COLLECTIONS

South Dakota School of Mines, Rapid City (main mass), Washington (3.26 kg), London (537 g), Tempe (330 g).

DESCRIPTION

The mass, with overall dimensions of 35 x 25 x 16 cm, is covered with 0.1-0.4 mm thick adhering oxide-shales from terrestrial weathering. It is roughly sculptured with thumbprints, 2-5 cm in diameter, and with edges and ridges. There is no doubt that the pits and the general morphology were created in the atmosphere, since the heated rim zone of α_2 is preserved as a 1-2 mm wide zone along the edges of several sections. Corrosion has at the most removed 1 mm, but also penetrates to the center of the sections along grain boundaries.

Etched sections display a somewhat distorted Widmanstätten structure of slightly undulating, long ($\frac{L}{W} \sim 30$) bundled lamellae with a width of 1.15±0.15 mm. About 30% by area is covered by taenite and plessite. The latter is mostly an open-meshed comb plessite, partly resorbed in the matrix, but may also display martensitic and fine-grained, duplex structures. The matrix must have been shocked above 130 k bar, since the ferrite is of the hatched-acicular variety. At high magnification it appears that the matrix is two phased; all linear elements of the hatched structure are, in fact, produced by rows of less than 0.5 μ thick taenite particles. The structure may be interpreted as a result of shock and gentle reheating that decomposed the supersaturated, deformed ferrite. In harmony with this interpretation is the low microhardness of 210±10, as shock-hardened, unannealed ϵ is normally 300±25.

Figure 326. Bear Lodge (U.S.N.M. no. 867). The fine γ-precipitates delineate the previous hatched ϵ-structure. Also four rhabdite crystals. Etched. Scale bar 10 μ.

Schreibersite is only present in minor amounts as 25 μ thick veinlets in the grain boundaries. Rhabdites occur as 1-5 μ thick prisms that often are sheared several microns. Troilite was seen as one scalloped inclusion 3 mm in diameter on a total of 300 cm^2; its microstructure could not be examined as it was in the middle of a large, deep-etched section. Daubreelite is present as 20-50 μ rounded blebs in the matrix.

Bear Lodge is structurally somewhat similar to such irons as Boxhole, Casas Grandes and Merceditas. It is, judging from the structure, a normal group IIIA iron that has been subjected to mild plastic deformation plus, at some later time, an intensive shock plus a mild reheating that may have been associated with the shock.

Specimen in the U.S. National Museum in Washington:
3,265 g endpiece (no. 867, 17 x 16 x 3 cm)

Bechuanaland, South Africa

A meteorite entered under this name in catalogs by Brezina (1896: 306), Wülfing (1897: 23) and Berwerth (1903: 51) is probably a mislabeled Gibeon sample. It never reappeared as a Bechuanaland sample, probably because the owners realized their mistake and corrected it.

Bella Roca, Durango, Mexico
24°55′N, 105°25′W

Medium octahedrite, Om. Bandwidth 0.70±0.10 mm. ϵ-structure. HV 260±10.

Group IIIB. 9.91% Ni, 0.55% Co, 0.85% P, 2% S, 16.7 ppm Ga, 31.1 ppm Ge, 0.014 ppm Ir.

HISTORY

A mass of 33 kg was found before 1888 on a peak of the Sierra de San Francisco, called La Bella Roca, near Santiago Papasquiaro. Acquired by H.A. Ward during one of his collecting trips to Mexico, the meteorite was described by Whitfield (1889), who presented two woodcuts of the exterior appearance. After being cut in slices and widely distributed by Ward, it was described again by Brezina (1896: 271) and by Cohen (1905: 374) with photomicrographs in the Atlas (Brezina & Cohen 1886-1906: plate 37). Etched sections later appeared in many publications, e.g., Ward (1904a), Mauroy (1913), Nininger & Nininger (1950) and Mason (1962a: figure 26).

BEAR LODGE – SELECTED CHEMICAL ANALYSES

	percentage			ppm							
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
O'Harra 1932	8.12											
Moore & Lewis 1968	7.88	0.51	0.14	50	20							

Olsen & Fredriksson (1966) identified the ferrous orthophosphates, sarcopside and graftonite, coexisting as millimeter-sized inclusions in troilite.

COLLECTIONS

Vienna (12.2 kg), London (3.5 kg), New York (2.2 kg), Harvard (1.9 kg), Tempe (716 g), Chicago (680 g), Washington (665 g), Dorpat (612 g), Ottawa (431 g), Yale (405 g), Prague (274 g), Budapest (206 g), Vatican (196 g), Bonn (128 g), Helsinki (125 g), Copenhagen (84 g), Warsaw (55 g), Berlin (38 g).

DESCRIPTION

Before cutting, the three greatest dimensions were 35, 24 and 14 cm. The surface is characterized by many circular depressions, 2-3 cm in diameter, due to partial ablation melting of the near-surface troilite nodules during atmospheric passage. Ablation-melted metal is redeposited in many places as a 1-2 mm thick, laminated lace-like crust. In some areas, terrestrial corrosion has removed it, but the

Figure 327. Bella Roca (Vienna no. G 120). Medium octahedrite of group IIIB. The metal globules in the troilite are situated in the same side. Compare Cape York. Etched. Scale bar in cm.

Figure 328. Bella Roca (Copenhagen no. 1891, 53). General view at low magnification. The shock-hatched kamacite displays various nuances. Large skeleton crystals of schreibersite are common. Deep-etched. Scale bar 300 μ.

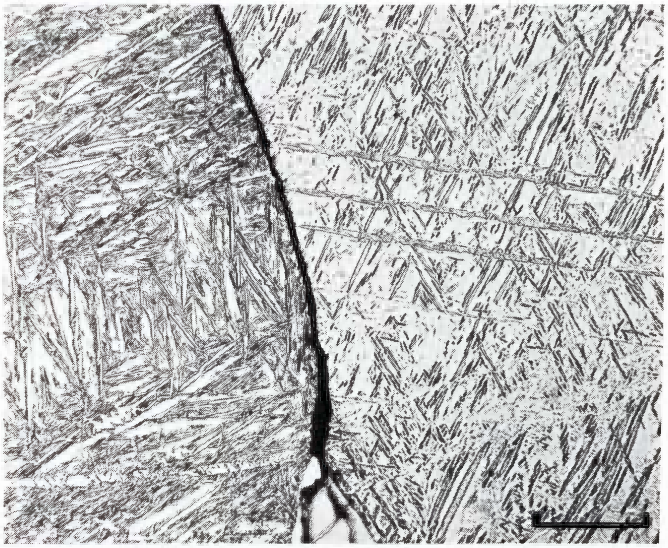

Figure 329. Bella Roca (Copenhagen no. 1891, 53). Two differently oriented kamacite grains display shock-hatched structures of different appearance. The reason is that the attack of the etchant (Nital) is conditioned by the crystallographic orientation of the dissolving material. Etched. Scale bar 50 μ.

BELLA ROCA – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Knauer in Cohen 1905	9.78	0.55	0.31		500		200					
Buchwald 1966, unpubl.	9.75	0.62	0.85							28		
Wasson & Kimberlin 1967	10.16								16.7	31.1	0.014	
Moore & Lewis 1968	9.95	0.47	0.21	105	20		130					

Reed (1956b) analyzed the kamacite with a microprobe and found it homogeneous on the 7.50% Ni level.

corrosion attack is small for an iron meteorite find. The fusion crust has a hardness of 325±25, but locally where it is enriched in phosphides, due to the presence of Brezina lamellae, the hardness increases to above 400. An ablation-heated α_2 zone with a hardness of 210±10, is present to depths between 0.5 and 3 mm. Below the α_2 zone the hardness rapidly rises to interior values of 260±10 (hardness curve type I).

A well-developed Widmanstätten pattern, with an average bandwidth of 0.70 mm, occurs along with 1-2 mm wide ribbons of swathing kamacite, which are common around the larger schreibersite crystals (Brezina lamellae). These crystals, however, tend to obscure the regular Widmanstätten array. Kamacite was converted by shock to the typical hatched ϵ-structure, indicative of shock pressures above 130 k bar. Almost submicroscopic precipitates are present everywhere in the ϵ-phase. The hardness is 260±10.

Taenite and plessite cover 40-50% by area, both as comb and net plessite and as various dense fields. A typical field will exhibit a yellow-etching taenite border (HV 390±20) with some martensite immediately following. Following this, a brown-etching martensitic zone (HV 415±15) may occur, and then probably duplex $\alpha + \gamma$ textures of varying hardness (HV 270-350). The coarser precipitates are associated with the softer structure.

The dominant feature of Bella Roca is a heavy concentration of rather uniformly dispersed schreibersite and troilite. On a 110 cm^2 section 103 schreibersite crystals with a total area of 494 mm^2 were counted. This corresponds to a bulk phosphorus content of 0.85%, a value much larger than the reported chemical values. The typical Brezina lamella is a plate 20 x 10 x 1 mm, but irregular L, H, V and Y shapes are often seen. They are anisotropic and monocrystalline, but brecciated with a microhardness of 885±25. The Brezina lamellae precipitated from the gamma phase before the Widmanstätten pattern formed, and served in many cases as nucleation centers for the precipitating alpha phase.

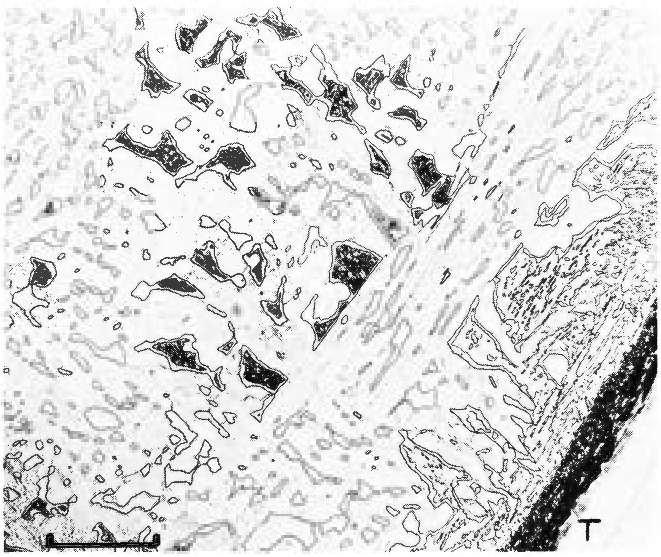

Figure 330. Bella Roca (Copenhagen no. 1891, 53). Taenite rim (T) with black martensitic transition zones and duplex, fine-grained $\alpha + \gamma$ interiors. The α-phase shows subboundaries.

On a total of 156 cm^2 sections were 14 cm^2 troilite (one nodule 2 cm in diameter, one 4 x 2 cm, and several smaller). This corresponds to 2% S, which no doubt is a more realistic bulk value for the meteorite body than the low values quoted in different analyses, apparently on inclusion-free material. The troilite nodules are polycrystalline aggregates of polyhedric, 5-10 μ anisotropic grains, a probable reflection of shock melting and rapid solidification.

Schreibersite is also present as 25-50 μ wide grain-boundary precipitates, and in the interior of many plessite fields as 2-10 μ thick blebs. Rhabdites were not observed. The phosphates described by Olsen & Fredriksson (1966) are present as 1-5 mm almost euhedral, black, shiny, hard inclusions in some troilite nodules. In addition, they occur as 50-200 μ blebs in schreibersite and in the alpha phase. It is interesting to note that large phosphates so far seem to be a characteristic for irons of group IIIB.

Locally, the metal injects a tongue in the troilite nodules, as has been observed in other meteorites, e.g., Chupaderos, Cuernavaca, Altonah, Duchesne and Merceditas, but for which no good explanation has been offered. It may indicate plastic deformation and shear at an elevated temperature on the meteorite parent body.

Along the edge of several specimens the kamacite lamellae are slightly bent. This may be interpreted as evidence of a late atmospheric separation of this mass from another mass not yet identified.

Bella Roca is a shock-hardened medium octahedrite of group IIIB. It resembles closely Augustinovka, Chupaderos and Cuernavaca; were it not for its hardness, it would be extremely difficult to tell Bella Roca apart from the latter two. Bella Roca might be a paired fall with these irons, but this is uncertain as too little is known about the range in hardness and detailed microstructure present in a large meteorite. Bella Roca is about 250 km south of Chupaderos. Except for Gibeon, there are no well-documented paired falls where individual blocks have fallen so far apart. Taking everything into consideration, it must therefore be concluded that Bella Roca is a separate fall.

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

151 g part slice (no. 142, 6.5 x 5 x 0.8 cm)
85 g part slice (no. 1494, 7 x 5 x 0.3 cm)
134 g part slice (no. 2660, 6.5 x 5.5 x 0.6 cm)
85 g part slice (no. 2661, 6.5 x 4.5 x 0.4 cm)
210 g part slice (no. 3286, 12 x 7 x 0.4 cm)

Bellsbank, Cape Province, South Africa

28°5'S, 24°5'E

Phosphide-rich hexahedrite, H. Neumann bands. HV 182±10.

Anomalous. 5.3% Ni, 0.55% Co, 2% P, 39 ppm Ga, 55 ppm Ge, 0.15 ppm Ir.

HISTORY

A mass of 38 kg was discovered in 1955 by a diamond miner, J.W.E. Keeble, on the Bellsbank Estate some 80 km northwest of Kimberley. It was found two feet below the surface in dolomitic limestone, probably in one of the many joints in the dolomite; these joints are cleaned and prospected for eluvial diamonds for short distances away from the kimberlite pipes and fissures. The meteorite was donated to the Geological Survey in Pretoria, and was described and analyzed by Groeneveld (1959) who also presented a map and several photomicrographs. Henderson (1965) gave a short description with a photomacrograph of the specimen in Washington.

COLLECTIONS

Geological Survey Museum, Pretoria (main mass), London (524 g), Washington (343 g).

DESCRIPTIONS

Bellsbank is a weathered mass with approximate overall dimensions of 26 x 22 x 17 cm. Adhering limonitic shale is locally 4 mm thick, and several veins of 30-500 μ wide oxidized material crisscross the polished sections, mainly following the phosphide inclusions. A polished and etched surface shows Bellsbank to be a hexahedrite with an unusually large proportion of schreibersite. The metallic matrix is a ferrite monocrystal larger than 10 cm in diameter, but it is veined by many subgrain boundaries decorated with less than 2 μ wide rhabdite precipitates. Neumann bands are common, and the hardness is 182±10. Locally around schreibersite inclusions, the bands are deformed, and some additional slipline systems indicate plastic deformation with unconformities around the non-metallic inclusions. In such places the hardness increases 20-30 units.

Schreibersite occurs as centimeter-sized crystals and rosettes that occupy 10-15% by area of the polished sections, in harmony with an analytical average of about 2% P. Monocrystalline, the schreibersite has some crystallographic facets, probably developed in accord with the surrounding ferrite lattice; other boundaries may be convex or concave, producing, e.g., the shape of an anchor. The hardness is 960±20, the hardest schreibersite yet measured. It is very low in nickel, about 10%, as reported by Schutte in Groeneveld (1959), apparently supporting my observation that the hardness of schreibersite increases with decreasing nickel content. Phosphides are furthermore common as long and extremely thin plates, e.g., 3 mm long but only 5 μ wide, and as a profusion of rhabdites less than 2 μ in diameter. The larger schreibersite inclusions are surrounded by 2-3 mm wide nickel- and phosphorus-depleted ferrite zones; the smaller inclusions show zones 50-100 μ wide; this gives any heavily etched surface a blotched or stained appearance. In these relatively nickel-poor zones the hardness decreases to 145±5.

Most schreibersite crystals are brecciated and somewhat displaced in accord with the general mild deformation of the metallic matrix. Locally small, rounded inclusions, about 100 μ in diameter, are seen in the schreibersite. They are grayish-blue, opaque and weakly anisotropic, and composed of 20-30 μ grains; they may well be chromium sulphides like Brezinaite. Although troilite was not observed on the London and Washington specimens, it appears to be present, irregularly distributed as usual. A rounded nodule about 10 mm in diameter is located on the specimen photographed by Groeneveld (1959: figure 2); it was not identified by him. The silicates mentioned by Groeneveld could not be confirmed. A heated rim zone from atmospheric penetration has been removed by corrosion, and Neumann bands near the surface are selectively corroded.

Bellsbank is a rather simple hexahedrite, similar to La Primitiva and Tombigbee in its high proportion of schreibersite, poverty of troilite, and several other details. Tombigbee, however, shows areas of recrystallization, and La Primitiva has ε-structure, so there are small, but significant structural differences. Bellsbank is also related to the normal hexahedrites of group IIA, e.g., Uwet, but it is

BELLSBANK – SELECTED CHEMICAL ANALYSES

Schutte also found minor amounts of MgO, SiO_2 and Al_2O_3, which he and Groeneveld attributed to unspecified inclusions of silicates. It may be more plausible, however, that these elements were introduced from the dolomite-kimberlite environment by terrestrial weathering.

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Schutte in Groeneveld 1959												
kamacite	4.53	0.59	0.34	100			200			100		
schreibersite	9.75	0.29	12.49	2500			500					
whole meteorite, calculated	5.28	0.55	2.05	400			200					
Moss in Hey 1966	4.5											
Wasson & Kimberlin 1967	4.13								39.2	54.6	0.15	

far more rich in phosphorus. It is probably best regarded as forming its own distinct group with LaPrimitiva and Tombigbee, as supported also by the trace-element analyses.

Specimen in the U.S. National Museum in Washington:
343 g slice (no. 2162, 10.5 x 7 x 0.9 cm)

Bendegó, Bahia, Brazil
10°7′29″S, 39°4′W; 450 m

Polycrystalline, coarse octahedrite, Og. Bandwidth 1.8±0.3 mm. Neumann bands. HV 175±10.

I – Anomalous. 6.52% Ni, 0.46% Co, 0.22% P, 0.1% C, 0.3% S, 52 ppm Ga, 233 ppm Ge, 0.20 ppm Ir.

HISTORY

A large mass, later shown to weigh 5.36 tons, was found in 1784 by a boy named Bernardino da Motta Botelho, as he was tending his cattle on the slopes above the small river Bendegó; the site is located 35 km north-northeast of Monte Santo and about 250 km from the nearest coast. It lies in the semi-arid backlands, the Brazilian sertão, a region of uncertain rainfall which presents great obstacles to settlement and economic development. As the mass was believed to be silver, 30 men with 20 pair of oxen made an attempt to remove the meteorite in 1785. However, they had to abandon the task after the primitive wheelcart went out of control down the slope; an axle caught fire, and the meteorite and its carriage buried themselves in the dry riverbed, only 180 m from where the journey had begun.

In 1811 Mornay visited the place and recognized the mass as a meteorite; he gave the average dimensions as 7 x 4 x 2 feet and estimated its weight to be 6,400 kg. He also secured a few kilograms of fragments which were sent to Wollaston, the Geological Society (London), the collector Heuland, Alexander von Humboldt, and others. Mornay presented a sketch of the mass and described the chestnut-brown surface as "slightly indented all over, as if it had been hammered with a rather large, round-headed hammer. There are several cavities in it, from the diameter of a 12-pound cannon ball, to that of a musket ball; the larger ones being shallow, but the others much deeper" (Mornay 1816).

Wollaston (1816) showed nickel to be present in significant amounts and also noted the octahedral shape of the detached fragments. He concluded that the material was badly weathered and that the meteorite had fallen in a remote age. Spix & Martius (1828) visited the locality and secured several kilograms of fragments which were distributed to European collections. A forged specimen of 22 g is in the Göttingen collection (no. 343, Koritnig 1962: 356). Partsch (1843) observed the similarity to Bohumilitz, and Wöhler (1860) presented analytical data and two figures of etched sections. Reichenbach (1862a: 627) observed the presence of finger-thick, parallel, belemnitic-columnar fillings of troilite, but most of this had disappeared on his specimen and only holes were left. Other old publications concerning Bendegó (or Bahia as it was often called) are listed in Wülfing (1897: 24).

In 1883, Professor Derby realized that the new railway being constructed about 100 km southwest of the Bendegó locality might provide an opportunity to transport the mass

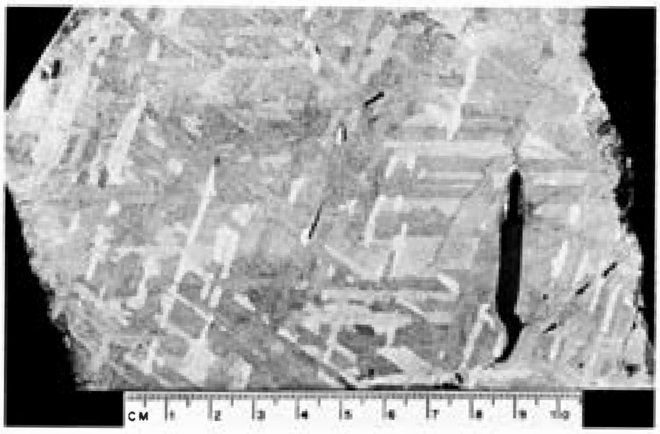

Figure 331. Bendegó (Tempe no. 355.1). A coarse, somewhat anomalous meteorite. A large elongated troilite inclusion and several small ones are seen. Etched. Scale bar in cm. (Courtesy C.B. Moore.)

BENDEGO – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Lovering et al. 1957		0.44				32	174		47	203		
Nichiporuk & Brown 1965											0.3	9.8
Smales et al. 1967						16	142	19	50	232		
Wasson 1968, pers. comm.	6.39								54.0	234	0.20	
Moore & Lewis 1968	6.64	0.47	0.22	155	20		150					
Crocket 1972											0.35	10.9

Reed (1969) found 6.4% Ni, and 0.10% P in solid solution in the kamacite.

to the coast for further shipping to Rio de Janeiro. A retired naval officer, José Carlos de Carvalho, with his son, Vicente, an engineer, devised an ingenious way of hauling the heavy mass to the railway. Their interesting, detailed and bilingual report (1888) tells of the construction of a wrought iron cart with two sets of wheels, one set of cast iron for narrow, light rails, and the other set of wood for the rough terrain over which they, their men and 20 oxen hauled the meteorite 113 km to the newly built railroad. They first ascended from 443 m altitude to 696 m, and from there slowly descended to about 300 m, passing many gorges and rivulets. The transport, which lasted for 172 days and often had to stop for trivial repairs, was not without dramatic moments, as when (1888: 41) the cart ran wild down a slope heading for a gorge but fortunately came to an early stop by turning a somersault. The weight of the mass registered on the railroad scales was 5,360 kg. Derby (1896) gave a detailed description of the history, structure and composition of the mass with many photographs. He confirmed the parallel troilite rods, and further showed cohenite to be present in significant amounts.

A 62 kg piece was cut from one side of the meteorite; a part of this is still in Rio, while at least 10 kg was distributed through Kunz and Ward (Ward 1892; Wülfing 1897). A good photograph of the mass, as exhibited in Rio de Janeiro, was given by Vidal (1936). Perry (1944) gave a photomicrograph, and Curvello (1958) discussed the troilite crystals, arguing that they showed a peculiar exsolution structure of α-troilite and β-troilite. Olsen (1964) included Bendegó in his study of the stability of cohenite, in which he concluded that cohenite may have persisted metastably during low-temperature annealing of the metal phase and therefore is not a reliable high pressure indicator. An English translation and description of the transport in 1887-1888 was recently presented by Sears (1963).

Isotope and age studies have been presented by Hayakawa et al. (1961), Voshage & Hintenberger (1963) and most recently reviewed by Voshage (1967), who found a $^{40}K/^{41}K$ cosmic ray exposure age 910±90 million years.

COLLECTIONS

Rio de Janeiro, National Museum (about 5,300 kg and a large slice); London (3.5 kg), Munich (3.0 kg), Chicago (2.7 kg), Tübingen (2.6 kg), Vienna (2.4 kg), Washington (2.0 kg), Paris (1.5 kg), Tempe (901 g), New York (?? g), Copenhagen (886 g).

DESCRIPTION

The mass as exhibited in the National Museum in Rio de Janeiro is irregular in shape, with a beak at one end and a reentrant portion at the opposite end. It somewhat resembles a huge mitten and has average dimensions of 220 x 145 x 58 cm. A large surface of 108 x 39 cm is cut and roughly polished so that the parallel orientation of the troilite bodies can be observed.

As noted by Mornay (1816) there are numerous pits and cavities. On the top side they are particularly prominent, being, e.g., 6 x 3 cm across and 6 cm deep, 16 x 9 cm across and 6 cm deep, 10 x 10 cm across and 6 cm deep. There are also smaller holes, 1-2 cm across and a few centimeters deep, as well as some parallel 1 cm wide grooves. These smaller holes and grooves no doubt were produced when the meteorite penetrated the Earth's atmosphere and troilite inclusions ablated away more rapidly than the surrounding metal. The larger holes may have started the same way, and then perhaps became enlarged and undercut by localized terrestrial corrosion.

On the underside there are no holes of the type observed on the top side. Instead, the surface is covered by large shallow pits. Perhaps this may be explained best with the assumption that holes were present all over immediately after landing, but that a long exposure to terrestrial surroundings created significant differences between the uncovered top side and the buried underside. The buried underside would be exposed to bulk corrosion from terrestrial groundwater, while the top side at most would suffer some local attack from standing pools of rain water. Locally 1-2 cm^2 patches of weathered fusion crust have in fact been preserved on the top side, supporting this viewpoint.

Thus, it may be cautiously concluded that the present top side quite closely represents the shape after landing, while the buried underside has lost a skin of 10-30 mm thickness by weathering. Corrosion does not, however, penetrate very far into the massive interior and cannot be made responsible for the major shape of the mass with several reentrant angles.

Large polished slabs show two significant features, namely, polycrystallinity and parallel troilite cylinders. The grain boundaries between the original large (>25 cm in diameter) austenite crystals are straight or gently curved and distinctly seen because there are 50-200 μ wide schreibersite precipitates in them, and because corrosion has primarily attacked along them. Adjacent grains do not

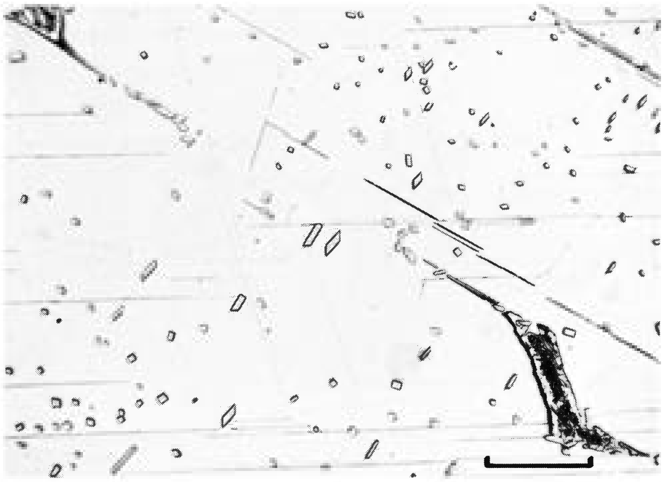

Figure 332. Bendegó (Chicago no. 5). A host of large rhabdite needles, and numerous Neumann bands in the kamacite. Two acicular plessite fields. Etched. Scale bar 400 μ.

appear to be in twin position. The Widmanstätten structure is well developed with a bandwidth of 1.80±0.30 mm. Due to considerable grain growth of the ferrite phase, most linear boundaries are now curved and irregular, and locally almost equiaxial ferrite grains, e.g., 8 x 12 or 4 x 5 mm in size, may be seen. Neumann bands are well developed, and the hardness is 175±10. Taenite is very scarce, only present locally as 5-10 μ wide ribbons. Somewhat more common are almost resorbed 100-500 μ wide plessite fields, which may be developed as comb plessite or have acicular, spheroidized, or pearlitic interiors. The untransformed taenite ribbons have hardnesses of 300±30, while the acicular martensite has the unusual high hardness of 650±30. Many fields, originally squeezed between neighboring kamacite lamellae, are now completely enveloped by any lamella able to move its grain boundaries under the grain growth process. Subboundaries in α are common, especially where plessite "recently" was present.

Schreibersite is mainly observed as 25-100 μ monocrystalline grain boundary precipitates between adjacent kamacite lamellae. Some are located as 10-20 μ irregular particles in plessite, and some are present as 5-20 μ inclusions in the cohenite crystals. A special, not very conspicuous, form consists of 50 x 20 μ irregular bodies, composed mainly of cohenite with 10-25% schreibersite inclusions; these intergrowths have also been observed in several other irons, e.g., Santa Rosa and Arispe. Rhabdites exist in profusion, in sizes from 50 μ to 5 μ in diameter. The longer ones are often sheared and displaced 5-10 μ along Neumann bands.

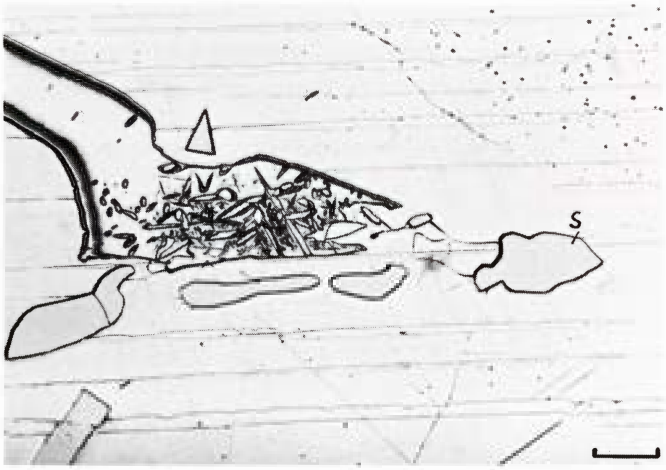

Figure 333. Bendegó (Chicago no. 5). Grain boundary schreibersite (S) and an acicular plessite field that repeats the bulk Widmanstätten directions. Etched. Scale bar 50 μ.

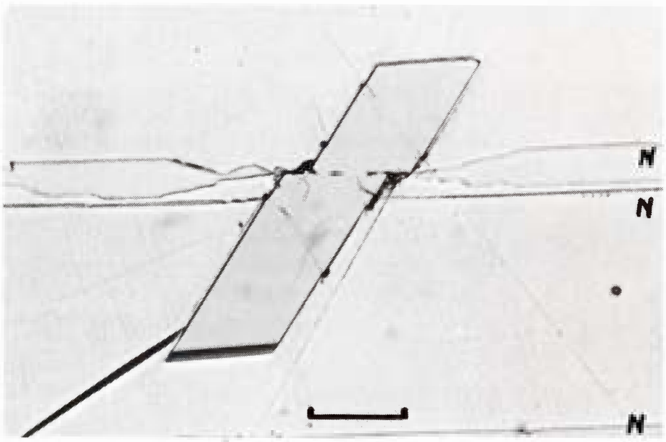

Figure 334. Bendegó (Chicago no. 5). A rhabdite needle was shear-displaced as a consequence of twin formation in the ferrite phase. Neumann bands (twins) marked N. Etched. Scale bar 20 μ.

Pencil-like troilite inclusions are arranged parallel or almost parallel to the exterior flattened sides of the meteorite. Typically 50 mm long and 7 mm in diameter, they have tapered ends and other minor deviations from full symmetry, frequently appearing to be ellipsoidal rather than spherical. When this is the case, the ellipsoids have roughly parallel major axes. The troilite has daubreelite lamellae, which as usual are exsolved parallel to (0001) of the hexagonal troilite. The troilite is monocrystalline, but with a profusion of lenticular twins, indicating plastic deformation that perhaps occurred simultaneously with the Neumann band formation. No trace was observed of the α- and β-exolution lamellae of which Curvello (1958) speaks. The average sulphur content was estimated by point counting of large sections. On 3,500 cm^2 31 inclusions with a total area of 4,650 mm^2 were registered, corresponding to about 0.3% S.

Chromite is present as 1-10 mm tabular octahedrons (U.S.N.M., no. 2663), the facets of which were measured by Hussak (Derby 1896: 165). They are rather rare in the α-matrix, but are frequently found as euhedric inclusions in troilite. Here they are completely penetrated by 1-10 μ thick veinlets, which explains Derby's observation regarding their unusual brittleness, falling into splinters at the slightest pressure. A close inspection shows that the chromite fragments are slightly rounded, and that the veinlets normally consist of troilite, but may consist of daubreelite, schreibersite and metal.

Cohenite is irregularly distributed; where most abundant, it is centrally clustered in the α-lamellae as 0.5 mm wide fingers and rosettes near the larger troilite cylinders. Point counting of a large section showed an area percentage of 1.4, corresponding to about 0.09% C. If we add the 0.01% C found by Moore & Lewis (1968) in the matrix, we have 0.1% C as a fair average for the whole mass. Derby (1896: 138) presented a good chemical analysis for cohenite-isolates: 2.20% Ni + Co, 6.73% C, 91% Fe, and he also found 5.7% schreibersite; the result is typical for cohenite intergrown with minor amounts of schreibersite, so often seen in coarse octahedrites.

Schreibersite and cohenite do occasionally form the well-known 0.1-0.5 mm swathing rims around troilite; these are, of course, nothing more than precipitates from the solid state onto favorable nucleation sites. Graphite has been reported by Reichenbach (1862a); if present it is in very minor quantities and irregularly distributed, since it was not observed here on a total of 3,500 cm^2.

Haxonite occurs as scattered, small and irregular particles, usually intergrown with kamacite, taenite and schreibersite, forming "roses;" unless viewed under crossed Nicols the isotropic haxonite may easily be mistaken for cohenite or schreibersite.

The genetically most important characteristic of the unusual Bendegó meteorite is the parallel troilite bodies which indicate that the meteorite solidified slowly in the weak gravity field of a minor planet, much like Cape York. However, since the two meteorites are widely different in chemical composition and structural details, they probably came from entirely different places. In chemical composition, Bendegó is somewhat related to Arispe and Santa Rosa, but in details it differs. Structurally it is in some respects similar to Campo del Cielo and Seeläsgen (and many group I meteorites), and to Arispe and Santa Rosa, but again in details and total assemblage there are significant differences: in polycrystallinity, troilite- and cohenite-morphology, and bandwidth. No other meteorite thus pairs perfectly with Bendegó.

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

132 g part slice (no. 351, 11 x 4 x 0.4 cm)
104 g fragment (no. 2207, 6 x 4 x 1 cm)
1,017 g part slice (no. 2323, 19 x 12 x 1 cm)
253 g fragment (no. 2663, 10 x 3 x 2 cm)
420 g part slice (no. 3287, 11 x 5.5 x 1 cm)

Bennett County, South Dakota, U.S.A.
43°20'N, 101°15'W

Hexahedrite, H. Single crystal larger than 25 cm. Neumann bands. HV 165±10.

Group IIA. 5.37% Ni, 0.44% Co, 0.23% P, 57 ppm Ga, 181 ppm Ge, 44 ppm Ir.

HISTORY

A mass of 89 kg was found in 1934 by a farmer disking a field before planting corn on the ranch of W.L. Dale. The ranch is located at the head of Black Pipe Creek, Bennett County, about 20 km south-southwest of Norris, and has the coordinates given above. The meteorite was preliminarily described with an analysis by O'Harra (1935). Henderson (1948: plate 3) gave a photomacrograph of the specimen in the U.S. National Museum, and this was reprinted by Mason (1962a: figure 51). Nininger & Nininger (1950: plate 12) presented a photograph of another section.

COLLECTIONS

South Dakota State School of Mines, Rapid City (main mass of about 75 kg), Washington (8,135 g), Tempe (1,311 g), London (950 g).

DESCRIPTION

The irregular, angular mass has maximum dimensions of 41 x 32 x 27 cm. It is somewhat weathered, but warty and striated ablation crusts may still be found in protected places. There is thus no doubt that the main morphology of angular edges and 2-5 cm thumbprint marks are due to atmospheric penetration and were only slightly modified by later terrestrial corrosion. This view is corroborated when etched slices are inspected. The heated α_2 rim zone is 0.2-2 mm in width and before corrosion set in was probably 2-3 mm wide, dependent on the actual curvature of the surface.

Figure 335. Bennett County (U.S.N.M. no. 1199). Deep-etched endpiece. Neumann bands run uninterruptedly from edge to edge. Lenticular troilite-daubreelite aggregates (T) are black. Scale bar 20 mm. S.I. neg. 36094.

BENNETT COUNTY – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	**Ni**	**Co**	**P**	**C**	**S**	**Cr**	**Cu**	**Zn**	**Ga**	**Ge**	**Ir**	**Pt**
O'Harra 1935	5.25	0.46			400							
Smales et al. 1967						169	136	0.48	55	182		
Moore & Lewis 1968	5.59	0.42	0.23	80	330		150					
Wasson 1969	5.28								59.1	179	41	
Crocket 1972											47	12

Etched slices show conspicuous sets of Neumann bands crossing the mottled surface in four directions; several other directions are represented on a microscopic scale. This indicates that Bennett County is a single ferrite crystal, larger than 25 cm in diameter. The microhardness of the matrix is 165±10. It decreases to a minimum of 145 at the transition to the α_2 zone, which ranges from 150 to 195 in hardness, being hardest where the metallic matrix has become most phosphorized by resorption of the rhabdites. Some of the Neumann band systems are decomposed to shorter ribbons, decorated along both sides with rhabdites 2-5 μ across. This morphology corresponds closely to that described and illustrated from Scottsville (Buchwald 1967a: 54, figures 53-57). Most of the Neumann bands are straight, very narrow ribbons that penetrate a matrix loaded with 0.5-2 μ rhabdites. Locally larger rhabdites, e.g., 400 x 2 μ or 50 x 25 μ crystals, occur singly or in clusters.

Troilite is common as 0.3-5 mm nodules and lenticular bodies, which contain 20-40% daubreelite. The troilite is shock melted and solidified to aggregates of 1-2 μ grains with 1 μ metallic beads in a eutectic structure. The daubreelite is shattered and dispersed as 5-15 μ subangular fragments in the melt. Preexisting 10-50 μ wide rims of schreibersite are preserved but partially penetrated by veinlets of shock-melted troilite. Locally 50-100 μ ill-defined blebs of graphite clusters are composed of radiating sheaves.

Bennett County is a shocked hexahedrite exhibiting a relatively high proportion of daubreelite and decorated Neumann bands. Closely resembling Scottsville in structure and chemistry, it belongs to group IIA.

Specimen in the U.S. National Museum in Washington:
8,135 g endpiece (no. 1199, 21 x 19 x 6 cm)

Billings, Missouri, U.S.A.

37°4'N, 93°29'W; 400 m

Medium octahedrite, Om. Bandwidth 1.15±0.15 mm. ϵ-structure. HV 235±15.

Group IIIA. 7.84% Ni, 0.49% Co, 0.10% P, 19.6 ppm Ga, 37.4 ppm Ge, 4.0 ppm Ir.

HISTORY

A mass of 24.5 kg was found by George Wolf during farm work in 1903 about 6 km east of Billings, Christian County. It was exhibited at a street fair in Billings in the same year and took first prize – as an iron ore! A horseshoe nail was forged from a part of it and a hole was drilled to test its quality. Eventually it was obtained by Ward, who described it (1905) and cut and distributed about half.

COLLECTIONS

Chicago (11.9 kg half mass and 925 g slice), New York (2.20 kg), London (590 g), Harvard (531 g), Tempe (510 g), Washington (434 g), Helsinki (362 g), Budapest (305 g), Vatican (73 g), Yale (15 g).

DESCRIPTION

The mass had the shape of an ax or hatchet, with maximum dimensions of 38 x 22 x 12 cm (Ward 1905). The half mass in Chicago measures 17 x 16 x 8.5 cm and exhibits two cut faces, mutually perpendicular. The mass is weathered, and exfoliation along the Widmanstätten lamellae is present at one end. The fusion crust and heat-affected α_2 zone have disappeared. Since the hardness of the kamacite lamellae exhibits a significant drop to about 200 towards the surface, it is estimated that on the average a zone 3-4 mm thick has been lost by corrosion. The corrosion also penetrates the whole mass along Widmanstätten planes and phase boundaries, and selective corrosion is frequent around the various phosphides.

Etched sections display a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 25$) kamacite lamellae with a width of 1.15±0.15 mm. The kamacite is of the contrast-rich, crosshatched ϵ-type normally associated with shock pressures above 130 k bar. Its hardness is, however, surprisingly low, 235±15, suggesting an annealing effect, either preterrestrially or connected with the activities mentioned above in Billings. The second possibility appears the more plausible.

Taenite and plessite cover about 30% by area, mostly as open-meshed comb and net plessite. Black taenite, i.e., dark-etching, martensitic or duplex $\alpha + \gamma$ fields, is common. A typical triangular field will exhibit a yellow taenite rim (HV 325±25), followed by a martensitic transition zone (HV 455±25), black martensite (HV 360±30) and finally, in the center, poorly resolvable duplex $\alpha + \gamma$ structures (HV 250±25). The coarsest interiors approach the surrounding kamacite lamellae in hardness.

Schreibersite occurs sparingly, in harmony with the analysis, as 20-50 μ wide grain boundary veins and as tiny

BILLINGS – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Smales et al. 1967						69	154	2.0	21.1	38		
Moore & Lewis 1968	7.91	0.49	0.10	120	30		175					
Wasson 1969, pers. comm.	7.77								19.6	37.4	3.7	
Crocket 1972											4.3	12

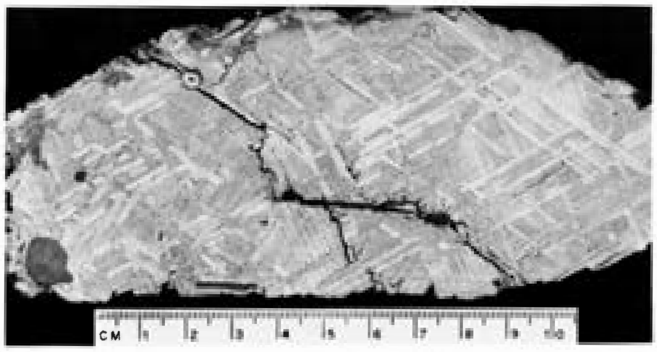

Figure 336. Billings (Tempe no. 151a). Medium octahedrite of group IIIA. Troilite as globules and lenticular bodies. Black is terrestrial limonite along Widmanstätten grain boundaries. Etched. Scale bar in cm. (Courtesy C.B. Moore.)

blebs inside the plessite. Rhabdites, 1-4 μ across, are common. The phosphides are anisotropic and monocrystalline, and often crystallographically similarly oriented along the same grain boundary.

Troilite occurs locally as a 10 mm nodule with a discontinuous 0.1 mm thick schreibersite rim, which is followed by a 1 mm thick rim of swathing kamacite. It is also present as elongated or lenticular bodies, e.g., 10 x 1 or 2 x 1 mm in size.

The operations of the blacksmith, noted by Ward, have not visibly damaged the specimens I have seen (Tempe no. 151a, Helsinki no. A 1589, and the Washington specimens). Perhaps the somewhat low hardnesses are an effect of imperfect artificial annealing.

Billings is a typical group IIIA iron, similar to, e.g., La Porte, Cape York and Glasgow.

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

407 g slice (no. 444, 17 x 7.5 x 0.6 cm)
27 g fragments (no. 2665)

Bingera, New South Wales, Australia
29°51′S, 150°38′E

Hexahedrite, H. Recrystallized to 1 mm grains. A few Neumann bands. HV 155±5.

Group IIA. 5.64% Ni, 0.49% Co, 0.24% P, 59 ppm Ga, 185 ppm Ge, 3.2 ppm Ir.

Barraba and Warialda are part of the Bingera shower and are here and elsewhere called Bingera No. 3 and No. 4.

HISTORY

A small, pear-shaped mass of 241 g (No. 1) was found by gold miners in 1880 near Bingera (now Bingara) in Murchison County (Liversidge 1882). Before 1904 another mass of about 1.4 kg (No. 3) was found near Hillgrove and Barraba and was described under the name Barraba, with a photograph of the exterior (Mingaye 1904). A third mass of 2.8 kg (No. 4) was found in 1919 near Adams Scrub on W. Campbell's property 24 km north of Bingara. This locality is, however, only 10 km from Warialda, and, consequently, the specimen was described under this name by Mingaye (1921) who also presented macro- and microphotographs of the other known Bingera specimens. The largest mass, 6.4 kg (No. 2), was found before 1924 about 15 km north of Bingara, and was analyzed as Bingera No. 2 (White 1925). Comparing the little we know of the localities, it becomes apparent that the shower extended along a north-south line at least 40 km long. Bingara is located approximately midway, and the coordinates given above are for this village.

Besides by the already mentioned authors, description and photographs have been presented by Brezina (1896), Cohen (1899; 1905). Berwerth (1914: 1055, 1066), Hodge-Smith (1939) and Henderson (1965). Lovering and Parry (1962) examined the thermomagnetic properties. Most authors agree that the various specimens belong to one fall. They are, nevertheless, listed with separate entries in several modern catalogs, e.g., Hey (1966), and often counted separately in statistical studies, a praxis which should be discontinued.

COLLECTIONS

Sydney (54 g No. 1; 4.4 kg No. 2; 337 g No. 3; 2.5 kg No. 4), New York (268 g No. 2; 93 g No. 4), London (15 g No. 1; 228 g No. 2), Washington (63 g No. 2; 38 g No. 3; 95 g No. 4), Vienna (85 g No. 1; about 150 g No. 3), Chicago (1 g No. 1; 3 g No. 4), Canberra (584 g), Copenhagen (163 g).

DESCRIPTION

The four masses are individuals with flight markings on all sides, and with a well-preserved, black, brittle fusion crust consisting of magnetite and wüstite. No. 1 has the size and form of a nose and is smooth, while the somewhat larger, other specimens are platy (No. 3) or otherwise

BINGERA – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Mingaye 1904 (No. 3)	5.54	0.51	0.26	250			100					
Mingaye 1921 (No. 4)	5.68	0.78	0.22	1200								
Lovering et al. 1957												
(No. 2)	5.75	0.54				33	118		66	170		
(No. 3)		0.46				55	107		46	126		
(No. 4)	5.66	0.45				53	139		45	143		
Wasson 1969 (No. 2)	5.58								59.7	185	3.2	

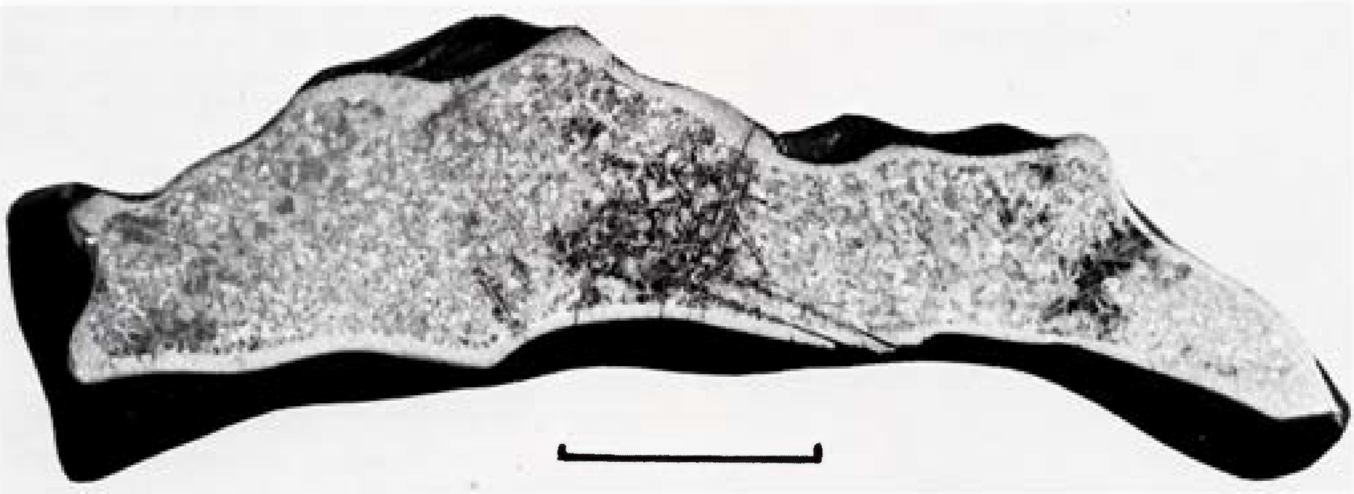

Figure 337. Bingera (Vienna no. J 2667). A section through the whole Barraba mass, No. 3. The heat-affected α_2 zone forms a continuous matte band around the unaffected, recrystallized interior. Etched. Scale bar 20 mm.

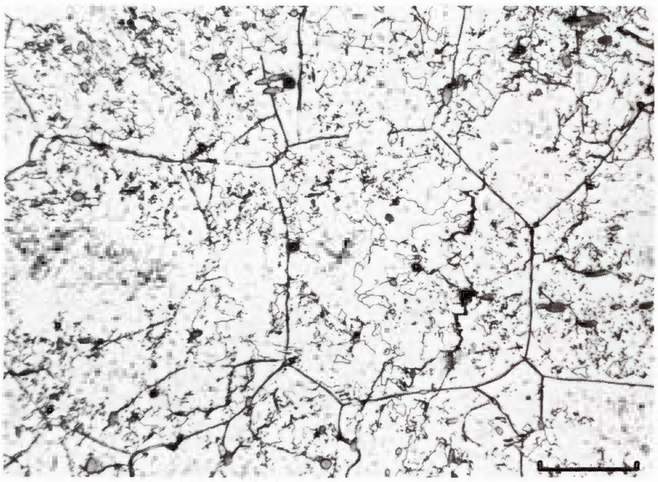

Figure 338. Bingera (U.S.N.M. no. 1744). Heat-affected α_2 zone of mass No. 3. Although transformed to unequilibrated α_2 structure, the matrix still displays the old boundaries of the equiaxial, recrystallized grains. Etched. Scale bar 200 μ.

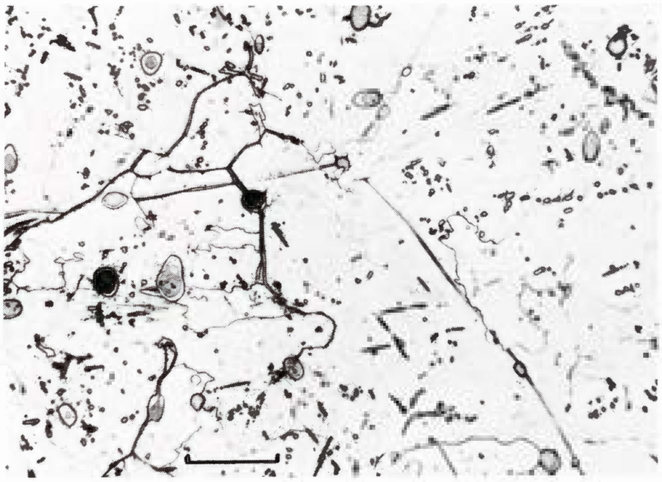

Figure 339. Bingera (U.S.N.M. no. 1744). Detail of the heat-affected zone A, with micromelted phosphides. Three old kamacite grains meet near the center. Zigzagging phosphide melts are in the left half of the photo. Etched. Scale bar 40 μ.

irregular and have numerous 1-2 cm wide thumbmarks. All have heat-affected α_2 rim zones of 1-2.5 mm width, and all are covered with an ablation crust consisting of laminated, metallic sheets of several generations, overlapping each other discordantly in up to 7 layers of 1 mm total thickness. The dendritic, metallic fusion crust has a hardness of 315±15. The meteorite parent mass must have split in the high atmosphere, and the individuals must have had long independent pathways before they hit the ground, in harmony with what we know of their locations. The surroundings of the near-surface schreibersite inclusions are somewhat corroded, but otherwise the specimens are well preserved. The heat-affected α_2 zone has a hardness of 185±20 decreasing to a minimum of 145±5 at the transition to the unaffected interior, which has a hardness of 155±5 (hardness curve type II).

The interior is composed of polygonal ferrite grains about 1 mm in diameter, with extremes of 0.1 and 3 mm. The larger grains are normally found around the schreibersite and troilite inclusions, probably because the matrix here is rather poor in growth-impeding inclusions, and perhaps it also reached a somewhat higher peak temperature during recrystallization, assuming that the sulfide inclusions in particular were shock absorbers. Neumann bands appear locally, apparently associated with the fracture zones from the violent atmospheric splitting; large areas away from these zones are free of Neumann bands. Subboundaries with less than 1 μ rhabdite precipitates are common. These precipitates have visibly impeded the grain growth of ferrite in many places. Locally, loops of 5-25 μ grains have become arrested in their grain growth and appear as isolated islands. Bingera has, however, come farther against a state of equilibrium than the related meteorites Kopjes Vlei, Forsyth County and others. The kamacite has a uniform hardness of 155±5, corresponding to well-annealed material.

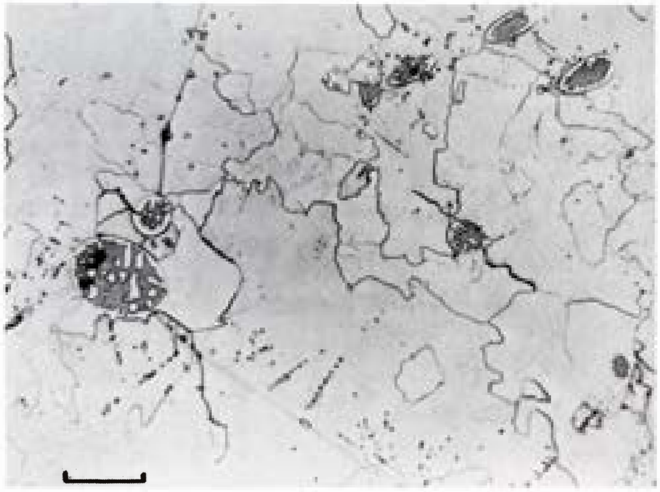

Figure 340. Bingera (U.S.N.M. no. 1744). Detail of zone A. Serrated α_2 blocks have grown across old recrystallized grain boundaries. Dendrites inside rhabdite micromelts. Etched. Scale bar 50 μ.

Rhabdites are present in parallel planes with, on the average, 10 mm distance. The individual platelets are typically 2 x 0.1 mm, and they are monocrystalline but fractured. Rhabdites are also extremely common as 5-10 μ thick prisms, but all are well rounded because the parent kamacite phase has recrystallized, and in the process the rhabdites have had to readjust themselves. This rhabdite distribution resembles that of Hex River.

Troilite-daubreelite-schreibersite intergrowths occur as 10 x 4 or 6 x 3 mm nodules, micromelted and/or fragmented due to shock. Now the nodules consist of 2 μ grains of sulfide, daubreelite and schreibersite, in which larger fragments of schreibersite and daubreelite with tiny metallic inclusions are dispersed. Ferritic islands, 25 μ in diameter, or aggregates of these, are also common, and the boundary between the nodules and the metallic matrix is converted to a spongy network of ferrite with sulfide in the grain boundaries. The hardness of the shock melts ranges from 180 to 250, depending upon the actual proportions of the components.

Graphite, which is rare in group IIA, is present in narrow rim zones around some of the schreibersite crystals. It is developed as feathery flakes, 100-200 μ long and 2-5 μ wide, and is situated in much the same way as graphite that is deposited during the decomposition of cohenite in group I meteorites, e.g., Oscuro Mountains, Wichita County and Dungannon.

The structure of Bingera may be interpreted as that of a normal hexahedrite, like Hex River, that after initial cooling suffered significant cosmic reheating, probably the result of severe shock as indicated by the morphology of the troilite nodules. The metallic matrix recrystallized, and the sharp facets of the rhabdite crystals were destroyed, but they were never completely dissolved, as probably occurred in, e.g., Kopjes Vlei. The Neumann bands disappeared and the cohenite rims decomposed to graphite. Various developments of the same theme, probably because of different shock intensities and associated relaxation temperatures, may be observed in Boguslavka, Indian Valley, Keen Mountain, Forsyth County, Zacatecas (1969) and Dungannon.

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

63 g part slice, No. 2 (no. 1743, 6 x 5 x 0.5 cm)
38 g corner, No. 3 (no. 1744, 3 x 2 x 1 cm)
95 g slice, No. 4 (no. 1745, 6 x 4 x 0.8 cm)

Bischtübe, Kustanai Oblast, Kazakh SSR
51°57'N, 62°12'E

Coarse octahedrite, Og. Bandwidth 1.80±0.30 mm. Neumann bands. HV 172±10.

Group I. 7.50% Ni, 0.39% P, 0.1% C, 68 ppm Ga, 238 ppm Ge, 1.9 ppm Ir.

HISTORY

A mass of about 2 Pud (~ 33 kg) was plowed up in 1888 by Kirghize farmers 3 km north of the village Bischtübe. Searching revealed another fragment of about 17 kg and one of 205 g within a meter's distance and only 30-40 cm below the surface. The smallest mass was acquired by Kislakovsky who used it up in his investigation, published 1890. He correctly observed that Bischtübe was very similar to Toluca. Brezina (1896) gave a short metallographical description, and Cohen (1897a) presented detailed analyses of the separate constituents, kamacite, taenite and schreibersite, besides the total analysis quoted below. Zavaritskij & Kvasha (1952) described the specimen in Moscow, and Zavaritskij (1954) discussed the plessite morphology. Buchwald (1966) gave a photomicrograph of grain growth around schreibersite, and Jaeger & Lipschutz (1967b) X-rayed schreibersite crystals and showed them to be unshocked. Starik et al. (1960; 1963), Fisher (1963) and Sobotovich (1964) discussed the age problems, and

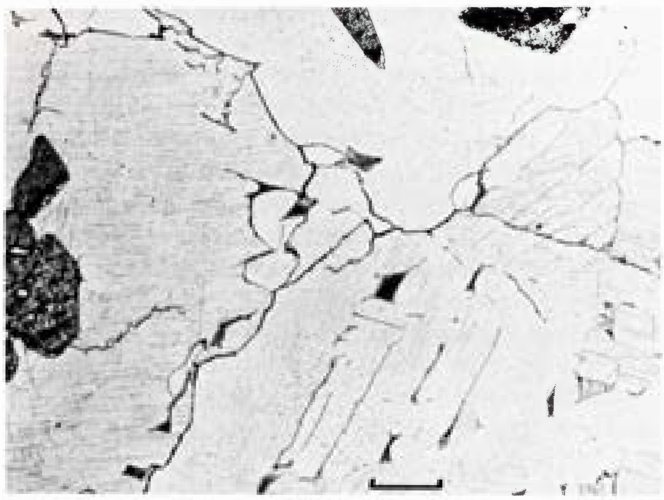

Figure 341. Bischtübe (Copenhagen no. 1903, 1362). Grain growth, mainly on part of swathing kamacite around troilite-graphite-silicate aggregates, has partially washed out the previous Widmanstätten structure. Etched. Scale bar 2 mm. See also Figure 98.

Voshage (1967) found the cosmic radiation age to be 825±80 million years.

COLLECTIONS

Three-fourths of the largest mass (24.6 kg) is in Leningrad, an endpiece is in Bonn (5.7 kg). The 17 kg mass was divided into 7-10 mm thick plates about the year 1900, probably by Stürtz or Krantz in Bonn, and was widely distributed: Washington (3.4 kg), Chicago (2.5 kg), London (1.9 kg), Vienna (1.9 kg), Uppsala (1.7 kg), New York (402 g), Yale (361 g), Harvard (333 g), Stockholm (288 g), Prague (270 g), Tübingen (267 g), Budapest (221 g), Copenhagen (216 g), Philadelphia (199 g), Amherst (149 g), Paris (45 g), Vatican (31 g), Moscow (12 g). The total preserved weight is thus over 45 kg, including a few minor specimens not specified here. This is in harmony with the original report of a total of about 50 kg.

DESCRIPTION

The exterior dimensions are not reported, but the smaller 17 kg mass must have been an irregular parallelepiped with overall dimensions of about 23 x 15 x 13 cm. The three pieces were found within a meter's distance, suggesting the mass first broke up upon impact with the Earth, or under later corrosion. The masses are weathered, with adhering oxides up to 1 mm thick; some limonitic veins are present in the interior, especially along grain boundaries and sulphide-phosphide inclusions. However,

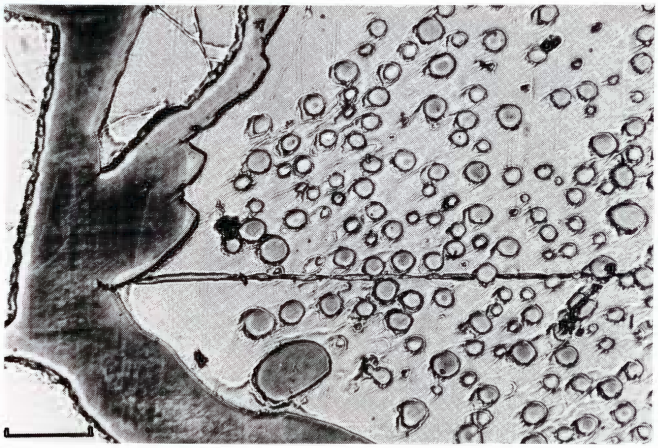

Figure 343. Bischtübe (Copenhagen no. 1903, 1362). Cloudy taenite around spheroidized plessite. A deformation twin in the kamacite proceeds horizontally across the photo. Etched. Scale bar 30 μ.

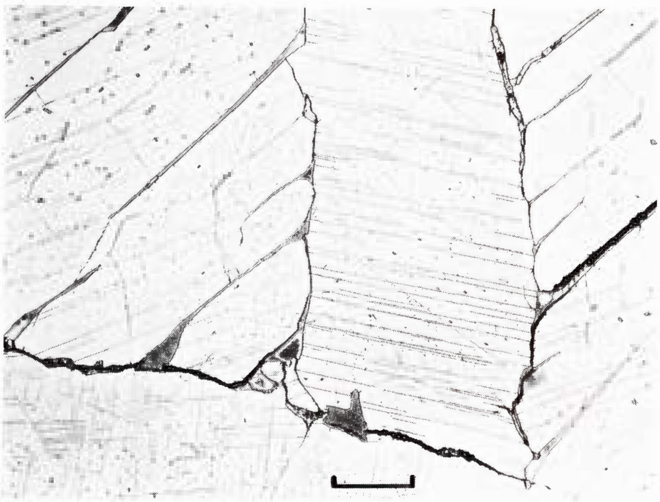

Figure 342. Bischtübe. Detail of right side of Figure 341. Subboundaries, Neumann bands and rhabdites are obvious in the kamacite. Taenite and plessite are almost resorbed. Etched. Scale bar 500 μ.

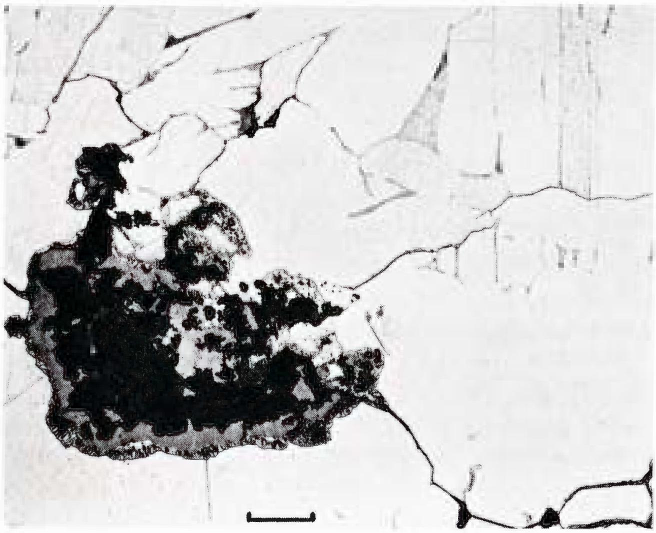

Figure 344. Bischtübe (Copenhagen no. 1903, 1362). A view of a complex nodule. Silicates and graphite (black), troilite (gray), schreibersite (light gray) and decomposing cohenite (exterior rim). See also Figure 345. Etched. Scale bar 200 μ.

BISCHTÜBE – SELECTED CHEMICAL ANALYSES

Excluding the 1957 analysis as erroneous (mislabeled material?) we find an average nickel value of 7.50%. The discrepancies are, however, so significant that a new analysis would be helpful. Kislakovsky (1890) reported 8% anorthite and 9.9% olivine, and he isolated some of the silicate grains.

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Cohen 1897a	7.12	0.84	0.39	1000			200					
Lovering et al. 1957	6.52	0.42				23	112		50	157		
Smales et al. 1967						10.1	137		63	218		
Wasson 1970	7.88								68.4	238	1.9	

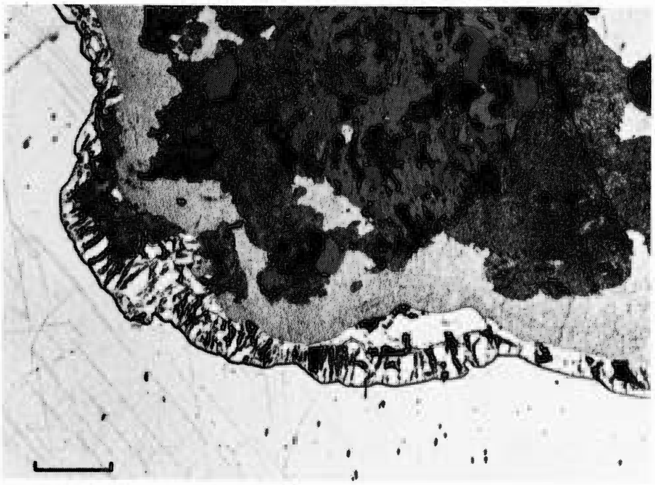

Figure 345. Bischtübe. Detail of Figure 344. Silicates (glossy black), graphite (black), troilite (gray), schreibersite (white), and kamacite matrix with rhabdites. The 200 μ wide exterior cohenite rim is cracked and has partially decomposed to granulated ferrite and lamellar graphite. Etched. Scale bar 500 μ.

the heated rim zone with α_2 structure is still preserved locally, e.g., on the Copenhagen specimen no. 1903, 1362.

The Widmanstätten structure is coarse-octahedric with α-bandwidths of 1.8±0.3 mm. Some α-grain growth has started, eliminating the straight lamella boundaries and locally creating almost equiaxial grains 5-10 mm in diameter. All ferrite is beset with Neumann bands. The microhardness is 172±10. Taenite and plessite cover 2-5% by area; plessite fields may have martensitic, pearlitic or spheroidised interiors, normal for group I irons, or they may be developed as ordinary comb plessite. Minute amounts of haxonite occur in some of the plessite fields.

A dominant feature is the irregular distribution of schreibersite crystals. These occur as elongated bodies, 35 x 1.5 mm, hollow prisms, 10 x 10 mm, or massive aggregates, 8 x 6 mm in size with small "windows" of α-iron. Monocrystalline but heavily brecciated, they are surrounded by 2-5 mm of swathing kamacite. No doubt these crystals precipitated from the austenite before the Widmanstätten structure formed, and served as early nucleation sites for swathing kamacite. Schreibersite is also common as 25-50 μ wide grain-boundary precipitates and as vermicular 5-50 μ bodies in the comb plessite. Rhabdite prisms of 5-20 μ are common in the α-lamellae.

Cohenite, with a microhardness of 1120±40, is associated with many of the large schreibersite bodies as 30-100 μ discontinuous rims. It is cracked and along the cracks decomposed to 1-2 μ wide graphite leaves, surrounded by a 2.5 μ α-phase. As the corrosion preferentially attacks the ferrite of this composite it may be difficult to resolve the structure optically, unless the polished section is perfect.

Complex troilite-graphite-silicate-schreibersite-cohenite aggregates 1-2 cm wide appear to be quite common. If Kislakovsky's specimen was rich in this material it may explain his reporting of large amounts of olivine and anorthite. The troilite nodules appear to be of the same general composition as noted from Campo del Cielo, Odessa, Toluca and other group I meteorites.

Bischtübe is structurally similar to Toluca, Ogallala and many other group I irons.

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

1,284 g slice (no. 229, 22 x 13 x 0.7 cm)
345 g part slice (no. 698, 11 x 6 x 0.8 cm)
190 g part slice (no. 2666, 7 x 4.3 x 0.8 cm)
1,539 g slice (no. 2667, 21 x 12 x 0.9 cm)

Bishop Canyon, Colorado, U.S.A.

Approximately 37°57'N, 109°0'W; 2000 m

Fine octahedrite with silicates, Of. Bandwidth 0.30±0.05 mm. Neumann bands. HV 154±6.

Group IVA. 7.76% Ni, about 0.05% P, 2.24 ppm Ga, 0.12 ppm Ge, 2.6 ppm Ir.

HISTORY

A mass of 8.6 kg was found in 1912 by a Mr. Hammond four miles west of Bishop Canyon, in San Miguel County, near the Utah-Colorado state line. The corresponding coordinates are given above. It was acquired by the Field Museum and was described and figured by Farrington (1914). Voshage (1967) found ^{40}K and ^{41}K concentrations to be too low for a reliable cosmic ray exposure age determination.

COLLECTIONS

Chicago (main mass of 6 kg), London (529 g), Denver (408 g), Washington (226 g), Tempe (198 g).

DESCRIPTION

The mass resembles a triangular pyramid with a 15 x 15 cm base and a height of 15 cm. It is considerably weathered and at least the finer details of the atmospheric sculpturing have disappeared. No heat-affected α_2 zone is preserved; it is estimated that 2-3 mm of the surface has been lost by corrosion. Locally, heavy hammer marks from the finder's unsuccessful attempt to split the iron may be seen.

BISHOP CANYON – SELECTED CHEMICAL ANALYSES

Reference	percentage Ni	Co	P	ppm C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Wasson 1967	7.76								2.24	0.116	2.6	

Etched sections display a fine Widmanstätten structure of long ($\frac{L}{W} \sim 35$) kamacite lamellae with a width of 0.30±0.05 mm. The lamellae are straight, except under the hammered surface where they are bent to a depth of a few millimeters. Neumann bands are common and well developed, also in the interior of the open-meshed comb plessite. The hardness is 154±6, but drops in places to a minimum of 125.

Taenite and plessite cover about 50% of the sections. The taenite ribbons are only 1-10 μ wide and play a minor role in the structure; some black taenite wedges are present. The hardness is low, 180±10. Many of the fields are developed as cellular plessite, so typical for group IVA. Individual cells are 50-200 μ across and almost equiaxial; they are differently oriented, as may be concluded from the directions of the Neumann bands and from the arrangement of the short rods and lamellae of taenite. Many taenite blebs are well spheroidized. The plessite and taenite development clearly antedates the Neumann bands.

Neither schreibersite nor rhabdites have been observed, so the bulk phosphorus content is probably about or below 0.05%. Sulfides are present as 1-2 mm nodules of troilite, containing parallel daubreelite lamellae.

Most interesting are the silicates, normally rare in group IVA. They occur as subangular large crystals 5-10 mm in diameter, and have often served as a substrate for troilite-daubreelite nodules. In one place the whole assemblage was observed to be severely shocked, with the maximum damage within an area 10 x 10 mm in size. In the center the troilite has been melted, and also part of the adjacent metal. Farther out the kamacite has recrystallized to 5-10 μ wide units, and still farther out the normal Neumann bands reappear. The troilite shows, in the various sections, all gradations from total melting through heavy brecciation to little-damaged crystals with good anisotropy. Large, monocrystalline troilite and daubreelite fragments may be separated by 10-100 μ wide veins composed of minute fragments of the same material. The silicate is

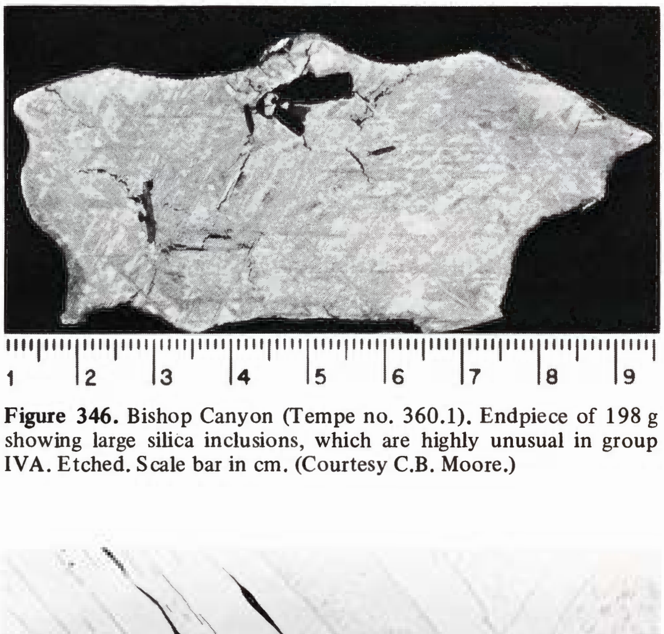

Figure 346. Bishop Canyon (Tempe no. 360.1). Endpiece of 198 g showing large silica inclusions, which are highly unusual in group IVA. Etched. Scale bar in cm. (Courtesy C.B. Moore.)

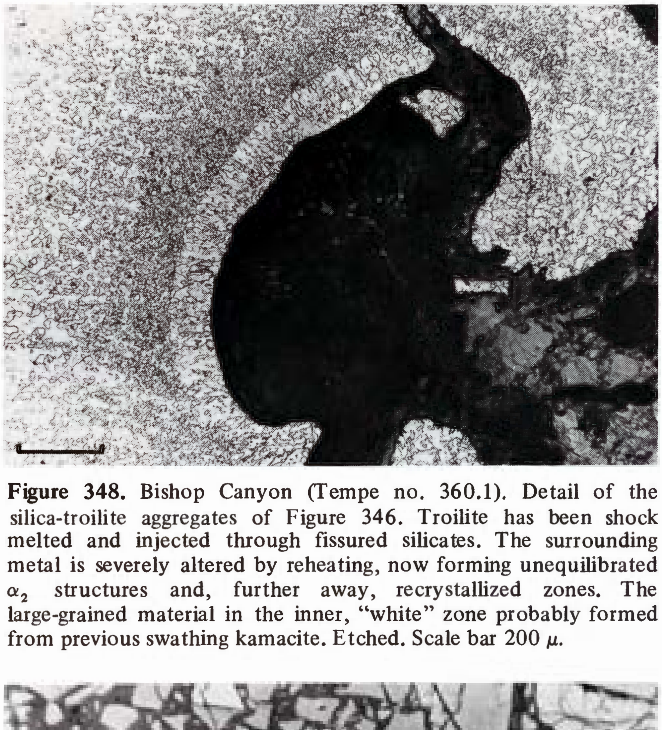

Figure 348. Bishop Canyon (Tempe no. 360.1). Detail of the silica-troilite aggregates of Figure 346. Troilite has been shock melted and injected through fissured silicates. The surrounding metal is severely altered by reheating, now forming unequilibrated α_2 structures and, further away, recrystallized zones. The large-grained material in the inner, "white" zone probably formed from previous swathing kamacite. Etched. Scale bar 200 μ.

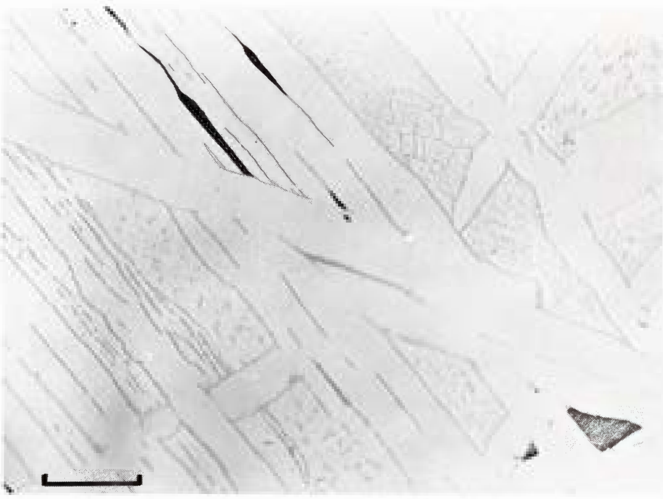

Figure 347. Bishop Canyon (Tempe no. 360.1). Typical group IVA structure. Clean kamacite lamellae (with Neumann bands) and open-meshed plessite fields, some of them with oriented γ-particles. Etched. Scale bar 500 μ.

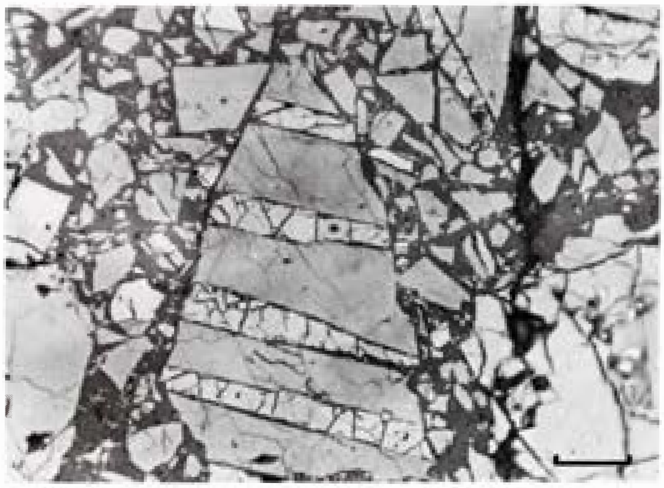

Figure 349. Bishop Canyon (Tempe no. 360.1). A severely brecciated troilite-daubreelite aggregate. Terrestrial corrosion has later invaded the breccia and recemented the fragments with limonite (black). Polished. Scale bar 20 μ.

fibrous and brecciated, and 1-100 μ wide veins through it are filled with a glass in which silicate fragments and a little troilite are embedded. It is surprising to note how the shock has been able to create such heavy local transformation; 10 mm away nothing unusual is observed. The local damage resembles in several respects the structural changes associated with spot welding. Examination under the electron microprobe suggests that the unknown silicate is almost pure SiO_2, possibly tridymite.

Bishop Canyon is chemically and structurally a typical phosphorus-poor, fine octahedrite of group IVA, resembling in particular Gibeon. It is, however, unusual in its silicate inclusions, the shock damage and low hardness.

Specimen in the U.S. National Museum in Washington:
226 g slice (no. 770, 9.5 x 4.5 x 0.9 cm)

Bitburg, Rhineland, Germany
49°58′N, 6°32′E

A mass said to have weighed 1.5 tons was smelted in a furnace before 1805. It was recognized as a meteorite (Chladni 1819: 353), but virtually nothing was saved of the undamaged material (Hey 1966: 57). The smelted material, e.g., no. 1881, 1534 of 546 g in

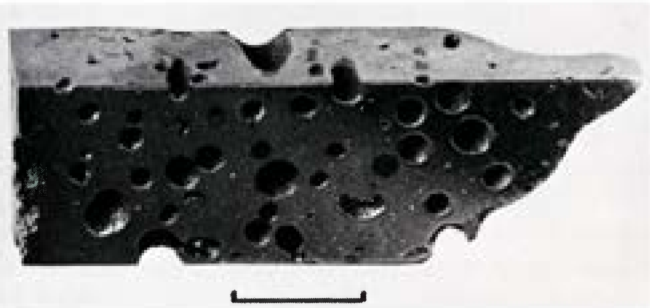

Figure 350. Bitburg (Copenhagen no. 1886, 493). A rectangular bar cut from melted material of the Bitburg meteorite. The numerous spherical gasholes are typical for most Bitburg samples presently in collections. Scale bar 10 mm.

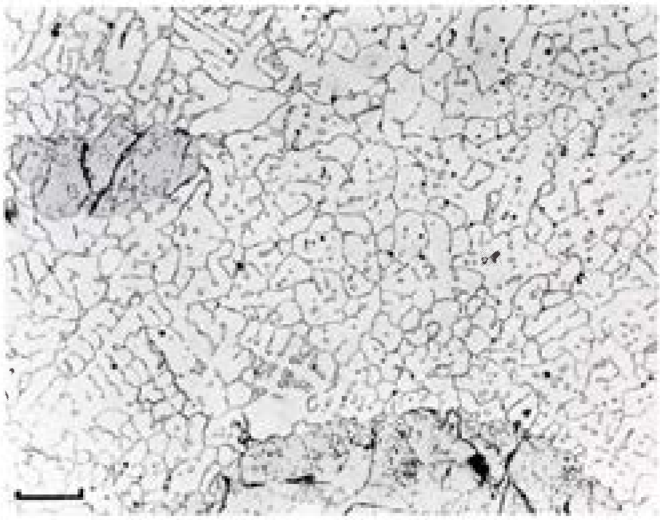

Figure 351. Bitburg. Detail of Figure 350. Two sulfide nodules. Metallic dendrites separated by sulfide-rich eutectics. Etched. Scale bar 200 μ.

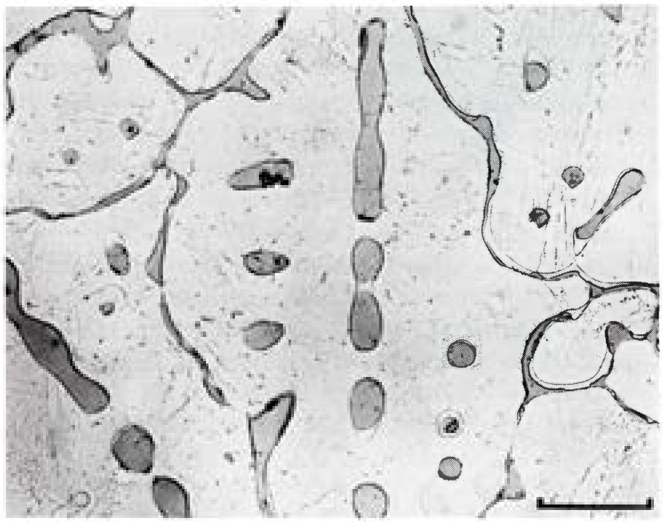

Figure 352. Bitburg. Detail of Figure 350. The dendritic metal was at high temperature austenite but transformed upon cooling to unequilibrated α_2. Etched. Scale bar 50 μ.

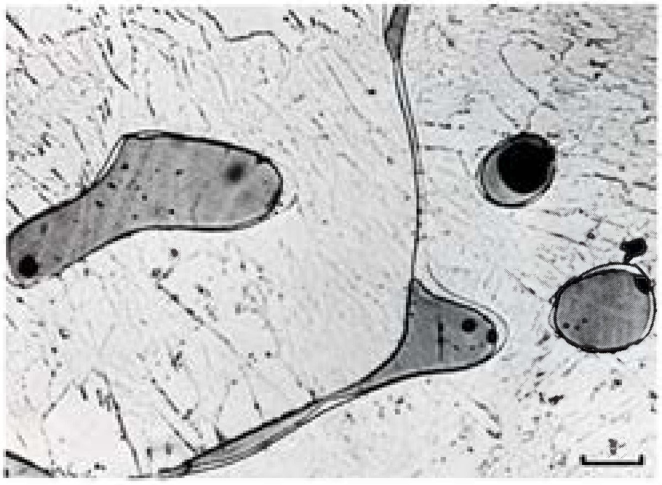

Figure 353. Bitburg. Detail of Figure 350. Sulfide globules in the grain interior and lamellae in the grain boundaries. Black gasholes. α_2 metal. Etched. Scale bar 10 μ.

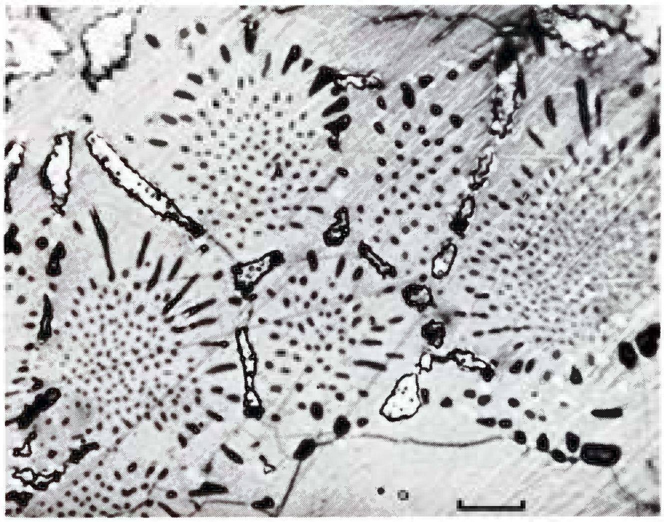

Figure 354. Bitburg. Detail of Figure 350. When the meteorite was melted, oxygen was absorbed from the air, causing complex ternary Fe-S-O eutectics to form locally. Etched. Scale bar 10 μ.