Taenite and plessite cover about 40% by area, both as comb and net plessite, and as acicular and dark-etching optically unresolvable fields. It is noteworthy that the fields almost lack the normal heterogenous frame of taenite with transitional structures.

Schreibersite is common as elongated or slightly branching crystals, usually 2 x 0.5 or 1 x 0.3 mm in size and located centrally in the kamacite lamellae. It also occurs as 10-40 μ wide grain boundary precipitates and as 2-25 μ irregular blebs inside the plessite fields substituting for taenite of similar sizes. Rhabdites occur locally as 5-10 μ angular tetrahedral prisms.

Troilite was not present in the section, but was reported by Vogel. He observed two hemispherical cavities, 8 and 6 mm in diameter, in the surface and proved that they were the seat of troilite nodules that burned out in the atmosphere.

In places the meteorite has preserved a fusion crust, composed of exterior oxidic layers (50 μ thick) and interior laminated dendritic metal (up to 100 μ thick). Under the fusion crusts, a 1.5-2.5 mm wide heat-affected α_2 zone is well-preserved. Micromelted phosphides are present in the exterior half of this zone. The α_2 zone has a hardness of 210±10, and the recovered transition zone a hardness of 170±5 (hardness curve type II).
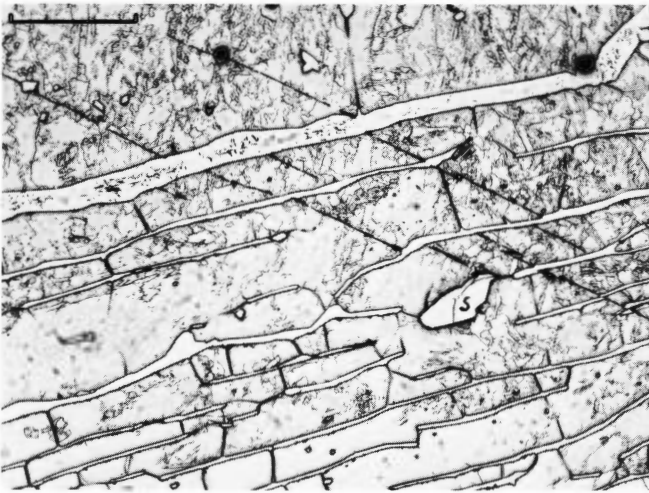

Figure 760. Emsland (Copenhagen no. 1973, 2081). Heat-affected zone above. In the exterior part the phosphides have been melted; they solidified rapidly, with gas holes (black). In the interior part the phosphides (S) are unaffected. Etched. Scale bar 200 μ.

Emsland is a medium octahedrite which would be difficult to tell apart from medium octahedrites of group IIIA and B, if it were not for the anomalous concentration of trace elements. Emsland is, thus, more related to Mbosi, than to, e.g., Treysa, Grant and Joe Wright Mountain with the same approximate nickel contents. The phosphorus content of Emsland is, however, definitely lower and causes less schreibersite to be present than in Treysa, etc.

Espiritu Santo. See Chupaderos, (Espiritu Santu)

Etosha. See the Supplement.

Fair Oaks. See Canyon Diablo (Fair Oaks)

Filomena. See North Chile

Floydada, Texas, U.S.A.
33°59′N, 101°17′W

A mass of 12.5 kg was found before 1912 in Floyd County but was first recognized as a meteorite by the Nininger (A.D. Nininger 1939: 212; Nininger & Nininger 1950: 52). It appears to be a medium octahedrite; but since no material was available for examination, I can add no comments. The Texas Observers Collection, Fort Worth has 12.5 kg (Barnes 1939a: 594), and 21 g is in Tempe.

Föllinge, Jämtland, Sweden
63°44′N, 14°51′E

Finest octahedrite, Off. Bandwidth 40±10 μ. α_2 matrix. HV 165±10.

Group IIID. 18.1% Ni, 0.64% Co, 0.2% P, 4.0 ppm Ga, 3.2 ppm Ge 0.072 ppm Ir.

HISTORY

A small, almost complete individual of 400 g was found during plowing in 1932 at Föllinge, near Ottsjön, about 60 km north of Östersund. It was acquired by the Riksmuseum in Stockholm, where it was cut and analyzed

FÖLLINGE – SELECTED CHEMICAL ANALYSES

References	percentage			C	S	Cr	Cu	ppm Zn	Ga	Ge	Ir	Pt
	Ni	Co	P									
Blix in Buchwald 1967a,b	18.05	1.1	0.13		800	500	500					
Buchwald 1967a,b	18.16	0.64	0.18		<60		430		2	1		
Wasson & Schaudy 1971	18.13								4.0	3.15	0.072	

The chromium value appears erroneously high.

by Blix. It was briefly mentioned by Wickman (1951) who reviewed the meteorites found on Swedish territory. Buchwald (1967a, b) examined the structure and the exterior shape and presented numerous photomacrographs and -micrographs.

COLLECTIONS

Stockholm (about 350 g), Chicago (18 g), Washington (14 g).

DESCRIPTION

The overall dimensions are 74 x 45 x 30 mm, so the mass is one of the smallest individuals ever found; see Table 21 (Volume 1 of this handbook). It is of a smoothly rounded, drop-like shape and is still partly covered with a 0.1-2 mm thick, metallic ablation crust. Corrosion has, however, attacked the mass somewhat and caused the crust to spall off in many places. A selective transformation of the nickel-poor kamacite lamellae and of part of the dendritic crust has taken place in the immediate surface and locally in semicircular, concentric waves to a depth of about 5 mm. The terrestrial age is probably low, that is below 1,000 years.

Etched sections display a beautiful Widmanstätten pattern of straight, long ($\frac{L}{W} \sim 50$) kamacite lamellae with a width of 40±10 μ. While the kamacite lamellae originally, no doubt, had Neumann bands and subgrain boundaries and constituted well defined crystallographic units, they now display an irregular aggregate of ragged α_2 grains of numerous orientations. This is because the whole mass, when passing through the atmosphere, was heated above 750° C for a short time, thereby transforming the alpha phase to gamma and rapidly back to α_2 (see, e.g., Buchwald 1966: 13). The hardness is 165±10, which is unexpectedly low, but the reason is probably the same as in Tazewell: that the kamacite lamellae only contain about 6% Ni, which is significantly less than in medium octahedrites.

Plessite occupies about 85% by area, almost everywhere in the form of a poorly resolvable, martensitic matrix. Since the whole mass was reheated above 750° C,

the plessite fields, high in nickel, were also altered and have transformed into a multitude of individual martensitic packets of varying orientations. It is important to note that the original, monocrystalline plessite units, with martensitic plates developed parallel to the bulk Widmanstätten pattern have been transformed, upon reheating, to a multitude of 25-50 μ austenite units, which then, upon cooling, generated a random arrangement of martensitic packets; the hardness of the martensite is 365±20.

Schreibersite is very common but only as tiny, irregular, monocrystalline bodies, 10-500 μ across. The phosphides are evenly distributed with 1-2 nodules per mm^2,
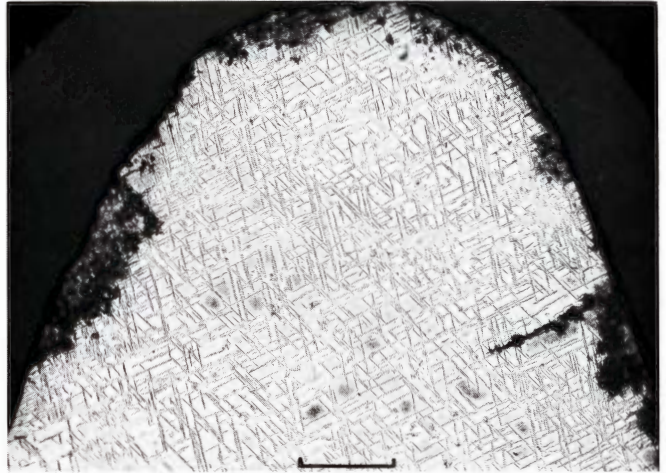

Figure 762. Föllinge (Stockholm no. 335,317b). The smoothly rounded end is solely due to atmospheric ablation. The black edging illustrates the process of terrestrial corrosion. Much of the fusion crust still survives. Compare Figure 71. Etched. Scale bar 3 mm.
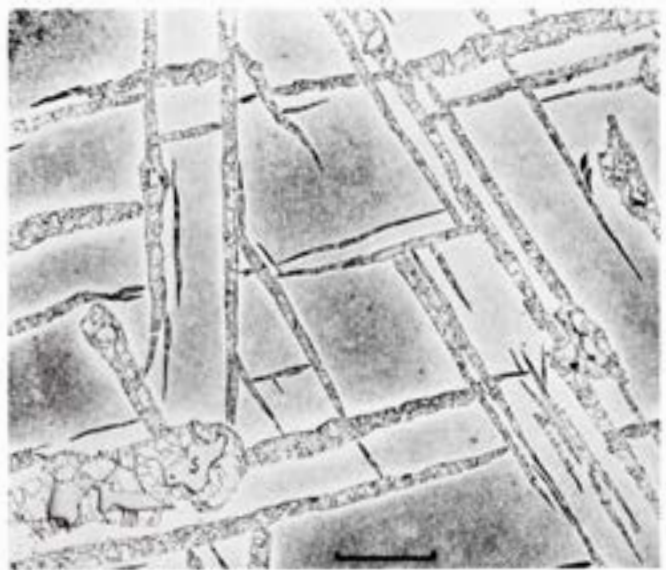

Figure 761. Föllinge (Stockholm no. 335,317b). The pear-shaped main mass measured only 74 x 45 x 30 mm and weighed 400 g. Fusion crust is preserved in many places. Scale bar 10 mm. (Photo by A. Karlsson 1932.)

Figure 763. Föllinge (Stockholm no. 335,317b). Even the interior of this small iron meteorite is affected by the atmospheric flight. Since all kamacite lamellae are now transformed to α_2 the temperature in the center briefly exceeded 750° C; the schreibersite crystals (S) are, however, unmelted so the temperature did not exceed 1000° C. Etched. Scale bar 300 μ.

Figure 764. Föllinge (Stockholm no. 335,317b). To the left a layered fusion crust. To the right the heat-affected α_2 zone (A) with a fused schreibersite crystal. Terrestrial corrosion has selectively converted some kamacite lamellae to limonite (black). Etched. Scale bar 300 μ.
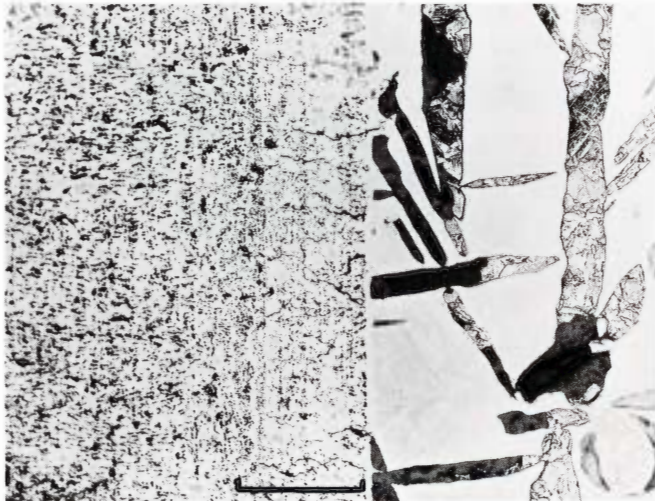

Figure 766. Föllinge (Stockholm no. 335,317b). The plessitic fields of Figure 763 reveal, upon heaving etching, martensitic structures. The orientation is random, in sharp contrast to the $(111)_\gamma$ martensite platelets of unreheated meteorites. See, e.g., Figures 690 and 816. Scale bar 10 μ.

Figure 765. Föllinge (Stockholm no. 335,317b). The fusion crust (left) is multilayered. Each layer solidified independently to a fine dendritic structure, with intercalated iron oxides, before the next was deposited. Upon cooling the primary austenite dendrites transformed to unequilibrated α_2 structures. Etched. Scale bar 200 μ.

always enveloped in 20-200 μ kamacite. The total phosphorus content is estimated to be 0.2%. The phosphides probably precipitated from the cooling, homogeneous austenite single crystal at a temperature of 650-600° C and rapidly acquired their irregular envelopes of swathing kamacite. At a lower, but undetermined temperature, the Widmanstätten pattern was created, probably by homogeneous nucleation and growth. The diffusion-controlled reaction soon ceased to operate (at about 350° C), so the lamellae never reached any appreciable width. The remaining matrix transformed to martensitic structures, $\gamma \rightarrow \alpha_2$, repeating the macroscopically visible octahedral pattern. As

discussed above, both the kamacite lamellae and the martensitic plessite were completely altered by the reheating during atmospheric entry.

An examination of the evenly distributed phosphides shows that they are micromelted in an unusually large rim zone, 2-18 mm wide, around the periphery of the mass. The 1000° C isotherm was mapped in two perpendicular sections (Buchwald 1967b). Only a few other meteorites are known to have suffered this thorough heating during atmospheric entry.

Föllinge is a finest octahedrite, and one of the few that show a continuous Widmanstätten structure on the 18% Ni level. It is structurally closely related to Tazewell and Dayton, and it is also chemically closely related to these irons. Somewhat further away stand Wedderburn, Freda and perhaps, Britstown, all rather small meteorites of the resolved chemical group IIID (Wasson & Schaudy 1971).

Specimen in the U.S. National Museum in Washington:
14 g part slice (no. 1873).

Forsyth County, North Carolina, U.S.A.

Approximately 36°5'N, 80°20'W; 250 m

Shocked and recrystallized hexahedrite, H. 0.2-0.5 mm equiaxial new grains. HV 102-185.

Group IIA. 5.54% Ni, 0.47% Co, 0.21% P, 60 ppm Ga, 176 ppm Ge, 31 ppm Ir.

HISTORY

A mass of about 50 pounds (23 kg) was plowed up in 1894 on a farm in the southwestern part of Forsyth

County, North Carolina. It was briefly mentioned with four drawings of the exterior shape a few years later when it came into the possession of G.F. Kunz (Schweinitz 1896). Through Kunz in New York the mass came to Stürtz in Bonn, where it was completely sliced up by a wire cutting technique in 1896. Cohen (1897c; 1905) presented a thorough description, based upon the examination of 17 kg in the form of slices; he also gave a few photomacrographs and an analysis. Berwerth (1914: 1078) concluded that Forsyth County had been artificially reheated, and at one time I came to the same conclusion, but this was, however, based on inferior material. Farrington (1915: 200) translated Cohen's treatise into English, and Perry (1944) gave four photomicrographs. Reed (1969) determined the composition of the kamacite with respect to nickel and phosphorus (5.4% Ni, 0.20% P). Schaeffer & Fisher (1960) determined the noble gases and estimated a cosmic ray exposure age of 95 million years.

While Schweinitz (1896) noted that the meteorite came from Forsyth County, North Carolina, Cohen (1897c) stated that it came from Forsyth County, Georgia; and based this change upon information received from Stürtz in Bonn and Brezina in Vienna, the first of whom had acquired the whole mass for cutting and who might be considered to have special knowledge of the place of origin. Unfortunately, research into this problem was never carried out by Cohen or later authors. If the locality were Forsyth County in Georgia, the site of discovery would be just about 100 km east of Holland's Store, where another shock-recrystallized hexahedrite with the same unique structure had been discovered a few years before. The two irons might then be candidates for being fragments of the same original fall. However, considering the meager and uncertain information and the slight but distinct differences in chemical composition, it has been decided here (i) to keep the two irons as separate meteorites, and (ii) assume

that the Forsyth County mass was really found in North Carolina. Some support for this conclusion may perhaps be found in the fact that the North Carolina State Museum, in Raleigh still preserves a 480 g sample and labels it as a North Carolina meteorite.

COLLECTIONS

Washington (1,121 g), New York (906 g), London (538 g), Chicago (536 g), Raleigh (480 g), Bonn (473 g), Berlin (412 g), Vienna (395 g), Ann Arbor (384 g), Tübingen (340 g), Leningrad (307 g), Greifswald (158 g), Prague (150 g), Harvard (52 g), Ottawa (10 g). Most specimens are slightly curved due to the old-fashioned wire
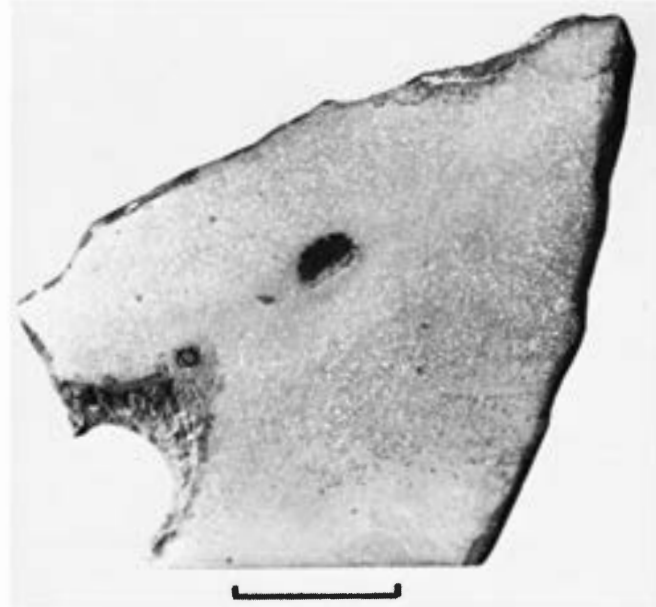

Figure 767A. Forsyth County (Vienna no. G 8419). Plate, 7 mm thick, which is curved due to imperfect cutting with a wire saw. Recrystallized and corroded. The remainder of a shock-melted troilite nodule in center. Deep-etched. Scale bar 30 mm.

FORSYTH COUNTY – SELECTED CHEMICAL ANALYSES

Cohen had analyses performed on both the dense-structured (first line) and the fine-grained material (second line) and proved the composition to be identical within analytical error, except with regard to chlorine: only traces of chlorine were found in the grain boundary-free, dense material, while 0.17% Cl was detected in the fine-grained variety; but 3.5-5% Cl was found in the thick oxide scales. Nevertheless, Cohen concluded that all the chlorine was cosmic and originally present as lawrencite. He did not

observe the mineral but referred to reports by Smith (1855) and Hidden (1886a) who allegedly had observed lawrencite in other irons. The present author suggests rather that lawrencite was never present as a well defined mineral, and that 99% of the chlorine observed was of terrestrial origin, supplied by the ground water which only penetrated that part of Forsyth County that had high-angle grain boundaries and, therefore, easy diffusion paths.

| References | percentage | | | ppm | | | | | | | | |
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Sjöström in Cohen 1897c	5.55	0.53	0.23	200	300		200					
the same, fine-grained	5.56	0.60	0.19	400	500		200					
Lovering et al. 1957		0.47				51	123		57	162		
Wasson, pers. comm. 1970	5.50								60.8	176	31	

cutting technique applied by Stürtz when slicing the meteorite. An endpiece of 7.5 kg may still exist in some (private?) collection, since the cumulative weight of the recorded specimens, including loss by cutting, does not exceed 10 kg, and since the total shape of cut sections indicates that an end specimen escaped the general, extensive cutting; compare Cohen (1897c: 389).

DESCRIPTION

The heavily corroded mass had the approximate dimensions 25 x 16 x 14 cm and weighed about 23 kg. When the oxidized crust had been removed, it weighed only 20.3 kg (Cohen 1897c). It had the roughly triangular, smooth shape of a Napoleonic cap, and Cohen showed that the top end, comprising about 15% of the total volume, was fine-grained, while the rest of the mass showed only occasional patches of fine-grained material. His detailed description is, however, marred by the frequent comparisons to Campo del Cielo, Newstead (a pseudometeorite), Cape of Good Hope, Locust Grove and Babb's Mill (Blake's Iron), since none of these irons actually resemble Forsyth County.

Etched sections display a mottled structure where patches of polycrystalline ferrite are irregularly interwoven with an apparently normal hexahedrite structure. The number of polycrystalline aggregates increases when approaching the top end of the specimen. No fusion crust and no heat-affected α_2 zones are preserved, and the surface is covered with 1-5 mm thick oxide crusts. Corrosion penetrates along cubic cleavage planes and along the grain boundaries of the fine-grained material. The troilite inclusions, which themselves are fine-grained mixtures of metal and sulfide, are particularly prone to oxidation and are destroyed on many museum specimens.

An annoying fact is that the surfaces tend to develop angular micropits, about 10 μ across, upon routine preparation of polished slices (see, e.g., Perry 1944: plates 8 and 9). The square to triangular pits are similarly oriented within the same ferrite grain; they may be eliminated by careful preparation on a diamond-impregnated lap, followed by polishing with alumina and light-etching with 1% Nital. The genuine microstructure then turns out to consist of a network of 20-80 μ ferrite subgrains with sensitive grain boundaries and with numerous intricate loops and island grains. A large number of subgrains unite to produce the macroscopically visible grains of oriented sheen, 0.2-0.5 mm in cross section.

The grain aggregates are apparently far from equilibrium. In the grain boundaries, that under high magnification appear double or ditch-like, numerous 0.5-2 μ wedge-shaped and angular phosphides are precipitated. With a frequency of about 500 per square millimeter there occurs a small, easily attacked unit, apparently a 5-10 μ wide ferrite grain with 1-2 μ phosphides clustered in the grain boundary. This unit etches extremely rapidly around the boundary and disappears, leaving the observed angular pit. It is interesting to note that the same preferential attack has taken place in the corroded rim zone of the meteorite, where grain boundaries and these micrograins are the first to become limonitized.

Neumann bands were not observed in the fine-grained parts. They are, however, present in the part of the meteorite which appears dull and structureless to the naked eye. Under high magnification the structure is seen to be similar to the one described above, with sensitive grain boundaries and rapidly developing etch pits. The grains are, however, apparently all similarly oriented and thus produce no oriented sheen, but reflect the light uniformly over an area of many square centimeters. Within such areas the Neumann bands are also uniformly oriented. The hardness is 165±16 but ranges in an erratic way down to 102 (!). Such a low hardness may either be caused by mild artificial reheating to about 500° C, or it may be a pseudo-hardness
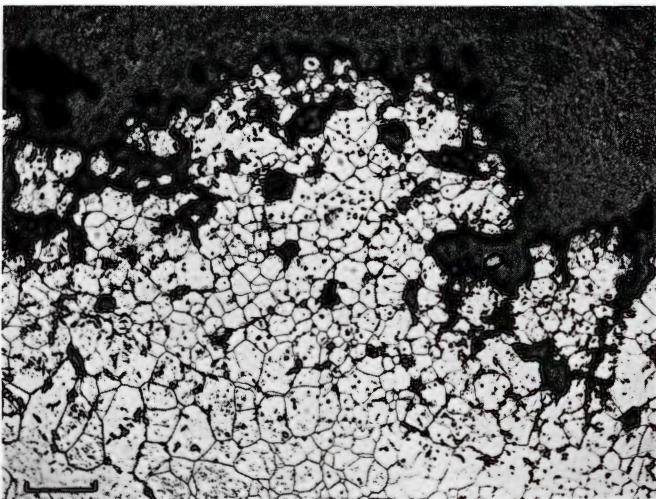

Figure 767B. Forsyth County (U.S.N.M. no. 620). Shocked and recrystallized hexahedrite. Terrestrial corrosion has formed a limonite layer (black), and the corrosive attack has continued along grain boundaries. Etched. Scale bar 200 μ. (From Perry 1944: plate 9)
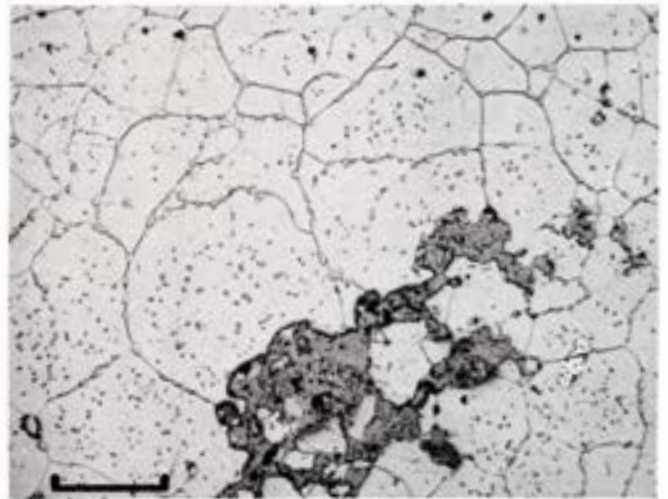

Figure 768. Forsyth County (U.S.N.M. no. 2269). Kamacite forms more or less equiaxial grains with numerous phosphides in the grain boundaries, and smaller ones in the interior. Invasion of limonite (gray). Etched. Scale bar 100 μ.

due to some scattered micropores below the plane of section.

Rhabdites were formerly present, typically as 2 x 0.1 mm plates and prisms. They are now almost unrecognizable, having been transformed to fine aggregates of 20 μ ferrite with 1-10 μ irregular, cavernous taenite and phosphide blebs in the boundaries. The general shape of the giant rhabdites has, however, been preserved together with the 100-200 μ wide, phosphorus depleted halos around them. This can only mean that whatever the event was that transformed the structure it must have been intense, but of short duration, so that phosphorus and nickel had little time for redistribution and homogenization. Small rhabdites in the 1-15 μ range are not present at all. It appears, however, that the easily attacked loops and unequilibrated structures described above are, in fact, altered rhabdites.

Troilite occurs as 1-20 mm nodules with ragged edges. They have been completely micromelted and consist now of eutectics of 2-10 μ sulfide grains enmeshed in a network of metal. Tiny fragments, 1-3 μ across, of daubreelite and a few larger fragments of schreibersite are also included; these are evidently the shattered remnants of former daubreelite lamellae and a rimming schreibersite. The troilite has melted and dissolved part of the surrounding metal and penetrated up to 1 mm from the original nodule site along grain boundaries of the metal. Late corrosion has transformed most of the metal of the eutectic mixture into terrestrial oxides, and the troilite also shows various stages of weathering to pentlandite and possibly other sulfide intermediates as well. The nodule structure appears to be the result of shock melting. Locally, a poorly defined 100-150 μ wide graphite nodule is embedded in the metal phase.

Apparently Forsyth County was originally a single hexahedrite crystal, which later was exposed to shock-deformation and associated reheating. The variation in grain size may be explained if we assume that part of the mass was strained beyond the critical deformation limit for recrystallization, while most of the mass was less severely deformed. Under this assumption the most deformed material would recrystallize to small grains, 0.2 mm in diameter, the less deformed material to somewhat larger grains, while the least deformed material would not recrystallize at all. All of the meteorite would, however, have recovered and polygonized to the 20-80 μ units; but, as indicated by hardness values, etching and corrosion characteristics, the structure is very unequilibrated.

Forsyth County is so closely related to Holland's Store that it is difficult to distinguish between them on the basis of the structural observations of the two. It is also related to Kopjes Vlei and Mejillones.

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

412 g part slice (no. 620, 10 x 10 x 0.6 cm)
482 g part slice (no. 2780, 10 x 10 x 0.7 cm)
151 g part slice (no. 2779, 7.5 x 5 x 0.7 cm)
 76 g part slice (no. 2269, 5 x 3 x 0.7 cm)

Fort Pierre, South Dakota, U.S.A.
44°21'N, 100°23'W

Medium octahedrite, Om. Bandwidth 1.05±0.15 mm. α_2 structure. HV 185±7.

Based upon what is left of the original structure: Group IIIA. About 7.6% Ni, 0.1% P.

The whole mass has been reheated to about 800° C by the finders.

HISTORY

A mass of about 16 kg (35 pounds) was found 20 miles from Fort Pierre, Stanley County, and in 1857 brought down the Missouri River by fur traders and presented to the St. Louis Academy of Sciences. It was described with a lithographic plate of the exterior shape by Holmes (1860), who also stated that a fragment of about 4 1/2 pounds had been detached and kept by the finders. The meteorite was almost simultaneously described by Shepard (1860) and Haidinger (1860a) who each had acquired about 800 g slices from Holmes. Haidinger presented a nature print of the Widmanstätten structure. Since the exact locality is not known, the coordinates above refer to Fort Pierre. Except for brief remarks in various papers the only further description of the iron is by Brezina (1896: 277). Berwerth (1905) included Fort Pierre in his group of artificially reheated metabolites, and I reached a similar conclusion on the basis of some specimens in European collections (Hey 1966). The slices examined in this study also indicate that the peculiar structure is artificial.

COLLECTIONS

St. Louis (3,370 g), London (1,950 g), New York (1,827 g), Vienna (1,715 g), Yale (355 g), Amherst (194 g), Tempe (149 g), Stockholm (139 g), Prague (137 g), Paris (100 g), Washington (99 g), Chicago (64 g), Harvard (63 g), Rome (40 g), Strasbourg (39 g), Sarajevo (37 g), Göttingen (28 g).

ANALYSES

Only two analyses have been performed, by Prout (7.19% Ni, in Holmes 1860) and by Madelung (7.61% Ni, in Buchner 1863). A new complete analysis is highly needed.

DESCRIPTION

The mass had the average dimensions of 28 x 12 x 12 cm but was irregular, with rounded corners and obtuse edges (Holmes 1860). The preserved specimens show that the iron was an oriented mass, which was not too corroded when found. It had a smooth, rounded front side and a flatter rear side with many pits and grooves. The fusion crust is preserved in many places as a composite of 200 μ magnetite plus 100 μ laminated, dendritic metal, and it is clearly seen how the layers wedge out and mix into each other. Under the fusion crust that contains many striae and hairlines, there is a continuous 1-3 mm thick, heat-affected

zone which is best seen with the naked eye, while it becomes indistinct at higher magnification.

Unfortunately, the mass, which otherwise would have constituted a well-preserved find, must have been thoroughly heated by the finders, although no report to this effect has been preserved.

Etched sections display a matte, indistinct Widmanstätten structure of straight, long ($\frac{L}{W} \sim 20$) kamacite lamellae with a width of 1.05±0.15 mm. On many specimens in collections the structure is slightly opened along the octahedral planes, and some oxidic veinlets also occur here. The kamacite matrix is a fine-grained aggregate of 15-50 μ α_2 grains, indicating artificial reheating above 750-800° C. At high magnification there is no essential difference between the heat-affected rim zone and the interior of the mass, which is to be expected if the meteorite has been reheated after its fall. The hardness of the α_2 phase is rather uniform throughout, 185±7. It is not easy to determine whether the kamacite displayed Neumann bands or shock-hardened ϵ-structures before the artificial reheating. Plessite occupies about 35% by area. It was originally an open-meshed comb plessite, but due to the reheating, it is now partly resorbed and displays ragged edges with thorns projecting into the surrounding matrix. The taenite is annealed to low hardness values; the 40 μ wide ribbons thus show values of 200±15, as opposed to 350±30 normally found in these ribbons.

Schreibersite is rare, but where it does occur, as 5-25 μ wide bodies in the grain boundaries, it is surrounded by 2-5 μ wide creamcolored taenite rims. Rhabdites were originally numerous as 1-3 μ rhombs in the matrix, but they are almost resorbed now because of the heat treatment.

Troilite occurs as scattered 1-10 mm nodules and lenticular bodies, sheathed in 0.5-1.5 mm swathing kamacite. The troilite is recrystallized to 20-100 μ units, some of which are composed of stacks of daubreelite and troilite in form of parallel, 1-2 μ thick lamellae. Daubreelite also occurs separately as 10-25 μ angular bodies in the kamacite.

The magnetite fusion crust is altered due to the reheating by man. A high-temperature intercrystalline oxidation attack can be followed along the surface. Not the least characteristic of artificial reheating are the fine-grained, lace-like reaction zones between early hydrous corrosion products and the surrounding metal and minerals.

The conclusion appears to be that the finders reheated the mass for some hours (?) to about 800° C, maybe in order to split it more easily. If this is correct, all specimens in collections should show structures similar to those described here. The other possibility, that only some specimens are heat-treated, appears less likely.

Based upon what is left of the original structure Fort Pierre may originally have been similar to Boxhole, Russell Gulch or Cape York, but we will probably never be able to tell. It is, no doubt, chemically a normal group IIIA iron with about 7.6% Ni and 0.1% P.

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

38 g part slice (no. 555, 5 x 2.5 x 0.5 cm)
61 g part slice (no. 1544, 5 x 4 x 0.4 cm)

Four Corners, New Mexico, U.S.A.
36°51'N, 108°51'W; about 1500 m

Polycrystalline, medium octahedrite with silicate-graphite inclusions. Bandwidth 0.80±0.15 mm. Neumann bands. HV 180±12.

Anomalous. Group I. 9.24% Ni, 0.54% Co, 0.15% P, 0.2% C, 49 ppm Ga, 179 ppm Ge, 2 ppm Ir (for the metal phase).

HISTORY

A mass of 25 kg was said to have been found about 24 km southeast of the common corner of Colorado, New Mexico, Arizona and Utah. It was acquired by the mining geologist R.C. Hills of Denver in 1923, but, due to his untimely death the same year, no further information as to the circumstances of discovery became available. The locality is in San Juan County and has the approximate coordinates given above. The meteorite was cut on an exchange basis in the U.S. National Museum and was described with several photographs and with analyses of the silicate and the metal by Merrill (1924a). Perry (1944: plate 3) gave a photomacrograph, and so did Nininger (1952a: plate 28). Ramdohr (1963a) observed the graphite rims separating the iron from the rounded, idiomorphic silicates. Goldstein (1967) examined the germanium distribution within the kamacite and the taenite phases. Mason (1967a), Bence & Burnett (1967) and Bunch & Keil (1969) examined the composition of the various silicate inclusions.

COLLECTIONS

Washington (7,255 g), Canberra (2,500 g), New York (1,917 g), Chicago (1,842 g), Harvard (1,600 g), Denver (about 1,500 g), London (1,179 g), Tempe (547 g), Copenhagen (422 g), Los Angeles (63 g).

FOUR CORNERS – SELECTED CHEMICAL ANALYSES, METALLIC PORTION

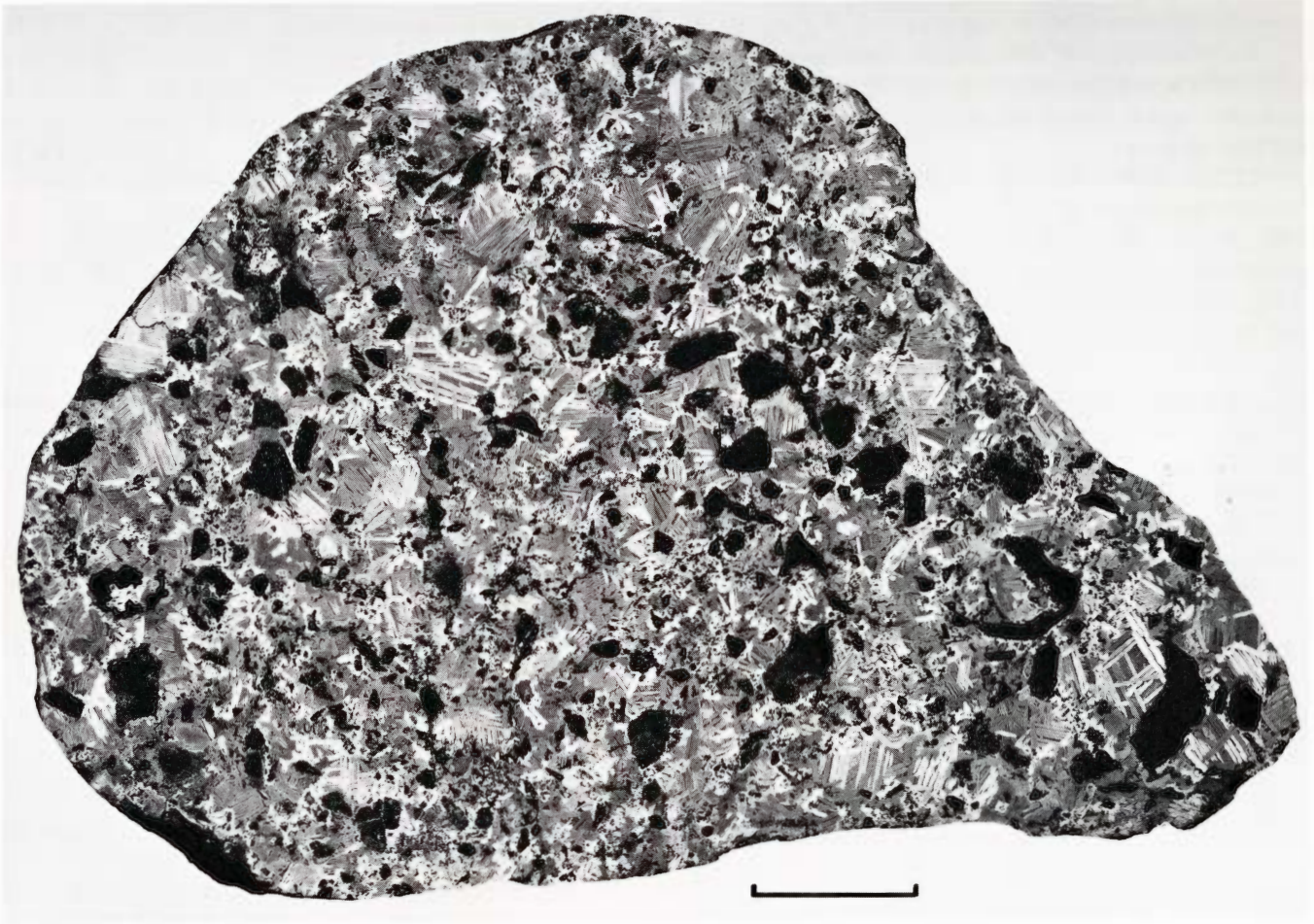| References | percentage | | | ppm | | | | | | | | |
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Whitfield in Merrill 1924a	9.58	0.59	0.15	2000	210		350					
Lovering et al. 1957		0.54				2.6	248		48	141		
Wasson 1970b	8.90								48.7	179	2.0	

Figure 769. Four Corners (U.S.N.M. no. 728). A full 1.36 kg slice which shows the polycrystalline precursor taenite crystals and their associated silicate-graphite aggregates (black). Deep-etched. Scale bar 30 mm. S.I. neg. M-328.

DESCRIPTION

The shape of the meteorite was compared to a water-worn boulder with the extreme dimensions 26 x 26 x 16 cm (Merrill 1924a). A smooth, 0.1-0.4 mm thick, weathered crust covers the mass uniformly.

Etched sections display a unique structure of polycrystalline metal interspersed with irregular, 0.1-10 mm inclusions of dark, nonmetallic material. The metal phase was, at high temperatures, polycrystalline austenite with a grain size of 5-25 mm. Upon cooling each crystal developed the Widmanstätten structure independently to form straight, long ($\frac{L}{W} \sim 20$) kamacite lamellae with a width of 0.80±0.15 mm. The grain boundaries between the original austenite crystals are often well-marked by irregular 1 mm wide kamacite ribbons. Other grain boundaries are loaded with 0.5-1 mm wide troilite and schreibersite veins. The kamacite has indistinct Neumann bands and subboundaries decorated with $<1\,\mu$ precipitates. The kamacitic matrix appears to be loaded with submicroscopic, uniformly dispersed precipitates (carbides and phosphides ?), but no large rhabdites were observed. The kamacite has a hardness of 180±12.

Plessite occupies about 40% by area of the metallic grains. It is developed as comb plessite and as poorly

resolvable, duplex $\alpha + \gamma$ fields. Pearlitic fields with 0.5-1 μ wide taenite lamellae, and spheroidized fields with 2-5 μ taenite spherules are also common. A contrast-rich carbon-martensite (HV 460±40) occurs frequently and indicates a relatively high, general carbon content of the meteorite. Some plessite fields have 0.1-1 mm wide central areas of poorly defined haxonite, similar to the complex haxonite-taenite-kamacite fields observed in, e.g., Colfax and Carlton.

Graphite is an important constituent, both as 20-100 μ cliftonite crystals in troilite and kamacite, as microcrystalline 10-50 μ rims around the euhedral, rounded silicate grains, and as amorphous carbon which constitutes about 20% of the larger, millimeter-sized graphite patches. In many places a primary, lenticular or rod-like graphite crystal is enveloped by secondary, non-epitactic graphite.

Schreibersite occurs as 1-2 mm skeleton crystals and as 50 μ wide grain boundary precipitates. It is later than the graphite, since it is frequently deposited upon a silicate-graphite crystal, and itself is never covered by graphite. The large schreibersite crystals are monocrystalline and only little broken, and normally enveloped in 1-2 mm swathing kamacite.

Troilite is very common, not as pure nodules, but as grain boundary fillings and as fillings between the silicate- and graphite grains. The troilite is shock melted and solidified to equiaxial, 1-5 μ, anisotropic grain aggregates. Along the metal-interphase boundary it has dissolved some iron and reprecipitated it, so that the troilite has ragged edges against the metal and contains 1-5 μ interior metal blebs. Some troilite has been injected through the graphite and silicate grains to form 25-100 μ pockets and 1-5 μ wide veinlets. The troilite has a hardness of 230±15.

Silicates occupy about 15% by area, but they are not uniformly dispersed. They form 1-20 mm angular clusters, which are rather loose aggregates of numerous 0.03-1 mm wide euhedral silicate grains. According to Bence & Burnett (1967), two species of pyroxene with lesser amounts of olivine and feldspar occur. The pyroxenes are predominant-ly Mg-Fe-pyroxene (nearly colorless enstatite with Fe/Mg < 0.1) with lesser amounts of calcic pyroxene containing 1-2% Cr_2O_3 (a bright green diopside). The olivine is Mg-rich forsterite, and the feldspar is sodic plagioclase (oligoclase). The mineral assemblage is evidently very similar to that described from Campo del Cielo by Park et al. (1966).

While the heat-affected α_2 zone is almost corroded away, the interior of the meteorite is well-preserved. Some troilite is, however, converted to pentlandite, and the fine-grained metal in the shock-melted troilite is, as usual, partially transformed to purplish, limonitic products. Some alteration products also occur along the schreibersite and in the silicate-graphite interphase boundaries.

Four Corners is, strictly speaking, a unique meteorite. It shows, however, a certain structural analogy to Copiapo
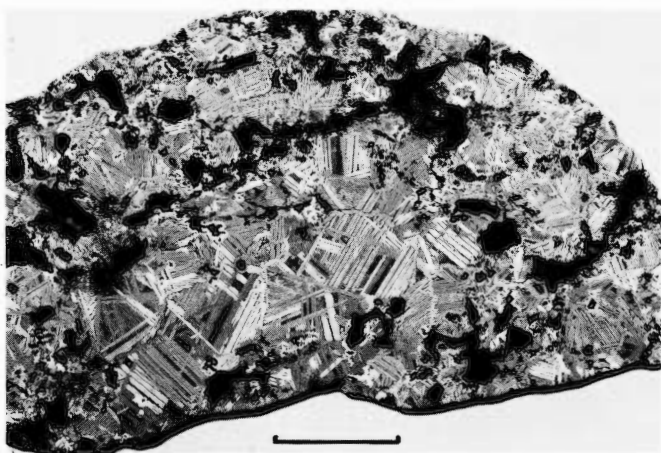

Figure 770. Four Corners (U.S.N.M. no. 728). Each original taenite crystal transformed to independently oriented Widmanstätten patterns. First, however, swathing kamacite precipitated in grain boundaries and around silicate inclusions. Etched. Scale bar 30 mm.

as already pointed out by Merrill (1924a). According to the present description it becomes possible that it is also related to the group I meteorites, both structurally and chemically. It does, in fact, resemble a Campo del Cielo (El Taco) specimen on a reduced scale. Four Corners is polycrystal-line with smaller, original austenite grains, smaller band-width and smaller silicate inclusions than Campo del Cielo; but the general morphology and structural details are the same, and a smaller bandwidth would be expected (for the same cooling rate), because the nickel percentage is higher. Four Corners plots rather well on the extrapolated, smooth curve defined by the group I meteorites, both when plotting bandwidth against nickel content and germanium versus nickel content, two criteria which normally must be filled to have the classification correct. The iridium content is further the same as in group I, and the silicate-minerals and the carbon-minerals are also the same.

The metallic portion of Four Corners is closely related to Balfour Downs and Colfax, while the silicate portion is related to Balfour Downs and Campo del Cielo, and probably to that of other group I meteorites.

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

3,231 g slice (no. 728, 23 x 13 x 2 cm)
2,049 g slice (no. 728, 24 x 14 x 1.1 cm)
1,361 g slice (no. 728, 24 x 15.5 x 0.8 cm)
 614 g part slice (no. 1596, 16 x 10 x 0.6 cm)

Franceville, Colorado, U.S.A.

Approximately 38°47'N, 104°35'W; 1800 m

Medium octahedrite, Om. Bandwidth 1.10±0.15 mm. Neumann bands. HV 250±10.

Group IIIA. 8.39% Ni, 0.48% Co, 0.21% P, 20.4 ppm Ga, 42.4 ppm Ge, 0.38 ppm Ir.

HISTORY

A mass of 18.3 kg was found in 1890 by D. Anderson, 2.5 km southwest of the home ranch of Skinner and Ashley, which is east of Franceville in El Paso County. The meteorite was totally exposed on the surface of the sagebrush cactus desert. The corresponding coordinates are given above. For 12 years the meteorite was in the possession of the Anderson family in Colorado Springs, but was then acquired by Ward's Establishment and described with photographs of the exterior and of an etched slice by Preston (1902b). The photomacrograph was reprinted by Ward (1904a: plate 8), while a photomacrograph of another slice was given by Mauroy (1913: plate 2).

FRANCEVILLE – SELECTED CHEMICAL ANALYSES

| References | percentage | | | ppm | | | | | | | | |
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Moore et al. 1969	8.39	0.48	0.21	100	35		170					
Scott et al. 1973	8.2±0.2								20.4	42.4	0.38	

COLLECTIONS

Harvard (2,260 g endpiece), Chicago (888 g), London (772 g), New York (656 g), Tempe (417 g), Budapest (355 g), Vatican (320 g), Prague (319 g), Washington (297 g), Berlin (123 g), Tübingen (88 g), Los Angeles (79 g), Ottawa (14 g). This only adds up to about 6.6 kg. It appears that a large specimen of 7,512 g offered for sale as late as 1921 (Ward's Price List No. 237) comprises most of the remaining weight, but it is not known who purchased this specimen.

DESCRIPTION

The extreme dimensions were 23 x 21 x 11 cm; the mass was likened to a flattened, rhombic pyramid with a rather sharp ridge extending around the center of the mass on the four rhombic sides (Preston 1902b: 75, figure 2).

An examination of the slices in Prague, Tempe and Washington clearly shows that the mass is corroded with oxides penetrating deep into the interior along the octahedral planes and along schreibersite precipitates. The heat-affected α_2 zone is nevertheless preserved as a 0.1-2 mm wide rim around many sections, and, on the U.S. National Museum specimen, 0.5 mm thick deposits of laminated mixtures of metallic and oxidic melts are also present. While most of the deposits are dendritic, cellular (5 μ cells) laminae, some parts are intricate "whirlpools," similar to those observed on the lee side of Algoma, Arlington, and Durango. Due to the rather extensive slicing and the corrosion of Franceville, it is now difficult to study the distribution of the fusion crust relative to the orientation during the flight through our atmosphere.

The microhardness of the α_2 zone is 205±20; the hardness decreases to a minimum of 170 in the recovered transition zone, and then rapidly increases to the interior level of 250±10 (hardness curve type I).

Etched sections display a somewhat distorted Widmanstätten structure of slightly wavy, long ($\frac{L}{W} \sim 35$) kamacite lamellae with a width of 1.10±0.15 mm. Indistinct, densely crowded Neumann bands are present; and, also, these are locally bent by a late cosmic, plastic deformation. The microhardness of 250±10 corresponds well to the observed degree of deformation. The kamacite subgrain boundaries are frequently decorated with 0.5-1 μ rhabdites. Plessite occupies about 35% by area, mostly in the form of comb and net plessite with angular taenite blebs, but also partly in the form of fine-grained duplex $\alpha + \gamma$, and martensite with plates parallel to the gross Widmanstätten structure.

Schreibersite is rare as larger inclusions, but common as 10-50 μ wide, elongated bodies in the grain boundaries. In many places the schreibersite bodies form island arcs 5-25 μ

in front of the taenite and plessite fields. Small amounts of phosphides occur in the interior of the comb plessite as 2-5 μ vermicular grains, substituting for taenite.

Troilite is not common. Preston (1902b), who sliced the whole mass, saw only one nodule, 14 mm in diameter. On the sections examined by the author several rhombic troilite bodies, 1-2 mm in cross section, were observed; also a few nodules, 5-6 mm in diameter, were seen in some deep-etched sections. No schreibersite rims are present, but 0.1-0.5 mm swathing kamacite is usually seen around them. In the kamacite matrix there are several 5-10 μ daubreelite grains; they are precipitated early, since they often form the nuclei of the larger schreibersite bodies.

Franceville structurally resembles Aggie Creek and Tamarugal but apparently lacks the phosphide bodies centrally in the kamacite lamellae. It also resembles Kyancutta and Thule but is different from these in the island arc-morphology of the phosphides.

Specimen in the U.S. National Museum in Washington:
297 g slice (no. 328, 18 x 10 x 0.3 cm)

Frankfort (Iron), Kentucky, U.S.A.

Approximately 38°6'N, 84°59'W; 250 m

Medium octahedrite, Om. Bandwidth 1.15±0.20 mm ϵ-structure. HV 325±20.

Group IIIA. 7.85% Ni, about 0.17% P, 20.2 ppm Ga, 40.4 ppm Ge, 1.8 ppm Ir.

HISTORY

A mass of about 11 kg was found in 1866 on a hill eight miles southwest of Frankfort, Franklin County. The corresponding locality is apparently in the neighboring Anderson County and has the coordinates given above. The mass was suspected to indicate an iron mine and was brought to the blacksmith in Frankfort to be tested. In 1867 it was acquired by J. Lawrence Smith who described and analyzed it (1870) and added some important considerations regarding the chemical composition of meteorites. He had, so far, always found cobalt and copper associated with nickel in the irons and he questioned, rightly, the numerous analyses which failed to report these components. Huntington (1886) examined the 7.2 kg main mass, and, since it was found to be bounded by octahedral cleavage planes, he concluded that the mass was a fragment of a larger meteorite which split in the atmosphere. He gave a sketch of the exterior later (1888: plate 4).

FRANKFORT (IRON) — SELECTED CHEMICAL ANALYSES

Reference	percentage			ppm								
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Scott et al. 1973	7.85								20.2	40.4	1.8	

COLLECTIONS

Harvard (5,400 g), Washington (1,638 g), Amherst (1,275 g), Paris (347 g), London (216 g), Calcutta (59 g), Stockholm (52 g), Göttingen (52 g), Yale (37 g), Vienna (37 g), Vatican (26 g), Chicago (5 g).

DESCRIPTION

The mass is heavily corroded with about 1 mm adhering oxide crusts. It displays, as stated by Huntington, rather plane octahedral cleavage faces, and corrosion penetrates deep into the interior along several octahedral planes. Frankfort is evidently an old fall, where all fusion crust and heat-affected α_2 zone long since are corroded away. It is probable that long-term corrosion has cooperated with flight sculpturing in producing the exterior shape by slowly peeling off layer after layer of the mass.

Etched sections display a medium octahedrite structure of straight, long ($\frac{L}{W} \sim 20$) kamacite lamellae with a width of 1.15±0.20 mm. The variation in the primary bandwidth appears to be larger than usual. The kamacite has many subboundaries with 1-2 μ rhabdites. The kamacite is, due to shock above 130 k bar, transformed to a densely hatched ϵ-structure of little contrast. The hardness is high, 325±20, showing that no significant annealing has occurred after the shock event. Plessite occupies about 35% by area, mostly in form of partly resorbed comb and net plessite. Also present are fine-grained, duplex $\alpha + \gamma$ fields with characteristic, acicular kamacite windows, typically 20 x 2 μ in size. The taenite etches bluish-gray in irregular mottled areas, indicating a certain high carbon content in the taenite ribbons. The taenite has a hardness of 340±20 (40 μ wide ribbons), while the indistinct martensitic transition zones have hardnesses of 385±30.

Schreibersite is common as 20-50 μ wide grain boundary precipitates, that are monocrystalline, but somewhat broken and locally corroded. Rhabdites, 1-4 μ in size are ubiquitous in the matrix, both in the primary kamacite lamellae and in the interior of the comb plessite. The total phosphorus content is estimated to be 0.17±0.03%.

Troilite is not common but is locally present as 2-5 mm nodules without schreibersite rims. Bluish chromium sulphide grains, 5-50 μ across, probably daubreelite or brezinaite, occur scattered in the kamacite. In the matrix there are also numerous hard, fine plates, typically 20 x 2 x 0.5 μ, of chromium nitride, also observed in Costilla Peak, Cape York and others.

Since the block was originally "tested by the blacksmith," it was to be feared that it had been reheated. However, the specimens examined have not been maltreated, except by a violent hammering and chiseling in order to break off specimens. It was also checked whether Frankfort displayed the same structure as the other Kentucky iron meteorites of which several are of poorly known locality. Frankfort was found to be different from Campbellsville, Clark County, Casey County, Kenton County, Providence and Williamstown, so if it split in mid air during atmospheric entry the other fragments have as

yet not been recovered. With one possible exception: Marshall County is of similar composition, and perhaps of similar structure and terrestrial age. It has, however, been thoroughly reheated artificially, so that a satisfactory comparison can not be carried out.

Frankfort is a shock-hardened group IIIA iron, which is related to Merceditas, Kyancutta and Thunda.

Specimens in the U.S. National Museum in Washington:
1,275 g slice (no. 926, 12 x 8 x 1.6 cm)
 363 g slice (no. 2553, 13 x 8 x 0.4 cm)

Freda, North Dakota, U.S.A.
46°19′N, 101°12′W; 600 m

Nickel-rich ataxite, D. α-spindles 15±5 μ. Martensitic plessite. HV 340±20.

Group IIID. 23.1% Ni, 0.66% Co, 0.15% P, about 0.1% C, 2 ppm Ga, 2.2 ppm Ge, 0.02 ppm Ir.

Related to Tazewell, Dayton, Föllinge and Wedderburn.

HISTORY

A mass of 268 g was plowed up in 1919 by Henry G. Meyer about two miles southwest of Freda, in Grant County. It was in Meyer's possession until 1939 when it was purchased by the U.S. National Museum, where it was fully described by Henderson & Perry (1942). They presented photographs of the ablated exterior and of etched slices and showed it to be a unique iron. Perry (1944: plate 28) reproduced two of the photomicrographs, typical of the structure. Brentnall & Axon (1962) suggested that the anomalous structure was due to atmospheric

Figure 771. Freda (U.S.N.M. no. 1342). The entire mass of one of the smallest meteorites ever found. Fusion crusts are well-preserved, radiating from the apex (above). Scale bar 20 mm. S.I. neg. 258A.

heating of sufficient intensity to penetrate the bulk of the specimen. This appears, however, not to be the case as discussed below.

COLLECTION

Washington (247 g).

DESCRIPTION

The mass measures 4.5 x 4.0 x 3.0 cm and is shaped like a broad, smooth nose. It is an oriented individual which is only insignificantly weathered. The magnetite fusion crust is partially preserved as a 0.1 mm thick, warty or striated layer; some parts of it have been pealed off, presumably while it was a curiosity in private possession, whereby the bright, metallic fusion crust has become exposed. The fluted crust radiates from the rounded apex of the mass in marked ridges and furrows, and, locally, the metal spills over the edge and builds up to about 1 mm thickness. Freda and San Francisco Mountains may be the best examples of irons which during flight built up small flanges around the leading surfaces. The antiapex is covered with 0.2-0.3 mm thick deposits of laminated, metallic melts. Each layer is about 50μ thick and composed of cellular, dendritic material with an arm-spacing of $1-2 \mu$. The hardness is 300 ± 25, somewhat variable due to porosity.
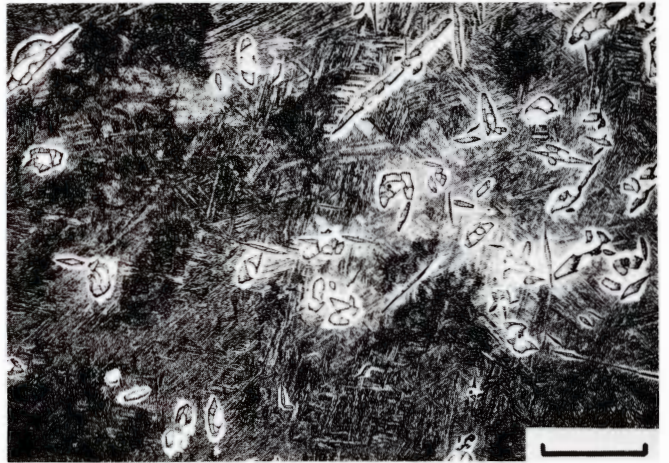

Figure 772. Freda (U.S.N.M. no. 1342). Fine kamacite spindles, often with a schreibersite nucleus, in a martensitic matrix. Etched. Scale bar 400μ. (Perry 1950 volume 2.)
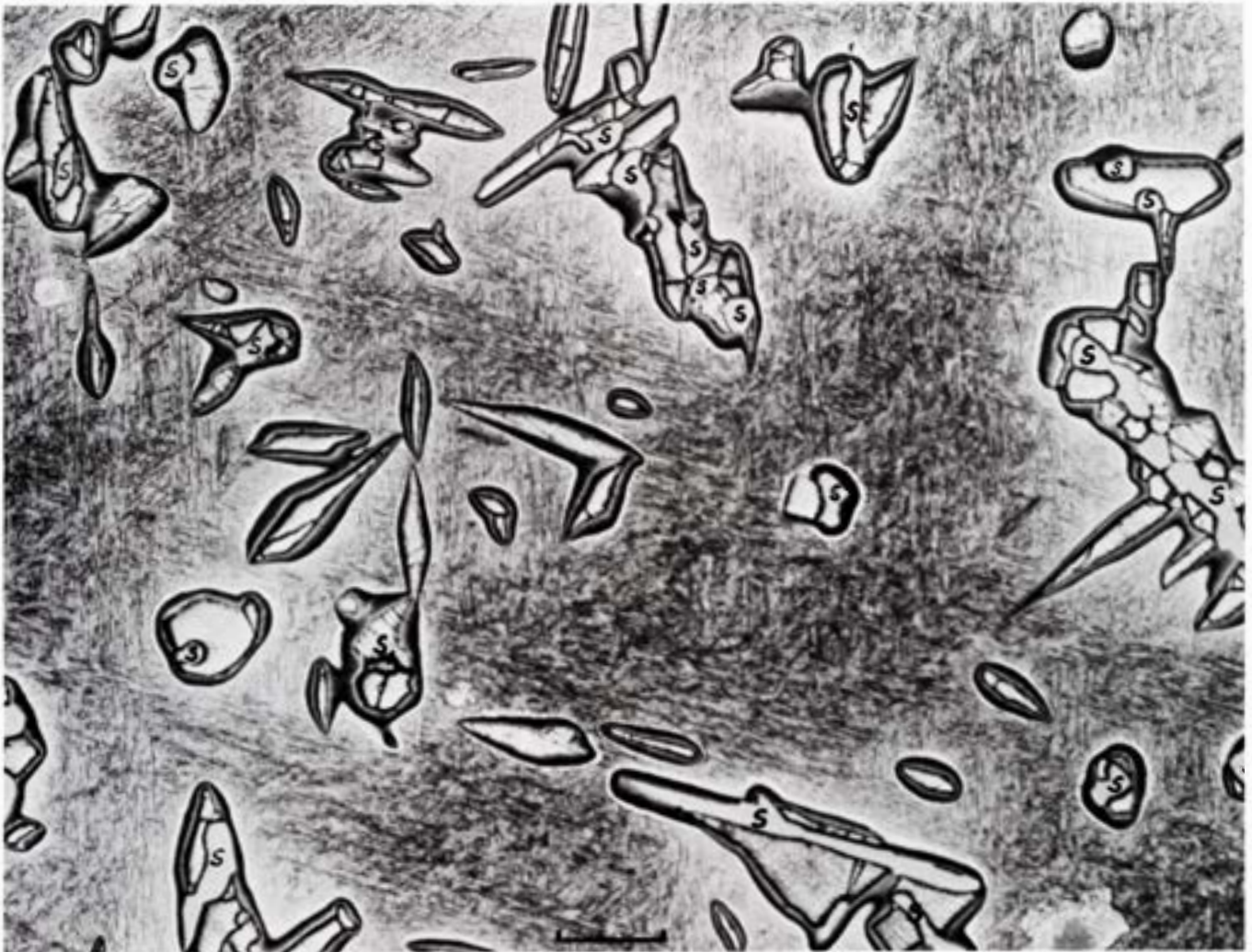

Figure 773. Freda (U.S.N.M. no. 1342). Kamacite spindles and blebs, with schreibersite (S). The matrix is martensitic, with occasional graphite spherulites (not shown). Etched. Scale bar 100μ.

Under the two fusion crusts, the oxidic and the metallic, is a heat-affected zone of unusually small extent. Because of the few sections made, it is not possible to obtain a complete mapping through the mass, but it appears that micromelted phosphides do not occur below 0.7 mm depth, and α_2 does not occur below 1.5 mm depth. This structural observation is confirmed by microhardness traces perpendicular to the surface. The hardness increases smoothly from 210 (100 g Vickers) at the edge to 340±20, where it remains constant from about 2 mm depth. The observations were all made close to the antiapex surface; but, since this is assumed to be the face associated with the flattest temperature gradient during oriented flight through the atmosphere, other parts of Freda should be still less affected.

Etched sections are structureless to the naked eye, but low magnification discloses a nickel-rich ataxitic structure, where alpha spindles are scattered through a martensitic matrix. The spindles, which are homogeneously nucleated, have a width of 15±5 μ and are about 10 times as long. The more conspicuous part of the alpha phase is developed as 50-150 μ irregular grains, heterogeneously nucleated by the numerous phosphide inclusions. The kamacite has sub-boundaries, and a microhardness of 170±10. In the heat-affected zone it is transformed to serrated α_2.

Taenite and dense, martensitic plessite constitutes about 90% of the sections. Most of it is in the shape of

Figure 774. Freda (U.S.N.M. no. 1342). Heat-affected A-zone with fused schreibersite crystals. Etched. Scale bar 40 μ. (From Henderson & Perry 1942.)

indistinct platelets oriented uniformly through the mass parallel to the octahedral directions of the α-spindles. The hardness is 340±20, but it drops, as mentioned above, to about 210 near the fused edges. The atmospheric reheating evidently annealed it significantly. The taenite is located around the α-grains; it is stained by etching, except in the heat-affected rim zone, which may be attributed to a significant carbon content in solid solution in the taenite.

Interestingly enough, graphite is present as 50-250 μ spherulites, composed of radiating sheaves of 1 μ wide crystallites. Carbon is also responsible for many local patches of soft, retained taenite (250-300 Vickers). These spots are irregular, lobed patches which stain rapidly when etched; they are 50-200 μ across, and they are in the reheated rim zone converted to acicular martensite in light-etching, retained austenite. Freda and San Cristobal are, so far, the nickel-richest irons in which graphite has been observed. The bulk carbon content is estimated to be about 0.1%.

Some kamacite spindles and parts of swathing kamacite around schreibersite have been replaced by haxonite that locally attain sizes of 100 x 15 μ. Scattered irregular cohenite crystals of micron size may be identified in the martensitic plessite matrix.

Schreibersite occurs as 8 x 0.5 mm and 1 x 0.3 mm crystals, enveloped in 50-100 μ rims of swathing kamacite. It is further ubiquitous as 5-50 μ polycrystalline units, which have nucleated rims of 25-100 μ kamacite. The small schreibersite crystals occur with a frequency of about 12 per mm^2. Troilite was not found.

The mass is attacked a little by corrosion; the alpha spindles and the alpha rims around schreibersite are partially converted to limonite near the surface. The fall may be anything from 50 to 500 years old, as estimated from the corrosion appearance.

Freda is an anomalous iron which is characterized chemically by its high-nickel and significant carbon content and structurally by its martensitic matrix with two generations of alpha grains, the first one having formed around the phosphides, which precipitated early from the austenite phase, the second one having formed later by homogeneous nucleation and growth. It is remarkable for having had, in the atmosphere, a very steep temperature gradient from the fused edge to the unaltered interior, which is found below 2 mm depth. In this respect it is quite different from the

FREDA – SELECTED CHEMICAL ANALYSES

| References | percentage | | | C | S | Cr | Cu | ppm | Ga | Ge | Ir | Pt |
	Ni	Co	P					Zn				
Henderson & Perry 1942	23.49	0.66	0.15									
Fairchild, quoted in above	23.27											
Wasson & Schaudy 1971	22.57								2.09	2.24	0.021	

400 g Föllinge iron which was found to have been heated to above 750° C to the very center.

An interesting parallel may be drawn to Wedderburn, Föllinge, Dayton and Tazewell. The metallic structure and the chemical composition suggest a very close genetic relationship to these meteorites.

Specimens in the U.S. National Museum in Washington:
241 g main mass (no. 1342, 4.5 x 4.0 x 3.0 cm)
  6 g polished section (no. 1342)

Galleguillos. See Ternera (Galleguillos)

Gallipoli. See Supplement

Ganado, Arizona, U.S.A.
35°43′N, 109°34′W

A small mass of 38.9 g was traded by an Indian on the Navajo Reservation and in 1938 recognized as being of meteoritic origin (A.D. Nininger 1940: 555; Nininger & Nininger 1950: 53, 108). Half of it is in Tempe, half in London (Brit. Mus. no. 1959, 918), and it has been cataloged as a hexahedrite.

A check of the 19.8 g sample in Tempe (November 1972) indicated that Ganado is a Canyon Diablo fragment.

Gancedo. See Campo del Cielo

Garden Head, Saskatchewan, Canada
49°49′N, 108°27.6′W

Plessitic octahedrite, Opl. Scattered 0.1 mm wide α-spindles.

Anomalous. 16.96% Ni, about 0.2% P, 10.7 ppm Ga, 16.6 ppm Ge, 0.12 ppm Ir.

HISTORY
According to a note in the Meteoritical Bulletin (No. 32, 1964), a mass of 1,296 g was discovered in 1944 near Garden Head, and recognized as a meteorite in 1964, when it was acquired for the Canadian National Meteorite Collection. It has been classified as a nickel-rich ataxite by Hey (1966: 170) and Douglas (1971: 15), but the present author would prefer to classify it as a plessitic octahedrite.

COLLECTIONS
Ottawa (941 g main mass, 295 g endpiece, 10 g slice).

DESCRIPTION
A few notes were taken during a brief examination of an 11 g sample from the main mass, no. 707301, in Ottawa. The etched section, with a surface of 38 x 15 mm, displayed an indistinct Widmanstätten structure, where the directions were indicated by a large number of separate α-spindles, typically 0.1 mm wide and 1 mm long. A number of these, perhaps all, were formed around minute 0.05-0.1 mm schreibersite crystals, which were the first to precipitate from the precursor taenite single crystal.

Schreibersite is also present as a few cuneiform or L-shaped crystals, typically 3 x 2 mm in size. This very early schreibersite has nucleated kamacite correspondingly early; consequently the swathing kamacite had ample time to grow to widths of 0.5 to 1.0 mm.

Troilite occurs as a few subangular crystals, 0.5-1 mm in size. Due to a mild shock, the troilite displays multiple twinning.

Garden Head is structurally and chemically an anomalous meteorite. Its closest relatives are Kofa and Gay Gulch, two other plessitic octahedrites.

Garhi Yasin, Sukkur district, Pakistan
27°53′N, 68°32′E

Medium octahedrite, Om. Bandwidth 1.05±0.20 mm. Neumann bands, Annealed. HV 148±5.

Group unknown, Composition unknown, but about 8.3% Ni and 0.15% P.

HISTORY
"After appearance of 'ball of fire,' and detonations, a mass of 380 grams was seen by a Sikh to fall, [near Garhi Yashin, Shikarpur taluk], and was given next day to E.L. Moysey" (letter of E.L. Moysey of October 2, 1924, in Mineralogical Department, British Museum). The fall occurred at night time in January 1917. It has never been examined but allegedly has a "remarkable similarity to Samelia" (Hey 1966: 170).

COLLECTIONS
London (337 g main mass, and three pieces, totaling 23 g).

ANALYSIS
The material is unanalyzed. From the structural examination below, I would, however, estimate 8.3±0.5% Ni and 0.15±0.04% P.

GARDEN HEAD – SELECTED CHEMICAL ANALYSES

Reference	percentage				C	S	Cr	Cu	ppm	Ga	Ge	Ir	Pt
	Ni	Co	P						Zn				
Wasson & Schaudy 1971	16.96									10.7	16.6	0.12	

DESCRIPTION

The main mass (Brit. Mus. no. 1924, 832) is an entire monolith which measures 50 x 45 x 35 mm; a few slices have been cut from one end leaving a section of 30 x 15 mm. Regmaglypts are well developed and 10-16 mm across. At the opposite end, the smoothly curved surfaces terminate abruptly against a late fracture surface, measuring about 45 x 25 mm. It appears that another fragment also fell but has never been found. After the fracture in the atmosphere, the flight velocity was still sufficiently high to smooth somewhat the angular fracture edges, and completely cover the fracture surface with fusion crusts. The black fusion crust is, as usual, mamillated and provided with warts and ridges.

On a section, the crust is observed to be a composite of an exterior oxidic crust, 10-100 μ thick and an interior metallic crust, 5-300 μ thick. The oxidic part displays, when etched with dilute Nital, a duplex structure consisting of an inner wüstite layer and an outer magnetite layer. In the wüstite, numerous 1-3 μ skeleton crystal of magnetite have precipitated in the solid state. The metallic part is composed of 1-8 dendritic layers, each 5-50 μ thick. They are crossbedded and irregular, evidently due to eddies in the rapidly shifting air currents playing around the flying meteorite.

Under the fusion crusts there is a 1-2 mm thick heat-affected zone. It is composed of coarse, serrated α_2 grains, with a hardness of 180±15. The transition zone to the unaffected interior displays hardnesses of 155±5 (hardness curve type III). The rather thin α_2 zone supports the idea that the recovered mass is only one of several fallen fragments.

Three small sections (Brit. Mus. no. 1924, 832) each of about 2 cm^2 were examined. They show a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 20$) kamacite lamellae with a width of 1.05±0.20 mm. The kamacite is rich in subgrain boundaries, decorated with 1 μ phosphides,

and Neumann bands are common. They display rather parallel sides and are broken up in segments, apparently due to slight annealing. In accordance with this impression, the microhardness is very low, 145±5. This is among the lowest hardnesses ever recorded for the kamacite of an octahedrite. The reason may be a thorough annealing of the small mass during the atmospheric flight.

Taenite and plessite cover 10-15% by area, particularly as comb and net plessite. All fields are composed of annealed and somewhat homogenized taenite lamellae and wedges. Etching reveals only few structural details, such as duplex or martensitic-bainitic textures. Most taenite wedges have a 1-5 μ clear yellow rim zone and a mottled, somewhat darker yellow interior. Apparently the interior is decomposed to duplex structures on a submicroscopic scale. The hardness is 153±7, suggesting thorough annealing.

Schreibersite occurs as 20-50 μ wide grain boundary veinlets and as 5-50 μ blebs inside the plessite fields.
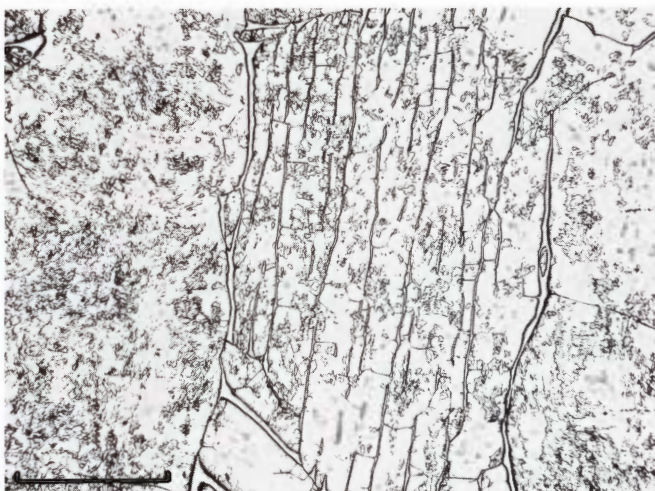

Figure 776. Garhi Yasin (Brit. Mus. no. 1924, 832). Fine-grained α_2 zone, in which an open-meshed comb plessite field is clearly seen. Etched. Scale bar 1 mm.
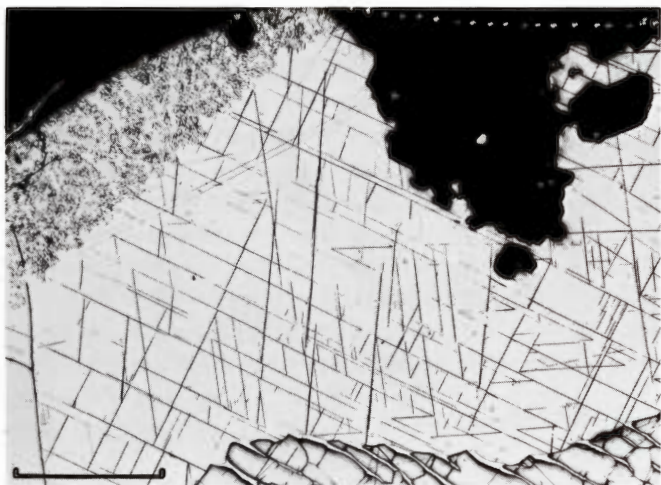

Figure 775. Garhi Yasin (Brit. Mus. no. 1924, 832). Near-surface section with heat-affected α_2 zone (above left), silicates (black; their edge indicated by a dashed line) and comb plessite (below). Etched. Scale bar 1 mm.
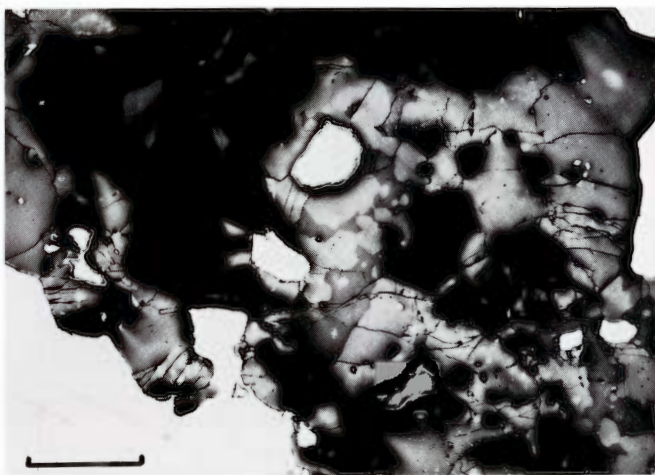

Figure 777. Garhi Yasin (Brit. Mus. no. 1924, 832). Detail of the silicates in Figure 775. There are at least three different silicates involved, and they have metallic inclusions (white). Polished. Reflected light. Scale bar 200 μ.

Typical rhabdites are absent, but a host of microrhabdites, 0.5-1 μ across, appear in many kamacite lamellae. Troilite and cohenite were not present in the sections.

Silicates occur in one place close to the surface. Individual grains range from 50μ to $500 \times 300\mu$ in size and either occur singly in the kamacite or form loosely packed aggregates with metallic pockets and veins. The metal inside the silicate grains consists of zoned taenite particles or cellular kamacite, normally $5\text{-}100\ \mu$ across. The silicates were not positively identified but apparently consist of olivine, pyroxene and plagioclase, either singly or in composite intergrowths. Where the silicates contact the surface they are preferentially ablated away during the atmospheric flight, evidently because they have a melting range about $300°\ C$ lower than the surrounding metal. The pits, after the ablation-melted silicates, lie 1-2 mm below the adjacent metal.

Garhi Yasin is a medium octahedrite which has been thoroughly annealed. The annealing, particularly of the taenite areas, has been surprisingly effective. It can, however, not be excluded that the effects occurred during the atmospheric flight. The total mass is small, and the examined samples came from an end. In order that a final decision can be drawn, material from the center of the mass should be examined and the hardness gradient towards the surface measured.

Garhi Yasin is an anomalous meteorite which, structurally, appears to have only one relative, Netschaevo, page 891. Since, however, the original structure of Netschaevo was altered by artificial reheating and that of Garhi Yasin was altered by atmospheric annealing, several structural features which otherwise could have served for classification purposes, have been deleted.

Garhi Yasin is unrelated to Samelia; the structural similarities are only superficial. It is recommended that Garhi Yasin be fully analyzed.

Gay Gulch, Yukon, Canada
63°54′N, 139°16′W; 600 m

Plessitic octahedrite, Opl. Spindle width $60\pm15\ \mu$. Neumann bands. HV 155 ± 10.

Anomalous. 15.1% Ni, about 0.3% P, 6.7 ppm Ga, 10.7 ppm Ge, 0.11 ppm Ir.

The small mass has hitherto been considered a part of Klondike (Skookum Gulch), but it is an independent fall.

HISTORY

A mass of 483 g was found in 1901 in one of the sluice boxes on claim No. 6 on Gay Gulch, south of Klondike. It was found deep in auriferous deposits, the so-called white channel gravels, and probably in contact with bedrock. The geologic setting indicated that it was of Pliocene age. It was acquired by the Geological Survey in Ottawa in 1906, but only a preliminary examination by Johnston (1915) has been published. He presented a locality map and photographs of the corroded exterior and of polished and etched sections. He concluded that Gay Gulch was part of the same shower as Skookum Gulch, and since then the two masses have been listed together as Klondike; see, e.g., Hey (1966: 245).

Since the photomicrographs in Johnston (1915) suggested that the two meteorites were entirely different, I borrowed a small section of Gay Gulch from the Ottawa Collection by the kind cooperation of the curator, Dr. J.A.V. Douglas. The following descriptions definitively prove that Gay Gulch and Skookum Gulch are different meteorites. We thus have the rare coincidence of finding two high-nickel irons within 5 km distance, deep in Pliocene gravels. The finding of two nickel-rich irons close together and the grouping of them as one fall has its almost exact parallel in Babb's Mill, where Troost's Iron and Blake's Iron for a long time were considered identical (Buchwald 1967a: 21).

Douglas (1971) and Wasson & Schaudy (1971) have independently reached the same conclusion.

COLLECTION

Ottawa (373 g endpiece, 2 g fragments).

DESCRIPTION

The mass had the approximate dimensions $6 \times 5 \times 4$ cm and weighed 483 g. It belongs with Föllinge, Freda and a few other irons to the smallest individuals we know of (see Table 21 in Volume 1). It is rather smoothly rounded, but displays a few straight surface scars, approximately 10 mm long and 1 mm wide. These grooves probably indicate where a few larger schreibersite bodies were situated and melted out in the atmosphere. Contrary to what one would expect from the circumstances of finding, Gay Gulch is surprisingly well-preserved. Sections perpendicular to the surface show a heat-affected rim zone 5-10 mm wide, in which are located numerous micromelted schreibersites. A complete mapping of the temperature gradient as in Föllinge (Buchwald 1967b) was not possible, but indications are that the micromelted schreibersites are found to a depth of 4-5 mm, while the α_2 phase is found to a depth of about 10 mm. Only a nucleus of about 2 cm in diameter can have escaped reheating above $700°\ C$ in the atmosphere, but it would still have been heated several

GAY GULCH — SELECTED CHEMICAL ANALYSES

| Reference | percentage | | | ppm | | | | | | | | |
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Wasson & Schaudy 1971	15.06								6.68	10.7	0.11	

hundred degrees, sufficiently for stress relieving of the metal.

The etched section displays a microscopic Widmanstätten pattern of well-developed, straight ($\frac{L}{W} \sim 15$) kamacite needles with a width of $60\pm15\,\mu$. The pointed needles or platelets are dispersed as a felt-like meshwork, but do not form continuous, lamellar systems. Neumann bands were probably present previously, but, in the specimens seen by me, the kamacite is now convered to serrated α_2 units due to the atmospheric reheating. The microhardness is 155 ± 10, which is unusually low for an α_2 phase.

In addition to the kamacite lamellae precipitated in the Widmanstätten pattern there is an almost equal amount of kamacite nucleated around the primary schreibersite bodies. This kamacite is bulky and mainly follows the outline of the schreibersite crystals as a $10\text{-}150\,\mu$ wide zone total amount of kamacite is about 30% by area.

The matrix between the kamacite grid is an easily resolvable, duplex $\alpha + \gamma$ mixture, where the γ component constitutes $1\text{-}2\,\mu$ wide, winding ribbons. The gross Widmanstätten pattern is repeated in the α and γ directions of the matrix. The microhardness, with a 100 g impression averaging over numerous $\alpha + \gamma$ units, is 155 ± 10 and, thus, identical to that of the kamacite alone.

Schreibersite occurs as scattered crystals, $400 \times 30\,\mu$ or $200 \times 300\,\mu$ in size, and there are indications that larger bodies occur locally. It is further rather uniformly distributed as $10\text{-}100\,\mu$ angular bodies, that occur with a frequency of about 5 per mm^2. The bulk phosphorus content is estimated to be 0.3%. Most of the phosphides precipitated directly from the high temperature austenite phase and later nucleated rims of swathing kamacite that grew to a width of $10\text{-}150\,\mu$, before the remaining matrix started to decompose by homogeneous nucleation. Very few kamacite plates grew in a Widmanstätten pattern from the swathing kamacite zones.

The meteorite has a corroded crust. In particular the alpha needles and the alpha part of the duplex matrix are converted to limonite. The micromelted schreibersite and the high-nickel taenite ($\sim 30\%$ Ni) survive for a long time and serve as a grid that retains the corroded crust for a long time.

Gay Gulch is different 'from Skookum Gulch in all structural details. Gay Gulch resembles Cowra in many respects, but Gay Gulch has a better equilibrated plessitic matrix of easily resolvable $\alpha + \gamma$. It further resembles the meteorites of group IIC somewhat, such as Kumerina and Wiley, but lacks the frequent chromite inclusions of that group. However, chemically, it is different from all the meteorites mentioned.

Gay Gulch is closely related, both structurally and chemically, to two other small iron meteorites, Kofa and Garden Head. They are all here classified as plessitic octahedrites, with 15-18% Ni and a significant schreibersite content.

Gerzeh, Lower Egypt
29°19′N, 31°17′E

During archaeological excavations of royal graves at Gerzeh, or El Girza, on the western bank of the Nile 70 km south of Cairo, a few completely rusted beads were found in 1911 (Petrie et al. 1912; Wainwright 1912). They were fully described, figured and analyzed by these authors, who showed that the material was of predynastic age, i.e., from about 3,000 B.C., and thus were the most ancient iron material ever recorded. Their analysis indicated that all was limonite, and nickel was not reported.

The beads were part of a necklace where metal alternated with precious and semi-precious stones. On a brief visit, in January 1972, to University College, London, the Curator of the Egyptian Collection, Dr. C.M. Dixon, showed me the specimens in question. Evidently, what is presently available is three beads, Nos. 10,738, 10,739 and 10,740, each weighing about 1 gram. The largest piece, a cylinder 15 mm long and 12 mm in diameter, had been the centre of the necklace, while two smaller cylinders 16 mm x 5.5 mm and 16 mm x 3 mm, had been placed on either side at some distance, with other stones in between. All iron beads were strongly oxidized, had a black porous appearance, and were only weakly magnetic; a hand magnet hardly attracted them. Petrie and Wainwright assumed that the beads had originally been produced by flat-hammering and folding to cylinders. Perhaps additional material, now used up in analytical work, was then sufficiently well-preserved for such conclusions to be drawn.
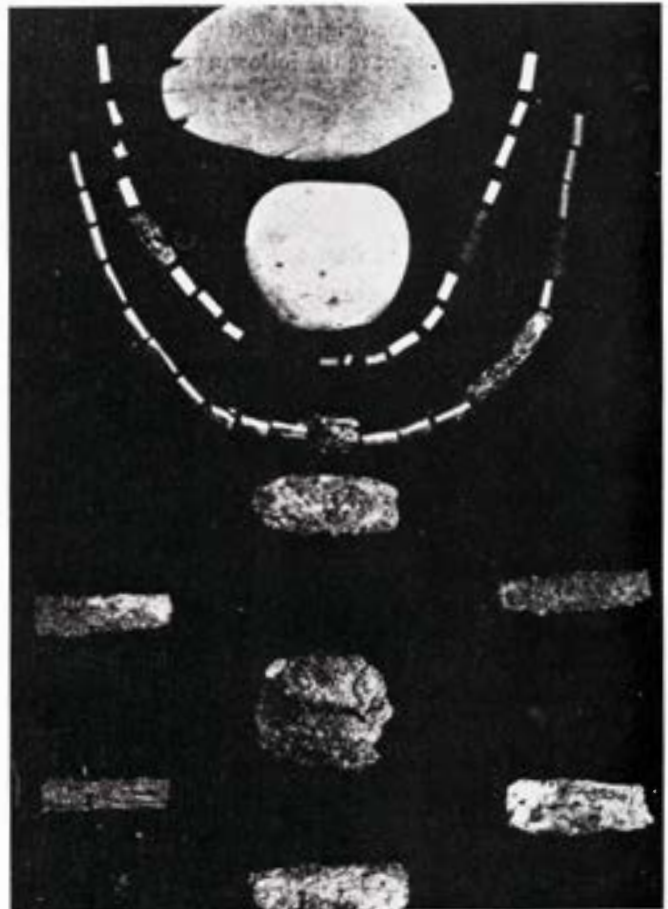

Figure 778. Gerzeh (Brit. Mus.). Two predynastic Egyptian necklaces in which meteoric iron beads (dark) alternate with precious stones (white). Seven of the iron beads are shown at higher magnification below. (From Wainwright 1912.)