg was found in 1961, 7 km southwest of Kayakent in central Turkey. The corresponding coordinates are given above. The meteorite was thoroughly described,
with a map, figures of the exterior and of etched sections, by Kizilirmak et al. (1969). According to Professor Kizilirmak the mass was discovered in August 1961, but was associated by the villagers with a burst in the air at an uncertain date of April 1961. No crops reportedly grew within a circle 2 m in diameter around the small impact hole, 30 cm deep. The circumstances of fall will probably never be learned; whether or not the mass fell in April, as assumed, there is little doubt that it is a recent fall showing little corrosion as discussed below. Rare gas analyses have been performed by Schaeffer & Cobb and by Zähringer. The results are very similar, and Cobb estimated a cosmic ray exposure age of 425 million years (Kizilirmak et al. 1969).

COLLECTIONS
Department of Astronomy, Ege University, Izmir (main mass), Tempe (200 g), Copenhagen (112 g), London (100 g).

DESCRIPTION
The meteorite has the maximum dimensions 30.5 x 26 x 25.5 cm. The figure shows the mass after two cuts had been made. It is covered with regmaglypts, 2-4 cm in diameter and 0.2-1 cm deep. The surface is somewhat corroded, but the black fusion crust with fine striae and warts is preserved in many places. Sections show that other places are covered by terrestrial oxides, 0.1-0.3 mm thick; the sections also reveal that a number of internal fissures are filled with 10-50 μ wide veinlets of limonite. It appears plausible that such a corrosion attack may have developed within the months of April to August under the given climatic conditions.

Etched sections display a medium Widmanstätten structure of straight, long (W ~ 25) kamacite lamellae with a width of 1.20±0.15 mm. The kamacite has subboundaries decorated with 1 μ phosphide precipitates. It shows a marked, crosshatched e-structure with a hardness of 310±15, apparently as a result of shocking above 130 k bar. No cosmic annealing or recrystallization have occurred.

Taenite and plessite cover about 30% by area, mostly as comb and net plessite or as dense and duplex fields. A typical field will exhibit a tarnished taenite rim (HV 360±15) which is followed by a martensitic transition zone (HV 415±15). The martensite forms brown-etching, marked plates which follow the bulk Widmanstätten structure. Farther inwards duplex, poorly resolvable α + γ structures occur, the so-called “black taenite” (HV 360±15), and finally the centers may be developed as readily dissolvable α + γ (HV 340±15). The open-meshed plessite varieties approach the surrounding kamacite lamellae in hardness.

Schreibersite is common as 10-70 μ wide grain boundary precipitates and as 5-40 μ irregular blebs inside the plessite fields. It is often shattered and displaced by shear, e.g., in successive steps of 10 μ each. Its hardness is 750±30. Rhabdites are uncommon, but a host of very fine precipitates, ~ 0.5 μ, in the kamacite may be fine rhabdites.

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Reichenbach lamellae appear to be rather common, occurring with a frequency of one per 3 cm$^2$, but the sections available were too small for a determination of their orientation. They have directions which are unrelated to the Widmanstätten structure but may be parallel to (100)$\gamma$ as reported by Brezina (1880b) and Spencer (1951). A typical lamella in Kayakent is $10 \times 4 \times 0.05$ mm, but lamellae as thin as $3 \mu$ are present. They primarily consist of chromite, with a hardness of about 1,100. They have served as a substrate for troilite which forms irregular monocristalline seams and blebs. Schreibersite has also been nucleated upon the chromite, likewise as irregular, 10-50 $\mu$ thick blebs, mainly associated with $\alpha$-grain boundaries. The chromite lamellae are slightly bent and sheared. The $\epsilon$-structure is visibly distorted at the interfaces, and microfissures have been formed over long stretches along the lamellae. These fissures probably date back to the $\epsilon$-forming event and were thus readily available for corrosive attacks when the meteorite landed.

The fusion crust is, as usual on fresh falls, composed of two distinct layers: an oxidic layer, here, 50-100 $\mu$ thick, and a metallic, dendritic layer, 0-300 $\mu$ thick. Generally, the oxidic layers are found in the outer part of the crust while the metallic layers are in contact with the meteoritic metal, but due to irregular swelling and tapering, oxides may be found embedded in the fused metal as both laminae and globules. The inner part of the oxides displays a two-phase structure, probably a fine mixture of wüstite and magnetite. The magnetite is located on the grain boundaries but is also found as cubic 1-5 $\mu$ skeleton crystals precipitated in the wüstite interior. The outer part of the oxide crust appears to be massive magnetite.

The metallic fusion crust is composed of numerous layers, each 15-50 $\mu$ thick. Except for the innermost one, they can not have formed by melting in situ but must have been deposited as successive sheets of melts, ablated from

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**Figure 971.** Kayakent (Tempe no. 791). A coarse Reichenbach lamella of chromite, which has served as a substrate for two schreibersite crystals (white). Subboundaries in the kamacite, somewhat obscured by the later shock-transformation structure. Etched. Scale bar 200 $\mu$.

**Figure 972.** Kayakent (Tempe no. 791). Typical association of a chromite backbone (gray, 3 $\mu$ thick) and an elongated schreibersite crystal (white) which has nucleated and grown upon the chromite. A subsequent cosmic shock event has brecciated and fissured the aggregate and made it easily accessible to corrosive ground water with the result that the fissure is now partly filled with terrestrial limonite (black). Etched. Scale bar 20 $\mu$.

**Figure 973.** Kayakent (Copenhagen, no. 1973, 2082). Metallic fusion crust (above) and heat-affected $\alpha_2$ zone. The taenite has a lower melting interval than kamacite and is, therefore, selectively fused away (above right). Etched. Scale bar 100 $\mu$.

**Figure 974.** Kayakent (Copenhagen no. 1973, 2082). Part of a comb plessite field in the heat-affected $\alpha_2$ zone. As in Figures 973 and 975, carbon has diffused outwards from the taenite in the brief interval of atmospheric flight. Etched. Scale bar 20 $\mu$. 
other parts of the surface. The metal is dendritic with an armspan of 2-5 \( \mu \) and a cell or columnar width of 5-20 \( \mu \). Phosphides fill the interdendritic spaces, and the matrix has at low temperature transformed diffusionless to martensitic-like \( \alpha_2 \) structures with a hardness of 350±15. The innermost layer adheres firmly to the meteorite and locally penetrates into cavities, previously filled by schreibersite crystals. The relatively low-melting, nickel-rich taenite is clearly melted at a higher rate than the adjacent kamacite; its level may be 5-40 \( \mu \) lower than that of the kamacite, Figure 973.

Under the fusion crusts is a 2-3 mm wide, heat alteration zone of \( \alpha_2 \). The serrated \( \alpha_2 \) grains are small, generally 2-25 \( \mu \) across. In the exterior 50% of the \( \alpha_2 \) zone the phosphides are micromelted. The hardness is 202±10 but increases steeply inside the \( \epsilon \) border to 310, a level which is reached at a depth of 6-10 mm (hardness curve type I). The taenite has also responded to the atmospheric reheating. The following observations concern taenite ribbons, 30-60 \( \mu \) wide. Such taenite will in the deep interior etch in bluish-brownish tarnishings and display a hardness of 360±15. Approaching the rim the hardness drops steeply. At the \( \epsilon/\alpha_2 \) border the hardness has fallen to 240±20 with little change in the etching appearance. In the rim zone at approximately the 900° C isotherm the hardness reaches a minimum of 180±10, and the tarnishing reveals a remarkable play between angular, yellow and brown patches; Figure 978. Still farther out, above the 1000° C isotherm, the taenite appears yellow and structureless. At the 1200° C isotherm and beyond the taenite is yellowish or shows an indistinct martensitic structure, the hardness having increased to 250±10; Figures 974-975. Simultaneously, 10-40 \( \mu \) wide zones on both sides of the taenite have transformed to bainitic-martensitic structures with a relatively high hardness, 315±15, as opposed to 200 of the normal \( \alpha_2 \) structure. It appears that the observed structure alterations, at least for a major part, may be explained as the result of carbon diffusion. Carbon is probably the only element which in the short times available could diffuse markedly. Its disappearance from the taenite would explain the change in tarnishing, and its appearance in the adjacent kamacite would account for the hard bainite.

The above discussion assumes that most of the carbon present in an iron meteorite without graphite and cohenite will be in solid solution in the rim zones of plessite and in the taenite. It is likely that the carbon concentration in the taenite phase is 10-20 times higher than the measured bulk value, which in Kayakent was determined by Kızılirmak et al. (1969) to be 180 ppm. From the etching characteristics and other observations it is, however, also clear that the carbon is far from evenly distributed between the taenite ribbons. Some, perhaps a fourth of them all, appear to have significantly more carbon in solid solution than the rest.

Kayakent is a shock-hardened medium octahedrite with \( \epsilon \)-structure. It is related to Juncal, Bagdad, Augusta

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**Figure 975.** Kayakent (Copenhagen no. 1973, 2082). Another view of heat-affected taenite lamellae in the rim zone. The diffusing carbon has given rise to dark zones of carbon-nickel bainite in original kamacite. Etched. Scale bar 20 \( \mu \).

**Figure 976.** Kayakent (Copenhagen no. 1973, 2082). Fused iron oxides (wüstite and magnetite) somewhat altered by corrosion (black); then, a dendritic-cellular metallic fusion crust; and, finally, the heat-affected \( \alpha_2 \) zone. Etched. Scale bar 20 \( \mu \).

**Figure 977.** Kayakent (Copenhagen no. 1973, 2082). Transition from heat-affected \( \alpha_2 \) zone (above) to unaffected shock-hardened interior. The shock-hatched \( \epsilon \)-structure alternates in appearance (white, gray, almost black) due to shift in kamacite crystal orientation. Etched. Scale bar 400 \( \mu \).
An area 2 kg. Marvin (1969) found 1,000 mm/sec. Since 1,000 million years, while 100 Keen Mountain & 10Be measurements. (1960) Scale 200±50 Ar/C peak temperature. The cloudy taenite lamellae are homogenizing and show yellow patches in a mosaic structure. Compare Figure 114. Etched. Scale bar 100 μ.

County, Thund & Trenton and is, chemically, a typical group III A iron. The relative freshness of the crust indicates that it is a recent fall and may have fallen in April 1961 as speculated by the villagers.

Keen Mountain, Virginia, U.S.A.
37°13'N, 81°59'W; 650 m

Hexahedrite, H. Deformed, showing incipient recrystallization. HV 225±15.

Group III A. 5.59% Ni, 0.42% Co, 0.23% P, 0.3% S, 62 ppm Ga, 182 ppm Ge, 12 ppm Ir.

HISTORY
A mass of 6.7 kg was found in 1950 by Fred Matney near a footpath, 10 m from the crest of the south face of Keen Mountain, Buchanan County. The meteorite was purchased in 1952 by Stuart H. Perry and donated to the U.S. National Museum where it was fully described by Henderson & Perry (1958) with photographs of the exterior and of etched sections. They estimated the fall to have occurred between 1940 and 1950, but 39Ar and 36Cl measurements by Vilcek & Wänke (1963; Henderson 1965: 19) indicate that the terrestrial age rather is 1100±200 years. Hoffman & Nier (1960) measured the 3He and 4He concentrations and deduced a cosmic ray exposure age of 200 million years. Signer & Nier (1962) also estimated the cosmic age to be 200±50 million years, while Bauer (1963) found 220 million years by an approximative method. Vilcek & Wänke (1963) found an exposure age of 120±10 million years, while Chang & Wänke (1969) found 140±20 million years from 36Ar/10Be measurements. An estimate of the preatmospheric mass was presented by Signer & Nier (1962); their figure, 1,000 kg, would imply that over 99% had been lost during atmospheric entry. Maringer & Manning (1959; 1962: 138) examined the heat-affected rim zone. They showed that the α2 zone varied systematically from a width of about 2 to a width of about 7 mm. The average width on the leading edge was 2 mm, on the trailing edge 4 mm, and the ablation rates were estimated, respectively, as 3 and 0.8 mm/sec. Since the flight time is unknown, an estimate of the total loss is difficult; but indications are that the preatmospheric mass was rather of the order of 50 kg than of 1,000 kg. Marvin (1963) identified strong lines of magnetite and diffuse lines of wüstite in X-ray films of the fusion crust. Buchwald (1971d) discussed the gas content in relation to the metallographical structure.
COLLECTIONS
Washington (4,773 g main mass, and 850 g slices), Sydney (293 g), Tempe (219 g).

DESCRIPTION
The overall dimensions of the mass were about 16 x 12 x 8 cm before cutting. It is very smoothly rounded with no regmaglypt sculpturing. The leading face is best identified by the thin covering of black, magnetic fusion crust and the small crests and ridges of spilled-over ablated metal along the edge of this face. The only larger pit is on the rear side; it is a cavity 10 mm in diameter and about 4 mm deep in the bottom of which the remainder of a troilite nodule is located. From the bottom of another pit, 2 x 2 mm, extends a 6 x 1.5 mm troilite lens into the main mass as seen upon a section through the pit. Smaller craters, 0.5-5 mm in diameter, are also present, and at least some of them were produced by ablation, since they are filled by metallic melts.

The black fusion crust is preserved irregularly over many square centimeters, and, where it is best, striae may be seen. It is two-phased with small (~2 μ) cubic iron oxides suspended in a continuous phase of a different oxide. The oxide crust varies in thickness between 5 μ and 1 mm. Under it is a 0-400 μ thick, laminated, metallic fusion crust, composed of columnar dendrites, perpendicular to the base. The metal is transformed to martensitic-bainitic structures, and embedded in it are numerous, more or less hollow iron-oxide spherules, typically 10-60 μ in diameter. They resemble the magnetic spherules which are collected by dredging of the ocean and by sieving river sand and soil in the Sikhote-Alin area. Squeezed between the outermost metallic and the innermost oxidic layer is a yellowish, 10-60 μ thick, very nickel-rich melt, presumably the result of a selective oxidation and removal of iron from the ablation-melted metal. The phenomenon has not been previously recorded as an integrating layer of the crust and is probably quite rare. Corrosion has converted the fusion crusts pretty thoroughly to limonitic products, and it also penetrates deep into the mass particularly along the heavily brecciated phosphides and sulfides. Under the fusion crusts there is a 30 μ thick carburized zone and then follows a heat-affected α2 zone, 2-7 mm wide. In the exterior 50% all the phosphides have been micromelted, and it is clearly seen how they solidified from the inside. In the inner part of the heat-affected zone ultrafine precipitates decorate both sides of the Neumann bands. From the general appearance of the mass it appears plausible that it has been exposed to weathering for about 1,000 years, as deduced by Vilcek & Wänke (1963).

Figure 979. Keen Mountain (U.S.N.M. no. 1513). The rounded main mass before cutting. Well-preserved, with major portions still covered by fusion crusts. Scale bar approximately 3 cm. S.I. neg. 41979A.

Figure 980. Keen Mountain (U.S.N.M. no. 1513). A hexahedrite with two large shock-melted troilite nodules. They are surrounded by narrow rims of cohenite, decomposed to graphite. The bright areas around the troilite nodules are depleted in phosphides, as opposed to the rest which is rich in schreibersite and rhabdite. Deep-etched. Scale bar 20 mm.

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<th>KEEN MOUNTAIN – SELECTED CHEMICAL ANALYSES</th>
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<td>References</td>
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<tr>
<td>Henderson &amp; Perry 1958</td>
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<td>Lewis &amp; Moore 1971</td>
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<td>Wasson 1971 pers. comm.</td>
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Henderson also determined the nickel content of rhabdites from the insoluble residue and found 37.7% as an average.
Etched sections display a normal hexahedrite structure. Neumann bands run across the whole surface, but they are in many places violently bent. They are frequently discontinuous, and one set of parallel bands is heavily decorated with 2-5 μ thick rods of phosphides. Also the subgrain boundaries of the kamacite are decorated with 1-2 μ phosphides. Recrystallization of the matrix has just begun and leads to new ferrite grains, 20-50 μ in diameter, located in the Neumann band junctions and along the interface of the sulfides and the larger phosphate crystals. Less than 0.1% by area is recrystallized. The hardness is 225±15; this is high for a hexahedrite but in accordance with the cold-worked appearance of the matrix. The hardness drops to 190±10 in the heat alteration zone (hardness curve type I).

Schreibersite is present as 0.3 mm thick, discontinuous rims around the troilite nodules. Rhabdites are relatively evenly scattered as plates, typically 5-15 μ thick and 1-5 mm long. Also present is a later generation of 0.5-2 μ thick, prismatic rhabdites that cover the area as a cloud between the plates. All phosphides are severely shattered. Irregular displacements of individual segments often reach 20 μ. It appears that microcracks also were created along the interfaces and that some of these cracks were still present when the meteorite landed, so that corrosive agents could penetrate relatively easily deep into the mass. The terrestrial corrosion products, most of which are located along these brecciated phosphides, support this explanation.

Troilite occurs as 1-15 mm irregular nodules and lenticular masses which are partially enveloped in schreibersite. Daubreelite occupies 10-15% of the nodules. Cohenite was previously present as 30-50 μ thick deposits on some of the schreibersite crystals, but it has decomposed, perhaps at the same slight annealing that produced the partial recrystallization and the decorated Neumann bands. Now only 50 x 4 μ graphite plumes in a microcrystalline ferrite indicate the location of the former cohenite crystals. A total of 225 cm² sections was point counted for sulfides. Fourteen large and small inclusions with a total area of 300 mm² were observed; this corresponds to about 0.3% S in the meteorite.

The troilite is shock-melted and has a hardness of 235±15. It has partially dissolved the surrounding metal, and it has penetrated the fragmented schreibersite and daubreelite crystals. A few 10-25 μ fragments of schreibersite have become dispersed in the sulfide-metal melt before it solidified rapidly to 1-10 μ eutectics. That the fine-grained material is far from equilibrium may be seen where a troilite nodule happens to contact the heat-affected rim zone. Along the 700°-800° C isotherm the troilite has recrystallized to well defined 50 μ polygonal units, albeit the available time may be estimated to have been below one minute.

Keen Mountain is a shocked and plastically deformed hexahedrite, in which slight annealing has created specific microstructures. It is closely related to Bruno, Scottsville and Boguslavka and is a normal member of group IIA.

Specimens in the U.S. National Museum in Washington:
4,773 g main mass (no. 1513, 14 x 11 x 7.5 cm)
327 g endpiece (no. 1513, 9 x 6.5 x 1 cm)
339 g slices (no. 1513, each about 9 x 7 x 0.4 cm)
About 300 g smaller slices and polished specimens

Kendall County, Texas, U.S.A.
29°50'N, 98°40'W

Polycrystalline aggregate of kamacite, silicate and graphite. Neumann bands; α₂, HV 195±15.
Anomalous. 5.42% Ni, 0.34% P, about 1.3% C, 71 ppm Ga, 355 ppm Ge, 1.7 ppm Ir.
Some samples have been artificially reheated above 800° C. Perhaps the whole mass has been artificially reheated.

Figure 981. Kendall County (Vienna no. D83885). A full section, showing the anomalous structure of angular silicate-graphite inclusions in polycrystalline kamacite. Deep-etched. Ruler is 10 cm.

Figure 982. Keen Mountain (U.S.N.M. no. 1513). The rhabdites are severely brecciated and displaced to a degree rarely seen in meteorites. The kamacite is correspondingly cold worked to the high hardness of 225 Vickers. Etched. Scale bar 400 μ.

Figure 983. Kendall County (Vienna no. D83885). A full section, showing the anomalous structure of angular silicate-graphite inclusions in polycrystalline kamacite. Deep-etched. Ruler is 10 cm.
HISTORY

Little is known of this interesting iron meteorite. Brezina (1887) briefly noted that an entire 20.5/6 kg mass had been acquired for the Vienna collection. Later (1896: 236, 292, 306) he gave the locality as Kendall County, San Antonio, with no further information as to the circumstances of finding. He had the mass divided keeping one-half for Vienna and distributing the remainder in the form of slices. In a brief description he classified it as a brecciated hexahedrite with troilite, related to São Julião and Holland's Store. Cohen (1900b) analyzed and examined the mass in detail and summarized the literature and his own findings later (1905: 241). He also found it related to Holland's Store but recognized the significant carbon content and noted a cristobalite-like silica. The carbon was assumed to be present in an amorphous state, not as graphite. Schreibersite, troilite, chromite and decomposed silicate grains were also noted.

Maury (1913: plate 3) and Merrill (1916a: plate 20) presented photomicrographs of etched slices showing the highly unusual distribution of metal, graphite and silicates. Perry (1944: plate 55) gave a photomicrograph of a schreibersite crystal. Marvin (1962) showed that the "Cristobalite" grains noted by Cohen were, in fact, tridymite, and suggested that the material had crystallized at high temperature (>900°C) and low pressure (<3,000 atm.). Such conditions would support the asteroidal-size parent bodies of the type postulated by Gales et al. (1960) and Anders & Gales (1961), with radii of about 250 km and core pressures well below 3,000 atmospheres.

Mason (1967a), while examining a number of irons with silicate inclusions, identified silicates as minor constituents of troilite and graphite nodules. Almost pure end members of enstatite, olivine, and diopside were noted, and, in addition, plagioclase of albite-oligoclase composition was found. The composition of the silicates resembled those of chondritic meteorites, particularly with regard to the sodic nature of the plagioclase. With mesosiderites there was little in common. Wasson (1970b) found Ni and trace element contents which indicated some relationship between Kendall County and the resolved chemical group 1, e.g., Campo del Cielo and Linwood.

Since the locality of discovery is not known with any degree of certainty, the coordinates given above are those for the center of Kendall County.

COLLECTIONS

Vienna (8.95 kg half mass; 1,750 g), Washington (2.0 kg), Chicago (696 g), Ann Arbor (636 g), Budapest (573 g), London (556 g), Harvard (477 g), Ottawa (405 g),

KENDALL COUNTY – SELECTED CHEMICAL ANALYSES

Cohen (1905) reported 1.62% and 1.05% C in two different portions, showing that Kendall County is among the most carbon-rich meteorites known. He also reported lawrencite, but only on circumstantial evidence. No doubt the chlorine detected in the analysis derives from terrestrial ground water, since the meteorite is extensively corroded and penetrated by limonitic veinlets. Isolated schreibersite crystals were found to have an average composition of 61.8% Fe, 21.9% Ni, 15.7% P, 0.38% Co and 0.21% Cu.

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New York (380 g), Bally (346 g), Prague (344 g), Rome (294 g), Paris (262 g), Tartu (197 g), Yale (186 g), Bonn (146 g), Vatican (122 g), Tempe (117 g), Dresden (110 g), Warsaw (91 g), Utrecht (85 g), Strasbourg (61 g), Berlin (51 g), Stockholm (46 g), Leningrad (21 g), Amherst (13 g), Uppsala (11 g), Hamburg (11 g), Philadelphia (9 g).

DESCRIPTION

It appears that the mass was not described before it was cut. From the preserved samples in collections it is, however, possible to reconstruct the shape to an irregular lens with the approximate dimensions 20 x 20 x 16 cm. The mass is weathered, and fusion crust and heat-affected zones could not be detected. An estimated average loss of 3 mm has occurred due to terrestrial exposure. Corrosion penetrates to the center of the mass along a-grain boundaries and along brecciated schreibersite and silicate inclusions.

Etched sections display an anomalous mixture of metal, graphite and silicates. In places the metal constitutes 95% by volume, in other places the non-metallic phases predominate. The metal is pure kamacite without taenite or plessite. The kamacite forms a polycrystalline aggregate of almost equiaxed grains, ranging from 1 to 40 mm across. Most common grain sizes are of 2-5 mm. The grains are independently oriented, and no trace of Widmanstätten structure occurs. The irregular arrangement of the kamacite grains has given rise to the term “brecciated hexahedrite,” but this term is unfortunate, since the structure is a normal polycrystalline metal structure which may have formed by simple grain growth. Neumann bands are common, and subboundaries with fine precipitates, probably of phosphides, subdivide the grains into numerous cells.

The polycrystalline nature of the metal, which is clearly visible to the naked eye after prolonged etching, is further brought out by the presence of schreibersite in many boundaries. The schreibersite forms 10-200 μ wide, irregular vermicular bodies which are monocrystalline and brecciated. It also occurs as a few 1 x 0.4 mm skeleton crystals, often in association with troilite and silicate. Rhabdites proper were not observed. The microhardness of the schreibersite is 920±30.

Troilite and daubreeelite are common as rounded or subangular particles 50-500 μ across. Troilite with multiple twinning usually constitutes 60-80% of the particles, while one or two broad daubreeelite lamellae make up the rest. Occasionally the smaller, 20-50 μ particles, are composed of alternating 1 μ thick lamellae of troilite and daubreeelite. Schreibersite — and occasionally a little 10-100 μ wide cohenite — are nucleated by the sulfides and form discontinuous rims upon them. Sometimes the original troilite nucleus is now only a minor part of a large schreibersite skeleton crystal.

Figure 985. Kendall County (U.S.N.M. no. 1657). Acicular graphite precipitates in kamacite, that by late artificial reheating to about 800° C was transformed to unequilibrated α2. Compare Figures 168 and 169. Etched. Scale bar 40 μ.

Figure 986. Kendall County (U.S.N.M. no. 1657). Two troilite-daubreeelite (D) nodules connected by a schreibersite vein. Multiple twinning in the troilite. Artificial reaction zone between daubreeelite and troilite at D. Artificial α2 in matrix, but old grain boundaries are indistinctly visible. Two black silicate crystals (above). Etched. Slightly crossed polars. Scale bar 200 μ.

Figure 987. Kendall County (U.S.N.M. no. 1657). A nodule, typical for Kendall County, with a soft graphite center (black) surrounded by a silicate-metal troilite-graphite mantle, which again has nucleated a rim of schreibersite. Polished. Scale bar 500 μ.
Graphite occurs as well developed crystalline units in oriented intergrowths with kamacite. Clusters of arrowheads, triangles or bars are very common, sometimes covering a square centimeter of the section. In crossed Nicols the graphite is seen as well defined crystals up to 100 μ across, often with undulatory extinction. In several places schreibersite has precipitated around the graphite crystals, suggesting that the graphite morphology in the metal antedates the schreibersite formation and thus took place at elevated temperatures, probably in excess of 700° C. The graphite morphology should be compared to that of Morrill, Waterville and Mundrabilla.

The silicates occur scattered in the kamacite as 10-100 μ grains, or they form messy intergrowths with graphite, troilite, kamacite and schreibersite. Nests up to 3 x 2 cm in size are separated from the bulk metal by highly irregular borders. In several cases it appears that previously coherent aggregates have been sheared and are now separated by metallic veins one or two millimeters wide. Similar textures are present in the silicates of Campo del Cielo (El Taco). The phenomenon resembles true brecciation and must be due to shear-displacements at elevated temperatures (900° C?). At such high temperatures the diffusion in the metal would be rapid and allow for veining and recementation of the brecciated minerals to occur, while the metal itself would recrystallize and preserve no indications of the shear event.

A typical non-brecciated inclusion 3 x 3 mm in size, had a core of microcrystalline (1 μ) disordered graphite with a few scattered silicate and troilite blebs. The shell, constituting about 50% by volume of the whole aggregate, was an intimate mixture of kamacite, silicates, twinned troilite and graphite, with individual particles measuring 5-100 μ across. The whole aggregate had served as a substrate for later precipitation of 50-150 μ thick, discontinuous schreibersite rims. As noted by Marvin (1962) and Mason (1967a), the silicates mainly consist of enstatite, forsterite, albite, diopside and tridymite.

Some of the single silicate grains in the kamacite phase have nucleated rims of troilite, or schreibersite, or both. On the whole, almost any conceivable combination of graphite, silicate, troilite, schreibersite and kamacite is realized somewhere in Kendall County. It appears, however, that silicate grains were the primary factor, around which other components aggregated or precipitated.

Some, or perhaps all, of the Kendall County samples have unfortunately been artificially reheated. The small sample, U.S.N.M. No. 1657, is typical for the reheated specimens. The Neumann bands have disappeared and serrated α₂, 20-200 μ across, dominate all kamacite grains. The hardness is rather variable, because equilibrium was not achieved, but it is usually 195±15. Troilite and daubreelite have reacted across their interfaces and formed unequilibrated polycrystalline structures. Schreibersite is surrounded by 1-3 μ wide reaction rims. The limonitic veinlets which,
upon corrosion, had recemented the schreibersite, troilite and silicate breccias, have decomposed to oxides with 1 μ metallic particles, frequently forming 5-10 μ wide laceworks against the metallic matrix. Locally, the corroded troilite has melted and again solidified to fine-grained Fe-S-O eutectics. High temperature intercrystalline oxidation and minor amounts of sulfide melts have penetrated along the grain boundaries of the high temperature austenite phase. In this way the austenite grain size is revealed to have been 5-15 μ.

These observations indicate that the specimen was subjected to artificial reheating to about 850° C for a short time. Whether the reheating took place while Kendall County was still an entire 20.8 kg mass is unknown. No report to that effect exists. If so, there must have been a rather steep temperature gradient from 850° C at one end to perhaps 600° C at the opposite end, since Neumann bands seem to be preserved in many specimens cut from the mass.

Kendall County is an iron which only superficially bears some resemblance to Holland's Store and other meteorites with 5-6% Ni. Its graphite and silicates, and its trace element composition, suggest rather a remote relationship to Campo del Cielo and similar irons of group I. Its texture could probably be the result of mixing of metal particles with silicate and graphite particles and subsequent compression and sintering at a not too elevated temperature, perhaps about 1100° C. There are no unambiguous indications that the meteorite as we not know it was once a product of a solidifying magma.

Figure 991. Kendall County. Detail of the altered nodule in Figure 990. An extremely complex high temperature reaction mixture of limonite, kamacite, troilite, schreibersite, graphite and silicates. Etched. Scale bar 40 μ.

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Specimens in the U.S. National Museum in Washington:
742 g slice (no. 255)
1,164 g slice (no. 343)
14 g part slice (no. 1657)
123 g part slice (no. 2846)

Kenton County, Kentucky, U.S.A.
38°48'N, 84°34'W; 270m

Medium octahedrite, Om. Bandwidth 0.90±0.10 mm. e-structure. HV 325±15.
Group IIIA. 7.45% Ni, 0.48% Co, 0.08% P, 18.2 ppm Ga, 35.0 ppm Ge, 14 ppm Ir.
Williamstown is a 31 kg fragment of Kenton County.

HISTORY
A mass of 163 kg was found in 1889 by G.W. Cornelius on his farm, located about 13 km south of Independence, in Kenton County. The meteorite was discovered while cleaning a spring situated at the head of a gully; the mass was about 1 m below the surface and interlocked in the roots of an ash tree. It was purchased by Ward's Establishment and briefly described with a picture of the exterior by Preston (1892). In the following years it was extensively cut and distributed through Ward's from whom slices were still available as late as 1940. Brief descriptions were given by Brezina (1896: 284), Klein (1906: 119) and Farrington...