is 265±10, a hardness which — due to cosmic cold-work — is slightly higher than that of an experimental alloy of the same structure annealed 96 days at 350°C (Buchwald 1966: 18-19).

As is the case with Freda and Wedderburn, the hardness of the matrix drops smoothly and appreciably in the heat alteration zone to a minimum of 220±5. In all three cases we have very small meteorites with a steep temperature gradient; below about 5 mm depths no significant hardness change or diffusion has taken place.

Kofa is a small meteorite, which is rather well-preserved and locally even retains its fusion crust. In many respects it is structurally related to Föllinge, Freda and Wedderburn, but its detailed Ni-Ga-Ge-Ir composition and structure put it somewhat apart from these irons. In its structural details and in its chemical composition, Kofa is particularly closely related to Gay Gulch and Garden Head, two other plessitic octahedrites. Wasson & Schaudy (1971) reached a similar conclusion.

**Kokomo, Indiana, U.S.A.**

40°25'N; 86°2'W; 250 m


Group IVB. 15.82% Ni, 0.08% P, 0.193 ppm Ga, 0.031 ppm Ge, 31 ppm Ir.

**HISTORY**

The original reports of this iron came independently from two authors, E.T. Cox (1873) and J.L. Smith (1874). As already noted by Cohen (1889a: 150; 1905: 149) and Farrington (1915: 261) the reports differ in several important particulars as to the year of find, the weight, the circumstances of finding and the structure. While the last problem can be solved today the first three are open to interpretation. I combine here from both sources those data which in my opinion are correct, leaving the least internal conflicts. A mass of 1.85 kg (4 pounds, 1.5 ounces) was found by E. Freeman in 1862 while he was excavating a ditch on his farm. The mass was embedded in clay at a depth of about 60 cm, and the place was seven miles southeast of Kokomo, in Howard County. The mass was taken to the blacksmith who broke two chisels in his attempt at cutting a specimen free.

The mass went through several hands before it was described by Cox (1873) and Smith (1874). In the years immediately following, small specimens were distributed, particularly to European collections, while the largest known section remained in Smith’s collection and in 1883 was purchased by the Harvard University (Huntington 1888: 37, 82). Wülfing (1897: 184) believed that originally there was two pieces found, weighing 4 and 1.85 kg, respectively, but this is a misinterpretation of the original.
reports. Cohen (op. cit.) described and analyzed the specimen in the Copenhagen Collection which is also the main basis for the present description. Berwerth (1918: 419) was the first to publish a photomicrograph of Kokomo; this shows the pearlitic, two-phase structure quite well. Owen & Burns (1939) X-rayed the meteorite and determined the lattice parameters to be $\alpha = 2.8630\text{Å}$ and $\gamma = 3.5793-3.5807\text{Å}$. There were well defined lines from both $\alpha$ and $\gamma$ in both the original state and in the annealed state, as determined on filings. Perry (1944: plate 23) gave two photomicrographs, and Buchwald (1966: figure 36; 1967a: figure 8) presented micrographs that showed the striking, selective weathering of the kamacite phase.

**COLLECTIONS**

Harvard (348 g), Chicago (62 g), Paris (54 g), London (45 g), Los Angeles (39 g), Budapest (35 g), Copenhagen (24 g), Ottawa (23 g), Vienna (15 g), New York (9 g), Berlin (7 g), Vatican (3 g). The specimens add up to 664 g; allowing for expenses in cutting and analyzing, and for specimens not in public collections, it appears plausible that the original weight was 4 lbs as stated by Cox (1873), and not 4 kg as stated by Smith (1874).

**DESCRIPTION**

According to Cox (1873) the average dimensions of the turtle-shaped mass were $12.5 \times 8.7 \times 4.2 \text{ cm}$, which corres-

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**KOKOMO – SELECTED CHEMICAL ANALYSES**

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Sjöström’s cobalt determination is probably about 50% too high, due to incomplete separation of cobalt and nickel.
ponds very well to a total weight of 1.85 kg. The mass is corroded and irregularly indented by pits, 1-2 cm in diameter. Fusion crust and heat-affected zones have not been identified. Instead, terrestrial oxidation products form shallow, cup-shaped deposits which often display a strikingly rhythmic, concentric pattern. The crust on the Copenhagen specimen (No. 1876, 2245) is locally 5 mm thick and composed of 4-5 layers, each showing increasing oxidation, until the outermost layer is completely transformed to limonite with no remaining metal at all.

Etched sections have an ataxitic appearance; the only pattern being visible to the naked eye is a parallel banding. The bands, which display a pearditic luster, are 0.1-10 mm wide and fade out locally. Only two sorts occur, giving rise to bright or dull reflections in turn as the specimens are viewed against the light. High magnification reveals a two-phase structure of kamacite and taenite in the proportion 2:1. The decomposition of the original austenite single crystal is very complete and homogeneous, the taenite forming 1-3 μ wide, irregular lamellae in a matrix of kamacite, 1-5 μ across. In the sections studied the taenite lamellae are oriented parallel to the bands. The kamacite, which is the continuous phase, is subdivided in equiaxial cells, 1-3 μ across.

There is at high magnification only a minute difference, barely appreciable, between the texture within the two sets of bands. The main difference appears to lie in the length of the individual taenite lamellae, the length-width ratio, the number of branches and the angles these branches form with the main direction. Also the α-phase may be oriented a little differently from band to band. These subtle differences, when repeated over and over on a microscale, are responsible for the oriented sheen. The microhardness integrating over many α + γ units is 178±7; there is no appreciable hardness difference and no composition difference between the bands of the oriented sheen.

In the matrix occur a few, scattered kamacite spindles. They are 20±10 μ wide and 50-150 μ long; they occur with a frequency of about one per mm².

Schreibersite was only observed as minute particles, 0.5-1 μ across, lying in the kamacite boundaries of the matrix. Troilite was not observed on a total of 55 cm² sections. Daubreelite grains, 2-10 μ across, are present quite locally.

Some specimens are marred by hammering and chisel marks; it appears, however, that the blacksmith did not heat the material violently, since no secondary, metallic phases and no high temperature, intercrystalline oxidation are present. Perhaps some softening by recovery has occurred, as suggested by the low hardness.

As discussed previously (Buchwald 1966: 39) the structure may be interpreted as the result of a two-stage transformation where the austenite first formed a metastable α₂ phase which then at subsequent cooling, or perhaps limited cyclic reheating, decomposed to the characteristic α + γ texture.

Kokomo is closely related to Iquique and Cape of Good Hope and forms a typical member of group IVB.
Matatiele iron. In the following, it is shown that Kokstad is structurally identical to Matatiele; and since the structures are almost unique, it is concluded that the two masses do belong together. Later during my work, this conclusion was confirmed by Wasson, who kindly analyzed fragments of both Kokstad and Matatiele (Scott et al. 1973).

**COLLECTIONS**

Vienna (38.6 kg main masS and 1 kg slices), Chicago (268 g), Budapest (213 g), London (203 g), Prague (78 g), Stockholm (67 g), Dresden (59 g), Paris (49 g), Berlin (7 g).

**DESCRIPTION**

The shape of Kokstad has been compared to that of a compressed ham (Cohen) or the enormous jaw of a mammal (Brezina). The dimensions are not given, but it appears that the whole mass was 65 cm long, about 25 x 12 cm thick in the massive end and 8 x 8 cm in the pointed end. The mass is considerably weathered, with loosely attached oxide-shales and with some shallow corrosion pits. Locally, a surface-grid is developed by the weathering, indicating the orientation of the Widmanstätten lamellae.

A section was kindly loaned to me by Dr. E. Olsen, Chicago, so that I could test my hypothesis that the Kokstad mass was identical to the Matatiele mass. The specimen, No. Me 1015, is a 14 x 11 x 0.25 cm slice through the mass. Its surface is weathered, and the heat-affected $\alpha_2$ zone has disappeared. It exhibits a beautiful coarse Widmanstätten structure with straight, somewhat bulky ($W \sim 10$) kamacite lamellae with a width of 1.35±0.25 mm. The lamellae are locally recrystallized in a very characteristic way to almost equiaxial units, 0.1-1.5 mm across. On this particular section the recrystallized grains cover about 20% by area; other sections in, e.g., Prague and Vienna, range from 2 to 30% in recrystallization. The nonrecrystallized parts of the lamellae are subdivided into numerous cells, 10-50 $\mu$m across. While the old Neumann bands extend completely across the kamacite lamellae, the Neumann bands in the recrystallized units are short and oriented differently in adjacent grains. The first generation of Neumann bands presumably formed when the meteorite was released by a violent shock from the parent body. The second generation of Neumann bands may have formed at the deceleration and breakup in our atmosphere. The microhardness of the kamacite ranges from 165 to 195 with a tendency for the lower values to occur in recrystallized areas.

Taenite and plessite cover about 25% by area. The comb and net plessite fields are well annealed with very few martensitic or unresolvable, duplex structures. The individual taenite units are homogeneous with respect to nickel and have frayed edges indicating partial dissolution and spheroidization. They are usually soft, HV 185±10. Very important for the comparison to Matatiele is the presence — in one out of five plessite fields — of lamellar graphite in a unique development. The graphite forms clusters, 100-200 $\mu$m across, of 5-10 $\mu$m wide lamellae which may be up to 50 $\mu$m long. The graphite is microcrystalline, composed of 1 $\mu$m units, and is surrounded by a nickel-poor, polycrystal-

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**KOKSTAD – SELECTED CHEMICAL ANALYSES**

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Kokstad — Kokstad (Matatiele fragment)

Kokstad (Matatiele fragment), Cape Province, South Africa
30°20'S, 28°49'E

Coarse octahedrite, Ov. Bandwidth 1.35±0.30 mm. Partly recrystallized. HV 180±15.
Group IIIE. 8.32% Ni, 0.19% P, 0.08% C, 17.7 ppm Ga, 34.4 ppm Ge, 0.54 ppm Ir.

HISTORY
A mass of 298 kg was found before 1878, buried on a hill at the junction of Mabele and Kenegha Rivers. The location was “one hour from Matatiele, towards Ongeluk’s Nek in the Drakensbergen” (Cohen 1900c: 9). The meteorite was for some time preserved in a Basuto kraal before it was acquired by C.P. Watermeyer, who in 1885 presented it to the South African Museum in Cape Town. Cohen (1900c) examined eight slices and presented an analysis and photographs of the exterior and of an etched section. He compared it to the Kokstad iron which had been found in the same general region and was complementary in exterior shape to Matatiele, but he concluded hesitantly that Matatiele and Kokstad were individual falls, since the analyses and structures appeared to be different. The coordinates given above are for the town Matatiele.

COLLECTIONS
South African Museum, Cape Town (main mass), Calcutta (78 g), Washington (69 g), Vienna (58 g), London (40 g), Chicago (24 g).

DESCRIPTION
The mass is extremely irregular with the approximate maximum dimensions 95 x 55 x 40 cm. It may be compared to an oversize agitator of a washing machine. It is deeply indented by boldly sculptured depressions, up to 25 cm in diameter, and minor cavities are also present. At one location a hole, 7 cm in diameter, penetrates a 4 cm thick part of the mass. The fusion crust and much of the heat-affected $\alpha_2$ zone have been removed by weathering, and it is probable that a part of the sculpturing, and also the hole, is rather the result of terrestrial corrosion than of ablation. The fracture which developed during the atmospheric flight and separated Matatiele from Kokstad is no longer clearly defined, partly because of subsequent flight sculpturing, partly because of weathering.

Etched sections display a medium to coarse Widmanstätten structure of straight, rather stubby (W $\sim$ 10-15) kamacite lamellae with a width of 1.35±0.30 mm. They often have rounded ends and approach a sort of discoid shape. Neumann bands were previously present, but are now partly annihilated by recrystallization. They have often disintegrated into short units that have both sides decorated with 1-3 $\mu$ wide taenite blebs. The kamacite has recrystallized — but only partly and mostly in the vicinity of the larger phosphides — to irregular grains which are 50-500 $\mu$ across. About 2% by area of the section is covered by recrystallized grains. The microhardness is 180±15; the lower values occur particularly in those recrystallized areas which are Ni- and P-depleted.

Plessite and taenite cover about 25% by area. It appears that the plessite originally was in the form of well developed varieties of comb, net, and poorly resolvable, duplex $\alpha+\gamma$ fields, but that the annealing that produced the partial recrystallization of kamacite altered the plessite, mainly by coarsening and spheroïdizing the structures, so that now all phase boundaries between $\alpha$ and $\gamma$ are clear-cut and sharp. The microhardness is 180±15. It appears that individual taenite grains are pretty well homogenized with respect to nickel. The taenite is very soft, HV 185±10. About one third of the plessite fields contain tiny plumes of microcrystalline graphite in a most
unusual way. While the high-nickel rim zones of the plessite are developed in pearlitic or spheroidized mixtures of \( \alpha \) and \( \gamma \), the interior half, e.g., an area of \( 2 \times 0.3 \) mm, is decomposed to irregular intergrowths of recrystallized ferrite grains, 10-50 \( \mu \) across, and lamellar graphite, typically 200 x 25 \( \mu \) in size. The general size and shape of the graphite-ferrite areas correspond well to the carbide roses (haxonite) of several octahedrites, e.g., Coopertown and Rhine Villa. It is thus highly probable that preexisting carbide completely decomposed during the same annealing that produced the changes in the kamacite and taenite.

Schreibersite was not observed as large crystals, but is common as 40-80 \( \mu \) wide grain boundary precipitates and as 5-25 \( \mu \) irregular blebs within the various plessite fields. Rhabdites, 2-10 \( \mu \) thick, are common in the kamacite. At the annealing the nickel-richer phosphides particularly, both of the schreibersite and rhabdite type, have readjusted their nickel composition downwards and consequently detached a series of tiny, 1-3 \( \mu \) thick, beads of taenite along their circumference. The phenomenon is very characteristic and rarely seen to this perfection, although it is present in several other irons, such as Ballinoo, Zacatecas (1969), Seelägen and Willamette.

Troilite occurs as 0.5-3 mm rather “diffuse” nodules. The small contrast against the metallic surroundings is due to the finely granulated state of the nodules caused by shock melting. The nodules are composed of a 1 \( \mu \) network of troilite plus metal, in which are embedded numerous subangular 5-25 \( \mu \) daubreelite units and a few rounded or angular schreibersite fragments. At one place it was observed that only that part of a schreibersite bar, which actually had been in touch with the troilite-metal melt had been dissolved/melted, while the remainder was unaltered. Finely granulated veinlets of troilite extend several millimeters away from the troilite nucleus into the metallic groundmass. It is difficult to understand these structural details, unless we imagine that shock melting occurred and caused a localized heat peak of short duration in the compressible sulfide phase, while only influencing the surroundings to a minor extent.

Matatiele is an anomalous meteorite. Its primary structure and mineral assemblage indicate a relationship to certain medium to coarse octahedrites, such as Coopertown and Rhine Villa. On the other hand, it has suffered such pronounced alterations due to shock and annealing that its structure is now next to unique. The maximum temperature reached in the metallic matrix appears to have been about 550° C, while the temperature of the troilite must have been around 1000° C. The Matatiele mass clearly belongs with Kokstad, and is a member of group IIIE.

**Figure 1019.** Kokstad. Detail of Figure 1017. The shock-melted troilite nodule. Minute particles of daubreelite (D) and schreibersite (S), formerly associated with the troilite, are also seen. Etched. Scale bar 40 \( \mu \).

**Figure 1020.** Kokstad (Chicago no. 1015). On annealing, the phosphide crystals have readjusted their composition according to the Fe-Ni-P equilibrium diagram. A series of minute \( \gamma \)-particles (white) have been segregated along the schreibersite-kamacite interface. Etched. Scale bar 40 \( \mu \).

**KOKSTAD (MATATIELE FRAGMENT) — SELECTED CHEMICAL ANALYSES**

Fahrenhorst also found 0.03% Cl which, as usual, was ascribed to the presence of lawrencite, although the mineral itself was not observed. Fahrenhorst’s analysis is given here for historical reasons, and because his P, C, S and Cu determinations appear correct.

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Kopjes Vlei, Cape Province, South Africa
Approximately 29°19'S, 21°8'E

Hexahedrite, H, recrystallized to 0.05-1 mm ferrite grains. A few Neumann bands. HV 170±10.
Group II A. 5.65% Ni, about 0.3% P, 59 ppm Ga, 181 ppm Ge, 3.1 ppm Ir.

HISTORY
A mass of about 13 1/2 kg — or probably only 7-8 kg, see below — was found before 1914 near Kopjes Vlei, in the Kenhardt district of the Cape Province. The mass was apparently divided at an early date, but two pieces totaling 7 kg, were acquired by the South African Museum in 1914 (Hey 1966: 248). The town of Kenhardt has the coordinates given above. Smales et al. (1967) analyzed the mass and gave a photomicrograph which shows the polycrystalline nature and the characteristic etch pits, which easily develop in this type of hexahedrite. They suggested that Kopjes Vlei belonged with Bellsbank and Hex River to the same shower, but, as shown below, all three are distinct and independent falls. Axon (1968b) found that unetched specimens showed a number of microscopic holes and fissures in the kamacite; he also suggested that the particular structure was produced either by the thermo-mechanical effects of high-intensity shock or by shock followed by reheating. While the latter ideas are supported by the present examination, the postulated porosities could not be verified; if present at all, they must be on a submicroscopic scale.

COLLECTIONS
South African Museum, Cape Town (5.2 kg main mass and 400 g slice), London (1,136 g), Washington (64 g).

DESCRIPTION
The preserved samples can be restored to an original mass which has the shape of a triangular prism measuring 26 x 9.5 x 8.5 cm. Distinct regmaglypts cover much of the surface. This reconstruction is in good agreement with the shape of the original mass, a cast of which the author has inspected in the South African Museum. Assuming a

KOPJES VLEI – SELECTED CHEMICAL ANALYSES

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specific density of 7.8 g/cm³, the mass of Kopjes Vlei must accordingly have been 7-8 kg. Hey (1966: 248), however, supposed that the original mass weighed 30 lbs (13.5 kg). It is not easy today to solve this discrepancy, but there is strong circumstantial evidence that the smaller weight is the correct one.

The small endpiece in the National Museum is covered by terrestrial oxides, and no fusion crust is present. Locally, however, minor amounts of the heat-affected rim are preserved as 0.2-1 mm wide zones of serrated α₂ grains. In places, phosphides in a state of incipient melting are also present. Evidently the mass has only irregularly lost a few millimeters by terrestrial weathering. Several specimens show hammer and chisel marks, and some intercrystalline fractures are present. The fully opened fractures reveal the macrostructure as being composed of individual ferrite grains, 0.05-1.0 mm in diameter.

Etched sections display this structure well. The oriented sheen from each ferrite grain is different from its neighbors, so the sections somewhat resemble a technological polycrystalline steel product. The grain size varies irregularly, some sections being rich in aggregates of 50 μm grains, others composed of 1 mm grains. Numerous grains appear four-, three- and even two-sided in the sections, so it is evident that the network is far from equilibrium.

The individual grains display numerous subboundaries, arranged in equiaxed networks of 20-100 μm subgrains. Neumann bands pass freely across the subboundaries but are stopped by the high angle boundaries. The Neumann bands were only found in grains adjacent to fissured zones, so they probably date from cracking in the atmosphere or from hammering by the finders. While the microhardness of the undistorted interior is 170±10, the near-surface regions, displaying fissures, Neumann bands and hammer marks, increase to 200-240 in hardness. Well polished surfaces were found to be free from holes, cavities and fissures, except for those just mentioned. Corrosion is insignificant, but where it attacks the mass it is mainly along high angle grain boundaries.

The unequilibrated grain boundaries appear double, ditch-like, even after light-etching. Numerous 1-10 μ thick wedges and flags of phosphides are precipitated upon them. Small amounts of other phases are also present, closely associated with the phosphides. One consists of 1-5 μ bluish daubreelite grains, and another of 1-10 μ irregular, amoeba-like taenite blebs. These phases were verified with the aid of the electron microprobe. Very characteristic are the 5-15 μ wide grain boundary loops that are surrounded by small phosphides and apparently are surviving parts of completely unequilibrated metal. They appear to be depleted in phosphorus, which has diffused into the associated phosphides, and they are certainly highly sensitive to etching and to terrestrial corrosion. Upon etching they dissolve rapidly and enlarge, leaving the oriented square, hexagonal and triangular pits so commonly seen in Forsyth County,

Figure 1025, Kopjes Vlei (Los Angeles). Small recrystallized grains with angular phosphides at grain boundaries and smaller ones in the grain interior. Upon careful sample preparation, the number of artificial pits is drastically reduced. Etched. Scale bar 20 μ.

Figure 1024, Kopjes Vlei (Los Angeles). A near-surface section showing selective corrosion along kamacite subboundaries. The unequilibrated metal-phosphide mixtures are selectively converted to limonite. Compare the loops of Holland's Store. Polished. Scale bar 30 μ.

Figure 1026, Kopjes Vlei (Brit. Mus. no. 1950, 252). Transition from heat-affected α₂ zone (above) to unaffected interior (below). Straight Neumann bands in the right part of the picture indicate that most of the grain boundaries are kamacite subboundaries. Etched. Scale bar 200 μ.
Holland's Store, Mejillones and others. Upon corrosion, the sensitized loops slowly become converted to "limonite" in situ. The associated phosphides are not dissolved as believed by Axon (1968b); on the contrary, they may survive as discrete blebs in the crust of terrestrial oxides long after all metallic phases are gone. The number, size and distribution of the sensitized loops strongly indicate that they are the remnants of altered normal rhabdites. The bulk phosphorus content of the meteorite is estimated to be 0.25-0.30%.

Very fine rhabdites, 0.5-2 \mu m across, occur inside the kamacite grains. A few graphite spherulites, 15-40 \mu m in diameter, were also noted. No large schreibersite or troilite inclusions were observed, but several rounded chromite crystals, 10-150 \mu m in diameter, are present. If troilite inclusions should be present in other sections of Kopjes Vlei, I would expect them to be similar to those of Forsyth County and Holland's Store, due to shock melting.

No indications of artificial reheating are present. Small, but significant amounts of the heat-affected \alpha_2 zone are preserved along the surface, which proves that the structure is preatmospheric. Kopjes Vlei is related to Bingera, but it is much more unquilibrated. It was probably more intensely shocked than Bingera, since the original phosphide precipitates appear to have been more fully dissolved in Kopjes Vlei. It is also closely related to Forsyth County, Holland's Store and Mejillones and possibly represents a normal hexahedrite that, due to high-intensity shock waves followed by some reheating, started to recrystallize without ever reaching full annealing. Whether the reheating was directly associated with the shock or was of a later, but still cosmic, origin is as yet difficult to decide. Chemically, Kopjes Vlei is a typical member of group IIA.

Specimen in the U.S. National Museum in Washington:
64 g endpiece (no. 2610, 5 x 3 x 0.6 cm)
examination of the London material (Brit. Mus. no. 1916, 60) and of a small slice, loaned from Dr. Wasson before it was analyzed.

Etched sections display a medium Widmanstätten structure of straight, long (~20) kamacite lamellae with a width of 0.70±0.10 mm. The kamacite is rich in sub-boundaries, clearly visible due to copious precipitation of less than 1 μm phosphides. Neumann bands occur in profusion, sometimes slightly distorted, particularly near troilite inclusions. The hardness of the kamacite is 225±15.

Taenite and plessite cover 40-50% by area. Many varieties occur, but the most conspicuous are the black-etching areas, consisting of unresolvable duplex α+γ (HV 290±30). A typical fully developed field, e.g., 300 μm wide, will exhibit a very narrow (5 μm) cloudy taenite rim, immediately followed by indistinct yellow-etching martensite (HV 320±25). Next comes a brown-etching martensite with platelets parallel to the bulk Widmanstätten structure (HV 355±20); then the black, unresolvable α+γ structure (HV 290±30); and finally easily resolvable α+γ structures with 1-2 μm wide γ-particles (HV 215±15). Characteristic are the many kamacite lamellae that display dense grids of decorated sliplines, presumably due to straining from adjacent taenite wedges that have transformed diffusionless to martensitic structures under volume increase.

The 20-40 μm wide taenite lamellae usually display cloudy interiors (HV 330±25), apparently due to a sub-microscopic decomposition to α+γ particles. The lamellae display sub-boundaries, and they are crossed by a densely spaced grid of slipplanes parallel to the bulk Widmanstätten structure. The slipplanes must be caused by plastic deformation and are now visible due to precipitation from slight annealing.

Schreibersite dominates many sections as long, often branched Brezina lamellae. They are typically 10 x 0.6 mm in size, monocrystalline (HV 840±40) and surrounded by 0.8-1.0 mm wide rims of swathing kamacite. They contain minute veinlets, e.g., 400 μm long and 10 μm wide, of troilite that is now partially converted to pentlandite due to corrosion. Schreibersite is also common as 20-60 μm grain boundary veinlets and as 5-20 μm particles inside some plessite fields substituting for γ-particles of similar size. Very characteristic are those phosphides that line taenite...
and plessite as “island arcs.” The individual particles are subangular, 5-20 µ across, and situated 5-20 µ outside the present phase boundaries. Rhabdites proper are absent, but the numerous submicroscopic particles in the kamacite lamellae may be microrhabdites. The bulk phosphorus content is estimated to be 0.45±0.10%.

Troilite occurs as millimeter-sized nodules but also as minute blebs and veinlets associated with schreibersite. The troilite is rather pure, i.e., without daubreelite, but occasionally it is developed around 50-300 µ wide euhedral chromite crystals. The troilite displays multiple twinning due to slight plastic deformation.

Graphite, carbides, carlsbergite and silicates were not detected. There was no fusion crust and no heat-affected α₂ zone and no hardness gradient towards the surface. Apparently Kouga Mountains has been exposed to terrestrial surroundings for a long time and has on the average lost more than 4 mm.

The weathering has attacked along α-α, α-γ and α-schreibersite boundaries. The phosphide crystals, which were shattered and shear-displaced 1-5 µ due to a cosmic shock event, have provided easy lanes for the corrosive ground waters. The brecciated phosphides now appear recemented with limonitic products. The near-surface martensite of the plessite fields displays internal oxidation, very similar to that described in Tishomingo, but on a minor scale.

Kouga Mountains is a medium octahedrite which has as its closest relatives Grant, Wolf Creek, Joe Wright Moun-

tain, Sanderson and View Hill, all of the resolved chemical group III B. Structurally there are particularly close similarities to Sanderson, Wonyulgunna and Bald Eagle. See also the Supplement.

Kuga, Honshu, Japan

34°6'N, 132°5'E

A mass of 6 kg was found about 1960 near Kuga-gun, in the Yamaguchi prefecture, according to a note in Meteoritical Bulletin No. 28, 1963. It was described, with a map and photomicrographs, by Murayama (1953; 1960). The description suggests that Kuga is a medium octahedrite of the transitional variety between group IIIA and III B, and related to, e.g., Cleveland, Joe Wright Mountain and Barlett. For further references see Hey (1966: 251).

Kumerina, Upper Gascoyne, Western Australia

24°55'S, 119°25'E

Plessitic octahedrite, Opl. Spindelwidth 70±10 µ. HV 168±5.

Group IIC. 9.62% Ni, about 0.4% P, 36.8 ppm Ga, 93.4 ppm Ge, 8.1 ppm Ir.

HISTORY

A mass of 53.5 kg (118 pounds) was found in 1937 by J. Merrick close to Batthewmurnana Hill, which is 20 miles south-southwest of the center of the Kumerina copper field. The approximate coordinates of the field are given above. The meteorite was donated to the Western Austral-
Kumerina — Kyancutta

Spencer & Hey (1933b) reported lawrencite, only supported, however, by an observation of exudation of rust-promoting, minute drops. The chlorine observed probably comes from intruding terrestrial ground water.

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ablation regmaglypts which have been modified significantly by corrosion. Few of them are caused by the burning out of troilite, since troilite inclusions are too scattered. Spencer & Hey (1933b) show, however, that on one uncut surface there are four hemispherical pits, 3 cm in diameter and about 2 cm deep, and these are probably places where troilite burned out.

Etched sections display a beautiful, medium Widmanstätten structure of straight, long ($\approx$ 30) kamacite lamellae with a width of 1.05±0.15 mm. The kamacite has indistinct Neumann bands, and there are subgrain boundaries with numerous phosphide rods, less than 1 $\mu$ in thickness. In many places it may be observed that the primary alpha lamellae are in a state of grain growth, encroaching upon their neighbors and invading the open plessite fields. The kamacite has an unexpectedly high hardness of 270±20, corresponding to considerable cold-working, probably by a shock event.

Plessite and taenite cover about 30% by area. The taenite rims around the comb and net plessite fields are discontinuous, and the taenite islands of the interior normally display concave outlines, indicating only little annealing. The fields of higher average nickel content are parallel to the gross Widmanstätten structure or are composed of duplex $\alpha + \gamma$ mixtures in various finenesses, many fields actually being unresolvable with a 45x objective. Most taenite rims become brownish-tinted upon etching, presumably a result of some carbon in solid solution.

Schreibersite occurs mainly as 10-70 $\mu$ wide grain boundary precipitates and as irregular bodies, up to 50 $\mu$ across, inside the plessite fields. As usual, the coarsest bodies are developed in the coarsest plessite, evidently because they precipitated from the taenite simultaneously with the kamacite. No rhodobites are present.

Troilite was only seen as small, angular to lenticular grains, 0.5-5 mm across. It is monocrystalline and contains 10-20% daubreeelite in the shape of 1-100 $\mu$ wide, parallel bars. Larger troilite nodules appear to be present in other parts of the mass, as evidenced by the hemispherical pits mentioned above.

Reichenbach-lamellae occur sparsely as 20 x 10 x 0.1 mm plates cutting across the Widmanstätten structure. Their nature could not be examined, but it is believed that they mainly consist of troilite, possibly with associated chromite and schreibersite precipitates, as in, e.g., Thule and Cape York.

Kyancutta is a typical medium octahedrite with indications of a mild shock, witnessed by the kamacite hardness. It is structurally related to Thule, Franceville, Milky Milky and Briggsdale, and also, chemically, it is a close relative to these irons.

Specimens in the U.S. National Museum in Washington:
684 g part slice (no. 1241, 7 x 4 x 3 cm)
70 g part slice (no. 1241, 7 x 3 x 0.4 cm)

La Caille, Alpes-Maritimes, France
43°47'N, 6°44'E; 1,200 m

Medium octahedrite, Om. Bandwidth 1.10±0.20 mm. "Recrystallized." HV 180±5.
Anomalous. 9.1% Ni, about 0.35% P, 13 ppm Ga, 21 ppm Ge, 10 ppm Ir.
Most specimens have been reheated artificially to about 1000°C, but the main mass in Paris appears to be undamaged.

HISTORY
A mass of about 625 kg was reported by Thury (1829) and Brard (1829), who realized that the large chunk of iron situated in front of the church in Caille and used as a bench was a meteorite. The mass was purchased for the Paris Museum, and a few kilograms have since been distributed. According to Lacroix (1927c: 443) there is a local tradition that the mass was observed to fall; Brard and Thury stated, however, that the mass was discovered about 1650 on the mountain slopes of Audebert (Audiberge), about 5 km southeast of Caille. It was drawn by four oxen into the village of Caille, was for some time enclosed in a wall, but was later removed and eventually put in front of the church. "Two smaller masses were found with it, which were used for making horseshoes, nails, etc. It was also proposed to heat this mass, and thus divide it and apply it to the same purposes. Fortunately for the interests of science the greatness of the mass prevented the intended destruction" (Thury 1829). Caille is a small village, about 20 km northwest of Grasse and with the coordinates given above.

Figure 1034. Kyancutta (Tempe no. 285a). Medium octahedrite of group IIIA. Fissure and terrestrial corrosion along prominent Reichenbach lamellae. Deep-etched. Scale in centimenters. (Courtesy C.B. Moore.)
La Caille has been studied by Daubrée (1867a), Boussingault (1872) and Reichenbach (1862a: 628), but particularly by Meunier who in his various works repeatedly let some remark fall on La Caille. A large subgroup in his classification scheme (1884: 115; 1893a: 267, 270) was based upon La Caille. Berwerth (1905: 353) noted that the meteorite had been artificially reheated, since etched sections had a microcrystalline appearance, comparable to the heat-affected rim zone of freshly fallen meteorites. Huntington (1886; 1888) discussed the crystalline structure of the Harvard specimen and published a drawing. Otherwise, the structure appears only to have been superficially examined, and only in Meunier’s papers are there a few figures, (e.g., 1884: 33, 43, 57; 1893a: 267). Buchwald (quoted in Hey 1966: 256) noted that the specimens so far seen by him had been artificially reheated, and Jain & Lipschutz (1969) found that this was true also for the Chicago specimen.

COLLECTIONS

Paris (620 kg main mass, 900 g slices), London (364 g), Vienna* (340 g), Harvard* (304 g), Washington* (80 g and 24 g), Calcutta (103 g), Berlin (102 g), Chicago* (102 g), Prague (86 g), Stockholm (75 g), Amherst (72 g), Budapest (72 g), Dorpat (50 g), Göttinger (46 g), Tempe* (33 g), Leningrad (29 g), New York (29 g), Vatican (28 g), Ottawa (15 g), Strasbourg (10 g). The asterisk-marked specimens have been checked by the author and found to be artificially reheated.

DESCRIPTION

The mass is roughly in the shape of an irregular pyramid with the approximate average dimensions 65 x 50 x 50 cm. It is exhibited in the Paris Museum in Jardin des Plantes and shows various interesting surface features. Most of the surface is corroded with a terrestrial oxide crust of up to several millimeters thickness. Locally, the corrosion attack has weakened the adhesion between the Widmanstätten lamellae, so that octahedral fragments can be detached. A corrosion like this probably requires thousands of years, so the old reports of an observed fall around the year 1700 appear to be erroneous.

Characteristic are the 25-30 holes, which are found on many parts of the surface and appear to be parallel. They are 15-50 mm in diameter and of a more or less flat, cylindrical-conical shape. It appears that they once contained parallel troilite cylinders which partly burned out in the atmosphere, partly corroded away or were scraped out by curious people. Parallel troilite cylinders occur in several iron meteorites, e.g., Santa Rosa, Seelägen, Chihuahua City, Bendego, Chupaders and Cape York.

Another characteristic of the surface is the flat side, 50 x 50 cm in size, which apparently represents a fracture plane produced very late during the atmospheric flight. The fissure may have split the iron completely into two (or more) fragments just before it hit the Earth, or it may have split it partially, leaving it to the early possessors to complete the separation. Blacksmiths have certainly been active since hammer and chisel marks may be found on many parts of the surface, and since we also know (Brand 1829; Thury 1829) that horseshoes and nails were produced from fragments. It is interesting to observe that this interpretation of the surface features is corroborated by the first reports which mention that two smaller masses were found together with La Caille, a situation which resembles, e.g., Loreto, Bischünke and Wallapai.

The material presently in collections is of two varieties. Whether mislabeling is also involved is not clear, but it appears that the main reason for the existence of two varieties, none of which has been examined or analyzed for generations, is that some specimens represent genuine material while others are artificially reheated. It would be of considerable value to have the main mass cut again in

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**LA CAILLE – SELECTED CHEMICAL ANALYSES**

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The old French analyses are only of historical interest, the best being that of Boussingault (1872), showing 9.83% Ni.
order to examine large sections of authentic undamaged material.

Specimen No. 1060 in the U.S. National Museum was originally in Shepard's Collection (No. 4, acquired between 1851 and 1872), and will be used here for the description of undamaged material. It is a small slice of 6 x 3 x 0.8 cm with superficial hammering and with an octahedral fracture from chiseling. It is, however, not reheated by man, since the corrosion products are undisturbed, laminated hydroxides of various kinds. The fusion crust and the heat-affected rim zone are removed by corrosion. The etched section displays an anomalous, medium octahedrite pattern of straight (W ~ 15) kamacite lamellae with a width of 1.10±0.20 mm. The lamellae have microserrated borders because the originally continuous taenite ribbons between the lamellae are completely decomposed to spheroidized units. The kamacite lamellae are subdivided into recrystallized grains, 50-200 µ in diameter, and in the grain boundaries there are numerous phosphate wedges and spheroidized taenite blebs, generally 1-10 µ across. Neumann bands were not seen but may be present in grains near the fissure(s) which was created during the deceleration in the atmosphere. The hardness of the recrystallized kamacite is 180±7. It decreases to 160±5 at the very surface, indicating that the recovered transition zone is still preserved while the α₂ zone has corroded away (hardness curve type II, where the left leg is lost by weathering).

Taenite and plessite cover about 30% by area. It appears that the normal comb and net plessite types were once present, but that the gamma phase was completely altered by the same event which altered the kamacite. Presently, all taenite and plessite occur in a finely granulated form, with 5-10 µ wide, cavernous taenite blebs ("amoebae") dispersed in a granulated ferritic matrix. The appearance is related to that of Hammond and Reed City. The taenite has a hardness of 180±7, the same as the kamacite, which is unusual and suggests significant annealing.

Schreibersite is common as skeleton crystals, ranging from 1 x 0.3 to 8 x 0.5 mm in size, and enveloped in 1-1.5 mm swathing kamacite. It is unmelted, but its rim zone is decomposed to 50-100 µ wide aggregates of granulated kamacite, taenite and phosphide. The schreibersite crystals are often shattered and displaced along a sequence of steps, and the shear zones are marked by black fissures (terrestrial oxides?) and by rows of fine kamacite blebs, 1-2 µ across, in the schreibersite. Schreibersite is further present as 20-100 µ grain boundary precipitates which are also thermally altered. The bulk phosphorus content is estimated to be 0.35±0.05%. Graphite has been reported by Daubrée and Mennier, but this could not be supported in the present study.

Troilite is not present in No. 1060, but occurs in the Paris main mass as flat cylinders or cones, typically 20 x 15 mm in section and 50 mm long. They have 0.5-1 mm rims of schreibersite. The detailed structure of the troilite will probably be found to be similar to that of Hammond’s and Reed City’s troilite.

La Caille is thus a rare type of a medium octahedrite which is structurally related to Hammond and Reed City. It probably cooled to form an equilibrated Widmanstätten structure, but was later involved in a violent shock event which reheated the mass briefly, resulting in the granulated kamacite and taenite and the altered schreibersite.

As examples of artificially reheated material, of which significant amounts are in the principal collections without being recognized as such, the Tempe Specimen No. 254a, the Harvard Specimen No. 6B and the WashingtonSpecimen No. 2869 will be described. I assume that Vienna No. A735 and Chicago No. 900 represent similarly damaged material, but I have only had opportunity to briefly examine deep-etched hand specimens. Etched specimens display a granulated kamacite, but the grains are serrated and very irregular, corresponding to the α₂ grains which are generated by air-cooling from about 1000° C. The schreibersite is micromelted, and the troilite is micromelted and has reacted at high temperature with the associated, terrestrial corrosion products. At the surface and along corroded grain boundaries there are intricate laceworks of high temperature oxidation products. The taenite ribbons have diffuse borders, and the plessite is ill defined. Both the Harvard and the Tempe specimen are somewhat forged, as indicated by the overturned Widmanstätten lamellae near the surface, and by the parallel, diffuse ghost-lines in the α₂ matrix. Such diffuse lines, parallel to the hammered surface, are also present in Babb’s Mill, Troost’s Iron and in old, forged specimens of Campo del Cielo, Otumpa (Buchwald 1967a: 25) and are good evidence of mild forging. Several of the mentioned specimens are so altered by prolonged reheating in the 1000-1100° C range that it is difficult to understand that they ever possessed the structure seen in the genuine material, as represented by U.S.N.M. No. 1060. It is an interesting speculation whether

![Figure 1036. La Caille (Tempe no. 254a). Kamacite lamella transformed by artificial reheating above 800° C to blocky α₂. Dark spots are partly resorbed troilitite crystals. Etched. Scale bar 200 µ.](image-url)
the reheated material originates from the village smiths in Caille, or perhaps represent experimental fragments from the Paris laboratory. It is at least known that Daubrée and Meunier for many years experimented with heating, forging, dissolving and synthesizing meteorites; see, e.g., Daubrée 1868c: 31; Meunier 1884: 39, 321.

Summing up then, La Caille fell a long time ago and probably split in a few fragments of which the largest 625 kg mass was acquired by the Paris Museum in 1828. From Paris two types of material were distributed. Most specimens represented artificially reheated material, but a few, notably No. 1060 in Washington, represented undamaged material. Since undamaged material is available at all, it appears that the main mass has not suffered significant reheating; and it is urged that the mass be cut again in order to furnish authentic, undamaged material. La Caille is structurally anomalous by its shock-reheated, granulated structure and by its content of parallel belemnite-shaped troilite nodules. It is also chemically anomalous by its Ga-Ge-Ir combination.

Specimens in the U.S. National Museum in Washington:
80 g slice (no. 1060, 6 x 3 x 0.8 cm, Shepard Collection no. 4)
24 g slice (no. 2869, 4 x 4 x 0.2 cm), Reheated artificially.

La Grange, Kentucky, U.S.A.
38°24'N, 85°23'W; 250 m

Fine octahedrite, Of. Bandwidth 0.27±0.05 mm. Complex e-structure. HV 270±20.
Group IVA. 7.65% Ni, 0.41% Co, 0.03% P, 2.1 ppm Ga, 0.12 ppm Ge, 2.3 ppm Ir.

HISTORY
A mass of 112 pounds (51 kg) was found in 1860 by William Daring, near La Grange, in Oldham County. It was acquired by J.L. Smith who cut and distributed one third of it and gave a brief description with an analysis (1861). Cohen (1905) reviewed the literature and gave a new description. Brezina & Cohen (1886-1906: plate 20) presented three photomacrophraphs and grouped, inappropriately, La Grange with Russell Gulch, a medium octahedrite of group IIIA. Voshage (1967) found too low a potassium concentration to establish a cosmic ray exposure age by his \( ^{40}K/^{41}K \) method.

COLLECTIONS
Amherst (35.5 kg block and 500 g slice), Washington (2,160 g), Berlin (1,013 g), Tempe (912 g), Calcutta (503 g), Vienna (442 g), Paris (368 g), Göttingen (368 g), Bonn (222 g), Chicago (218 g), London (202 g), Harvard (193 g), Stockholm (136 g), Los Angeles (60 g), New York (56 g), Strasbourg (52 g), Tübingen (48 g), Yale (46 g), Leningrad (31 g), Rome (24 g), Vatican (23 g), Ottawa (21 g), Oslo (8 g).

DESCRIPTION
The extreme dimensions of the elongated, flattened mass were, according to Smith (1861), 50 x 27 x 16 cm. The present mass is cut at both ends, weighs 35.5 kg and measures 27 x 25 x 15 cm. It is turtle-shaped and rather smooth, with 0.1-2 mm thick oxide crusts from terrestrial weathering. In places the Widmanstätten structure may be suspected from the regularly oriented ridges in the weathered crust. No fusion crust and no heat-affected \( \alpha_2 \) zone are preserved.

Etched sections display a rather dull, indistinct Widmanstätten structure, that in places is quite distorted. The lamellae are long (\( \sim 30 \)) and very narrow, 0.27±0.05 mm. The cold-worked kamacite may perhaps best be described as a contrastless mixture of Neumann

La Grange is one of the better analyzed meteorites.

LA GRANGE – SELECTED CHEMICAL ANALYSES

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La Grange is one of the better analyzed meteorites.