

# IRON METEORITES

**Abakan.** See Toubil River (Abakan)

**Abancay.** See Saint Genevieve (Abancay)

## Adargas, Chihuahua, Mexico

See Chupaderos, of which the Adargas block is a part. Genuine Adargas specimens are small, near-surface fragments detached from the 3.5 ton mass which in the nineteenth century was situated on the Hacienda La Concepcion, near Jimenez, Mexico. There exist, however, due to the general confusion of Mexican iron meteorites in collections, several specimens labeled Adargas, which in fact come from other Mexican octahedrites. It will be wise in every instance to verify the authenticity of a specimen labeled Adargas. Adargas and Chupaderos have 9.9% Ni, a bandwidth of 0.65 mm,  $\epsilon$ -structure and dominant schreibersite and troilite inclusions. Violently detached specimens may be damaged and show distorted kamacite lamellae.



**Figure 230.** Chupaderos. The Adargas block of 3.4 ton is exhibited in Tacuba No. 5, Mexico City. Its maximum dimensions are 155 x 85 x 85 cm. To the left, the ragged surface that was produced when it split, in the atmosphere, from other masses of the Chupaderos shower.

## Adzhi-Bogdo (iron), Outer Mongolia

44°52'N, 95°25'E

A mass of about 70 x 50 x 45 cm was found on the Adzhi-Bogdo ridge about 1850 (Hey 1966: 7). No samples were available for examination in this study.

### AGGIE CREEK – SELECTED CHEMICAL ANALYSES

The cobalt value appears to be 30% too high, while the bulk phosphorus content, estimated from the amount of

## Aggie Creek, Seward Peninsula, Alaska

64°53'N, 163°10'W

Medium octahedrite, Om. Bandwidth 1.20±0.15 mm.  $\epsilon$ -structure. HV 300±15.

Group IIIA. 8.49% Ni, 0.2% P, 20.5 ppm Ga, 39.9 ppm Ge, 0.70 ppm Ir.

### HISTORY

A mass of about 43 kg was picked up by a dredge bucket working for gold in Aggie Creek on August 11, 1942. The meteorite was very close to bedrock, which at this point was perhaps 3.5 m below the surface (Henderson 1949). Stuart H. Perry acquired indirectly 150 g material, which was provisionally labeled "Fairbanks," but later when the finder, Mr. Dent of the Council Dredging Company, Nome, supplied more material and gave information of the location of find, the name "Aggie Creek" was given (Henderson, personal communication). Thus, the 75 g slice labeled "Fairbanks" in the Chicago Museum (Horback & Olsen 1965: 220, no. 2409) is in fact a piece of Aggie Creek obtained from Perry.

Aggie Creek was described by Henderson (1949) with a photomicrograph and the following is a close confirmation of his observations.

### COLLECTIONS

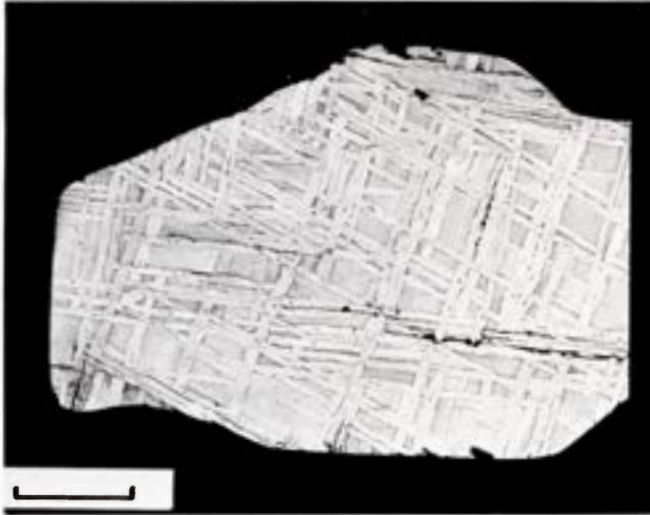
University of Alaska, Fairbanks (42 kg main mass), Washington (984 g), Chicago (75 g).

### DESCRIPTION

The endpiece in the U.S. National Museum is corroded and covered by oxide crusts. It appears, however, to be resistant, in the collection, to further corrosion. The oxides consist of laminated layers of varying oxidation states that penetrate along {111} planes deep into the interior. There is no heated  $\alpha_2$  rim zone left, thus no direct way to tell the original size of the meteorite.

phosphide inclusions, appears to be about 0.25%.

References	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Henderson 1949	8.54	0.67	0.18									
Wasson & Kimberlin 1967	8.44								20.5	39.9	0.70	



**Figure 231.** Aggie Creek (U.S.N.M. no. 1448). Medium octahedrite of group IIIA. Numerous 0.5 mm wide schreibersite particles are located centrally in the kamacite lamellae. Etched. Scale bar 20 mm. S.I. neg. 38261.

Aggie Creek appears to have been a single austenite crystal. The Widmanstätten structure is well developed with a bandwidth of  $1.20 \pm 0.15$  mm. The length-width ratio is 20-25, and kamacite areas cover about 60% of the section. All kamacite is converted to the hatched  $\epsilon$ -structure indicative of shock waves above 130 k bar. The microhardness is  $300 \pm 15$ .

Schreibersite is common as  $10 \times 0.3$  mm lamellae or 0.5-2 mm nodules centrally in the  $\alpha$ -lamellae. Schreibersite is also present as elongated grain boundary precipitates  $20-40 \mu$  thick. All schreibersite is monocrystalline, but brecciated. Rhabdites were not observed.

Troilite, partly converted to pentlandite by corrosion, is very scarce. One elongated monocrystalline body  $1.6 \times 0.4$  mm is partly surrounded by schreibersite precipitates. The same shock which produced the  $\epsilon$ -structure probably brecciated the schreibersite and troilite. The troilite, gripped as in a vice by two large schreibersite crystals, was faulted and brecciated and now displays twins under crossed Nicols. No cohenite, graphite nor chromite was observed.

The structure is thus typical of a group IIIA meteorite on the 8-8.5% Ni level. Other similar irons are Campbellsville, Casimiro (which, however, is recrystallized), Orange River, Plymouth, and Welland. The proposed similarity to a group of six other irons (Henderson 1949) could be shown to be less striking on a structural and chemical basis, so that it is highly unlikely that they ever were part of the same mass. Thus, Olivier's hypothesis (1949) that they were fragments from the same recurrent meteorite swarm is untenable.

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

909 g endpiece (no. 1448,  $10 \times 7.5 \times 4$  cm)

75 g fragments (no. 1786, previously labeled Fairbanks)

**Agram.** See Hraschina

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**Agricultural College, synonyms:**  
Petrovskoie-Rasumovskoie,  
Rousoumouski.

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Pseudometeorite. A nineteenth-century wrought iron with a ferritic grain size of  $100-500 \mu$ . HV  $129 \pm 5$ .

**HISTORY**

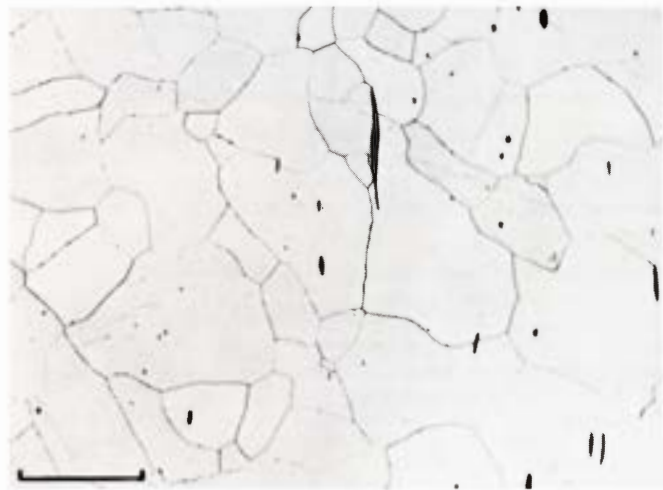
A 180 g slice in the American Museum of Natural History, New York, was described briefly by Reeds (1937: 531). A 725 g specimen labeled "Rousoumouski" in Museo de La Plata was shown to be from the same main mass by Radice (1950: 221), who concluded that it was a hexahedrite. Hey (1966) lists this as "doubtful."

**CHEMICAL ANALYSIS**

Qualitative spectrography has been performed by Radice (1950). A spot test on the Washington specimen indicates the absence of nickel.

**DESCRIPTION**

A 27.5 g slice (U.S. National Museum no. 1359), exchanged in 1940 with the American Museum of Natural History, was polished and etched. The structure is composed of  $100-500 \mu$  equiaxial ferrite grains, and small slag nodules are present in subparallel bands. No meteoritic minerals, i.e., schreibersite, troilite, cohenite, chromite, are present, and no heated  $\alpha_2$  rim zone from atmospheric penetration was found. The microhardness ( $129 \pm 5$ ) and structure are similar to those of a nineteenth-century wrought iron.



**Figure 232.** Agricultural College, a pseudometeorite. Metallographic examination reveals a wrought iron structure, composed of equiaxial ferrite grains and elongated slag inclusions. Etched. Scale bar  $200 \mu$ .

The large sample of 725 g in Museo de La Plata measures  $10.5 \times 6 \times 3$  cm and exhibits a polished surface of  $10 \times 6$  cm. On this face is deep-etched, in Ward's characteristic style, the name "Rousoumouski." Meteoritic minerals are absent, and the structure is fine grained, as discussed above. According to the label, the sample was

acquired in 1905 from Ward's Natural Science Establishment.

It is known that H.A. Ward, during his trip to Russia in 1898, visited the Agricultural College outside Moscow and obtained nine meteorites (Roswell Ward 1948: 266-267). I think that "Agricultural College" was one of these nine specimens, but that Ward, when he returned to Rochester, realized that "Agricultural College" was not a meteorite; he never included it in his price lists or catalogs. Some material has since been sold or donated without a clear indication that it is a pseudometeorite. Neither Zavaritskij & Kvasha (1952), nor Krinov (1962), nor Kvasha (1962) accept "Agricultural College" as a Russian meteorite, and Krinov states directly (Meteoritical Bulletin, No. 13, 1959) "No such meteorite exists."



Figure 233. Typical slag inclusion in wrought iron, in this case from a Danish fifteenth century naval gun. Similar slags are present in Agricultural College and prove that it is a pseudometeorite. Polished. Scale bar 50  $\mu$ .

**Agua Blanca, Castro Barras, Argentina**

28°55'S, 66°57'W

A mass of 49 kg was found before 1938. An insufficient description by Ducloux (1939) indicates that Agua Blanca is a well-preserved mass with few inclusions. It appears to be a medium octahedrite, similar to Cape York. It was not available for examination in the present study.

**AINSWORTH – SELECTED CHEMICAL ANALYSES**

Results reflect the difficulties encountered when sampling the coarsest octahedrites. The overall phosphorus content was found, by point counting of 140 cm<sup>2</sup> sections, to be 0.7%, far more than indicated by the analyses, which

**Ainsworth, Nebraska, U.S.A.**  
42°37'N, 99°56'W; 750 m

Coarsest octahedrite, Ogg. Bandwidth 6±3 mm.  $\epsilon$ -structure. HV 210±15.

Group IIB. 6.0% Ni, 0.46% Co, 0.7% P, 0.14% S, 56 ppm Ga, 144 ppm Ge, 0.023 ppm Ir.

Central Missouri and Ponca Creek will also be included in this shower.

**HISTORY**

A mass of 10.65 kg was found in 1907 by a boy who noticed it partly buried in the sand beside a small creek in Brown County, about six miles northwest of Ainsworth. Through his father, Mr. W.G. Townsend, and Mr. J.C. Toliver, an interested resident, the whole mass came to the American Museum of Natural History, where it was described by Howell (1908b). Eight parallel sections were cut and distributed; a previously made plaster cast of the whole mass was photographed and presented by Simcoe (1956). Schultz & Hintenberger (1967) determined the amount of noble gases. Voshage (1967) found the cosmic ray exposure age to be 920±300 million years.



Figure 234. Ainsworth (U.S.N.M. no. 375). Coarsest octahedrite, group IIB. Large skeleton crystals of schreibersite enveloped in swathing kamacite. Etched. Scale bar 20 mm. S.I. Neg. 1517B.

were probably made on material almost free from coarse inclusions. Point counting of the troilite inclusions gave 0.14% S.

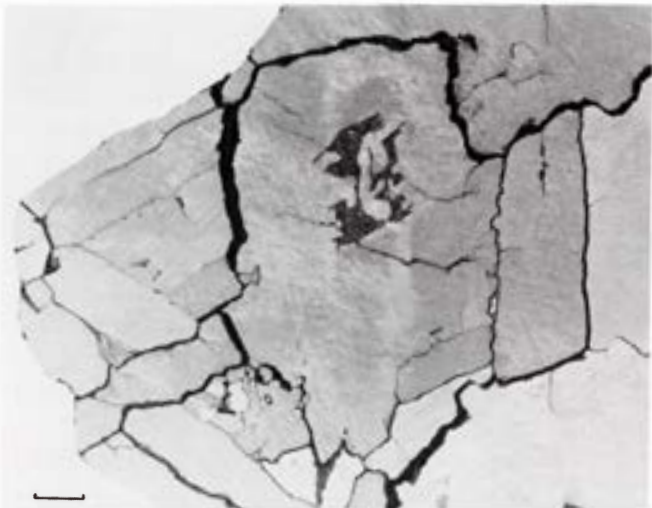
References	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Tassin in Howell 1908b	6.49	0.42	0.28	900	700	100	100					
Moore & Lewis 1968	5.57	0.49	0.19									
Wasson 1969	5.9±0.2								55.7	144	0.023	

## COLLECTIONS

New York (3,568 g), Washington (1,635 g), London (751 g), Chicago (705 g), Ann Arbor (400 g), Harvard (371 g), Vienna (about 350 g), Budapest (347 g), Tempe (273 g), Vatican (100 g), Yale (93 g).

## DESCRIPTION

The original shape was that of a flattened octahedron with the maximum dimensions 17 x 15 x 11 cm (Howell 1908). Howell expressly stated that one face looked like a recent fracture face, and he therefore supposed that a smaller mass had been broken from it when it fell. A renewed inspection of the mass corroborates this view. Ainsworth's exterior faces are parallel or almost parallel to the {111} planes of the octahedron, and along one of these planes an irregular fracture has taken place. As schreibersite precipitates partly fill these planes, it is only reasonable that an atmospheric breakup should have acted to split the meteorite here.



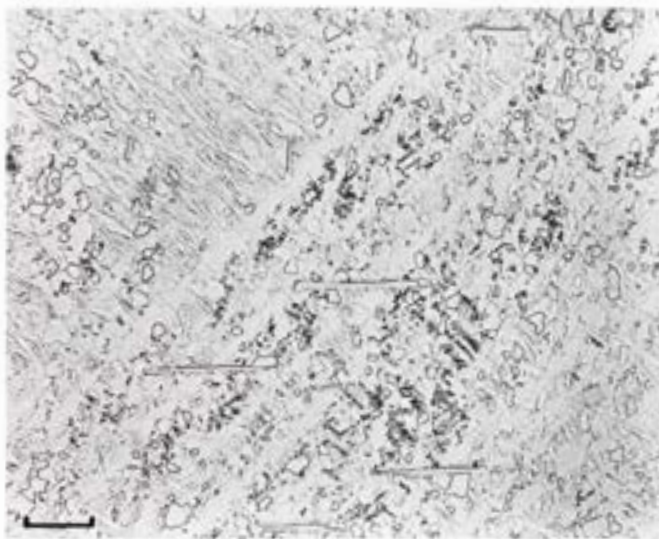
**Figure 235.** Enlarged area of Figure 234. A few comb plessite fields are squeezed between the broad kamacite lamellae. Terrestrial corrosion in the grain boundaries is black. Etched. Scale bar 5 mm. S.I. neg. 1518A.

Terrestrial corrosion has attacked the mass extensively; in one place only a 0.5 mm wide rim of heat-affected  $\alpha_2$  was observed, so at least 1-2 mm iron has been removed by corrosion, probably over a period of thousands of years. Selective corrosion has also converted the relatively nickel-poor surroundings of phosphides to limonite. Rapid corrosion progressed along phase boundaries and along such fissures that opened a fraction of a millimeter when the meteorite split in the atmosphere.

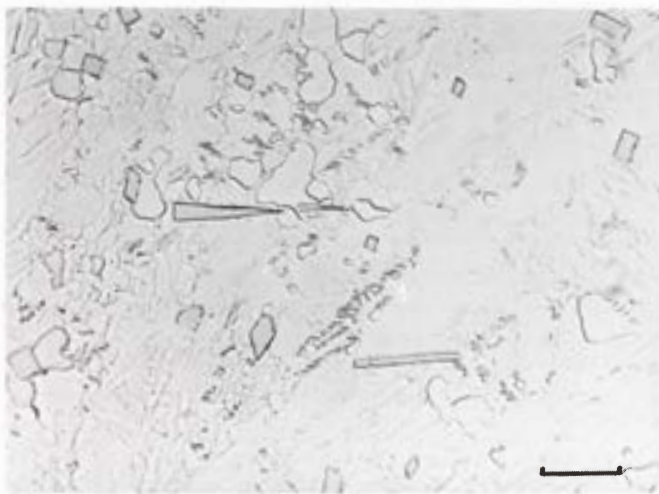
A typical section shows two characteristic structural elements. About half is taken up by irregular kamacite grains 2-5 cm in diameter, in the center of which are found rosettes of hieroglyphs of schreibersite 1-2 mm wide. The interstices between these large grains are filled with a very coarsely developed Widmanstätten structure, with a band-width of  $6 \pm 3$  mm and a length-width ratio of about 6. Taenite is very sparse, and only occasionally (eight fields of

about 2 mm<sup>2</sup> each on 140 cm<sup>2</sup>) is plessite present in the Widmanstätten areas. We will assume that the schreibersite rosettes were the first to precipitate from the high-temperature austenite single crystal, accompanied by a depletion of nickel and phosphorus around the rosettes, giving rise to a swathing kamacite formation. After this had grown to an average width of 1 cm, the remaining austenite transformed to the Widmanstätten structure, precipitating additional schreibersite in the  $\alpha$ - $\alpha$  and  $\alpha$ - $\gamma$  boundaries. Simultaneously, the profusion of rhabdites, typically 5-10  $\mu$  in diameter, were precipitated.

The structure was shocked to 130-400 k bars according to Jaeger & Lipschutz (1967a, b). The hatched  $\epsilon$ -structure, however, is annealed and locally recrystallized to 5-10  $\mu$  irregular ferrite grains. The microhardness is  $210 \pm 15$ , which also indicates considerable annealing since unannealed  $\epsilon$ -structures normally show hardnesses of about 300. Schreibersite is monocrystalline but fractured. Troilite,



**Figure 236.** Ainsworth (Tempe no. 420.1). The shock-hatched kamacite shows incipient recrystallization due to annealing in space. Several rhabdites are present. Etched. Scale bar 50  $\mu$ .



**Figure 237.** Ainsworth (Tempe no. 420.1). The recrystallization and the rhabdites are clearly visible here. Etched. Scale bar 20  $\mu$ .

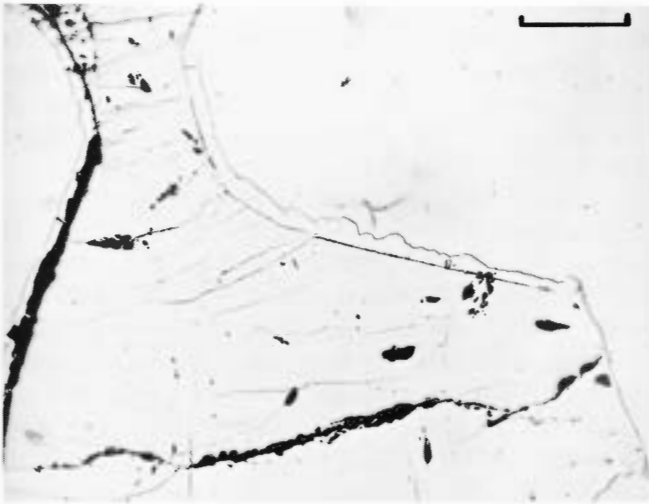


Figure 238. Ainsworth (Tempe no. 420.1). Schreibersite with fissures, enveloped in a narrow rim of cohenite. Polished. Scale bar 400  $\mu$ .



Figure 239. Enlarged area of Figure 238. Schreibersite (S), cohenite (C) and kamacite (K). Polished. Scale bar 100  $\mu$ .

which may have 2-5  $\mu$  wide daubreelite lamellae, is monocrystalline or beset with lenticular twin zones, suggesting mild plastic deformation. It is interesting to note that some of the larger schreibersite rosettes are sheathed in a discontinuous rim of 100  $\mu$  wide cohenite, a feature uncommon in group II.

It has been suggested (Jaeger & Lipschutz 1967b: 1824) that Ainsworth and Ponca Creek are a paired fall. As discussed above, Ainsworth is certainly a fraction of a larger mass, and a comparison with the description of Ponca

Creek on page 8 will show that there is nothing to contradict this hypothesis. In fact macro- and microstructure as well as main- and trace-element composition corroborate this view.

On the basis of Berwerth's short description (1914: 1078) I had supposed that Ainsworth had been artificially reheated (Hey 1966: 10), but there is no evidence for this in the microstructures of specimens in Tempe, Washington, and Vienna, so Berwerth had probably interpreted the  $\epsilon$ -structure to be the result of reheating by man.

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

1,585 g endpiece (no. 375, 14 x 11 x 2.5 cm) (Howell 1908b: figure 1; Merrill 1916b: plate 10)  
70 g fragments and slices (no. 375, no. 2624)

### Central Missouri, Missouri (?) U.S.A.

Coordinates unknown

Coarsest octahedrite, Ogg. Bandwidth  $6 \pm 3$  mm,  $\epsilon$ -structure. HV 220 $\pm$ 30.

Group IIB. 6.22% Ni, 0.5% P, 53.4 ppm Ga, 141 ppm Ge, 0.025 ppm Ir.

Central Missouri is in all probability a fragment of Ainsworth.

#### HISTORY

A mass of about 25 kg was found in the 1850s in "Central Missouri." Bearing in mind that at this time "Missouri" was a loose term including the states of Kansas and Nebraska, which obtained status as Territories in 1854 and became states in 1861 and 1867, respectively, it will be understood that the exact locality is unknown. The mass was cut into halves: one went to Professor Wm. Denton of Wellesley, Massachusetts, while the other half was purchased for Mrs. Newcomer, Cleveland, by Judge C.C. Baldwin. This latter piece was later presented to the Western Reserve Historical Society, Cleveland, Ohio (Preston 1900a). Ward reacquired this last piece (12.36 kg) for cutting in 1899, and about 2/3 was distributed as 7-10 mm thick plates. In 1940, the U.S. National Museum received as a gift from S.H. Perry a 6.6 kg endpiece, which is probably the remainder of what was in Professor Denton's possession.

The iron was described by Preston (1900a) with an analysis. Henderson (1965: plate 4) gave a photomicrograph of the very coarse Widmanstätten structure. Herr et al. (1961) measured the extremely low osmium and rhenium concentrations, and Hintenberger et al. (1967) measured the helium and neon isotopes.

#### CENTRAL MISSOURI – SELECTED CHEMICAL ANALYSES

An old analysis by Mariner & Hoskins (Preston 1900a) gave 0.44% P, which is a little lower than the author's

estimate of 0.50% P, based upon point counting of 135  $\text{cm}^2$ .

Reference	percentage			ppm								
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Wasson 1969	6.22								53.4	141	0.025	

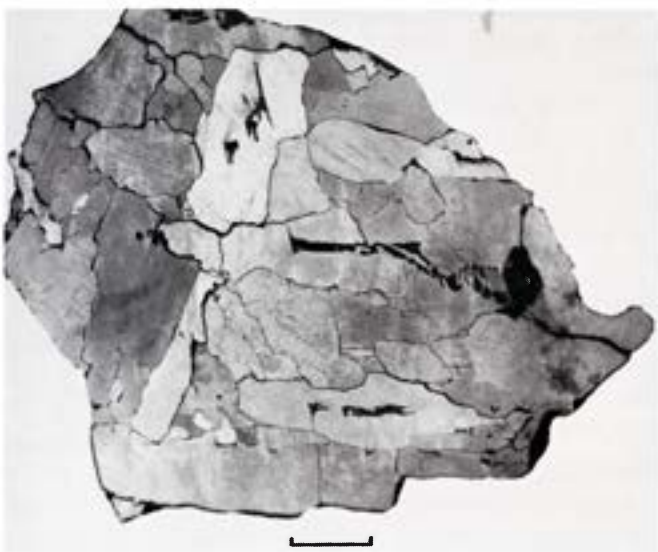
## COLLECTIONS

Washington (5 kg), Western Reserve College, Cleveland, Ohio (4.4 kg), Chicago (2,530 g endpiece), New York (1,055 g), Harvard (1,020 g), Mainz (about 1,000 g), Tempe (999 g), London (988 g), Los Angeles (558 g), Bally (555 g), Bonn (475 g), Vienna (390 g), Berlin (238 g), Tübingen (228 g), Vatican (100 g).

## DESCRIPTION

The U.S. National Museum endpiece has the dimensions 15 x 12 x 7 cm and weighs 4.7 kg. While three sides show a surface of corroded regmaglypts, the fourth side of about 11 x 8 cm shows a late fracture, zigzagging stepwise across the Widmanstätten fingers. This indicates that the mass is a fragment of a somewhat larger body that split during atmospheric entry. The fall is old, since no fusion crust and no heat-affected  $\alpha_2$  zone are preserved, at least not on the sections studied. Oxide crusts of 0.1-0.5 mm thicknesses cover all surfaces, and corrosion penetrates through the whole mass along the kamacite grain boundaries, often as 0.1-0.5 mm wide veins.

Etched sections display a confusing array of large kamacite grains, many of which have central schreibersite skeleton crystals. Sections which have relatively few primary schreibersite crystals display the best Widmanstätten structure; the bulky, irregular, short ( $\frac{l}{W} \sim 2-6$ ) kamacite lamellae have a width of 3-9  $\mu$ m. The lamellae would be almost indistinguishable as such were it not for a minor quantity of schreibersite (10-30  $\mu$ m veinlets) in the grain boundaries, and for the varying orientation, which is evidenced by the oriented sheen. The kamacite matrix is converted, due to shock in the 130-400 k bar range, to mixtures of Neumann bands and hatched  $\epsilon$ -structures. Incipient recrystallization to grains 5-10  $\mu$ m across may be detected locally, covering less than 0.1% by area. The



**Figure 240.** This section through the Central Missouri sample (U.S.N.M. no. 1377) shows the full structural identity with Ainsworth, Figures 234-235. The schreibersite skeleton crystals are black, and some of them have narrow cohenite rims, see Figures 238-239. Etched. Scale bar 20 mm. S.I. neg. M-495.

microhardness shows a wide range from 183 to 249, with the highest values occurring in visibly distorted areas. Plessite occurs locally as small (1-2 mm<sup>2</sup>) fields, perhaps with a frequency of one field per 15 cm<sup>2</sup>. They consist of almost resorbed comb plessite with intercalated schreibersite.

Schreibersite dominates many sections as angular, ragged, skeleton crystals, ranging from 50 x 5 x 2 mm or 10 x 10 x 1 mm to 1 x 0.5 mm. They are monocrystalline (HV 910±30), somewhat brecciated, and surrounded by a wide rim of swathing kamacite, normally extending 4-10 mm on all sides. The morphology of schreibersite plus swathing kamacite units, with units of normal Widmanstätten structure between, is exactly the same as in Ainsworth, and the discussion of the sequence of formation can be transferred to "Central Missouri" without modification. Schreibersite is further present as 20-250  $\mu$ m grain boundary precipitates. Rhabdites are ubiquitous as 3-15  $\mu$ m thick prisms; locally they are faulted and displaced by the shock event that created the  $\epsilon$ -structure. Graphite was tentatively reported by Preston (1900a), but this observation is not supported.

Troilite occurs in nodules and lenses up to 15 mm in size. They are, surprisingly enough, not surrounded by a schreibersite rim, but large skeleton schreibersite crystals may be situated a few millimeters away. Small troilite blebs, 20-50  $\mu$ m in diameter, are located along some schreibersite crystals; they are monocrystalline, or display lenticular twin plates due to plastic deformation.

Structurally, "Central Missouri" is closely related to Sikhote-Alin, Ainsworth and Ponca Creek. It shows a remarkable chemical similarity to the latter two. In view of the facts that both Ainsworth and "Central Missouri" are fragments from an atmospheric disruption, display the same structure and chemistry, and are in the same state of corrosion, it may perhaps be inferred that they belong to the same fall. If so, "Ainsworth" defines the place of fall, while "Central Missouri" is a fragment transported eastward by man. Perhaps one might even conclude that "Central Missouri" is part or the remainder of the hitherto evasive Ponca Creek mass, which was known to exist about 1860 but never reached Dr. C.T. Jackson, see below.

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

- 4,685 g slice (no. 1377, 15 x 12 x 7 cm)
- 273 g slice (no. 1377, 9 x 5 x 1.2 cm)
- 78 g endpiece (no. 1377, 5 x 4 x 1 cm)
- 35 g fragments (no. 1639)
- 31 g part slice (no. 427, 3 x 2 x 1 cm), found in the collection mislabeled Saint Francois County. The old label and the structure, however, clearly identify the sample as a section of "Central Missouri."

## Ponca Creek, Nebraska, U.S.A.

Coordinates unknown.

Coarsest octahedrite, Ogg. Bandwidth 6±3 mm.  $\epsilon$ -structure. HV 200-310.

Group IIB.  $6.3 \pm 0.4\%$  Ni, 0.45% Co, about 0.7% P, 55 ppm Ga, 145 ppm Ge, 0.041 ppm Ir.

Most probably a transported fragment of the Ainsworth shower.

## HISTORY

A mass of approximately 45 kg (100 lbs) was found about 1860 in the Dakota Indian Territory. Through the U.S. Indian Agent for the Ponca tribe of Indians, a fragment of 4.8 kg reached Boston, where Dr. C.T. Jackson described it (1863). His only available information was that "it was found on the surface of the ground, in the Dakota Indian Territory, ninety miles from any road or dwelling." The iron, under the name Dakota, was rapidly distributed by Jackson to many collections, and it was briefly described by Rose (1864a). Wülfing (1897) was only able to locate 790 g in collections, and questioned whether the main mass had ever been recovered.

Farrington (1907) proposed the name "Ponca Creek" for the meteorite, mainly to avoid confusion. Later, precise coordinates were assigned to the fall (Farrington 1915; Hey 1966), but these are meaningless since we know only that the meteorite was acquired from the Indians at the Ponca Indian Agency. This was, according to "Rand McNally & Co.'s Indexed Atlas to the World" (1882: 681), located where Ponca Creek meets the Missouri River ( $42^{\circ}48'N$ ,  $98^{\circ}8'W$ ), but the Ponca tribe occupied an area extending 200 km west from here.

Nininger & Nininger (1950: plate 5) gave a photomicrograph, and Moore & Lewis (1968) presented a new analysis. Voshage (1967) found the high exposure age of  $1200 \pm 100$  million years, and Schultz & Hintenberger (1967) measured the amounts of helium, neon, and argon isotopes. The results from both these papers appear to be similar to the same authors' results for Ainsworth, within analytical error.

It has been suggested on the basis of structural observations by Jaeger & Lipschutz (1967b) that Ponca Creek is a paired fall with Ainsworth. The present author is inclined to believe that "Central Missouri" also belongs to the same shower. This is difficult to prove geographically, since we know only that the Ponca Creek mass was recovered somewhere within the general area of the present Nebraska–South Dakota state line, where Ainsworth was also found in 1907, about 150 km west of the Ponca Agency, while we know practically nothing about the place of find of "Central Missouri." Distances between individual fragments of a shower are known to extend to about 50 km (Allende, Bingera, Cranbourne), so it is quite feasible that the Ponca Creek mass was originally located within this

distance from the Ainsworth mass; it is probable that "Central Missouri" was also found within these limits from Ainsworth. The main and trace element composition, the macro- and microstructure, the exterior fractured surfaces, the state of corrosion and the amount of noble gases all provide circumstantial evidence that they belong to one shower, but definite proof probably will never be obtained.

## COLLECTIONS

Amherst (934 g endpiece), Harvard (about 0.9 kg endpiece, and 81 g), Tempe (398 g), Chicago (303 g), London (224 g), Tübingen (164 g), Paris (103 g), Budapest (90 g, lost?), Calcutta (69 g), Göttingen (57 g), Berlin (55 g), Vatican (43 g), Washington (29 g), New York (27 g), Vienna (7 g), Yale (4 g). These samples only add up to about 3.3 kg; the remainder appears to be missing.

## DESCRIPTION

Jackson's fragment measured  $15 \times 12 \times 5$  cm and weighed 4.8 kg. He stated that one surface showed columnar grains, evidently being a fracture surface produced by a sledge hammer. The endpiece in Amherst shows areas of violent hammering with resultant squeezing and overfolding, corroborating this supposition. The meteorite is weathered and covered with 0.1–1 mm adhering oxides. Corrosion has pockmarked the surface with 1–2 mm pits and also penetrates the mass along grain boundaries.

Etched sections display a very irregular structure of coarse kamacite grains of various sizes;  $1 \times 2$ ,  $2 \times 3$ , and even  $6 \times 2$  cm grains may be observed. Locally in interstices between grains, remnants of Widmanstätten lamellae may be found. The bandwidth is  $6 \pm 3$  mm, but the bands are short ( $\lambda \sim 4$ ), bulky and irregular. Kamacite is variable but mainly of the hatched type, similar to that observed in Ainsworth, "Central Missouri" and El Burro. The kamacite shows a rather wide range in hardness from 245 to 312. The highest values are present where the  $\epsilon$  or Neumann bands are violently distorted by deformation. Plessitic areas were not observed on a total of  $40 \text{ cm}^2$ , but may be present in other sections. Taenite occurs as  $10\text{--}100 \mu$  rounded blebs associated with schreibersite along some grain boundaries; they are the remainders of former plessite fields and exhibit hardnesses of  $345 \pm 15$ , corresponding to coldworked taenite.

Schreibersite is common as massive, angular crystals, e.g.,  $20 \times 4$ , or  $5 \times 5$  mm, or as irregular, lobed bands 1–3 mm wide. They are monocrystalline, slightly brecciated and surrounded by 1–3 cm wide kamacite rims. Schreibersite bands,  $10\text{--}100 \mu$  wide, are frequently found in the

PONCA CREEK – SELECTED CHEMICAL ANALYSES

References	percentage			ppm								
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Moore & Lewis 1968	6.71	0.45	0.94	135	205							
Nava, Diss., 1968							112	15.5				
Wasson 1969	$6.3 \pm 0.3$								55.0	145.0	0.041	

kamacite grain boundaries, and 2-10  $\mu$  rhabdites are present in the matrix. Point counting indicates that the analytical value for phosphorus given by Moore & Lewis (1968) is rather high, and that 0.5-0.7% P may be more reasonable.

Troilite occurs locally, e.g., as an 8 x 2 mm lenticular body surrounded by, but not in contact with, angular and rosette-like millimeter-sized schreibersite crystals. A similar morphology exists in other irons of group IIB, but is otherwise rare. Typical developments are discussed under Santa Luzia and Sikhote-Alin.

Ponca Creek is structurally indistinguishable from Ainsworth and "Central Missouri." It also resembles El Burro and Sikhote-Alin in many respects. Considering the structural evidence, together with the geographical evidence presented above, and the chemical and noble gas data presented by others, the author feels sure enough to conclude that the three irons, Ainsworth, "Central Missouri" and Ponca Creek, belong to the same shower. The location is determined by the last find, Ainsworth, which has well-established coordinates.

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

29 g part slice (no. 543, 6 x 2 x 0.3 cm)

**SUMMARY**

Some essential facts on the three masses Ainsworth, "Central Missouri" and Ponca Creek are tabulated below. The fourth column presents the "average," here accepted as representing the parent body which split in our atmosphere yielding the three masses, and possibly more which have passed unrecorded. In the last column are data of a related meteorite, Sikhote-Alin. These show that a wide range in compositional data may be expected when dealing with the extremely coarse-grained structures of group IIB.

The wide range in hardness in the Ainsworth shower is probably best explained if it is assumed that the incoming

mass had a hardness of 200 $\pm$ 20, corresponding to shocked, annealed and slightly recrystallized material. The atmospheric disruption, however, produced local strains which coldworked the kamacite to peak-hardnesses of about 300. Similar strain-hardening is known to occur in connection with shower production from other meteorites, e.g., Cape York, Magura and Gibeon.

The naming of the masses is problematical here, since three different names are currently in use and all of them are well known. Ponca Creek was discovered and described first (as Dakota), but since the localities of this mass and of "Central Missouri" are unknown, I would give preference to Ainsworth, the locality of which is well documented. The other two masses might be termed Ainsworth (Central Missouri fragment) and Ainsworth (Ponca Creek fragment), respectively.

**Akpohon.** See Cape York (Akpohon)

**Alandroal.** See Juromenha

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**Albuquerque, New Mexico, U.S.A.**

Approximately 35°N, 106° 50'W

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Almost certainly a fragment of Canyon Diablo, shock-altered to Stage VI-VII. See page 137 and the Supplement.

A fragment of 157 g was obtained from a secondhand dealer in Albuquerque, and was described by Beck & LaPaz (1950), who suggested that it was a medium octahedrite with about 8.5% Ni. It is said to have come from a spot some 13 miles west-southwest of the town, but repeated searches have never disclosed the main mass. Another iron fragment had been described, with an analysis, as Albuquerque (Merrill 1916a: 31). It was, however, a part of Glorietta Mountain.

*The Ainsworth Shower* – Summary of data which support the conclusion that the Ainsworth, Central Missouri and Ponca Creek masses belong to the same shower.

	Ainsworth 10.65 kg	Central Missouri 25 kg	Ponca Creek 45 kg	Ainsworth Shower (average)	Sikhote-Alin 23 tons (range)
Ni%	5.57-6.49	6.22	6.0-6.71	6.3	5.78-6.42
Co%	0.42-0.49	n.d.	0.45	0.45	0.38-0.47
P%	0.19-0.7	0.50	0.5-0.94	0.5	0.28-0.56
Ga ppm	55.7	53.4	55.0	54.7	51.8
Ge ppm	144	141	145	143	161
Ir ppm	0.023	0.025	0.041	0.030	0.029
<sup>3</sup> He (10 <sup>8</sup> cm <sup>3</sup> /g)	530	711	517	—	148
<sup>4</sup> He	2160	2866	2005	—	574
<sup>3</sup> He/ <sup>4</sup> He	0.245	0.248	0.258	0.250	0.257
<sup>21</sup> Ne	5.97	7.20	6.10	—	1.65
Hardness	198-232	183-249	203-312	—	180-270
Troilite	mult. twin.	mult. twin.	n.d.	—	n.d.

Data from Hintenberger et al. (1967a), Schultz & Hintenberger (1967), Wasson (1969) and Dyakonova (in Fesenkov & Krinov 1963:345.)



## Alexander County, North Carolina, U.S.A.

35¼°N, 81¼°W

Coarse octahedrite, Og. Bandwidth 2.0±0.4 mm.  $\epsilon$ -structure. HV 175-325.

Group I on basis of structure. No modern analysis available.

## HISTORY

A specimen of 56 g had several owners before it was described by Professor Venable (1890a) and the mineral collector S.C.H. Bailey (1891). The piece was evidently a fragment of a somewhat larger mass which was never reported. Another specimen of 60 g was in Bement's collection (1894: 1) and is now in New York; it may be the specimen mentioned by Reeds (1937: 532). A third specimen of 76 g was in Ward's collection (1900: 1). These three add up to 192 g, which was probably the total amount Bailey received in 1875 (Bailey 1891: 17; Wülfing 1897: 396).

## CHEMICAL ANALYSIS

The analysis by Venable (Bailey 1891) gave 5.86% Ni, which is probably 1% too low.

## DESCRIPTION

On small specimens the coarse Widmanstätten pattern is difficult to ascertain, but the overall structure is similar to Magura and Canyon Diablo. Anisotropic, monocrystalline schreibersite crystals several millimeters in size are sheathed in 200-300  $\mu$  cohenite, also monocrystalline. Rhabdites up to 30  $\mu$  in diameter are very common. A little taenite and plessite (2% by area) are present. The ferritic phase is hatched due to shock, and the minerals are often heavily brecciated and displaced. Locally, a 0.2 mm wide zone of recrystallized ferrite grains, 5-10  $\mu$  in diameter, passes from one side to the other of the specimen. The heated  $\alpha_2$  rim zone has disappeared due to corrosion, and there is considerable selective corrosion around the rhabdite precipitates. Since the kamacite phase has been subjected to various degrees of cold-deformation, the microhardness ranges from 200 in little-affected areas, to 325 where the slipband systems are crowded. Typical  $\epsilon$ -structures range from 250 to 300, while the reheated, recrystallized shear zone has a hardness of only 175.

Alexander County is an intensely shocked coarse octahedrite which in many respects resembles the small slugs collected around Meteor Crater (Canyon Diablo) and Kaalijärvi. Whether it is a small, mislabeled Canyon Diablo fragment remains to be seen.

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

12 g endpiece (no. 951, 2 x 1½ x ½ cm, formerly no. 82 of the Shepard Collection)

## Algoma, Wisconsin, U.S.A.

44°39'N, 87°28'W

Medium octahedrite, Om. Bandwidth 0.60±0.10 mm. Neumann bands. HV 155±10.

Anomalous. 10.7% Ni, 0.25% P, 17.9 ppm Ga, 38.3 ppm Ge, 0.39 ppm Ir.

## HISTORY

In 1887 a discoid-shaped mass of somewhat more than 4 kg was plowed up four miles west of Algoma, Kewaunee County. It has been vigorously attacked with a cold chisel and hammer and still bears many indentations for the molestation. Hobbs (1903) gave a thorough description and presented several photographs. Problems connected with atmospheric entry were treated in an appendix by Schlichter.

## COLLECTIONS

University of Wisconsin, Madison (3.7 kg main mass), Washington (22 g), London (18 g), Chicago (10 g), Ottawa (7 g), Budapest (5 g), Bonn (2 g).

## DESCRIPTION

Algoma is an iron of anomalous shape, structure and chemistry. The figures and descriptions given by Hobbs (1903) show Algoma's remarkable form: shield-shaped with a major axis of 25 cm, a minor axis of 16.5 cm, and a maximum thickness of 2.5 cm. The slightly convex front side is carved by atmospheric friction and displays ridges and furrows radiating from a smooth central part. The slightly concave rear surface has large, shallow thumbmark grooves, coalescing with one another. The small slices in the U.S. National Museum contain parts of both surfaces and show the convex front to be almost free from deposits; the back is covered with 50-100  $\mu$  thick, laminated metal layers, overlain by a 0.1-1 mm thick deposit of complex, spherulitic aggregates. The deposits resemble those described on Arlington and Jamestown. Part of the ablated metal from the front redeposited, during the flight, on the relatively protected back surface, where it formed intricate intergrowths. The variation in the width of the heat-affected  $\alpha_2$  zone appears to be small: 2.0 mm thick on the convex and 1.6 mm on the concave side. A better estimate

## ALGOMA — SELECTED CHEMICAL ANALYSES

References	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Koch in Hobbs 1903	10.63	0.84	0.15									
Wasson 1968, pers. comm.	10.75							17.9	38.3	0.39		

might have been obtained from larger slices which, however, were not available. The meteorite is only mildly attacked by corrosion. Little if any of the heat-affected  $\alpha_2$  is removed, and the fusion crusts on the rear surface are well preserved.

The Widmanstätten structure is well developed with a bandwidth of about 0.6 mm. The kamacite lamellae are straight from edge to edge and do not reflect the exterior convex-concave shape, so we may conclude that the exterior form is due to atmospheric ablation, not to bending by frictional forces. This is interesting in view of the frequency with which various authors have suggested that bent Widmanstätten lamellae are due to friction in the atmosphere. The kamacite contains Neumann bands, and its microhardness is  $155 \pm 10$ . Hardness increases, in the heat-affected  $\alpha_2$  zone, to  $185 \pm 10$ . A hardness track across a full, 2 cm thick cross section is of type II, with two almost symmetrical minima of  $145 \pm 5$  at a depth of about 2 mm. Dense plessite and comb plessite fields occupy about 40% by area.

Troilite was not observed, but schreibersite occurs centrally in the lamellae as monocrystalline, slightly fractured crystals. These are generally irregular blebs,  $1 \times 0.5$  mm in size, but may increase to  $40 \times 20 \times 1$  mm platelets. Schreibersite also occurs as  $2\text{--}25 \mu$  wide grain boundary veinlets and irregular blebs inside the plessite fields, substituting for taenite. Larger schreibersite lamellae are surrounded by 1 mm swathing kamacite. Total phosphorus content was estimated, by point counting, to be about 0.25%.

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

10 g part slice (no. 273, polished section)

12.5 g part slice (no. 263F,  $40 \times 20 \times 1$  mm)

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### Alikatnima, Central Australia

$23^\circ 20'S, 134^\circ 7'E$

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#### HISTORY

Two masses of 20 and 15 pounds are in the South Australian Museum, Adelaide, and a third in Central Australia (Hey 1966: 16; Corbett 1968).

#### DESCRIPTION

A brief examination showed the material to be ataxitic, with an easily resolved  $\alpha + \gamma$  duplex structure. Minute  $\alpha$ -spindles, typically  $30 \mu$  wide, occur with a frequency of about one per  $5 \text{ mm}^2$ . Schreibersite occurs throughout the meteorite as fine blebs  $5\text{--}10 \mu$  across; large phosphides are apparently absent. A few daubreelite crystals, and some schreibersite crystals, up to  $50$  or  $100 \mu$  across, are present as nuclei for the larger  $\alpha$ -spindles. The fusion crust is not preserved, but a 2 mm wide heat-affected  $\alpha_2$  zone with micromelted phosphides is present along most of the surface. According to Reed (1972b), Alikatnima contains 13% Ni.

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### Alt Bela, Moravia, Czechoslovakia

$49^\circ 49'N, 18^\circ 17'E$

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Medium octahedrite, Om. Bandwidth  $0.70 \pm 0.15$  mm.  $\epsilon$ -structure. HV  $225 \pm 15$ .

Possibly group IID. 12.9% Ni, 0.39% P.

Some samples have been artificially reheated to about  $1000^\circ \text{C}$ , but the main mass is undamaged.

#### HISTORY

A mass of 3.9 kg was purchased from a farmer near Alt Bela (or Stara Bela) south-southwest of Ostrava. It had been in the farmer's possession for 50 years before it was acquired for the Prague Museum and described by Smyčka (1900). It is not entirely certain that the meteorite was discovered near Alt Bela; it is only known that it was "rediscovered" among farm tools in a shed on the farm, having been there since at least 1850. Smyčka assumed that the fall had taken place during the nineteenth century, but as shown below this cannot be the case. Cohen (1905: 302) gave a description, and Brezina & Cohen (1886-1906: plate 35) presented two photomicrographs of deep-etched sections. Tuček (1966: 69 and plate 5) gave the coordinates quoted above and a photograph of the main mass in Prague.

#### COLLECTIONS

Prague (2,710 g main mass), Vienna (410 g), Bonn (122 g), Strasbourg (25 g), Chicago (19 g), Budapest (14 g, lost in 1956), Washington (10 g), Berlin (9 g).

#### DESCRIPTION

The main mass in Prague measures  $14 \times 10 \times 8$  cm, and displays a cut and etched face of  $12 \times 7$  cm. It is weathered and covered with 0.5-1 mm thick crusts of terrestrial oxides; no fusion crust is preserved. On sections it is seen that the heat-affected  $\alpha_2$  zone has been removed by corrosion and that weathering products are present to depths of at least 10 mm. The  $\alpha$ -phase of the duplex plessite fields is selectively transformed to limonite, and limonitic veinlets follow the  $\alpha\text{-}\alpha$ ,  $\alpha\text{-}\gamma$  and  $\alpha$ -schreibersite boundaries. The troilite is veined by pentlandite. It is estimated that about 4 mm has been lost through terrestrial corrosion, so the mass must be of considerable age and cannot have fallen, as believed, in the nineteenth century.

Etched sections display a medium Widmanstätten structure of straight, long ( $\frac{L}{W} \sim 15$ ) kamacite lamellae with a width of  $0.70 \pm 0.15$  mm. The kamacite shows indistinct subboundaries decorated with less than  $1 \mu$  precipitates, but the boundaries are obscured due to a shock that has transformed the kamacite to an indistinct hatched  $\epsilon$ -variety. The hardness is surprisingly low for the structure,  $225 \pm 15$ , suggesting that slight annealing has occurred since the shock-transformation. Taenite and plessite cover about 40% by area. Beautiful comb plessite fields attain sizes of  $2 \times 3$  mm, while smaller fields usually are of the dense, martensitic or duplex types. A typical 1 mm field will

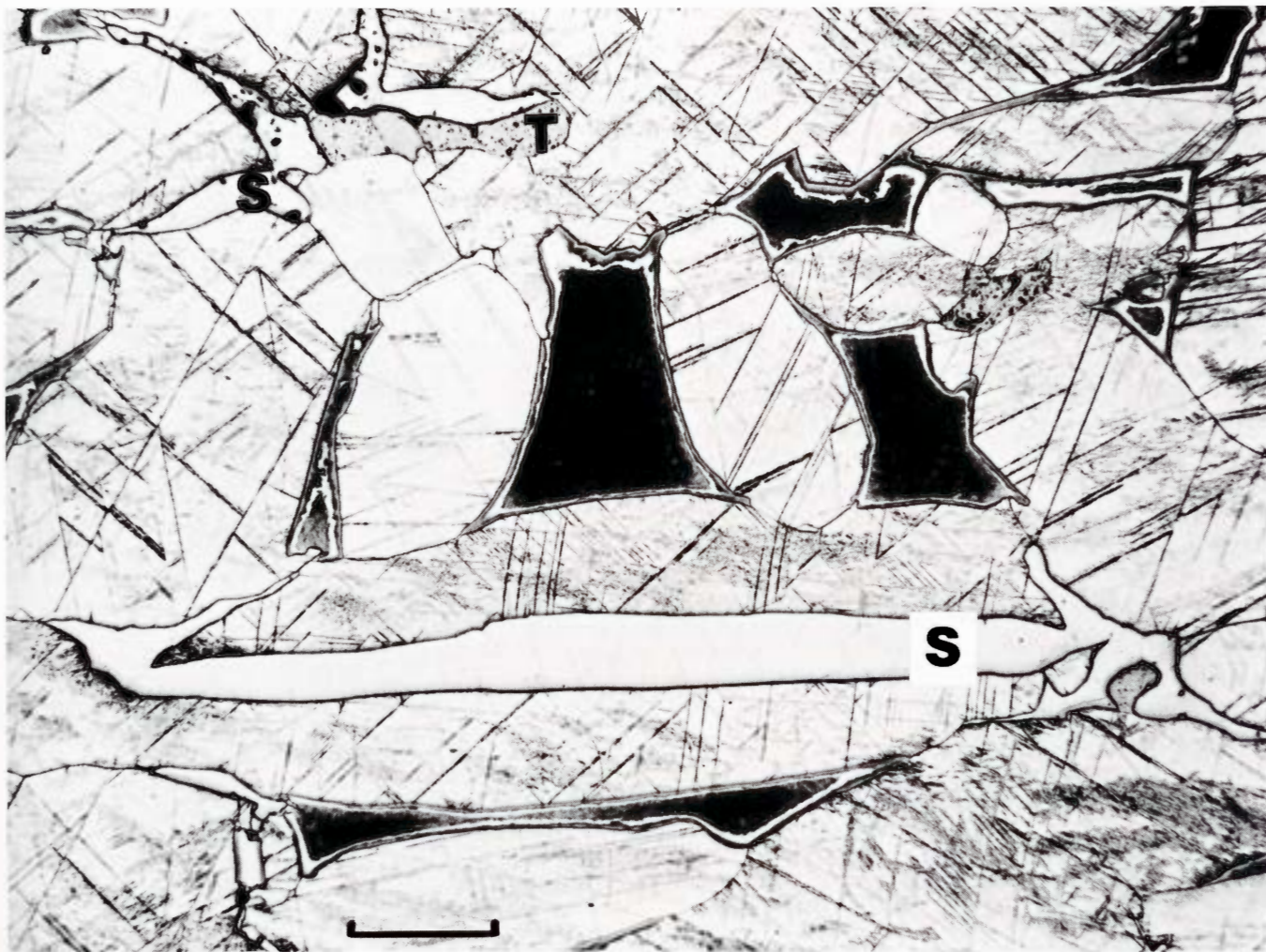


Figure 241. Alt Bela (Chicago no. 1070). Large schreibersite crystals (S) and troilite (T) with daubreelite. Etched. Scale bar 500  $\mu$ .

display a cloudy taenite border (HV  $320 \pm 25$ ) followed by a light etching martensitic transition zone (HV  $350 \pm 25$ ). Next come duplex unresolvable  $\alpha + \gamma$  mixtures, and finally easily resolvable  $\alpha + \gamma$ , with 1-2  $\mu$  thick  $\gamma$ -particles (HV  $270 \pm 25$ ).

Schreibersite is common as small cuneiform or plate-like crystals forming imperfect Brezina lamellae, usually 0.2-0.4 mm wide, 1-4 mm long, and enveloped in 0.5-0.7 mm wide rims of swathing kamacite. They are monocrystalline, but somewhat sheared and shattered. Schreibersite is also present as 30-80  $\mu$  grain boundary veinlets, and as 5-50  $\mu$  irregular blebs inside plessite, substituting for  $\gamma$ -veinlets of similar sizes. Rhabdites occur

locally as 2-10  $\mu$  prisms, and commonly as less than 0.5  $\mu$  precipitates in the kamacite lamellae.

Troilite is commonly present as small nodules. They are lenticular or globular, typically 0.1-0.6 mm across, and slightly shattered. Due to shock they are partly recrystallized to 5-25  $\mu$  aggregates, partly micromelted, especially along interfaces, to 1  $\mu$  eutectics of sulfide and metal. Daubreelite is commonly associated with the troilite as 20-150  $\mu$  bars and whole grains.

Carbides, graphite and silicates were not detected.

While the description above is valid for the material in Prague and Chicago (Me 1070, 19 g), at least one of the distributed specimens is severely damaged by artificial

#### ALT BELA – SELECTED CHEMICAL ANALYSES

Reference	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Smyčka 1900	12.89	0.41	0.39	200	600							

The nickel percentage appears high and should be checked.

reheating. The Washington sample (no. 2634, originally part of the Carl Bosch Collection) displays  $\alpha_2$  matrix, micro-melted phosphides and altered troilite-daubreelite aggregates. There are distinct laceworks of oxide-metal intergrowths along corroded grain boundaries, and linear structural elements are slightly bent. The microhardness is  $175 \pm 10$ . It appears that the specimen has been artificially heated to about  $1000^\circ\text{C}$  and slightly hammered. Most probably several of the other distributed specimens are also maltreated.

Alt Bela is a shocked and annealed medium octahedrite, which, if the nickel analysis is assumed to be correct, is anomalous with no immediate relatives. Structurally, it is closely related to groups IID and IIIB, displaying kamacite, taenite and phosphide morphologies which are quite common in, e.g., Wallapai, Elbogen, and Treysa. In particular there are close similarities with Wallapai, so Alt Bela in a modern, complete analysis may turn out to be a member of group IID. Another possibility

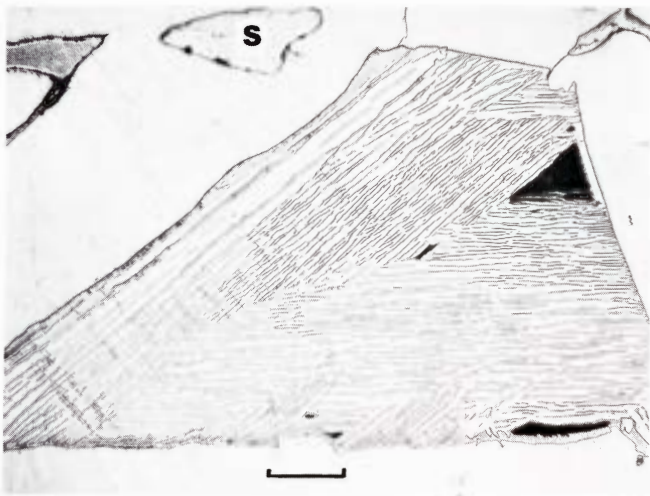


Figure 242. Alt Bela (Chicago no. 1070). Large comb plessite field with portions of black taenite. Fissured schreibersite (S). Etched. Scale bar  $500 \mu$ .

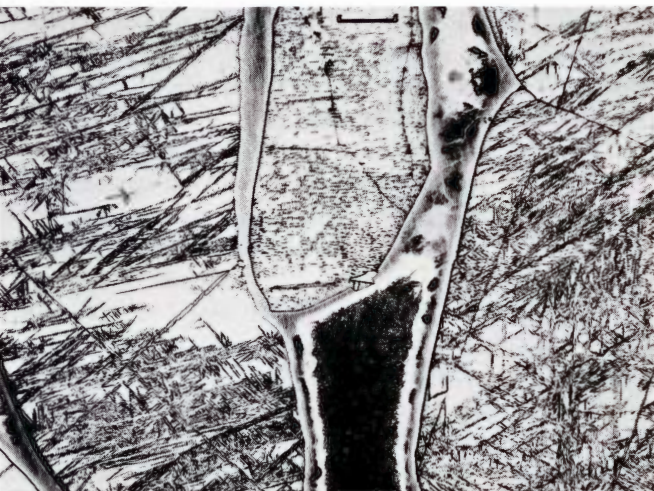


Figure 243. Alt Bela (Chicago no. 1070). Shock-hatched kamacite, and cloudy taenite with interiors of martensitic and duplex appearance. Etched. Scale bar  $100 \mu$ .

which should be considered is that it is a transported specimen from the Elbogen shower.

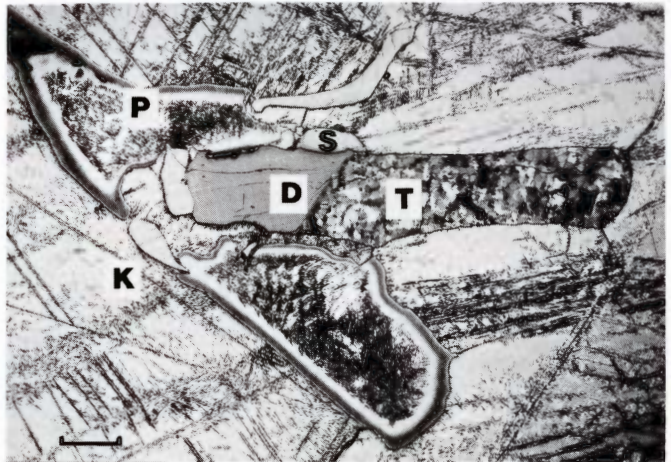


Figure 244. Alt Bela (Chicago no. 1070). Recrystallized troilite lens (T), in contact with daubreelite (D) and schreibersite (S). Plessite (P) and shock-hatched kamacite (K). Etched. Slightly crossed polars. Scale bar  $100 \mu$ .

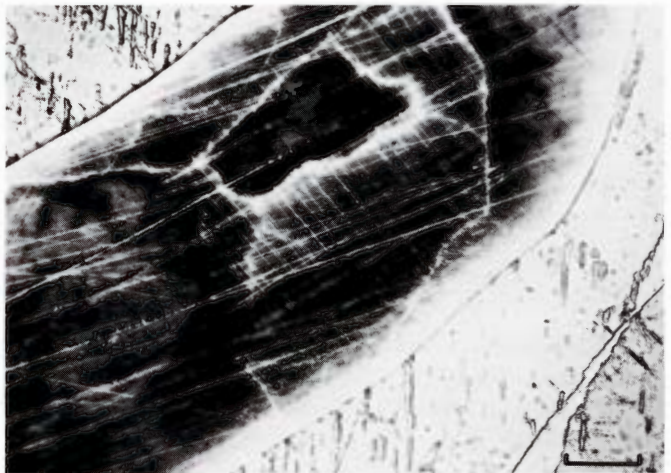


Figure 245. Alt Bela (Chicago no. 1070). Detail of shocked taenite lamella. A dense grid is developed after  $(111)_\gamma$  directions, suggesting either twinning or sliplines, due to shock-deformation. Etched. Oil immersion. Scale bar  $10 \mu$ .

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

10 g part slice (no. 2634,  $3.5 \times 3 \times 0.1$  cm)

**Altonah, Utah, U.S.A.**

$40^\circ 34' \text{N}, 110^\circ 29' \text{W}; 2500$  m

Fine octahedrite, Of. Bandwidth  $0.28 \pm 0.05$  mm.

Group IVA. 8.54% Ni, 0.41% Co, 0.09% P, 0.5% S, 2.3 ppm Ga, 0.15 ppm Ge, 1.5 ppm Ir.

One end was reheated artificially to about  $900^\circ\text{C}$ .

**HISTORY**

A mass of 21.0 kg (46.2 lbs) was found in 1912 by Lloyd Stewart about 600 m southeast of the outlet of Moon Lake (A.D. Ninger 1939; Hardy 1958). It was



35 mm long, penetrates one edge of the specimen. It appears to be a drilled hole, produced by some early owner. One face of 10 x 10 cm is severely flattened by hammering, and the Widmanstätten structure shows bent lamellae under this part.

Etched sections display a fine Widmanstätten structure of straight, long ( $\frac{L}{W} \sim 40$ ) kamacite lamellae with a width of  $0.28 \pm 0.05$  mm. Taenite and plessite cover about 40% by area, mostly as net plessite and duplex, poorly resolvable fields. Comb plessite is also present, and martensitic transition zones between the taenite and duplex interior are ubiquitous. Cellular plessite, which appears to be typical for group IVA, is also present. Schreibersite is almost absent, but may be found locally as short,  $5 \mu$  wide grain boundary veinlets, in accordance with the analytical value of 0.09% P.

Troilite is present as 15-20 mm nodules without schreibersite rims, and as a profusion of 0.2-1 mm bodies, often arranged as a corona around the larger troilites. Bulk sulfur content is estimated to be 0.5% by point counting. The troilite is shock melted and solidified to fine-grained eutectics of 1-2  $\mu$  sulfide and metal. The fine-grained border against the surrounding metal is fringed, serrated, and heavily attacked by corrosion.

Chromite occurs as lamellae, typically measuring 10 x 10 x 0.05 mm, and as euhedral crystals of 0.3-1.2 mm. These have frequently acted as a substrate for precipitating troilite and may be completely enveloped by it. Daubreelite is present as 10-50  $\mu$  bodies in the kamacite.

On the small specimens in the U.S. National Museum, the ferritic matrix is transformed to  $\alpha_2$  and the taenite is diffuse and provided with thorns. The microhardness of the  $\alpha_2$  phase is  $185 \pm 10$ . Limonitic corrosion products have decomposed to complex mixtures in which 1  $\mu$  metallic beads are embedded. Lace-like, 20  $\mu$  wide oxide-metal zones border the surface and the corroded fissures, and 2  $\mu$  wide, creamy veinlets separate the schreibersite from the terrestrial corrosion products. The microstructure indicates an artificial reheating to 800-900° C, a conclusion corroborated in a note by Nininger & Nininger (1950: 28): "... one end of the meteorite was heated in a forge so as to enable the finder to chisel off a sample for a friend." The temperature gradient through the mass at this occasion may have been sufficiently steep to leave the other end at room temperature.

Altonah is a fine octahedrite related to Charlotte, Muonionalusta, and Seneca Township. Chemically it belongs to group IVA.

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

10.54 kg half of original mass (no. 863, 20 x 10 x 10 cm)  
91 g slices from above (no. 863)

Amates. See Toluca (Amates fragment)

### Ameca-Ameca, Mexico State, Mexico

A small nodule in the Mexican National Museum was inadequately described by Castillo (1889), who assumed it was an independent meteorite. The material has never been thoroughly examined, and perhaps has been lost, since it was not listed by Haro (1931) in his catalog of Mexican meteorites, nor could I find it on a visit to Mexico City in 1968.

Anderson. See Hopewell Mounds

### Angelica, Wisconsin, U.S.A.

44°40'N, 88°19'W

Medium octahedrite, Om. Bandwidth  $1.20 \pm 0.20$  mm. Neumann bands and  $\epsilon$ . HV  $355 \pm 25$ .

Group IIIA. 7.46% Ni, 0.50% Co, 0.11% P, 0.4% S, 18 ppm Ga, 34 ppm Ge, 9.3 ppm Ir.

#### HISTORY

A mass of 14.8 kg was found, about 1916, by Albert F. Bonnin while he was plowing in the township of Angelica in Shawano County, 5 km east of Pulaski, with the coordinates given above. Described and analyzed by Buckstaff in 1944, the meteorite has recently been reanalyzed by Clarke & Jarosewich and by Wasson.

#### COLLECTIONS

Oshkosh, Public Museum (main mass of about 13 kg), Washington (331 g).

#### DESCRIPTION

The meteorite is an irregular angular mass, with maximum dimensions 20.5 x 15.3 x 15 cm. The exterior shape is apparent from photographs given by Buckstaff (1944; 1962). Weathering seems to have removed at least 2-3 mm of the surface, and the heat-affected  $\alpha_2$  zone has disappeared. Corrosion also penetrates deep into the interior, particularly along the grain boundaries.

Etched sections show a medium Widmanstätten structure with straight, long ( $\frac{L}{W} \sim 15$ ) kamacite lamellae having a

#### ANGELICA – SELECTED CHEMICAL ANALYSES

References	percentage			ppm								
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Clarke & Jarosewich 1970, pers. comm.	7.50	0.50	0.11			120	173		17.5	27		
Wasson 1971, pers. comm.	7.42								18.3	34.9	9.3	

width of  $1.20 \pm 0.20$  mm. Kamacite appears normal under the optical microscope and shows Neumann bands. The microhardness is, however, among the highest reported in this work, i.e.,  $355 \pm 25$ ; this suggests violent shock-deformation without subsequent annealing. Taenite is not abundant, and most plessite is developed as degenerated open-meshed comb plessite, in harmony with the rather low bulk nickel content of 7.46%. Locally the taenite and plessite are sheared and significantly displaced, evidently as a result of the same event which shock-hardened the kamacite. Schreibersite occurs as  $5\text{--}10\ \mu$  wide grain boundary precipitates and as  $1\text{--}5\ \mu$  blebs in the plessite interiors. The modest quantity is in good harmony with a bulk phosphorus analysis of 0.11%.

Troilite is common as nodules ranging from 0.1 to 10 mm in diameter. Planimetry indicates a bulk sulfur content of 0.4%. Some of the troilite nodules are monocrystalline, others are beset with lenticular, anisotropic twin systems, and still others exhibit recrystallization and micromelting. The range in troilite morphology within even small sections is surprising and rare.

A large troilite nodule, 10 mm in diameter, is partly recrystallized to  $5\text{--}20\ \mu$  anisotropic grains. A contacting troilite nodule,  $7 \times 5$  mm in size, is micromelted and now separated in an interior fine-grained zone ( $\sim 2\ \mu$  grains) and an exterior coarse-grained zone ( $\sim 10\ \mu$  grains). The included daubreelite lamellae are faulty and brecciated. A 1-2 mm wide metallic zone, surrounding the micromelted troilite, is converted to  $\alpha_2$  of  $25\text{--}50\ \mu$  grain size, and concentric with this is an exterior 1 mm wide zone where  $\epsilon$  shock structures are dominant. Farther away the structure is again "normal," with Neumann bands alone.

The interpretation seems to be that the shock wave, which produced the Neumann bands by local reflections and attenuation, reached a peak temperature and pressure value high enough to recrystallize and micromelt the troilite and to transform  $\alpha$  through  $\epsilon$  back to  $\alpha$  (hatched structure) and through  $\gamma$  back to  $\alpha$  ( $\alpha_2$  structure). It also appears that micromelted troilite was squeezed out in wedge-shaped foils along newly opened fissures from the larger troilite nodules.

Apart from the interesting shock story, Angelica has normal group IIIA structure and morphology. Daubreelite and chromium sulfide nodules,  $25\text{--}100\ \mu$  in diameter, are present; some of them are beautifully intergrown with  $< 1\ \mu$  parallel troilite lamellae. Carlsbergite, the chromium nitride, occurs as hard, rose-colored platelets ( $10 \times 1\ \mu$ ) in the  $\alpha$  phase, especially on the subgrain boundaries.

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

67 g part slice (no. 2177,  $4 \times 2.5 \times 1.2$  cm)  
264 g part slice (no. 2490,  $11.5 \times 5 \times 0.9$  cm)

### Angra dos Reis (iron), Rio de Janeiro, Brazil

#### Unknown origin

Hexahedrite, H. Single kamacite crystal. Decorated Neumann bands. HV  $150 \pm 8$ .

Group IIA. 5.46% Ni, about 0.2% P, 57 ppm Ga, 188 ppm Ge, 31 ppm Ir.

#### HISTORY

This mass, a whole individuum of 6,175g, was part of a mineral collection sent from Brazil in 1888 as a donation to Pope Leo XIII to form part of an exposition in the Vatican. The attached label read "Angra dos Reis, Brasile — Siderite" and, curiously enough, added as the fall date January 20, 1869. This is the date of fall of the well-known achondrite, Angra dos Reis, so no doubt this date of fall on an unknown occasion has been erroneously added to the old label. The history of the mass remains obscure, except from the fact that it was shipped out of Brazil in 1888, and was first mentioned in the literature by Salpeter (1957), who gave a brief description and identified it as a hexahedrite. Hey (1966: 22), for an unknown reason, classified it as a nickel-poor ataxite. After the present examination had been carried out, a paper by Axon & Waine (1971) appeared, giving additional observations and three figures of the structure. In particular, the paper deals with the sequence of events that led to the present structure.

#### COLLECTION

Vatican (main mass).

#### DESCRIPTION

According to Salpeter (1957) the specimen is well preserved, exhibits flight-markings, and averages  $16 \times 13 \times 9$  cm. Axon & Waine (1971) found a discontinuous 2-3 mm wide heat-affected  $\alpha_2$  zone when they examined a 70 g endpiece. Following is a preliminary structural description based upon a small segment of  $20 \times 15 \times 3$  mm, weighing 6 g, kindly put to the author's disposition by Dr. J.T. Wasson before it was dissolved and analyzed in 1969.

ANGRA DOS REIS (IRON) — SELECTED CHEMICAL ANALYSES

References	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Easton in Hey 1966	5.44	0.33				40	136		64	148		
Wasson 1970, pers. comm.	5.48								57.0	188	31	

The fragment contains part of the exterior surface, which here shows no fusion crust and no heat-affected  $\alpha_2$  zone. It is covered by a thin crust of terrestrial oxides, but is otherwise uncorroded. Interestingly enough, the surface is heavily distorted to a depth of 2 mm. Kamacite shows uniform deformation by shear, subparallel to the surface, and the hardness here reaches a high level of  $245 \pm 10$ , in contrast to a level 100 units lower in the interior (hardness curve type III). The included rhabdites are broken, displaced, and arranged in boudinage as hard and brittle particles in a flowing, plastic matrix. It appears that the surface represents a rupture face from a violent breakup by tensional-torsional forces in the atmosphere. If this interpretation is correct, the 6.2 kg mass presently recorded is only one mass of a larger shower.

The etched section shows a typical hexahedrite structure with Neumann bands extending across the whole surface. Some of the sets are indistinct and decorated by  $1-3 \mu$  wide rhabdites. No schreibersite bodies were observed, but rhabdites are very abundant, both as plates, typically  $1 \times 1 \times 0.005$  mm, and as sharp-edged prisms  $1-20 \mu$  in thickness. Patches of clear kamacite with large rhabdites,  $5-20 \mu$ , alternate with patches of kamacite densely crowded by fine rhabdites. The macroscopically visible, irregular staining of the etched surface is due mainly to the different size and population density of rhabdites. The hardness of the kamacite is  $150 \pm 8$ , with a tendency for the low values to occur in the clear kamacite around the large rhabdites. Bulk phosphorus content is estimated to be about 0.20%. Cohenite was noted in one place as a cluster of  $10-50 \mu$  frayed units. These are evidently the remains of a single cohenite crystal,  $150 \times 50 \mu$ , which is partially decomposed to irregular ferrite units and graphite. The graphite forms typical lamellae, e.g.,  $80 \times 2 \mu$ .

Troilite was present in one place only, as a  $200 \mu$  nodule with about 50% daubreelite. It has been shock melted, and dissolved significant parts of the surrounding metal. Upon resolidification, it formed the typical  $1-2 \mu$  mosaic of sulfide-metal eutectic with frayed, spongy borders; numerous  $5-10 \mu$  daubreelite fragments are dispersed through it.

Angra dos Reis is a normal hexahedrite with shock-melted troilite aggregates. It is structurally and chemically related to Edmonton (Canada), Bruno, and Scottsville. While it appears to be different from Patos de Minas and other South American hexahedrites, there are certain close conformities to Pirapora, another little known Brazilian

hexahedrite. The two should be compared in order to establish whether or not they are a paired fall.

### Anaheim, Saskatchewan, Canada

$52^\circ 21' N, 104^\circ 52' W$

Coarse octahedrite, Og. Bandwidth  $1.4 \pm 0.3$  mm. Neumann bands.

Group I, Anomalous. 7.77% Ni, 0.45% Co, 0.22% P, 79 ppm Ga, 302 ppm Ge, 3.6 ppm Ir.

#### HISTORY

A mass of about 13.8 kg was found by Mr. William Huiras when he was mowing hay on his farm in July 1916. The meteorite was, surprisingly enough, resting on the surface of the tough sod. The grass had not undergone complete decay, and the black fusion crust on the meteorite was extremely well preserved. It therefore occurred to Johnston & Ellsworth (1921), who described the Anaheim case in minute detail, that the fall might have taken place not long before, probably during winter when the ground had been covered with a heavy layer of snow and when the soil had been frozen.

With this in mind, Johnston made inquiries about meteoric phenomena in the district. He collected well-substantiated eyewitness reports from 10 locations west of Anaheim; all clearly indicated that a conspicuous fireball, accompanied by intense roaring and leaving a long trail of white smoke, had been observed on January 21, 1914, about 14:30 local time. It came from a northwesterly direction and had been seen from a point at least 60 km west of Anaheim. The impact site was on Huiras' farm, in a meadow traversed by a small creek, on Section 32, Township 39, Range 20, west of the second meridian, corresponding to the coordinates given above. The place is 8 km north of the village of Anaheim according to the sketch map in Johnston & Ellsworth (1921); the coordinates they quote in their text must be a printer's error, as they are entirely misleading.

The circumstantial evidence given by the authors and the completely unaltered appearance of the meteorite itself leave little doubt that the Anaheim mass actually fell on January 21, 1914, at 14:30 hours.

Johnston & Ellsworth proceeded to give a full metallographic description, accompanied by three excellent photographs of the exterior and 19 photographs of etched

#### ANNAHEIM – SELECTED CHEMICAL ANALYSES

References	percentage			ppm								
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Johnston & Ellsworth 1921	7.84	0.46	0.22	100	120	10	800					
Cobb 1967	7.50	0.44					545		76		3.7	
Sen Gupta 1968	8.00										1.7	3.4
Wasson 1970a	7.74								79.8	302	3.5	



sections. They also presented a bulk analysis and good analyses of separated phases: schreibersite (25.6% Ni, 0.47% Co, 0.09% Cu), rhabdites (41.4% Ni, 0.23% Co, 0.77% Cu), kamacite (6.39% Ni, 0.48% Co, 0.03% Cu), taenite (37.4% Ni, 0.67% Co, 0.64% Cu), and troilite (62.9% Fe, 35.45% S, 0.96% Cr, 0.28% Ni, 0.16% Cu). On the basis of their observations, they correctly classified Annaheim as a coarse octahedrite.

The meteorite has recently been reclassified as a medium octahedrite by Hey (1966: 22) and Douglas (1971: 4). Wasson (1970a), however, has retained the Og classification and notes that Ge-Ga and Ge-Ni plots fall slightly outside the group I fields; he thus designates Annaheim as an anomalous member of group I. The only gas-analytical work performed was published by Hintenberger et al. (1967) who determined <sup>3</sup>He, <sup>4</sup>He, <sup>20</sup>Ne, <sup>21</sup>Ne and <sup>22</sup>Ne.

**COLLECTIONS**

Ottawa (9.20 kg endpiece, 3.10 kg endpiece and 199 g fragments), London (359 g), Copenhagen (20 g). It may be noted here that there is a discrepancy concerning the actual weight of the meteorite as found. Johnston & Ellsworth (1921) stated that it weighed 11.84 kg, but this must be wrong since the Canadian National Collection includes samples adding up to 13.1 kg (Dawson 1963: 5). If we take this figure of 13.1 kg and add the 359 g of the London specimen acquired in 1924, and further add 300-400 g to allow for loss in cutting, polishing and analyzing, we may cautiously conclude that the mass originally weighed about 13.8 kg. Perhaps 11.84 kg was a simple printer's error for 13.84?

**DESCRIPTION**

According to Johnston & Ellsworth (1921) the mass was roughly crescentic in outline, measuring 30 cm in length and 15 cm across at the widest part. The specimen varied in thickness from 5 cm at the center to 8 cm on one of the horns and 9 cm on the other. Relatively shallow regmaglypts, 2-3 cm across, covered the surface. On the slope of one prominence, a 3 cm thick troilite nodule was exposed.

Etched sections display a coarse Widmanstätten structure of straight, long ( $l/w \sim 16$ ) kamacite lamellae with a width of  $1.4 \pm 0.3$  mm. The kamacite is rich in sub-boundaries decorated by  $1 \mu$  phosphide precipitates, and Neumann bands are common. Taenite and plessite cover about 5% by area. Comb and net plessite fields occur, but more common are individual taenite lamellae, often wide enough to display decomposed interiors. The taenite stains blue-black upon etching. Interiors display acicular martensite with retained austenite, or fine bayonet-shaped  $\alpha$ -particles.

Schreibersite is common as 10-100  $\mu$  wide grain boundary precipitates and as an occasional millimeter-sized skeleton crystal. Small grooves may be distinguished locally on the surface on the mass, indicating where a schreibersite

crystal was ablated away during the atmospheric passage. Rhabdites are common as 2-15  $\mu$  thick tetragonal prisms in the kamacite. Most schreibersite crystals are apparently slightly brecciated and shear-displaced.

Troilite-graphite intergrowths occur as nodules up to 3 cm large. One such nodule was analyzed by Johnston & Ellsworth (1921) and found to contain 38% Fe (and Ni,Co), 22.3% S, 0.68% Cr and 38.7% C (as graphite). From the nodule they also separated a whitish cylindrical grain, 3 mm long and 1 mm in diameter, which was assumed to be apatite(?).

The fusion crust covers the meteorite as an almost unbroken black layer of oxides. A laminated, dendritically solidified, up to 0.5 mm thick, metallic fusion crust follows irregularly below the fused oxides. The heat-affected  $\alpha_2$  zone is 1-3 mm thick and is composed of large, serrated crystallites, comparable to what is observed upon, e.g., Silver Crown and Bahjoi. Micromelted phosphides are common in the exterior half of the  $\alpha_2$  zone, and the taenite rims and lamellae have lost their tarnished appearance.

Annaheim is a coarse octahedrite, structurally very similar to Goose Lake, Bogou, Bahjoi, Bischtübe, and Toluca. Its detailed trace element composition places it, according to Wasson (1970a), slightly outside the bulk of the irons of the resolved chemical group I.

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**Anoka, Minnesota, U.S.A.**  
 $45^\circ 14'N, 93^\circ 15'W; 270$  m

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Fine octahedrite, Of. Bandwidth  $0.34 \pm 0.06$  mm. Annealed. HV  $200 \pm 10$ .

Group IIIC. 11.75% Ni, about 0.30% P, 17.8 ppm Ga, 16.2 ppm Ge, 0.4 ppm Ir.

**HISTORY**

A mass of 1,108 g was found in 1961 in Anoka County (Meteoritical Bulletin, No. 32, 1964). It was described with figures of the exterior and of etched slices by Huss et al. (1966). The meteorite was struck with a shovel at a depth of about four feet when Joe Field, on his farm four miles northeast of Anoka, was excavating for a cesspool. Huss purchased the mass in 1963, and slices have since been made available from the American Meteorite Laboratory at Denver. A field search by Huss in the summer of 1963 failed to disclose more specimens. Wood (1964) presented a photomicrograph and several electron microprobe traces across various structural elements. Jaeger & Lipschutz (1967b) estimated the meteorite to be unshocked, i.e., having suffered shock intensities less than 130 kbar. Wasson & Kimberlin (1967) found that the chemical composition put Anoka close to Edmonton (Kentucky), Mungindi, and Carlton. Hintenberger et al. (1967) determined the amount of occluded, noble gases, while Voshage (1967) by the <sup>40</sup>K/<sup>41</sup>K method estimated a cosmic ray exposure age of  $685 \pm 150$  million years.