

Martensitic plessite (HV 400 ± 30) with plates parallel to (111) γ gradually merges with duplex $\alpha + \gamma$ fields of various finenesses, the finest looking as “black taenite.” Their hardness range is 225-325.

Schreibersite occurs as large, 10-100 mm long and 1 mm wide lamellae surrounded by 1-2 mm wide rims of swathing kamacite, and as 0.2-0.5 mm wide crystals centrally in the α -lamellae. The schreibersite is monocrystalline and slightly fractured and has a hardness of 890 ± 30 . Schreibersite also occurs as 10-50 μ wide grain boundary precipitates and 2-50 μ irregular blebs inside the plessite fields. Rhabdites are numerous as 1-15 μ thick prisms in the wider kamacite lamellae.

Troilite occurs as scattered nodules and elongated bodies 2-20 mm in diameter. The larger ones are enveloped in irregular 1-2 mm wide schreibersite rims which have nucleated 1-2 mm wide rims of swathing kamacite. At least the smaller troilite bodies are shock-melted, polycrystalline mosaics of 2-10 μ wide grains. None of the larger nodules could be examined in polished section.

According to Kunz (1886a), who was a jeweler associated with Tiffany's, the olivines isolated from No. 1 were perfect, transparent crystals of gem quality. Mason (1963) found 13% fayalite. The olivine occurs in small, millimeter-sized clusters associated with troilite, and they are yellowish-green to olive-green. Quite locally, e.g., on New York no. 684, they form large, angular crystals 5-20 mm across. Such metal-olivine parts assume a pallasitic character, but they are apparently rare.

The fusion crust is well-preserved on numerous specimens as a layered zone of varying thickness, e.g., 300 μ dendritic metal (4 laminae) overlain by 50 μ magnetite. The heat-affected α_2 zone stretches 1.7-2.4 mm inwards, and in half this distance micromelted phosphides are present. The hardness is 210 ± 15 (hardness curve type III). Some slight corrosion is present in the surface zones, but, on the whole, Glorieta Mountain is very little altered, and the best specimens still show the black, shiny magnetite crust.

Glorieta Mountain is an anomalous, medium octahedrite with a few olivine inclusions. Specimens of a pallasitic appearance have been reported, but they are rare. The meteorite is related to Brenham and other pallasites. Its low hardness indicates a rather thorough, low temperature cosmic annealing.

Specimens in the U.S. National Museum in Washington

- 380 g part slice (no. 47, 12 x 6 x 0.7 cm)
- 56 g endpiece (no. 115, 6.5 x 2.5 x 0.8 cm; from No. 8 Pearce 1888)
- 9,318 g main mass of “Santa Fé” (no. 846, 36 x 10 x 5 cm)
- 408 g various slices from “Santa Fé,” some heat-treated (no. 846)
- 293 g complete finger-shaped individual (no. 905, 15 x 2.5 x 1.5 cm)
- 752 g part slice (no. 1033, 15 x 9 x 0.8 cm)
- 106 g various small slices and millings (no. 67, 1033, 1443, 2800)
- 292 g bar, forged in the Smithsonian Institution (no. 846, 12 x 1.8 x 1.8 cm)

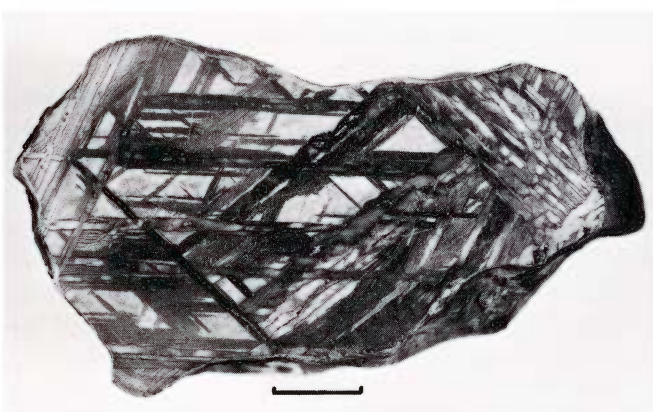


Figure 800. Glorieta Mountain (U.S.N.M. no. 846). Cross section of the club, Figure 796. Deep-etched. Scale bar 10 mm. S.I. neg. 43508.

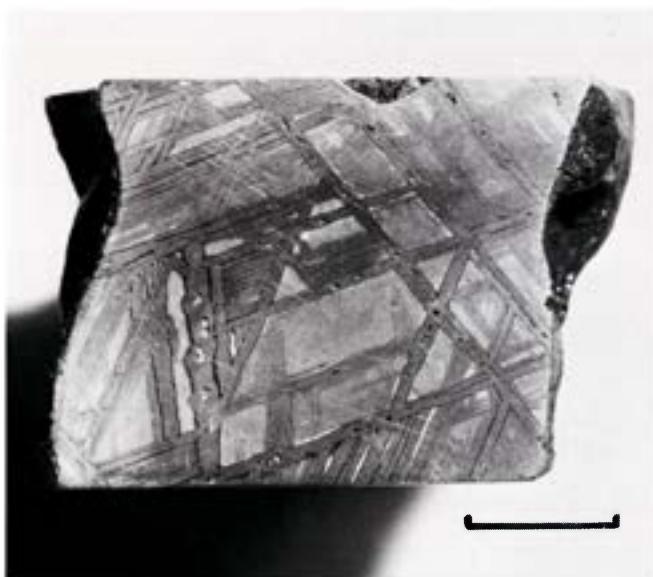


Figure 801. Glorieta Mountain (U.S.N.M. no. 846). Another section through Figure 796. Schreibersite crystals occur as angular blebs centrally in many kamacite lamellae. Deep-etched. Scale bar 10 mm. S.I. neg 43545.

Goose Lake, California, U.S.A.

41°58.6'N, 120°32.5'W; 1,500 m

Medium octahedrite, Om. Bandwidth 1.25 ± 0.15 mm. Neumann bands. HV 155 ± 10 .

Anomalous. Group I. 8.28% Ni, 0.47% Co, 0.4% P, 67 ppm Ga, 298 ppm Ge, 2.3 ppm Ir.

HISTORY

A mass of 1,167 kg (2,573 pounds) was found on October 13, 1938, by Joseph Secco, C.A. Schmidt and Ira Iverson, of Oakland, California, while hunting deer west of Goose Lake, in Modoc County only a few kilometers south of the Oregon State Line (Leonard 1939a,b). The meteorite was exposed on the surface of rough lava beds in the Modoc National Forest at an altitude of about 1500 m. The lava

flows here were weathered very much and covered with angular and rounded boulders, often several feet in diameter. The meteorite displayed several patches of inch-sized lichens, which had been able to grow on the weathered surface; at a distance the meteorite did not look very different from the lava boulders. There was no evidence of shattered rocks indicating a recent fall, and there was only a very slight depression where the meteorite rested, a depression which might have been produced by wind erosion as the air currents had eddied about it (Linsley 1939a). The difficult task of removing the mass was accomplished by the combined efforts of Leonard, Linsley, H.H. and A.D. Nininger and R.W. Webb, who, with four to six horses and a wagon in early May 1939, hauled the mass about 25 km across the trackless wilderness to the nearest road, where it could be loaded on a truck. The transport has been well described with numerous photographs of the mass in situ and of the actual transport by Leonard (1939a,b; 1940; 1950), Linsley (1939a,b) and Nininger & Nininger (1950: plate 4, 37; 1952: plate 43). The meteorite was exhibited at the Golden Gate International Exhibition in San Francisco 1939-40, and was afterwards transferred to the U.S. National Museum.

The meteorite was thoroughly described with photomicrographs and with a discussion of the numerous, unusual cavities by Henderson & Perry (1958). They argued that the holes could not be the product of corrosion, nor of atmospheric ablation, and they were, therefore, more or less forced to the conclusion that the cavities were present already while the meteorite circled in the cosmos. They visualized the meteorite penetrating the atmosphere producing screaming sounds because of the holes. Butler (1963; 1965) found, upon reexamination of the site in 1960 and 1961, numerous small fragments of more or less oxidized material. The metallic fragments, 0.1-0.2 g in size, showed considerable cold-deformation, and the oxidized fragments, 1-13 g in size, still included patches of metal and were magnetic. Although questioned by Nininger (1967), the fragments, no doubt, belong to the main mass, since the detailed structure is identical. The fragments appear to come from the weathered crust, which had spalled off the meteorite and had been washed 10-75 m down the 3-4° slope, away from the original place of find. Cook & Butler (1965), speculating over the absence of a crater, suggested that Goose Lake was a fragment of Canyon Diablo, having been thrown in a low arc the necessary 1000 km from



Figure 802. Goose Lake (U.S.N.M. no. 1332). The 1,163 kg main mass with its characteristic and enigmatic cavities. The white ruler measures 20 cm and is inserted in two connecting cavities. Below, another ruler is inserted into a hole which connects with the large cavity on the opposite side. Above right, a 30 x 10 cm cut indicates from where the only material for examination has been taken. S.I. neg. 41402.

Meteor Crater, Arizona. This is, however, untenable since Goose Lake in its structure and chemical composition is significantly different from Canyon Diablo specimens. Axon & Rieche (1967) described the specimen in London and compared this to some of Butler's fragments. They observed mechanically distorted surface layers along the edges of most polished sections and suggested that it might be due to deformation arising when a heavy mass of iron was hauled about by chains during the recovery process. The five photomicrographs given by them are very typical for the structure of Goose Lake.

COLLECTIONS

Washington (main mass of 1,163 kg and 2.8 kg slices), Ann Arbor (1,107 g), Calcutta (544 g), Chicago (517 g), Tempe (378 g), Moscow (336 g), Ferry Building, San Francisco (270 g), Sydney (114 g), London (72 g), New York (50 g). Also, 220 g in Chabot Observatory in Oakland, California, and about 400 g in private possession.

DESCRIPTION

The mass has the overall dimensions of 105 x 70 x 40 cm. Its shape is irregular, but may be figured as that of an oblong, 40 cm thick crescent, with one convex and one concave side. When found it was resting upon its convex side, as demonstrated unambiguously by Figure 2 in Butler (1963), where the rocks for the "cairn" are piled into the concave depression of the topside. Another good picture of the meteorite in situ was given by Leonard (1939b: figure 1). The sides meet along well rounded edges, and both sides and edges are marked with conspicuous holes, cavities and even a 25 cm long and 4-10 cm wide tunnel, connecting the two sides. The holes have been well described by Henderson & Perry (1958) who presented photographs of casts made of four typical holes. Since the holes have aroused such widespread speculations, they will be reconsidered here. They are present on all faces of the

meteorite, with about 12 on the concave side, 12 on the convex side and 10 along the irregular edges. Here, a hole is taken to mean a cavity, with a depth larger than its aperture. Some are funnel-shaped, some are considerably undercut; typical holes have an aperture of 10 x 8 cm and a depth of 11 cm; or 3 x 2 cm with a depth of 8 cm. The tunnel, which connects the two sides, starts from a large bowl, 25 x 30 cm in aperture and 20 cm deep. The tunnel itself has an almost elliptical aperture of 6-8 cm, but soon widens to about 10 cm and has, at the other end, an aperture of 4 cm. Some adjacent holes undercut and meet a few cm below the surface. With the exception of Willamette, probably no other meteorite displays such an intriguing variety of holes. Almost all holes have cold-deformed metal smeared in over the apertures, creating 0.5-2 mm thick, fringed lips. A close inspection of the surface shows that these lips are only one manifestation of a pronounced battering and cold-deformation which has taken place all over the surface of the meteorite, on both

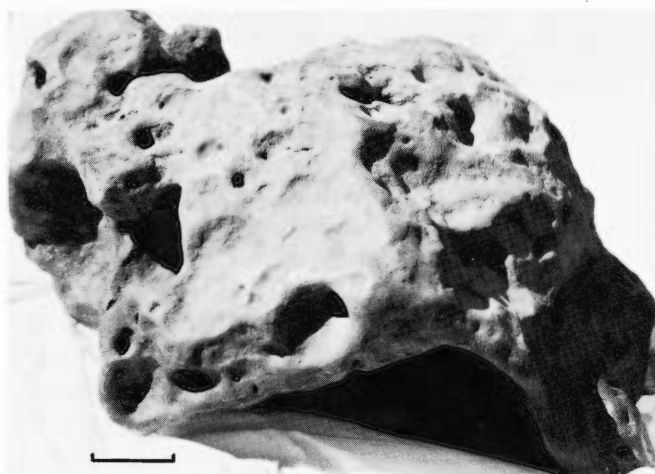


Figure 803. Goose Lake (U.S.N.M. no. 1332). The main mass seen from the opposite side. Scale bar approximately 10 cm. S.I. neg. 13508-2.

GOOSE LAKE – SELECTED CHEMICAL ANALYSES

The variation in nickel probably represents a real variation in the meteorite, corresponding to various structures. It appears that the relatively nickel-poor parts are associated with the carbon- and cohenite-poor parts of the meteorite. The phosphorus value of Moore & Lewis is the average of 0.26 and 0.80% P. Point counting of 400 cm²

showed that the phosphides, visible under a stereomicroscope, cover about 2% by area, corresponding to about 0.28% P. If we add 0.12% P, the value obtained by Henderson upon material free of visible inclusions, we get as an average value for the whole meteorite 0.40% P.

References	percentage			C	S	Cr	Cu	ppm Zn	Ga	Ge	Ir	Pt
	Ni	Co	P									
Goldberg et al. 1951	8.48	0.69							75.1			
Lovering et al. 1957		0.52				17	390		57	221		
Smales et al. 1958						17.5	184			290		
Henderson & Perry 1958	8.39	0.42	0.12									
Nichiporuk & Brown 1965											2.2	6.8
Moore et al. 1969	8.27	0.46	0.53	575	35		175					
Wasson 1970a	8.00								67.2	305	2.3	

sides and even, to a minor degree, in the bowl-shaped depressions. Etched sections through the deformed zones reveal a bewildering mess of distorted taenite, plessite and Neumann bands to a depth of 0.5-3 mm. The incompatible phosphide inclusions are fragmented, sheared and torn out in a boudinage pattern. It is important to note that corrosion has attacked the deformed material in situ, which means that the deformation is of old date, and can hardly be the result of man's transport or of hammering by some ancient Indian tribes. The deformation is, on the other hand, younger than the holes. It is unique in iron meteorites. It is not the result of impact with the ground, since it is present on all sides and even in the interior of many depressions. There is a slight possibility that the battering is due to transport by an extinct glacier; such an explanation would also account for the absence of an impact hole in the ground. The state of corrosion certainly indicates that Goose Lake is terrestrially old, that is, at least several thousand years and probably much more. The fusion crust and the heat-affected α_2 zone are removed, and in many places the Widmanstätten structure is discernible as a weathered grid on the maroon colored oxide surface.

It is, however, a curious fact that the cold-deformed surface material is partly recrystallized to 5-25 μ ferrite grains, indicating a gentle reheating to about 400 or 450° C. Inquiries at the museum show that the material has not been reheated here, neither has it been etched by heat-tinting. Since Axon & Rieche (1967) also noted the recrystallized zones, they appear to be well established. They are different from the heat-affected α_2 rims that are created during the ablation stages in the atmosphere, since they are strictly a recrystallization of cold-deformed material, and then only of the most intensely worked material. There is one source of terrestrial activity that may explain most of the anomalous surface features of Goose Lake, namely, lava flows.



Figure 804. Goose Lake (U.S.N.M. no. 1332). The section is almost parallel to (100) γ and, therefore, shows only two sets of Widmanstätten lamellae, almost perpendicular to each other. Troilite-graphite-silicate nodule to the left, and many large skeleton crystals of schreibersite. These are enveloped by narrow cohenite rims (black) and swathing kamacite. The thin, dark veins are terrestrial corrosion products. Deep-etched. Scale bar 30 mm. S.I. neg. 37144.

It appears, then, that the meteorite during its normal fall acquired a considerable number of holes and large depressions, the holes being carved particularly where troilite-schreibersite-cohenite complexes burned out. The frequency with which the holes occur is about one per 600 cm², and this is consistent with the number of similar holes on smaller falls, like Bahjoi and Bogou, of the same inclusion-rich group I type. Also the bold sculpture of the large depressions appears to be mainly the result of atmospheric ablation, similar to what may be observed on, e.g., Maria Elena, but on a larger scale. The meteorite corroded, the fusion crust and the heat alteration zone disappeared, and several holes were undercut and enlarged in the same way as the holes of Drum Mountain. After considerable exposure to terrestrial weathering, a lava flow

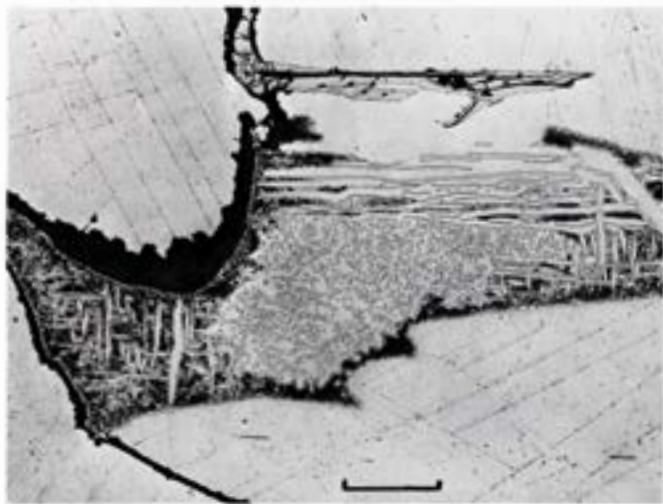


Figure 805. Goose Lake (U.S.N.M. no. 1332). Plessite field displaying both acicular and spheroidized areas. Terrestrial corrosion products (black) in the grain boundaries. Schreibersite vein (S). Etched. Scale bar 200 μ . (From Henderson & Perry 1958: plate 9.). See also Figure 121.

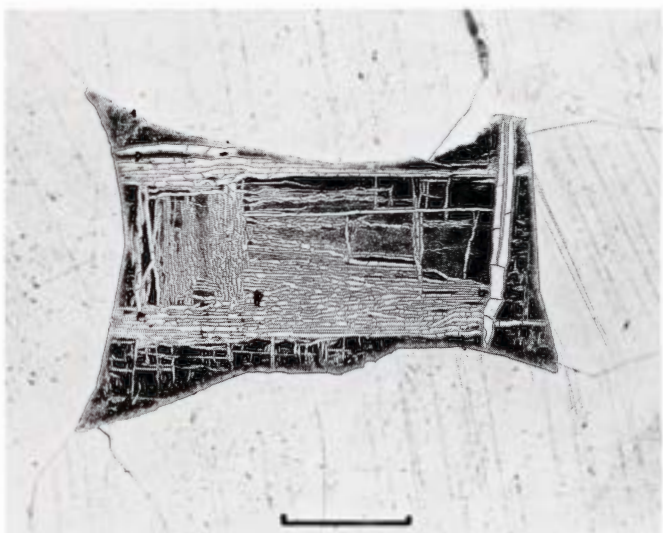


Figure 806. Goose Lake (U.S.N.M. no. 1332). Acicular plessite field. Fine rhabdites and Neumann bands in the surrounding kamacite. Etched. Scale bar 500 μ .

transported the mass to its present position, where it may have become partially embedded. During the transport the surface was deformed and smoothed, the lips around the holes were created and an incipient recrystallization in the deformed zones took place. From the details of the structure and the hardness it appears that the whole meteorite was annealed and recovered at this event, possibly having been reheated slightly above 400°C . Renewed weathering exposed the meteorite and started spalling off the deformed surface layer, which may be found as discrete fragments downhill relative to the place of find. Another possibility is glacier transport followed by deglaciation and, at a much later date, by intense forest fires. Geological fieldwork might help to distinguish between the alternatives.

The most difficult point in this sequence of events appears to be the enlargement of preexisting ablation holes by corrosion. From the appearance of several other irons with holes, notably Willamette, the present author believes, but is not able to prove, that it is possible to have long-term corrosion dig out such holes. Several sections through the holes failed to disclose any fusion crust or heat alteration zone. Therefore, to a significant degree, the holes must be due to corrosion.

Etched sections display a medium Widmanstätten structure of straight, long ($l \sim 25$) kamacite lamellae with a width of $1.25 \pm 0.15 \mu\text{m}$. Since all slices cut so far (about 14) come from a single $30 \times 10 \times 10 \text{ cm}$ knob at the edge, and were cut parallel, they all exhibit the same "basket weave" of two sets of lamellae, mutually almost perpendicular, indicating that the cut was almost parallel to a cubic plane (100) of the original austenite single crystal. The kamacite has numerous subgrain boundaries and Neumann bands decorated with $0.5 \mu\text{m}$ phosphides. Near the surface, the metal is, as discussed above, deformed plastically where heavy strain has created lenticular deformation bands and kneaded structures of taenite, kamacite and phosphides.

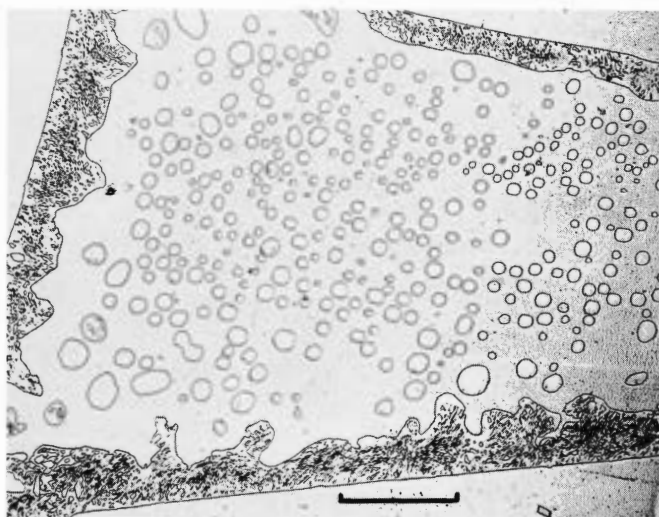


Figure 807. Goose Lake (U.S.N.M. no. 1332). Part of a plessite field with pearlitic frame and spheroidized interior. Etched. Scale bar 40μ .

Recrystallization to equiaxial $5\text{--}25 \mu$ grains occurs in the most deformed shear zones, and a later corrosion has selectively attacked the grain boundaries of the recrystallized grains. Corrosion has also selectively attacked the alpha phase of the duplex plessite fields and the alpha phase around the graphite plumes in the cohenite. The hardness of the deformed surface zones is locally 235 ± 20 ; but usually some recovery and recrystallization have occurred, and the hardness has dropped to low values; thus, a lip of recrystallized material showed a minimum hardness of 130. The interior of the mass, with the reservation that no specimen is more than 10 cm removed from the nearest surface, has a hardness of 155 ± 10 . Such a low hardness with no visible structural changes may be due to recovery at about 400°C for some time.

Plessite covers about 20% by area, mostly as open-meshed, comb plessite and as duplex, easily resolvable $\alpha + \gamma$ fields. The framing taenite is frequently discontinuous, and the plessite interior is decomposed to a somewhat spheroidized mixture, where individual taenite spherules range from 0.5 to 20μ across and some haxonite may be detected occasionally. Acicular plessite with poorly resolvable black taenite is also present, and, particularly near the cohenite-rich parts of the sections, pearlitic plessite with $0.5\text{--}1 \mu$ wide taenite lamellae is conspicuous. All elements of the plessitic structures are unusually soft. The 40μ wide taenite ribbons are thus 175 ± 10 , again indicating late annealing.

Schreibersite is common as skeleton crystals which take the shape of 5×5 , 10×4 and $20 \times 2 \text{ mm}$ hooks, hollow rods and rosettes. The schreibersite is monocrystalline and covered by continuous rims of $100\text{--}200 \mu$ wide cohenite crystals. The aggregates are enveloped in $2\text{--}4 \text{ mm}$ swathing kamacite. The cohenite is under decomposition to graphite and polycrystalline ferrite along cracks in the cohenite. A typical decomposed zone extends more or less perpendicular from the schreibersite-cohenite interphase as a 40μ wide ferrite channel, in the midst of which is a 10μ wide, microcrystalline graphite plume. The graphite resembles moss agate in its shape, and the overall decomposition stage resembles, e.g., that in Wichita County. Schreibersite is also present as $30\text{--}100 \mu$ wide grain boundary precipitates and as $10\text{--}50 \mu$ irregular blebs inside the various plessite fields. Rhabdites are ubiquitous, typically $5\text{--}15 \mu$ thick, and frequently up to 300μ long. They appear to have a very thin reaction rim, indicating a slight reheating to above 400°C .

Troilite is present as $5\text{--}10 \text{ mm}$ nodules, normally associated with a little graphite and unidentified silicates. As usual in group I, the rim consists of schreibersite and cohenite, and the aggregates are sheathed by $1\text{--}3 \text{ mm}$ swathing kamacite. At various locations along the surface the holes appear to be located where troilite was previously present, but is now removed by combined ablation and corrosion. The swathing rims around the troilite are partially preserved. The troilite itself is shock-melted. It is subdivided in $1\text{--}5 \mu$ anisotropic grains with graphite and silicate inclusions. Further, some troilite contains shattered

and partially melted fragments, about 2-20 μ across, of daubreelite and schreibersite. In several instances it was observed how 1-10 μ wide troilite melts were injected into fissures in the surrounding schreibersite or were injected along the schreibersite-cohenite interfaces. Unfortunately, late corrosion attacks these veinlets preferentially and makes them somewhat difficult to observe. It is, however, as so often shown in the descriptions of meteorites herein, interesting to note that it is possible to have shock-melted troilite and injected troilite melts without the metal phase showing anything else than Neumann bands.

Cohenite is present as 1 x 0.5 mm branched crystals situated in the midst of the kamacite lamellae. The cohenite is normally clustered in discrete areas of, e.g., 4 x 3 cm² size. A small number of chromium nitrides (carlsbergite) in form of 20 x 1 μ oriented platelets is present in the kamacite. Graphite is present locally in the kamacite as 50-100 μ angular grains with radial extinction, approaching cliftonitic morphology.

Goose Lake is a meteorite with shock-melted troilite, which is not too common in group I. Also, in other respects, particularly the rather narrow α -lamellae, it is a little different from the majority of the group I irons which are coarse octahedrites. It appears to be closely related to Bischtübe, Toluca and Deport. Its detailed story, particularly upon this Earth, is, however, unique, and has rightly attracted considerable speculation.

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

1,163 kg main mass with one cut surface of 30 x 10 cm
2.8 kg slices and sections (no. 1332)

Gosnell's Iron. See Mount Dooling

Gran Chaco. See Imilac (in the Supplement)

Grand Rapids, Michigan, U.S.A.

42°57'N, 85°40'W; 200 m

Medium octahedrite, Om. Bandwidth 0.55 ± 0.08 mm. Decorated Neumann bands. HV 200 ± 10 .

Anomalous. 9.31% Ni, 0.54% Co, about 0.2% P, 17 ppm Ga, 15 ppm Ge, 14 ppm Ir.

HISTORY

A mass of about 52 kg was found in 1883 by M. Clancy, a contractor, while making an excavation for building purposes on land belonging to the Catholic church in Grand Rapids. The mass was about 0.9 m below the surface and wedged between two large boulders. The finder, who believed he had found a valuable gold-silver ore, attempted in vain to split the mass with hammer and cold chisel (Eastman 1884). The meteorite was analyzed in the U.S. Geological Survey and a photomicrograph and a drawing of the exterior were given (Riggs 1888). Brezina (1895) and Cohen (1905) presented descriptions, and Brezina & Cohen (1886-1906: plate 33) gave two photomicrographs. Ward, who purchased the meteorite about 1890, cut and distributed it, and gave a photomicrograph (Ward 1892; 1904a). Other photomicrographs were given by Mauroy (1913: figure 8), Sickels (1917: figure 9), and by Perry (1944), who also gave the first photomicrographs. Voshag (1967) examined the ^{40}K - ^{41}K content, but found it too low for establishing a cosmic ray exposure age.

COLLECTIONS

Chicago (11.2 kg), New York (8,375 g), Washington (3,526 g), Tempe (1,538 g), London (1,442 g), Amherst (1,246 g), Harvard (1,008 g), New York City College (965 g), Vienna (706 g), Yale (679 g), Budapest (339 g), Calcutta (235 g), Vatican (198 g), Sydney (194 g), Stockholm (141 g), Bally (140 g), Rome (121 g), Prague (102 g), St. Louis (102 g), and numerous other collections.

DESCRIPTION

The somewhat pear-shaped mass had the overall dimensions 35 x 25 x 18 cm. It is corroded, with 0.5-2 mm thick adhering crusts of terrestrial oxides, but the corrosion does not penetrate far into the mass, except along Reichenbach lamellae. The heat-affected rim zone of granulated α_2 is preserved as a 0.5-5 mm wide zone around most of the slices. The phosphides are micromelted in the exterior half of the wider parts, but are unmelted in the narrower rim zones, which proves that these narrower parts have lost the outer part by corrosion. The original heat-affected rim zone was thus unusually thick, 4-5 mm. The α_2 zone has a hardness of 205 ± 20 . There follows a recovered transition zone with a minimum hardness of 155 ± 5 , and then comes the unaffected interior, HV 200 ± 10 , below 10-15 mm depth (hardness curve type II).

GRAND RAPIDS – SELECTED CHEMICAL ANALYSES

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Etched sections display a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 40$) kamacite lamellae with a width of 0.55 ± 0.08 mm. It is characteristic that 0.1–0.5 mm wide schreibersite bodies are located centrally in all the primary lamellae. Neumann bands are present as sharp double lines, and subgrain boundaries are numerous, often in wavy concentric arrangements. Fine precipitates of $0.5\text{--}2\ \mu$ rhabdites occur on both Neumann bands and subgrain boundaries, and it appears that the matrix itself is loaded with submicroscopic precipitates. Its hardness is 200 ± 10 .

Plessite covers 30–40% by area, partly as a dense comb plessite with a high proportion of taenite, partly as martensitic fields. The martensite is annealed and shows ultrafine precipitates (HV 265 ± 15) or grades into barely resolvable, duplex $\alpha + \gamma$ structures (HV 200 ± 20). The annealed taenite and plessite resembles what is present in, e.g., Anoka.

Schreibersite is evenly distributed as $0.2 \times 0.1 - 3 \times 0.3$ mm angular, monocrystalline bodies centrally in the kamacite lamellae. It further occurs as $30\text{--}50\ \mu$ grain boundary precipitates and as $1\text{--}5\ \mu$ grains of approximately the same size as the taenite in the comb plessite fields. An estimate of the phosphides leads to the conclusion that the analytical values of 0.14–0.17% P are somewhat low. The mass as a whole rather contains about 0.25% P.

Troilite occurs sparsely as scattered 1–20 mm bars and rounded nodules, but also as Reichenbach lamellae. These are typically $30 \times 10 \times 0.05$ mm lamellae, which are arranged in at least four directions and are observed with a frequency of about one per 25 cm^2 . They appear to be composed mainly of troilite with irregular precipitates on the sides and at the ends of schreibersite. Cohenite has been reported but is not present.

Corrosion has attacked the α -phase of the plessite fields selectively, and, also, the near-surface Neumann bands are limonitized. A few centimeters from the surface the attack appears to be of no consequence.

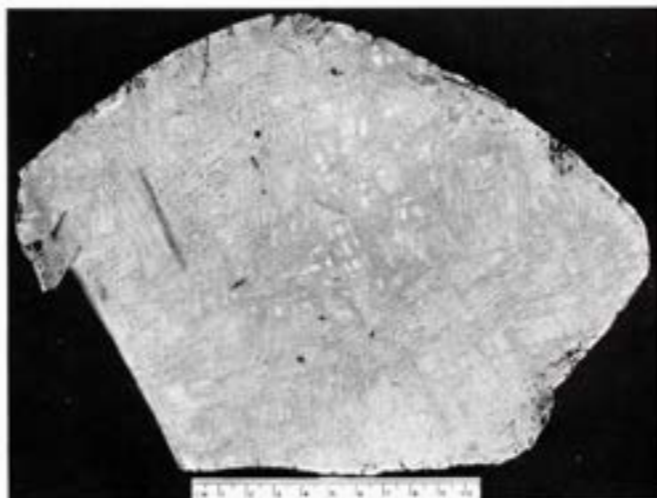


Figure 808. Grand Rapids (Tempe no. 54a). An anomalous medium octahedrite. Scattered troilite nodules and Reichenbach lamellae are visible. Deep-etched. Scale in centimeters. (Courtesy C.B. Moore.)

Grand Rapids is a medium octahedrite, but its bandwidth is different from other meteorites on the 9% nickel level. It falls between medium, phosphorus-rich meteorites like Grant (0.85 mm) and fine, relatively phosphorus-poor irons like Mart (0.43 mm). Chemically, its combination of Ni, Ga, Ge and Ir is anomalous.

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

1,208 g slice (no. 31, $16 \times 11 \times 1$ cm)
 74 g part slice (no. 683, $6 \times 4 \times 0.4$ cm)
 2,060 g slice (no. 3318, $23 \times 17 \times 0.9$ cm)
 184 g various slices (nos. 1034, 2802, 2803, 2804)

Grant, New Mexico, U.S.A.

Approximately $35^{\circ}0'N$, $108^{\circ}0'W$; about 2,000 m

Medium octahedrite, Om. Bandwidth 0.80 ± 0.10 mm, ϵ -structure, HV 310 ± 15 .

Group IIIB. 9.34% Ni, 0.60% Co, about 0.8% P, about 0.6% S, 19.7 ppm Ga, 37.5 ppm Ge, 0.04 ppm Ir.

A fragment of Grant has unfortunately become known as Breece.

HISTORY

In 1918 a fragment of 113 g, broken from a larger mass, was presented by N.H. Darton to the U.S. National Museum (Smithsonian Archives, no. 62880). It was said to come from San Rafael, a village 5 km south of Grants, in Valencia County, but it was impossible to get any more information. In 1921 another fragment, of 50 kg, was offered for sale to the Field Museum in Chicago. It was said to come from the hamlet of Breece in the Zuni Mountains (Beck et al. 1951b), and since has always been accepted as a



Figure 809. Grant (U.S.N.M. no. 836). The main mass shows a distinctly conical shape. Below left, a hackly fracture indicates from where the 50 kg fragment, long known as Breece, came. Height of cone approximately 55 cm.

separate fall, labeled Breece. As will be shown here, it is, however, a fragment of Grant.

Finally, in 1924 a certain Rodolfo Otero, of San Rafael, New Mexico, offered a meteorite of about 1500 pounds for sale to the Smithsonian Institution. This turned out to be the main mass of Grant; it actually weighed 482 kg (1060 pounds) and was in 1929 purchased for \$500 by the Smithsonian, assisted by a donation from the Roebbling Fund.

When Henderson (1934) described the main mass, he stated that it was difficult to get precise information from the owners as to the exact date and place of discovery. The places alluded to in the meager correspondence and records in the Smithsonian files are "South of Gallup," "in the Zuni Mountains" and "45 miles southwest of Grants in the Malipi lava." These data are, to say the least, conflicting, and it is the present author's opinion that the finders at the time, deliberately withheld the exact information, perhaps in the hope that more was to be found. The coordinates given above are for the lava flows south of Grants and San Rafael, the most likely point of finding. This is on the eastern slopes of the Continental Divide wherefore it would be natural to haul the large mass through Grants.

Henderson (1934) described the main mass with a photograph of the exterior, showing the pseudo-cone, and with one photomicrograph. Perry (1944) presented five photomicrographs. With the kind assistance of the Battelle Memorial Institute the mass was, in 1957, cut in two halves, producing two central, full slices each about 1 cm thick.

Material from known depths inside the meteorite has been thoroughly studied during the last ten years, which has resulted in several important papers on the production of spallation nuclides in iron meteorites. Hoffman & Nier (1958) reported on the distribution of ^3He and ^4He and

plotted contour maps which showed, as expected, the concentration of these isotopes to be lower at the center than at the surface by about 20%. They also extrapolated their data to a supposed preatmospheric surface, which would indicate that the preatmospheric mass of the meteorite had weighed about 2,000 kg. This estimate is probably considerably on the high side and has been questioned, particularly by Maringer & Manning (1960), who, by an entirely different approach, estimated the ablation loss to be significantly less, visualizing a preatmospheric mass of about 750 kg. Fireman (1959) reported on the distribution of ^3He and estimated the preatmospheric mass to be about 880 kg. Honda et al. (1961) measured the concentration of ^{10}Be , ^{26}Al , ^{36}Cl , ^{40}K and ^{53}Mn , and Herr et al. (1961) studied the extremely low amounts of osmium and rhenium.

Signer & Nier (1960; 1962) added measurements on the distribution of noble gases to the helium determination, and discussed the results so far obtained. The cosmic ray exposure age was estimated to be 600 million years. Honda & Arnold (1964) included Grant in their discussion of effects of cosmic rays on meteorites, and presented new and revised data. Schaeffer & Heymann (1965) found a $^{36}\text{Cl}/^{36}\text{Ar}$ exposure age of 640 ± 100 million years, while Lipschutz et al. (1965) found a $^{21}\text{Ne}/^{26}\text{Al}$ exposure age of 590 ± 50 , and Voshage (1967) a $^{40}\text{K}/^{41}\text{K}$ exposure age of 695 ± 70 million years. The discrepancies have been discussed by Fisher (1967), who suggested that a loss of 2×10^{-8} cm per year by space erosion would resolve the discrepancy and bring all the radiation ages into agreement within an error limit of $\pm 10\%$. Fisher also questioned the calculations of Lipschutz et al. (1965), normalizing their results to a different age of the standard, Norfolk.

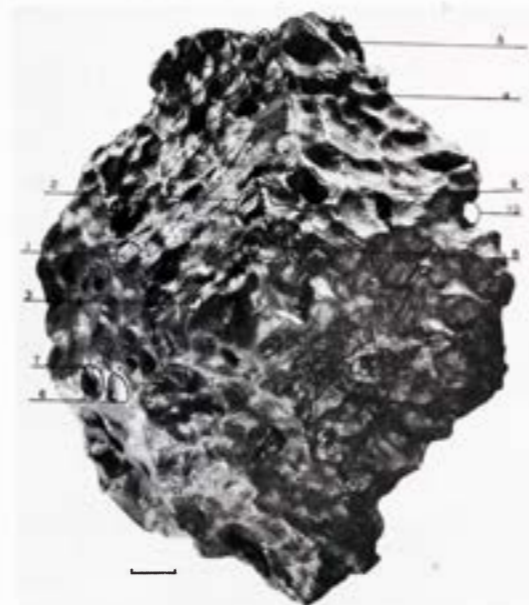


Figure 810. Grant (U.S.N.M. no. 836). The main mass seen from above. Apex in center of picture. Numbered points indicate areas that were photographed separately for their well-developed fusion crusts. Scale bar approximately 5 cm. S.I. neg. M-20.

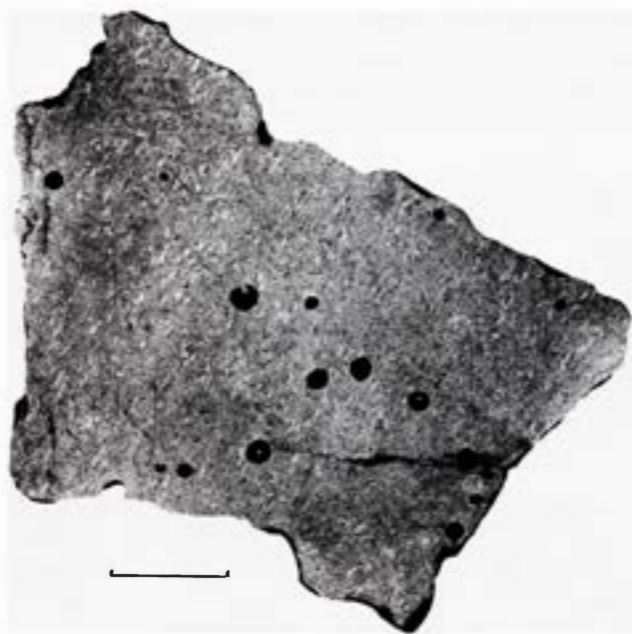


Figure 811. Grant (U.S.N.M. no. 836). Full section through Grant. Many large troilite nodules, some of them showing metallic globules. Numerous Brezina lamellae of schreibersite. Deep-etched. Scale bar 10 cm. S.I. neg M-126. See also Figures 153 and 159.

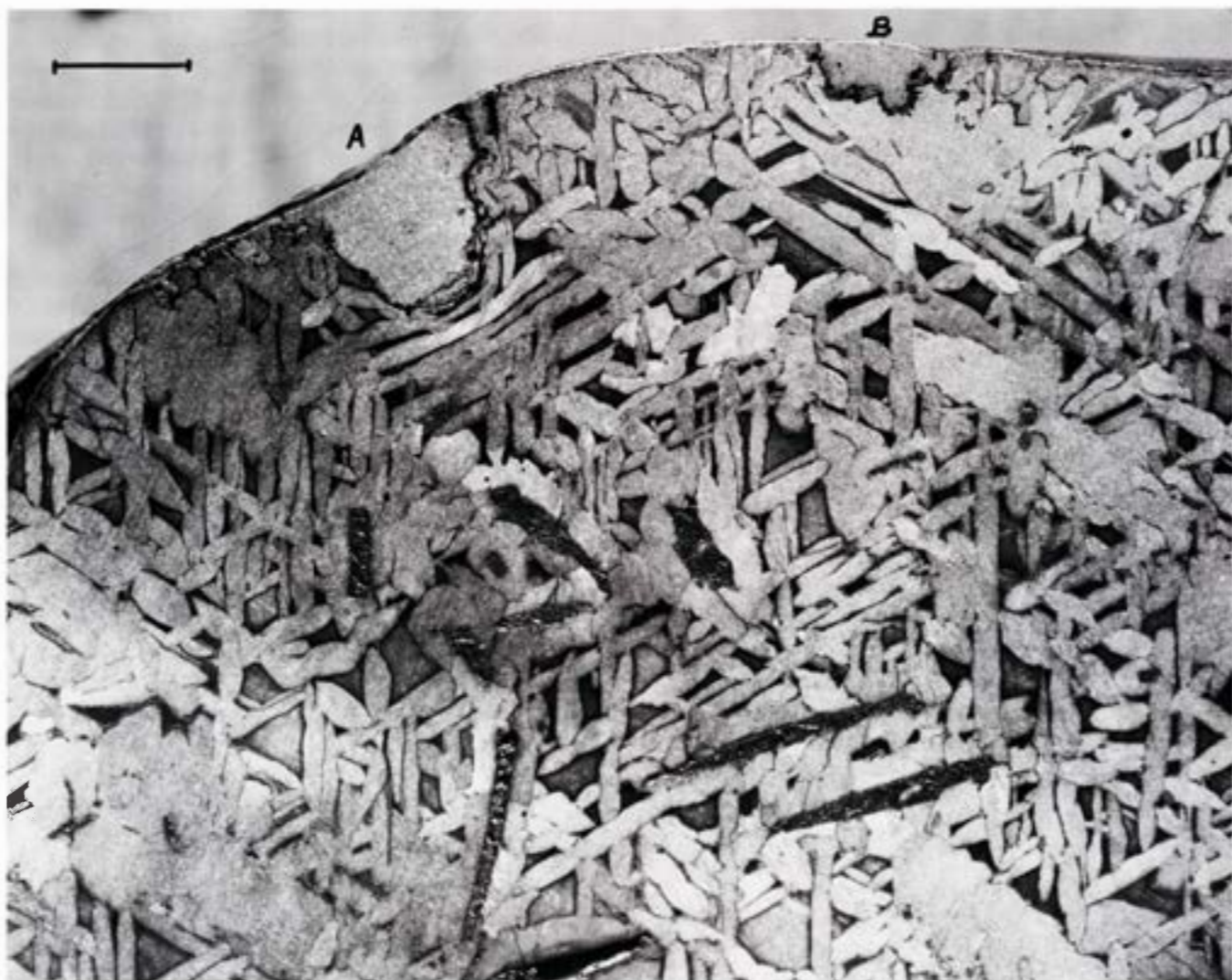


Figure 812. Grant (U.S.N.M. no. 836). Heat-affected α_2 zone along the surface. At A and B two pockets of intruding fused metal. The detailed structure of the pockets is similar to the whirlpools of Durango, Kalkaska, Roebourne, Sandtown, etc. Deep-etched. Scale bar 5 mm. S.I. neg. M-128e.

Kohman & Goel (1963) found by their $^{14}\text{C}/^{36}\text{Cl}$ method that the terrestrial age of Grant was greater than 6,000 years. Further publications on various aspects of the isotope distribution exist and may be found by consulting the relevant review papers, e.g., Anders (1962) and Voshage (1968).

Sims (1959) discussed the sulfide inclusions and concluded from experiments with ingot-solidification that Grant, or rather its parent body, had had a freezing time of about 30 days, but the extrapolation appears hazardous. Maringer & Manning (1960) treated the reentry problem mathematically with the help of hardness determinations of the heat-affected zone, and concluded that the ablation loss was of the order of 1-2 mm/sec. They gave a photograph of the heat-affected α_2 zone overlain by terrestrial oxides. A thorough discussion of the observations was published in April 1959 as Technical Report 59-164 of the Wright Air Development Center. Maringer & Manning (1962) discussed the hatched or "matte" kamacite matrix and suggested that

it was due to heavy shock. This has been confirmed by later experimental work. Another photomicrograph, of the taenite, shows closely spaced planes arranged parallel to the gross Widmanstätten pattern. These lines apparently represent slip planes faintly decorated by a precipitate, as is also reported in this work under, e.g., Anoka, Veliko-Nikolaevskij Priisk and Tamentit.

Maringer et al. (1959) were among the very first to use the electronprobe microanalyzer on meteorites. Their data from a line scan across a plessite field in Grant already clearly showed the typical M-profile. Feller-Kniepmeier & Uhlig (1961) presented two photomicrographs and examined the nickel variation with the microprobe. Further probe results, with refined resolution, and with some photomicrographs, were presented by Agrell et al. (1963), Wood (1964), Massalski & Park (1962; 1964) and Massalski et al. (1966). Goldstein & Ogilvie (1963) studied the phosphides, and Goldstein (1967) showed that the germanium was covariant with nickel, reaching a maximum of

about 100 ppm in the taenite phase, and a minimum of < 20 ppm in the kamacite, a result which was found to be generally valid for all iron meteorite types. McCall et al. (1967) reported extensive experimental work on Grant specimens annealed between 300° C and 700° C for periods up to 4,100 hours. Measurable reduction in the microhardness of ϵ occurred at temperatures as low as 300° C, and complete recrystallization of the ϵ -structure was observed at 500° C.

COLLECTIONS

Washington (main mass, about 450 kg), Chicago (2,990 g), Mainz (210 g), Berne (150 g), Los Angeles (118 g), Tempe (104 g), Ann Arbor (43 g), London (32 g). Also in several university research laboratories, now partly used up in the experiments quoted above.

DESCRIPTION

The well-preserved mass, which in numerous places displays fusion crusts, is an eminent, somewhat flattened

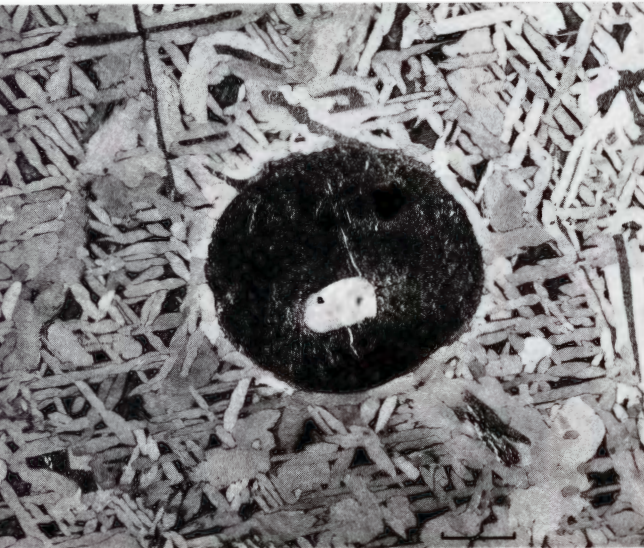


Figure 813. Grant (U.S.N.M. no. 836). Medium octahedrite with Brezina lamellae and troilite. A metallic bleb and a phosphate particle (glossy black) are seen in the troilite. The swathing kamacite is composed of many independently nucleated kamacite units. Deep-etched. Scale bar 5 mm. S.I. neg. M-128.

cone. From the apex to the opposite flat base it measured 55 cm. The base measured 57 x 73 cm in two perpendicular directions. Grant's general shape of a flattened cone is similar to what is observed in Morito and Willamette, where all dimensions are, however, magnified. Apparently this shape develops as a very important and stable ablation form under certain conditions of atmospheric entry.

Since the large meteorite which presently is exhibited in the Smithsonian Institution could not be turned over for examination, it was only possible to inspect the conical sides in more detail. Circular cavities, 0.5-3 cm in diameter and 0.5-3 cm deep are common here; 13 clearly defined cavities roughly cylindrical in shape, with steep sides and with a flat bottom, were counted. Remnants of sulfur-enriched fusion crusts were visible in many holes. The cavities clearly represent the loci of troilite nodules which wholly or partly burned out in the atmosphere. Even on the flat rear side there are several of these cavities. Corrosion has only altered the shape of the holes insignificantly.

In addition to the circular cavities there are numerous straight grooves, resembling chisel scars. They are typically 30 mm long, 1 mm wide and 1 mm deep. They indicate the

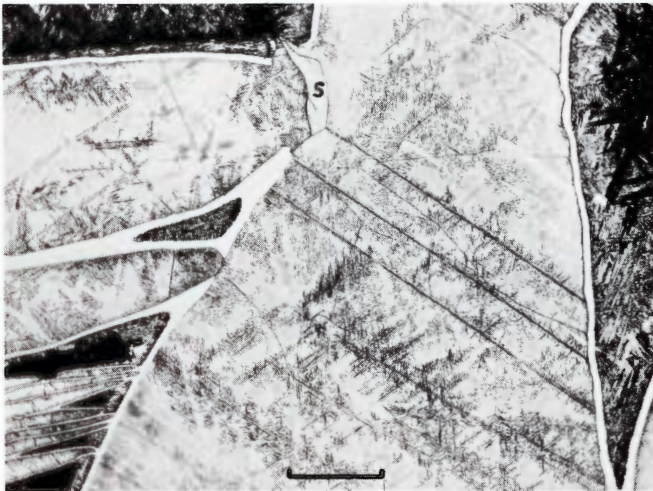


Figure 814. Grant (U.S.N.M. no. 836). Shock-hatched kamacite lamellae and characteristic martensitic and duplex plesite fields with yellow and cloudy taenite rims. Etched. Scale bar 400 μ .

GRANT – SELECTED CHEMICAL ANALYSES

References	percentage			C	S	Cr	Cu	ppm				Ir	Pt
	Ni	Co	P					Zn	Ga	Ge			
Henderson 1934			1.15	20	200								G
Henderson 1941c	9.35	0.63	0.57										G
Henderson & Perry 1958	9.17	0.64	0.57										B
Smales et al. 1967						7.5	115	1.7	19.7	33			B
Lewis & Moore 1971	9.44	0.52	0.61	100									B
Crocket 1972												0.10	B
Scott et al. 1973	9.24								19.8	37.0	0.040		G
Scott et al. 1973	9.48								19.7	37.9	0.044		B

In the last column a G indicates that authentic Grant material was analyzed, while B indicates material from the Breece meteorite, which is here identified as a fragment of Grant.

locations of Brezina lamellae, i.e., large schreibersite plates that were wholly or partly lost by atmospheric ablation. Similar scars are also conspicuous on Chupaderos and Hammond.

Regmaglypts are not very well developed, but may be observed in various places as shallow circular depressions 3 to 6 cm across. Locally they form subparallel flutings radiating from the apex. Where the lower part of the cone, the skirt, meets the base, fluted regmaglypts prevail and resemble what is present on, e.g., many Henbury samples. Warty and striated fusion crusts, one millimeter thick, are preserved over many square centimeters. Ochre colored limonite and caliche from terrestrial sources cover some parts of the surface.

While the surface in general is smoothly rounded and sculptured as described above, the removal of 2 or 3 specimens by chiseling has left scars. It was one such specimen that the Smithsonian received from Darton as early as 1918.

A still larger scar is present where the skirt meets the base. Here a hackly, nearly straight, fracture face measuring 43 x 13 cm runs almost perpendicular on both cone and base and which, by extrapolation, must have detached a specimen 10-15 cm wide. The surface appears reasonably fresh and is only little rusted. No fusion crusts are present on the surface, and the jagged protuberances are only slightly, if at all, softened by atmospheric flight. The break must, therefore, have occurred in the very last part of the trajectory or perhaps not until the meteorite hit the ground.

The finders and original owners of the Grant meteorite have not reported other fragments which could fit into the large and fresh fracture. However, there does exist, in the Field Museum of Natural History, a meteorite which in structure and chemical composition is the exact duplicate of Grant. This sample, labeled Breece, was discovered in 1921 and was described by Beck et al. (1951). It was said to come from a part of the Zuni Mountains in New Mexico, west of Grants, but little is known of the exact locality. I

have measured and photographed the sample (now of 40 kg) comparing its jagged fracture surface with that of the Grant meteorite, and must conclude that the Breece meteorite fits exactly in place, on the skirt of Grant, when allowance is made for samples removed from Breece after it was discovered.

Thus Breece is a minor fragment of Grant. Whether the two fragments were found as individuals as far apart as claimed by the finders, or whether they, in fact, came from a narrower region, will probably never be disclosed. The fresh, unablated character of the fracture faces suggests that the two fragments could not have had long individual flights, and thus should not have become widely separated.

Sections perpendicular to the surface reveal a 0.01-1 mm thick weathered fusion crust and a 1.5-2.5 mm wide α_2 zone. The exterior part of the fusion crust consists of a thin (10-100 μ) layer of fused oxides. A sequence of metallic melts then follows, each layer generally 50 μ thick. These layers consist of metallic dendrites with 2-5 μ

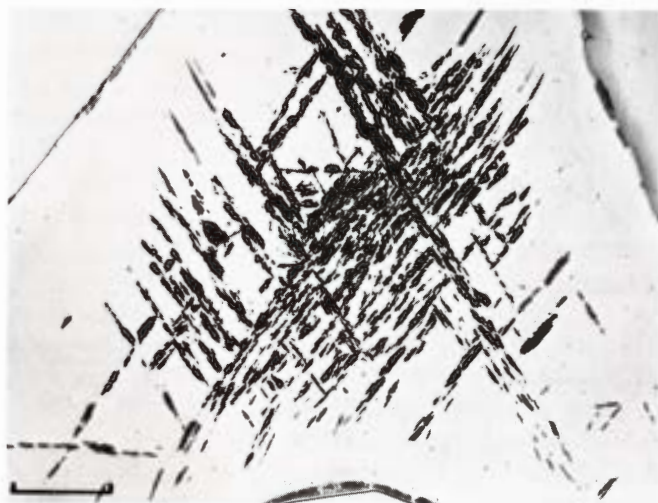


Figure 816. Grant (U.S.N.M. no. 836). Martensitic platelets developed parallel to the bulk Widmanstätten structure in a plessite field with 18-20% Ni. Lightly etched. Scale bar 100 μ .

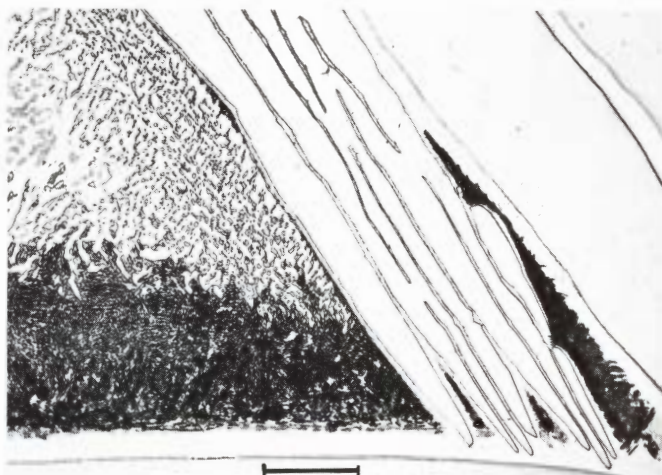


Figure 815. Grant (U.S.N.M. no. 836). Comb plessite and plessite with dark transition zone of tempered martensite. Lightly etched. Scale bar 100 μ .



Figure 817. Grant (U.S.N.M. no. 836). Shock-hatched kamacite. Slightly different development in two adjacent kamacite lamellae because they are oriented differently. Etched. Scale bar 50 μ .

armspacing, intercalated by phosphorus-enriched eutectic melts. The later layers often show columnar growth perpendicular to the previous layers. The metal has, upon rapid cooling in the atmosphere, transformed to fine-grained α_2 with a hardness of 300 ± 20 . Lower values are also found but are probably due to porosities and gasholes below the plane of section. Tiny, 1-100 μ , oxide globules are common in the metallic fusion crust, often as hollow spherules. The oxides contain both fine dendritic oxides of a different composition and 1-5 μ metallic and phosphide-rich spherules. These globules, trapped in the metallic fusion crust, are closely related to the globules which may be collected from the soil of recent meteorite falls; e.g., Sikhote-Alin.

Below the fusion crusts, which locally attain complicated whirlpool textures, a typical heat-affected α_2 zone is found. The zone is normally 2.0 mm thick, and micro-melted phosphides are present to half the depth of the α_2 zone. In several places the Brezina lamellae are partly removed. A 0.3 mm wide lamellae was thus ablation-melted and swept away, whereupon its groove refilled to a depth of 1.5 mm with a mixture of oxidic and metallic fusion crusts carried in from adjacent parts of the surface. The α_2 crystallites are small, 10-25 μ across, as usual when formed from the shock-hardened ϵ -structure. A hardness track perpendicular to the surface showed values of 215 ± 15 in the α_2 zone; the hardness increased rapidly inside the α_2/ϵ transition zone and reached, at a depth of 6-8 mm, typical interior values of 310 ± 15 (hardness curve type I).

Etched sections display a medium Widmanstätten structure of straight, but irregular, ($L/W \sim 15$) kamacite lamellae with an average width of 0.80 ± 0.10 mm. The kamacite is rich in subboundaries decorated by 0.5-1 μ precipitates, mainly of phosphides. The kamacite is shock-hardened to a microhardness of 310 ± 15 and displays the matte, hatched ϵ -structure suggestive of shock intensities above 130 k bar. There are no indications of annealing.



Figure 818. Grant (U.S.N.M. no. 836). A Brezina lamella of schreibersite. Most of the schreibersite lamellae are similarly cracked, probably a result of the same shock event that hardened the kamacite and taenite. Polished. Scale bar 50 μ .

Taenite and plessite cover about 25% by area, mainly as dense fields with bainitic-martensitic interiors and as net plessite. Comb plessite is uncommon. A typical fully developed field will exhibit a tarnished taenite rim (HV 415 ± 25) followed by a light etching martensitic transition zone (HV 470 ± 20). Then follows brown contrast-rich martensite developed parallel to the bulk Widmanstätten pattern (HV 380 ± 40) and finally duplex unresolvable $\alpha + \gamma$ mixtures, the so-called black taenite (HV 315 ± 15). All structural elements are significantly hardened by the same shock event that hardened the kamacite. In fact, the taenite displays numerous slipplanes developed parallel to $\{111\}$; they become visible by etching due to extremely small amounts of submicroscopic precipitates.

Schreibersite is very common as straight plates, the so-called Brezina lamellae, precipitated in the dodecahedral

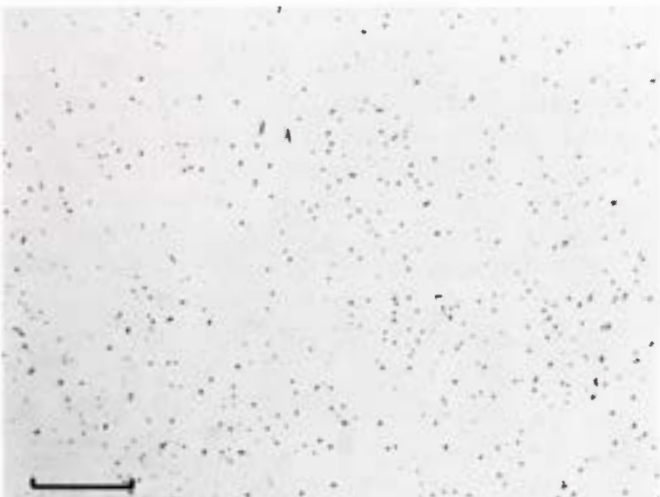


Figure 819. Grant (U.S.N.M. no. 836). There are numerous fine phosphide precipitates in the kamacite. They are, however, easily overlooked when the sample is etched, because the shock-hatched kamacite entirely swamps them. Very lightly etched. Oil immersion. Scale bar 20 μ .

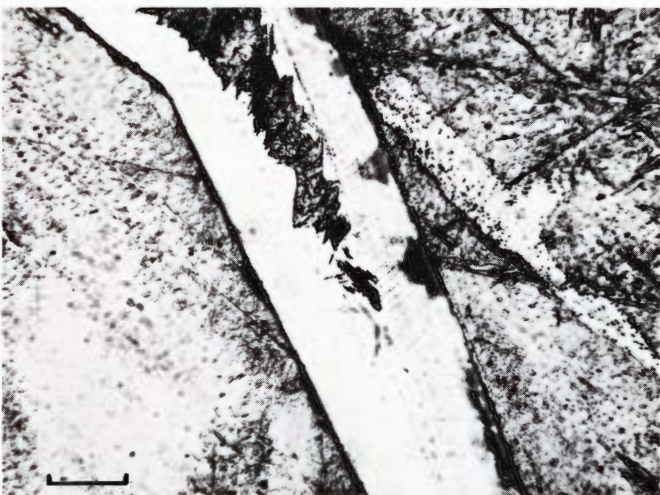


Figure 820. Grant (U.S.N.M. no. 836). A taenite lamella between shock-hatched kamacite lamellae. In the taenite center tempered high-nickel martensite. In the taenite rim a deformation grid parallel to $(111)_\gamma$. Etched. Scale bar 20 μ .

planes of the parent taenite. Some plates are highly irregular in outline; either they are provided with branches, or they form hieroglyphic skeleton crystals. The Brezina lamellae are typically 50 x 30 x 0.5 mm in size, but locally reach larger dimensions, particularly in length, at a rather constant thickness. The schreibersite is enveloped in very wide, irregular rims of swathing kamacite. Widths of 1.5 mm are common, and coherent kamacite regions 3-4 mm across are found without difficulty in most large sections. The swathing kamacite along a Brezina lamellae consists of a number of kamacite grains, individually nucleated and oriented; they have grown and coalesced to form the envelope.

Schreibersite is also common as 20-60 μ wide grain boundary veinlets and as minor particles inside the net plessite. Rhabdites are practically absent, or locally present as < 1 μ particles. Around the troilite nodules schreibersite forms irregular, discontinuous rims, on the average 0.5 mm thick. From these rims, protuberances radiate as Brezina lamellae several millimeters into the metallic matrix. Point counting of the schreibersite yielded an average of 0.7% P bound in the Brezina lamellae; to this may be added about 0.15% present in solid solution and as microscopic precipitates. The bulk phosphorus value of Grant is thus estimated to be about 0.85%, i.e., somewhat above the average of the reported wet chemical analyses. The schreibersite is monocrystalline, but normally severely brecciated.

Troilite occurs as well rounded nodules 5-32 mm in diameter. They are apparently spherical, not elongated or sausage-shaped as in Cape York. On a total of 3,100 cm² sections, 33 different nodules were counted in the size range noted above. Their total area was 8,060 mm², corresponding to an average content of 2.6 volume percent or 0.58 weight percent sulfur. The troilite is enveloped in 1 mm wide rims of swathing kamacite which are subdivided in a number of differently oriented grains.

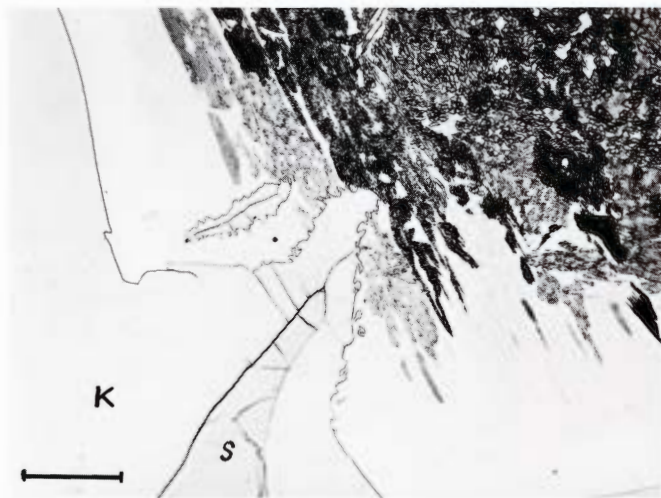


Figure 821. Grant (U.S.N.M. no. 836). Plessite, kamacite (K) and schreibersite (S). A rim of clear taenite is followed by indistinct martensite, tempered martensite and duplex, unresolvable mixtures of $\alpha + \gamma$. Electron microprobe profiles indicate that nickel correspondingly varies from 35 to 15% over the shown distance. Etched. Oil immersion. Scale bar 20 μ .

Globules of metal, 2-7 mm in diameter, are common inside the troilite nodules, either intergrown with the metallic wall or completely embedded as islands in the troilite. The larger, attached nodules are decomposed in a Widmanstätten pattern, which is a continuation of the bulk pattern. Similar textures are present in, e.g., Cape York and Chupaderos. Their interpretation is uncertain.

The troilite is monocrystalline, but due to plastic-deformation multiple twinning occurs abundantly. Some nodules are severely sheared; in such cases passive 0.2-1 mm blocks have become separated by 5-25 μ wide brecciation zones. Quite locally, along phase boundaries, it appears that incipient shock-melting has occurred and given rise to fine-grained aggregates which easily corroded.

Phosphates are quite common in the troilite as gray subangular inclusions which become pitted and channeled upon etching with Nital and display internal reflections due to some brecciation. The size range is 0.2-4 mm inside the troilite, but smaller particles occur in the kamacite and have, here, frequently nucleated schreibersite rims. No identification of the phosphates was attempted, but they are probably identical to the sarcopside and graftonite, $(\text{Fe,Mn})_3(\text{PO}_4)_2$, identified by Edward Olsen (personal communication).

Daubreelite was not detected, but chromite occurs as 30-100 μ angular crystals, both in troilite and kamacite. Graphite and carbides were not detected either, but tridymite (?), glass (?) or silicates (?) appear to be present as very minor accessories in the troilite nodules.

As noted above, the overall state of preservation of Grant is so good that even coherent fusion crusts on several square centimeters are extant. Corrosion is, however, present to some depth, following grain boundaries and, in particular, the brecciated schreibersite and troilite aggregates. Pentlandite occurs as thin veinlets in near-surface troilite, and limonitic corrosion products have recemented the cosmically brecciated minerals in the fissures.

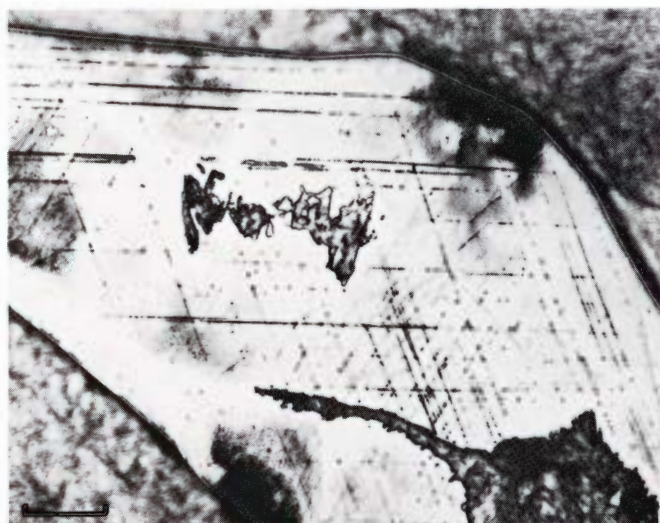


Figure 822. Grant (U.S.N.M. no. 836). Detail of a taenite lamella with deformation grid parallel to $(111)_\gamma$. Etched. Oil immersion. Scale bar 10 μ .

Grant is a shock-hardened medium octahedrite which displays no cosmic annealing. It penetrated the atmosphere in an oriented stabilized flight whereby the eminent cone shape developed. Late in the flight, or upon hitting the ground, a 50 kg fragment broke free; this fragment has misleadingly been labeled Breece and, as such, has been the subject of several independent studies. Grant is a normal member of the resolved chemical group IIIB, closely related to Wolf Creek, Knowles, Chupaderos and View Hill, to name a few.

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

- 113 g chiseled fragment (no. 587, 5 x 4 x 1.5 cm). Gift from N.H. Darton, 1918; Accession Number 62880.
- About 200 kg half mass, one surface polished and etched (no. 836, 50 x 45 x 22 cm)
- About 150 kg half mass, one surface polished and etched (no. 836, 50 x 30 x 25 cm)
- About 9 kg full slice, polished and etched (no. 836, 37 x 30 x 1.3 cm)
- About 40 kg several part slices, bars and irregular sections.
- About 10 kg full slice, on permanent loan to the Do All Company (no. 836)

Grant (Breece), New Mexico, U.S.A.

Medium octahedrite, Om. Bandwidth 0.80±0.10 mm. ϵ -structure. HV 310±15.

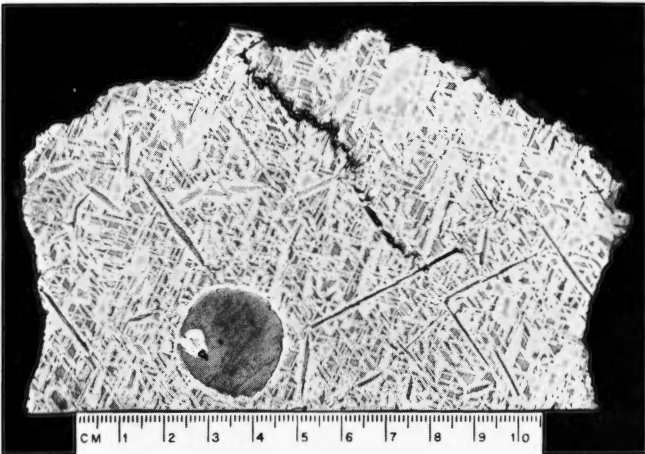


Figure 823. Grant. Section through the Breece fragment (Tempe no. 18 bx). Troilite with metal globule and phosphates (black). Numerous Brezina lamellae of schreibersite. A deep crack with terrestrial limonite. Deep-etched. Scale in cm. (Courtesy C.B. Moore.)

Group IIIB. 9.36% Ni, 0.58% Co, about 0.8% P, 19.7 ppm Ga, 37.9 ppm Ge, 0.04 ppm Ir.
Breece is a fragment of Grant.

HISTORY

A mass of approximately 50 kg was found about 1921 in the Zuni Mountains 50 km west-northwest of Grants. The meteorite was acquired and listed under the name of Breece by the Field Museum in Chicago, but was first described by Beck et al. (1951b), who identified the locality Breece and gave the coordinates 35°18'N, 108°18'W. Surprisingly, Beck et al. failed to find phosphorus in their chemical analysis and concluded that the characteristic Brezina lamellae were composed of cohenite. In this they were substantiated by Spencer (1951) who gave a photomicrograph. The Brezina lamellae in Breece had previously been erroneously called Reichenbach lamellae (i.e., mainly troilite) by Perry (1944: plate 47).

Henderson & Perry (1958) reexamined the iron and correctly concluded that the lamellae consisted of schreibersite. Goldstein & Ogilvie (1963) examined the phosphides of Breece and Grant with the microprobe and showed a 20-30 μ wide, adjacent kamacite strip to be depleted in nickel, from about 7 to 6% Ni. They did not comment upon the close correspondence of the measurements in the two irons. Goldstein (1965) included Breece in his discussion of the kamacite formation and composition. E. Olsen (1970: personal communication) identified the

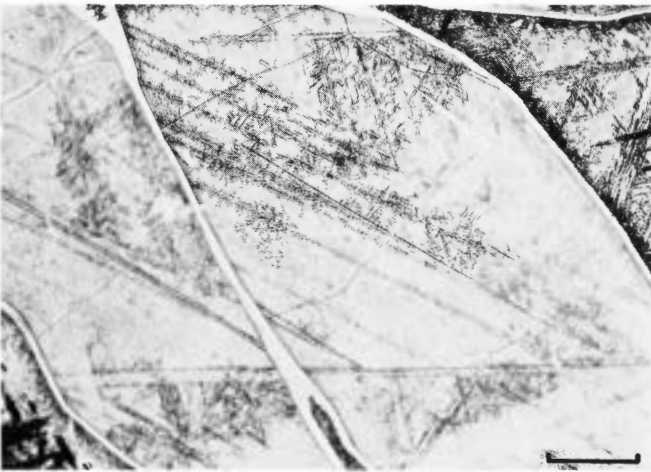


Figure 824. Grant. Detail of Figure 823. Shock-hatched kamacite and various types of taenite and plessite. Etched. Scale bar 400 μ .

GRANT (BREECE) – SELECTED CHEMICAL ANALYSES												
References	percentage			C	S	Cr	Cu	ppm Zn	Ga	Ge	Ir	Pt
	Ni	Co	P									
Henderson & Perry 1958	9.17	0.64	0.57	100		7.5	115	1.7	19.7	33		
Smales et al. 1967												
Lewis & Moore 1971	9.44	0.52	0.61									
Crocket 1972												
Scott et al. 1973	9.48											
											0.10	
									19.7	37.9	0.044	

iron-manganese phosphates, sarcopside and graffonite, in the troilite nodules.

COLLECTIONS

Chicago (40.4 kg), Ann Arbor (1,487 g), Washington (541 g), Tempe (400 g), London (360 g), Albuquerque (160 g).

DESCRIPTION

The exterior is only slightly corroded. Regmaglypts 3-5 cm across, and chisel-like impressions may be seen in many locations, the last mentioned indicating where 0.5-1 mm wide schreibersite lamellae partially burned out during penetration of the atmosphere. The end specimen in New Mexico was found by Beck et al. (1951b) to possess a hackly, fractured surface, but their enquiries in the general area of find failed to bring more meteoritic material to light.

Etched sections display a medium Widmanstätten structure with 0.80 mm wide α -lamellae and a length-width ratio of 15. The ferritic phase possesses the finely hatched ϵ -structure due to shock above 130 k bar. The hardness is 310 ± 15 , indicating severe shock hardening. The previously existing subboundaries of α , decorated with $< 1 \mu$ phosphides may still be seen "through" the ϵ -structure. Plessite covers about 30% of the sections and is mainly developed as martensite with directions parallel to the bulk Widmanstätten structure or as poorly resolvable $\alpha + \gamma$ structures (black taenite) with hardnesses similar to that of the adjacent kamacite lamellae.

The ubiquitous Brezina lamellae are schreibersite plates oriented parallel to $\{110\}$ of the austenite phase and typically $25 \times 15 \times 0.8$ mm in size. Point counting of the phosphides leads to an estimate of 0.8% P, i.e., somewhat higher than the analytical values. This remarkable content indicates that the lamellae precipitated directly from the

austenite phase. A polycrystalline rim of ferrite 1-1.5 mm wide, nucleated and grew around the lamellae before the homogeneous formation of Widmanstätten lamellae took place. Schreibersite is also present as 25-50 μ wide grain boundary precipitates. In several taenite rims small phosphide-rich areas, $15 \times 5 \mu$, are visible; presumably these are schreibersite crystals "in statu nascendi." Rhabdites are not present, or if so, only as scattered particles less than 1 μ thick.

Troilite occurs as 5-28 mm well rounded nodules with inclusions of sarcopside and graffonite (E. Olsen, personal communication). The troilite is monocrystalline but shows multiple twinning. Smaller troilite bodies, 50-100 μ across, occur closely associated with some Brezina lamellae. Such troilite is often brecciated or polycrystalline.

Cohenite is not present, and only weak carbon indications were observed. The results of Beck et al. (1951) probably are due to some misinterpretation. Their Figure 2 certainly shows a schreibersite crystal and not a cohenite grain as stated.

The heated α_2 zone is well-preserved as a 1.5-2.5 mm wide rim with many melted phosphide inclusions in the outer 40%. The fusion crust is preserved locally in protected areas. It is 0.5-1 mm thick and composed of 6-8 metallic, dendritic layers which are now somewhat corroded. The α_2 zone has a hardness of 215 ± 15 (hardness curve type I).

Breece is a shock-hardened medium octahedrite closely related to Grant. It is, in fact, impossible to tell the difference between Breece and Grant specimens. Macro- and microstructure, main and trace element chemistry, fusion crust and α_2 zone are all identical within analytical error. Both irons were found in the Zuni Mountains, west or southwest of Grants, but the exact localities may never be disclosed.

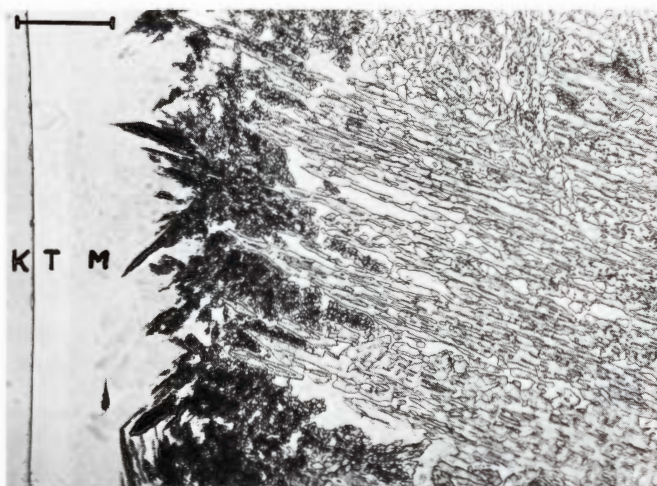


Figure 825. Grant. Detail of Figure 823. Kamacite (K, $\sim 7\%$ Ni), clear taenite (T, $\sim 35\%$ Ni) light-etching martensite (M, $\sim 28\%$ Ni), tempered martensite (black, $\sim 20\%$ Ni) and resolvable duplex interior of α ($\sim 7\%$ Ni) and γ ($\sim 30\%$ Ni). Due to the very steep Ni-gradients the figures are very approximate. Etched. Oil immersion. Scale bar 20 μ .

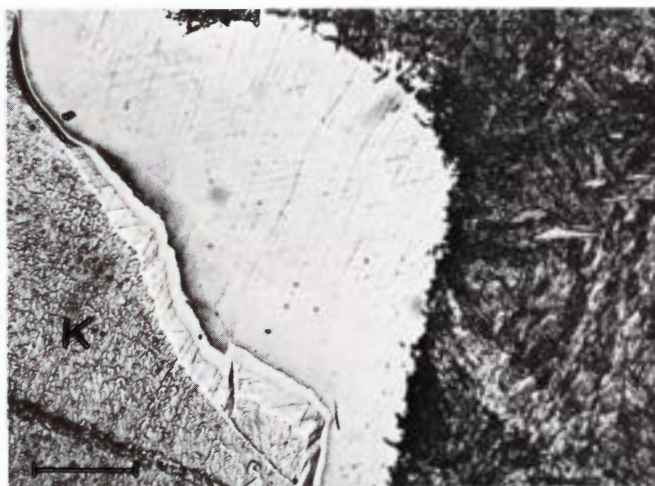


Figure 826. Grant. Detail of Figure 823. The edge of a plessite field, the interior of which shows tempered martensite. The clear rim of high-nickel taenite shows a deformation grid parallel to $(111)\gamma$. On the tapering interface with kamacite (K, etched to a lower level) the surface appears roughened due to the cosmic deformation. Etched. Oil immersion. Scale bar 20 μ .

Both Breece and Grant show external, hackly fracture zones which fit together and indicate where the masses separated late in flight or upon hitting the ground. If we accept the reported localities, the distance between the falls appears to have been about 50 km; however, the circumstances of discovery are uncertain and will probably continue to remain so.

The present author must conclude that Breece is a large fragment of Grant and should not, in future work, be regarded as an independent fall.

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

541 g part slice (no. 1482, 8 x 7 x 1.2 cm)

Greenbrier County, West Virginia, U.S.A.

Approximately 37° 50'N, 80° 18'W; 700 m

Medium octahedrite, Om. Bandwidth 1.00±0.15 mm. α_2 matrix. HV 173±7.

Group IIIA. 7.38% Ni, 0.08% P, 18.1 ppm Ga, 33.3 ppm Ge, 10 ppm Ir.

The whole mass was heated to about 900° C by a blacksmith.

HISTORY

A mass of 5 kg was found about 1880 in the Allegheny Mountains, 5 km north of White Sulphur Springs, in Greenbrier County. The meteorite was taken to a country smith's shop, heated and cut with a cold chisel. The pieces were distributed as specimens of iron ore, but when two of them were seen by M.A. Miller, a civil engineer of Richmond, he recognized them as being of meteoritic origin. It was, however, too late to recover more material. The two fragments, of 1,780 g and 880 g, respectively, were acquired by the British Museum, where they were examined by Fletcher (1887b). He reported a bandwidth of 0.8-1.2 mm, but Brezina's erroneous statement (1895) upon much less material carried evidently more weight, since the meteorite in all later catalogs is listed as a coarse octahedrite. Fletcher observed a tiny chromite crystal, one of the early well-founded reports of chromite in meteoritic irons. Berwerth (1905; 1914) included Greenbrier County in his metabolitic group of artificially reheated irons, and I came to the same conclusion (Hey 1966: 183), as will be discussed below.

COLLECTIONS

London (1,810 g), Washington (473 g), Harvard (64 g), Calcutta (33 g), Chicago (21 g), Vienna (3 g).

DESCRIPTION

Two specimens of Fletcher's original material are in the U.S. National Museum. The larger shows how the blacksmith has hammered and chiseled the iron in order to split it. The exterior surface shows fragmentation along octahedral planes, and the interior shows fissures and cracks along similar planes. Small troilite inclusions (1-2 mm in diameter) have reacted with oxygen and melted. Where near the surface, they have been able to seep out, leaving empty cavities. The cavities, reported by Fletcher as something unusual for the meteoritic irons, are thus artificial, partly from violent opening along {111} planes, partly from the emptying of mineral-filled spaces.

Etched sections display a medium Widmanstätten structure with no oriented sheen. The kamacite lamellae are long ($\frac{L}{W} \sim 20$) and straight, except where distorted by the blacksmith. The average bandwidth is 1.00±0.15 mm. The matrix is a 10-30 μ granulated α_2 structure, indicating heating into the austenite region. The original matrix was probably a hatched ϵ -structure from a cosmic shock wave. Its present hardness is 173±7.

The plessite fields occupy about 30% by area, mostly in the form of extremely open-meshed comb and net plessite. Due to the reheating, the interior of the taenite is blurred, and the rims are ragged with thorny spikes protruding into the surrounding α_2 phase.

Schreibersite is not present as large crystals but does occur as scattered 10-25 μ grain boundary precipitates. Rhabdites occur as 1-3 μ prisms in some grains, but both schreibersite and rhabdite are partly resorbed by the reheating, although not melted. The reheating temperature probably was 850°-900° C. Locally a few 50-100 μ daubreelite bodies may be seen in the metallic matrix.

In the matrix are numerous oriented, hard plates, typically 15 x 2 x 0.2 μ , and often slightly distorted. They are, no doubt, the carlsbergite as reported from Costilla Peak, Schwetz and other irons.

The reheating has given rise to high temperature intergranular oxidation along the surface and along fissures. Also, various reaction products between previously existing limonite (in cracks and around schreibersite and troilite) and the meteoritic material may be observed, often in forms of delicate oxidic laceworks with scattered 0.5 μ metal grains.

Greenbrier County is a medium octahedrite related to Costilla Peak and Henbury. It was already somewhat corroded when the country smith reheated it and thoroughly altered its microstructure. It is a normal member of the phosphorus-poor end of group IIIA.

GREENBRIER COUNTY – SELECTED CHEMICAL ANALYSES

Reference	percentage			ppm								
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Scott et al. 1973	7.38								18.1	33.3	10	

Fletcher (1887b) reported 0.08% P, which is in harmony with my structural observations.