Hopper is a medium octahedrite related to Ilinskaya Stanitza, Apoala and Smith's Mountain. Its chemical composition is not sufficiently known. Its structure resembles Smith's Mountain very much, but there appear to be three significant differences: (i) Hopper has Neumann bands; Smith's Mountain has ϵ-structure; (ii) Hopper's kamacite hardness is 220±20; Smith's Mountain's is 280±20; (iii) Hopper appears to have a higher terrestrial age than Smith's Mountain. It is, therefore, tentatively concluded that the two irons are separate falls.

Specimen in the U.S. National Museum in Washington:
25 g weathered, octahedral fragment (no. 159, 2.5 x 1.5 x 1 cm)

Horse Creek, Colorado, U.S.A.

Approximately 37°35'N, 102°46'W; 1350 m

Anomalous hexahedrite with abundant nickel silicide. No Neumann bands. HV 252±12.

Anomalous enstatite chondrite. Bulk composition: 6.3% Ni, 0.34% Co, 0.5% P, 2.5% Si, 47 ppm Ga.

HISTORY

In 1937, when H.H. Nininger made a survey for meteorites in a sparsely settled area of southeastern Colorado, he obtained from Charles W. Moore a small mass of 570 g. The specimen had been discovered at an Indian Camp site on Horse Creek, 20 miles north of Springfield, Baca County (A.D. Nininger 1937: 449; Nininger & Nininger 1950: 62, 111). Since the mass was found at a camp site, it had possibly been transported; the coordinates above are, therefore, very approximate.

The meteorite was described by Perry (1944; 61, plates 60 and 61), who realized that it was highly anomalous and not an octahedrite although superficially resembling one of the finer varieties. He gave eight photomicrographs and discussed the kamacite and the inclusions which were assumed to be schreibersite. However, about 1958, E.P. Henderson showed that most of the lamellar material was a new mineral, a nickel silicide, with the approximate composition $(Ni,Fe)_xSi_y$ (unpublished). Ramdohr (1963a: 2014) observed a similar mineral in the St. Marks, Indarch and Grady No. 2 meteorites and noted that this was isotropic and displayed octahedral cleavage.

Fredriksson & Henderson (1965) examined Horse Creek with the microprobe and found the mineral, for which they proposed the name perryite, to consist of 81% Ni, 3% Fe, 12% Si and 5% P. They assumed that the silicide of Horse Creek was identical to that of St. Marks, as have all later authors also erroneously done. Perryite of variable compositions was found in the St. Marks enstatite chondrite (Fredriksson & Reid 1967). Reed examined the silicides in Horse Creek and in the enstatite chondrites, Kota-Kota and South Oman, where the mineral was more massively developed than in Horse Creek, so that a better microprobe analysis could be obtained. The compositions were found to lie within the limits 75-81% Ni, 3-7% Fe, 12-15% Si and 2-5% P.

Wai & Wasson (1969) and Wasson & Wai (1970) analyzed the anomalous meteorites Mount Egerton and Horse Creek, and compared them to the enstatite achondrites, of which Norton County in particular was found to show similar features, such as a highly reduced kamacite phase with 0.6-2.5% Si, and the presence of perryite.

Strunz (1970: 97) and Fleischer (1972) do not agree with respect to the stoichiometric formula of perryite, giving, respectively, $(Ni,Fe)_2$ (Si,P) and Ni_5Si_2. It appears that the mineral is quite insufficiently described. From the examination that follows here, it furthermore appears that two different minerals, or perhaps two allotropic forms of the same mineral, are involved, one being a cubic mineral as typified in the St. Marks enstatite chondrite, and the other being an anisotropic mineral, present only in Horse Creek.

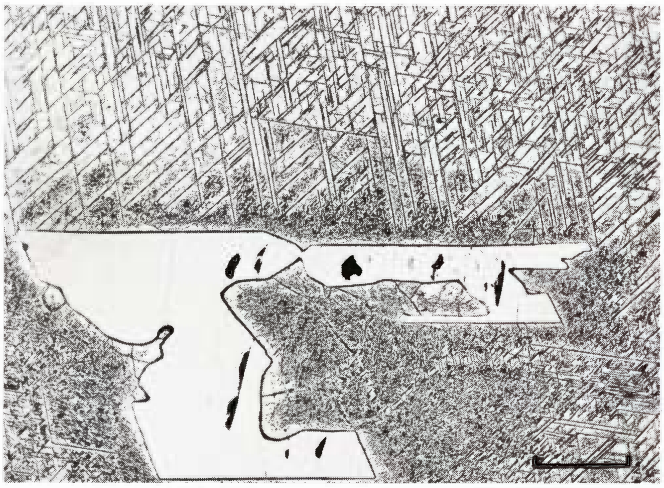

Figure 886. Horse Creek (U.S.N.M. no. 1237). An extremely anomalous iron meteorite. A large skeleton crystal of schreibersite. Etched. Scale bar 400 μ. (From Perry 1944: plate 60.)

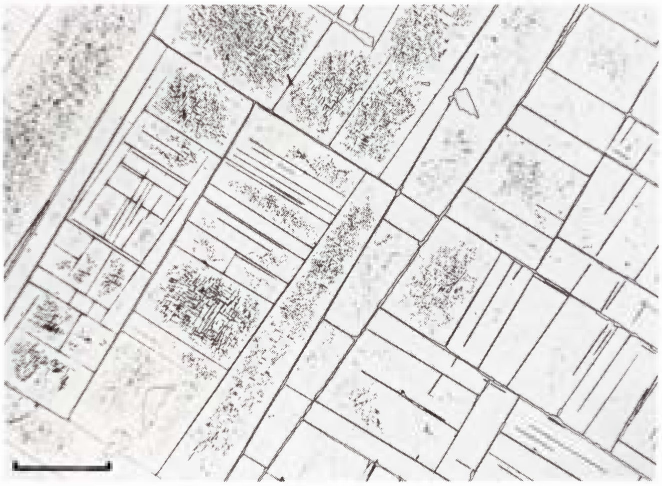

Figure 887. Horse Creek (U.S.N.M. no. 2499). A view of a section through the mass, cut at a different angle from Figure 886. Etched. Scale bar 300 μ.

COLLECTIONS

Washington (140 g), London (50 g), Tempe (49 g), Chicago (48 g), Harvard (39 g), Ann Arbor (2.6 g).

DESCRIPTION

The shape and dimensions of the original mass are unknown. Horse Creek has been divided and subdivided on numerous occasions, and the largest single samples now only weigh from 50 to 81 g.

Etched sections display a structure which may be termed hexahedral, since the bulk material is a single crystal of kamacite. It is, however, highly unusual, containing a large number of oriented exsolution products, believed by previous workers to be the same silicide as seen in St. Marks, Kota-Kota and Mount Egerton, i.e., perryite. It forms 1-20 μ wide and up to 10 mm long lamellae which are creamy-yellow in reflected light. It is distinctly developed and very conspicuous, also because terrestrial corrosion has penetrated along the lamellae and weakened the coherence so that the meteorite easily breaks up in small octahedral fragments. On various sections examined by the author, never more than four lamella directions were observed, and the measured angles between the directions could always be interpreted as Widmanstätten angles by means of the tables prepared by Buchwald (1968b). Many of the samples are parallel cuts displaying the following set of angles 51°-7°-51°-71°, which correspond to a section parallel to (0,1,1.09), or $(0,11,12)_\alpha$, through the cubic crystal.

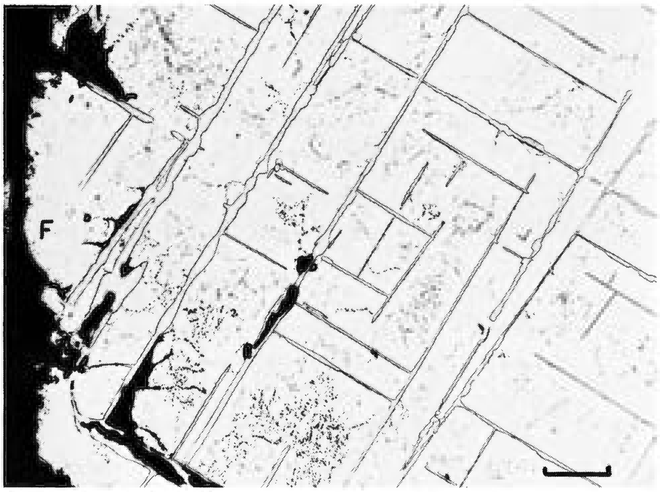

Figure 888. Horse Creek (U.S.N.M. no. 2499). Fusion crust (F) to the left and heat-affected zone in most of the picture field. Etched. Scale bar 100 μ.

Ramdohr (1964) suggested that the powder pattern of perryite (from stony meteorites) is very similar to that of kamacite, i.e., body-centered-cubic. If the perryite is assumed to have a body-centered-cubic structure, with two (nickel + iron) atoms per cell and (silicon + phosphorus) at interstitial positions, the formula should ideally be $(Ni,Fe)_2(Si,P)$. However, as Reed (1968) noted, there is a clear deficiency in (Si + P), indicated by the ratio 2:0.8. This would rather correspond to a formula unit $(Ni,Fe)_5(Si,P)_2$, as also accepted by Fleischer (1972). On the other hand, minute microprobe examinations seem to indicate that the silicide is far from homogeneous, displaying significant fluctuations in nickel, silicon and phosphorus.

HORSE CREEK – SELECTED CHEMICAL ANALYSES

A: Kamacite, microprobe analyses

	percentage					ppm						
References	Fe	Ni	Co	P	Si	C	Cr	Cu	Zn	Ga	Ge	Ir
Reed 1968		4.1			2.4							
Wai 1970	93.7	3.8	0.29	0.05	2.5			<200				

B: "Perryite", microprobe analyses on Horse Creek material

References	Fe	Ni	Co	P	Si	C	Cr	Cu	Zn	Ga	Ge	Ir
Fredriksson & Henderson 1965	3	81		5	12							
Reed 1968	4	79		4	12							
Wai 1970	4.0	80.5	0.04	4.1	12.0			2900				

From these data it is seen that the atomic ratio (Fe,Ni):(Si,P) is close to 5:2.

C: Bulk Chemical Analyses

References	Fe	Ni	Co	P	Si	C	Cr	Cu	Zn	Ga	Ge	Ir
Goldberg et al. 1951		5.87								47		
Bastron 1958, unpubl.		5.0	0.5				160	440				
Henderson 1959, unpubl.		6.15	0.48	0.49	2.6							
Wai 1970		6.3			2.3							

Wai estimated by point counting that Horse Creek contained 3.0% perryite and calculated the above bulk analytical values from the measured components. Bastron's analysis was performed by quantitative spectrography (U.S. Geological Survey report, dated June 5, 1958, Smithsonian Archives).

The parent crystal was a kamacite single crystal, not a taenite crystal as is usually the case when Widmanstätten structures in iron meteorites are discussed. The nickel silicide has exsolved on the $(111)_\alpha$ planes of the kamacite. It has penetrated the whole mass as slender primary platelets; subsequently a second generation of much smaller platelets, typically 5 x 0.5 μ in size, has precipitated in the interstices, following the same crystallographical laws.

Zones, 20-40 μ wide, along the larger silicide lamellae are depleted in nickel, silicon and phosphorus and more or less free of precipitates. The silicide itself is distinctly anisotropic and weakly bireflectory, both on polished and on etched sections, so it cannot be identical to the body-centered-cubic perryite mineral described by Ramdohr (1963a) from stone meteorites. The platelets are either platy single crystalline units or they are composed of numerous individuals, which can be clearly seen under crossed Nicols. They are ductile and rarely damaged and brecciated, as opposed to the schreibersite crystals. They do not exhibit octahedral cleavage, as do the perryite inclusions in enstatite chondrites.

The kamacite is monocrystalline but rich in winding subboundaries decorated with less than 0.5 μ precipitates. Neumann bands were curiously enough not detected; deformation twins are otherwise quite common in both iron-nickel and iron-silicon ferrite. The kamacite is hard, 252±12, mainly due to the presence of a significant quantity, 2.5%, of silicon. This element is known to strengthen the ferrite considerably by solid-solution hardening.

Schreibersite occurs as cuneiform and hook-like crystals that reach sizes of 5 x 0.5 or 2 x 3 mm. It is monocrystalline but brecciated and invaded by terrestrial corrosion products that have partially recemented the fragments. Schreibersite, with 15.3% P, covers about 2% by area; silicide, with 4% P, about 3% by area; and kamacite, with 0.05% P, the remainder. The bulk phosphorus content may thus be estimated to be 0.50±0.05%, which tallies well with Henderson's value, obtained by wet chemical analysis. The schreibersite has been analyzed by Wasson & Wai (1970) who found 19.3% Ni, 15.3% P and 0.17% Si and also showed its composition to be very similar to schreibersite in Mount Egerton and some enstatite chondrites. The microhardness is 910±30, similar to schreibersite crystals of the same bulk composition, but without silicon.

Troilite, chromite, carbides, graphite and silicates were not detected on the sections.

On two specimens (U.S.N.M. no. 1237 and Tempe no. 378.1x) parts of the original surface were discovered. Fusion crusts and heat-affected zones are present, indicating (i) that the terrestrial age is relatively low, and (ii) that Horse Creek is an independent small iron meteorite and not a metallic part of some composite enstatite chondrite, released by exposure to weathering.

The fusion crust consists of an exterior magnetite and wüstite layer, 30-50 μ thick, and an interior, 50-100 μ thick metallic layer. The metal, which is dendritic-columnar and

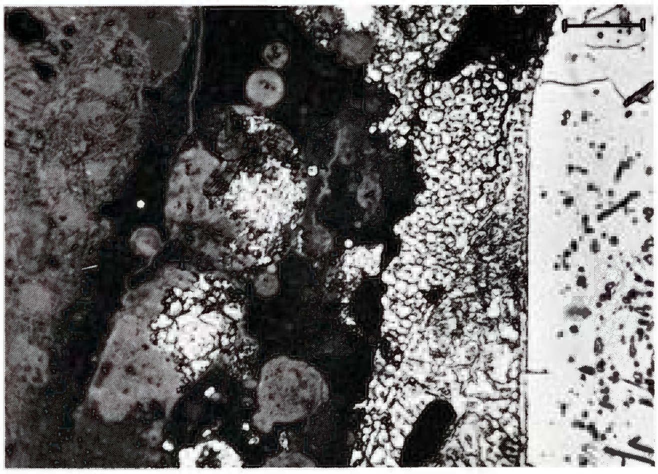

Figure 889. Horse Creek (Tempe no. 378.1). Detail of the fusion crust with its intricate mixture of dendritic metal and fused iron oxide globules. Etched. Scale bar 20 μ.

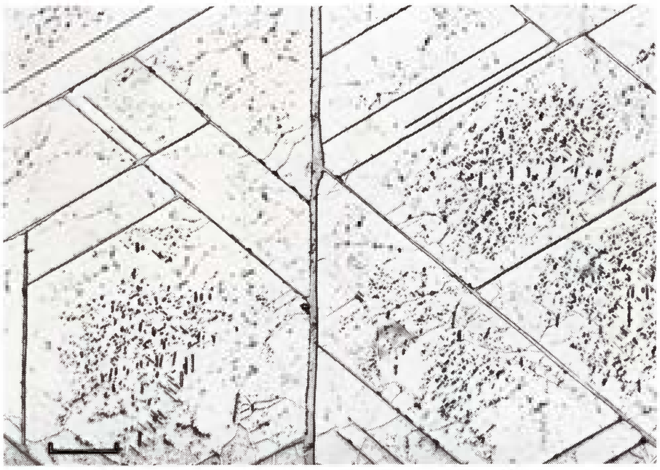

Figure 890. Horse Creek (Tempe no. 378.1). Wide and narrow silicide lamellae and subboundaries in the iron-silicon matrix, with additional precipitates. Etched. Scale bar 50 μ.

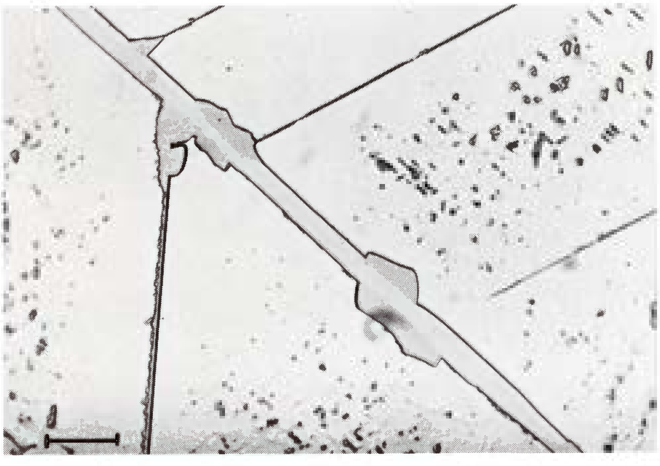

Figure 891. Horse Creek (Tempe no. 378.1). Detail of the silicide crystals. They are optically anisotropic and cannot be identical to the cubic perryite crystals described from St. Marks. The silicide exhibits two shades of yellowish colors, which is due to an orientation effect (pleochroism). Etched. Scale bar 20 μ.

shows microshrinkage cavities, has a hardness of 325±30; it etches slowly but is otherwise not different from the fusion crust of normal silicon-free iron meteorites. In the metallic fusion crust there are numerous 1-15 μ melted globules of trapped oxides.

Below the fusion crusts there follows a 1-2 mm wide heat-affected zone of a very unusual character. In the exterior part the schreibersite crystals are micromelted, but the silicides are also distinctly affected. It appears that they are micromelted wherever the temperature briefly exceeded about 1300° C, and are diffuse with ragged outlines in the temperature zone from 900° to 1300° C. The morphology of the micromelted silicides corresponds closely to that of micromelted schreibersite crystals observed in other irons.

The metal of the heat-affected rim zone has not developed the typical serrated α_2 structure which forms in normal iron meteorites when the temperature briefly exceeds 750° C. The reason is qualitatively clear. The analytical work quoted above has shown that the kamacite of Horse Creek averages 4% Ni, 0.3% Co, 0.05% P and 2.5% Si. Such a silicon-rich alloy must have a very high $\alpha \rightarrow \gamma$ transformation temperature, probably well above 1200° C. Unfortunately, the ternary Fe-Ni-Si and the quaternary Fe-Ni-Co-Si and Fe-Ni-P-Si diagrams are very insufficiently known so it is not possible to be exact as to boundary conditions in terms of temperature and composition for the α_2 formation.

The metal of the heat-affected zone displays, however, an indistinct granulation in the same zone in which the silicides are micromelted. This is an indication that the $\alpha \rightarrow \gamma$ transformation temperature for the Horse Creek kamacite lies round about 1300° C. The granulated kamacite has a grain size of 10-50 μ and a microhardness of 225±10.

The meteorite is slightly weathered, particularly along the nickel silicide and schreibersite lamellae. A 0.1-0.5 mm thick limonitic crust is locally preserved; in this the silicide is seen to survive more or less unaltered for a long time.

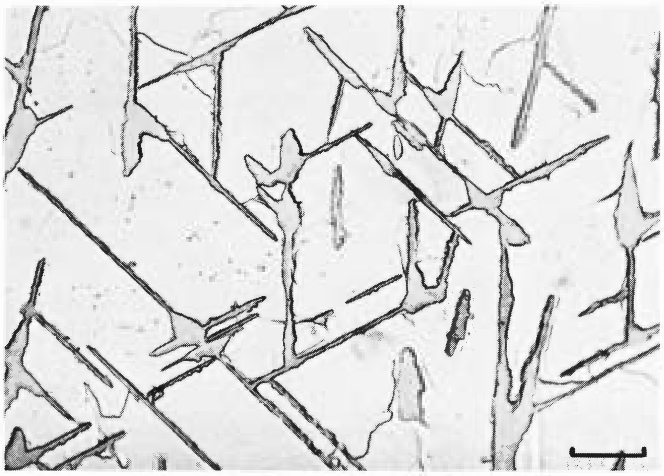

Figure 892. Horse Creek (Tempe no. 378.1). Detail of the heat-affected zone with granulated α_2 and diffuse silicides. It is estimated that the temperature here briefly exceeded 1300° C. Etched. Scale bar 20 μ.

Unfortunately, the main mass was never described, so it is unknown whether the 570 g mass was an entire meteorite or a fragment of some larger mass. The presence of heat-affected zones and fusion crusts do, however, indicate that Horse Creek probably never was much larger.

Horse Creek is very anomalous and has no relatives at all among meteorites normally accepted as irons. As shown by Wasson & Wai (1970) it belongs rather with Mount Egerton and a number of enstatitic chondrites and achondrites. Enstatitic meteorites are highly reduced so that silicon is generally found in solid solution in the kamacite (0.5-3%) and in the schreibersite (0.10-0.25%) (Ringwood 1961; Mason 1966b; Keil 1968; Wason & Wai 1970).

Horse Creek has a bulk composition that suggests that it was never in an austenitic phase. It apparently contains sufficient nickel, silicon, cobalt, and phosphorus to stabilize the kamacite phase at all temperatures. Consequently, the nickel silicide must have precipitated from a single kamacite crystal, initially homogeneous with respect to all elements. It precipitated upon the $(111)_\alpha$ planes. The bulk of the phosphorus had precipitated as large schreibersite crystals before the silicide exsolved. The silicide of Horse Creek is different from the silicides of St. Marks, Kota-Kota and other enstatitic chondrites. It is an anisotropic mineral, with a bulk composition approaching Ni_5Si_2. Synthetic Ni_5Si_2 has been tentatively described as orthohexagonal with a melting point of 1255-1282° C (Hansen & Anderko 1958: 1039). Perhaps the silicide of Horse Creek is identical to this, except for minor substitutions by Fe and P atoms.

Horse Creek thus presents numerous problems. The lack of information on the ternary and quarternary diagrams, involving Fe,Ni,Si,P and Co is apparent. Also, exact data on the silicide are still missing. It is recommended that the silicides of the chondrites be again compared with that of Horse Creek and that a full mineralogical description be given so that the relationships may finally be established.

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

57 g	part slices, polished sections (no. 1237)
81 g	part slice (no. 1534)
1.9 g,	11 fragments (no. 2499)

Hraschina, Croatia, Yugoslavia

46°6′N, 16°20′E

Medium octahedrite, Om. Bandwidth 0.70±0.10 mm. Partly recrystallized. HV 185±10.

Probably group IID. Estimated analysis: 10% Ni, 0.4% P.

Synonym: Agram, the German name for the Croatian capital, Zagreb.

HISTORY

Two masses of 71 and 16 pounds (Viennese pounds of 560 g, i.e., masses of about 39.7 and 9 kg) were observed to fall on May 26, 1751, at 6 p.m. near Hraschina, 45 km northeast of Zagreb. The fall is among the oldest on record and has won fame because it was on material from this fall that Alois von Widmanstätten first observed the structure that later was named after him (Neumann 1812: 207; Schweigger 1817). In the early literature the fall was always called Agram, after the German name for the Croatian capital, Zagreb. About 1920 it became known as Hraschina, but references can still be found to the old name.

The fall itself aroused great interest and some fear among the local farmers. Actuated by Emperor Francis I, a commission was sent from Zagreb to verify the news of the fall. On July 6, 1751, the commission, attended by many witnesses, reported its findings to the Bishop of Zagreb, and presented him with the largest mass. The record of the event, written in Latin and archaic German, is to be found in the Episcopal Archives of Zagreb, and has on various occasions been examined and translated (Güssmann 1785; Stütz 1790; von Ende 1804; Haidinger 1859). Additional handwritten reports and colored drawings were discovered much later by Haidinger (1859; 1860d). The following is a brief summary of the essential reports.

Seen from Hraschina, the meteorite appeared as a fireball on the clear eastern sky. It was observed to split into two fragments "which were linked together by fiery chains," and loud detonations were heard. The larger fragment of 40 kg made a funnel-shaped impact hole, about 120 cm deep and 50 cm wide, on the farmland of Michl Kollar who had plowed only a week before. The smaller mass of 9 kg made a similar hole about 90 cm deep and 90 cm wide at a distance of 2,000 paces from the first mass. The localities were immediately east of the village of Hraschina. In the sky, the eminent smoke trails were seen to change in color and shape within the next four hours. Haidinger (1859: plate I) has reproduced drawings of the fall and smoke trails made by witnesses in the town of Szigetvar, situated about 110 km due east of Hraschina. To these people, the huge fireball appeared to have descended slightly west of their town, just on the other side of the hills. This observation is very typical for most witnesses' reports of fireballs and meteorites. Although an actual fall can take place 100 km away, the general feelings are usually that the meteorite descended only a few kilometers distant and could easily be discovered in the vicinity. It is also worth noting that the Szigetvar witnesses, although reporting the sight most vividly, heard no detonations or typical whizzing sounds at all. Other reports came from Biskupecz, 25 km north, where detonations were heard (Haidinger 1860d), and from Graz, 100 km north-northwest, where witnesses only saw the fireball. The most distant eyewitness was located at Neustadt an der Aisch, near Nuremberg, 525 km northwest. On the basis of the admittedly very few and partly unsubstantiated reports, Haidinger (1859: 375) reconstructed the fall to have come from a northwesterly direction. Ramovic (1965: plate 12) reproduced an old copperplate print of the fall as seen from Hraschina itself; but no further details were added.

The trajectory of Hraschina has been calculated by Niessl (1925) and is also included in the recent catalog of bright meteors (Nielsen 1968) in spite of the very low degree of accuracy of the available observations.

The two masses were immediately excavated by the local farmers, and, for once, it is remarkable that there is no mention at all of the irons being hot or even warm. The large mass was delivered to the minister, who in turn forwarded it to the bishop. The Emperor, in Bratislava, ordered the mass to be handed over to him for inspection, and soon after it became incorporated in the Imperial Treasury, in Vienna. In 1777 it was transferred to the Vienna Natural-Cabinet, where it became the cornerstone of the coming, large meteorite collection. It was, however, not accepted as a meteorite in the beginning, as may be seen from this passage by the curator Andreas Stütz (1790): "Of course it is said that in both cases [i.e. the Hraschina iron meteorite fall in 1751, and the Eichstädt chondrite fall in Bavaria, 1785] the meteorites fell from the sky. Even the more enlightened minds in Germany may have believed that in 1751, in view of the then prevailing terrible ignorance of natural history and practical physics. But in our day it would be unforgiveable to regard such tales as likely." This attitude was common to men of learning during the second half of the eighteenth century

Figure 893. Hraschina. The 39.7 kg main mass in Vienna. The slightly convex front is covered with angular regmaglypts. Two bright spots indicate where a little material has been removed. Scale bar approximately 10 cm.

and was vigorously supported by the French Academy. But a different approach was soon to make itself known by such men as Chladni (1794; 1819, etc.), Howard (1802), Biot (1803), Ende (1804) and Silliman & Kingsley (1807).

The small mass was divided by blacksmiths in Hraschina, Zagreb and Bratislava, and while some parts were forged into nails, others were distributed as curios (Haidinger 1860d). This mass was thus already lost to science during the first few months after its fall, and nothing is to be found today in any major collection. The incident is quite important because it gives an indication of what must usually have happened in earlier times, when there were no authorities or mineral collectors actively engaged in tracing and compiling the material from new falls of iron meteorites.

The 40 kg mass was in the 1751 Commission report described as of irregular triangular shape, resembling a shoulder blade. Its fracture was of iron or steel color, and its exterior consisted partly of a rather smooth surface and partly of a cavity-covered surface (i.e., typical regmaglypts). In 1808, Alois von Widmanstätten, an expert in iron foundry techniques, but now Director of the Imperial "Fabriks-Producten Cabinet," hacksawed a 4 x 2.5 cm slab from the main mass in order to examine the nature of the metal. He carefully ground and polished the sample and then heated it over an open flame. When the octahedral structure developed, due to the different rate of oxidation of kamacite and taenite, he realized that he had produced a unique test for meteoritic iron, since such structures were unknown in artificial steel and iron. While artisans and scientists had usually judged the structure of a material by fracturing it – and continued to do so for another four generations – Widmanstätten's discovery indicated that much was to be gained from a study of polished and etched sections.

Shortly afterwards, he repeated the examination, but this time he applied nitric acid as an etchant, with a similar result. He related his experiments to friends within the circles of learned men in Vienna but never published the results himself. Soon after, it was common knowledge that octahedral, platelike figures would develop on (most) meteoritic irons when heat-tinted or annealed. The first printed reference was apparently by Neumann (1812: 207) who stated that Widmanstätten was the first to observe these figures on Agram, i.e., Hraschina, "and other masses." These other masses can only have been Toluca and Krasnojarsk, the only metallic meteorites available with distinct Widmanstätten structure – besides Hraschina – at that time in Vienna. A few years later, Elbogen, Lenarto, Campo del Cielo and Bendego also became available, and the Widmanstätten structure was identified on most of them. The first application of the term "Widmanstätten structure" is probably to be found in Schweigger's (1813; 1817) small treatises, while the first reproduction was given by Schreibers (1820). The term was not commonly applied to artificial structures until after Arnold & McWilliam (1904) had reported it in steel castings, and Belaiew (1909; 1914b; 1923) had thoroughly discussed the occurrences in many alloys. An early – perhaps the first – reference to Widmanstätten structure in a commonly applied textbook was given by Guillet & Portevin (1918: 162 and plate 49) who discussed hypoeutectoid steels. For a thorough elucidation of the history of the Widmanstätten structure, the reader is referred to Cohen (1894: 40), Paneth (1960), Smith (1960) and Mehl (1965).

Evidently Widmanstätten gave some of his etched samples away, because Chladni (1819: 327) stated that he had one in his own collection. However, the original heat-tinted sample remained in Widmanstätten's possession until he died at the advanced age of 96, in 1849 (Haidinger 1859: 338). The sample later came to the Museum of Natural History in Vienna where it is now on display (no. A 5 b).

Since the Hraschina mass has never really been sectioned – only small protruding knobs have been removed – its detailed structure and composition are virtually unknown. Schreibers (1820) gave a description which was adequate for its time and included a direct typographical imprint of a deep-etched section. Partsch (1843: 103) also gave a description, but apart from these early works only brief notes have appeared. Brezina (1885; 1896) made a few observations and in 1892 privately published some eminent photographs of the exterior. Wülfing (1897: 147) prepared an almost complete bibliography.

It was, therefore, my hope to examine the only cut and large specimen known, of 280 g, preserved in the British Museum since May 1846 when it was purchased from Mr. Heuland. The sample was kindly put at my disposal by Dr. Hutchison, but unfortunately it turned out that it was not a genuine Hraschina specimen at all, but rather a Toluca fragment. Apparently the Hraschina meteorite is so little known that a polished and etched sample has for 125 years passed for a genuine sample in the British Museum.

COLLECTIONS

Vienna (39.21 kg and minute sections), Göttingen (29 g), Berlin (20 g), Chicago (9 g), Sarajevo (7.6 g), Harvard (6 g), Amherst (4.3 g), Tübingen (3.9 g), Paris (2.5 g), Zagreb (1.7 g), Calcutta (1.6 g), Stockholm (1.3 g), Washington (0.7 g). In this study the specimen in the British Museum, no. 19963 of 261 g (Hey 1966: 207), allegedly from Hraschina, was discovered to be something else, most certainly a mislabeled Toluca sample. Also the sample in New York (AMNH no. 871 of 80 g), although having been accepted as true Hraschina for over 100 years, was found to be mislabeled.

ANALYSES

Holger (1830) reported 11.84% Ni and 1.26% Co. Wehrle (1835) found 8.88% Ni. Cohen & Weinschenck (1891) treated 31 g of shavings with dilute hydrochloric acid; in the undissolved remnants they found 0.133 g schreibersite, with the following average composition: 57.46% Fe, 25.78% Ni, 1.32% Co and 15.31% P.

From the examination below the author would estimate Hraschina to contain 10±1% Ni, 0.6±0.1% Co, and 0.4±0.1% P. The meteorite resembles the irons of group IID.

DESCRIPTION

The following is based upon a cursory examination of the main mass, as it is exhibited in Vienna, and on a more thorough study of small polished sections, kindly put at my disposal by Dr. Gero Kurat, Vienna, and Mr. Roy S. Clarke, Smithsonian Institution.

Hraschina is roughly shield-shaped, with a triangular outline. It measures approximately 38 x 28 x 10 cm in three perpendicular directions and weighs 39.7 kg. The slightly convex front is covered with conspicuous, somewhat angular regmaglypts, ranging from 1.5 to 4 cm across. They are usually about 1 cm deep and separated by smoothly rounded ridges. The opposite side is flat and covered with large, shallow regmaglypts with little relief. The morphological differences between the two sides correspond closely to what may be observed on, e.g., Ilimaes, Cabin Creek, Iron Creek and Quinn Canyon. The reason must be the same, i.e., the meteorites represent highly oriented stabilized falls where the convex, deeply carved surface was foremost during the flight. On both surfaces, but distinctly on the anterior one, straight scars resembling chisel marks may be observed. They are typically 1-5 cm long and 1-2 mm deep and wide, and are apparently oriented in a limited number of directions. They indicate where Brezina lamellae of schreibersite were partly removed by ablation melting during the atmospheric flight. There are no late fracture surfaces that immediately suggest where the 9 kg mass – now lost – was once attached. The two fragments evidently separated before the cosmic velocity decreased entirely; during the remaining high-velocity flight the fracture faces became altered, pitted and covered with fusion crusts, so that they are now unrecognizable.

The fusion crust is complex, being composed of an outer oxidic layer and an inner metallic layer. Together they are up to at least 1.5 mm thick, being irregularly crossbedded and locally forming intricate whirlpools due to eddies in the rapidly passing air. The oxidic layer is 30-100 μ thick and composed of 1-4 layers of wüstite and magnetite, in the same way as discussed under, e.g., Bogou. The metallic layer is composed of dendritic columnar layers with gasholes and minute, trapped oxide globules. In one place, no less than 30 consecutive laminae, each averaging 50 μ in thickness, were counted. This must for some time have been a protected "leeward" position on the falling meteorite so that part of the fused metal, stripped from the frontal regmaglypts, could be redeposited here. The microhardness is 340±40, highly variable due to the unequilibrated dendritic structure with shrinkage cavities.

Under the fusion crusts follows a heat-affected α_2 zone. It is unusually wide – 4 mm – but this is caused by the geometry: the examined specimens were from protruding knobs on the main mass. The real width, under straight untapering surfaces, is 2-2.5 mm. In the outer half of the α_2 zone micromelted phosphides are present. The hardness is 182±12 (hardness curve type II).

Etched sections display a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 20$) kamacite lamellae with a width of 0.70±0.10 mm. The kamacite is recrystallized to rather uniform aggregates of equiaxed 50 μ grains. Patches of grains, only 10-20 μ across, occur locally, and larger, equilibrated grains, up to 100 μ across, appear particularly in the nickel- and phosphorus-depleted zones adjacent to the schreibersite lamellae.

The kamacite has old subboundaries, decorated with 1-6 μ angular phosphides, and old Neumann bands, now indistinctly visible in the unrecrystallized parts of the kamacite. All recrystallized kamacite grains show new sharp Neumann bands, independently oriented from grain to grain. The hardness is 185±10, suggesting annealing and recovery. Since the examined specimens were nowhere farther than 8 mm from the ablated surface, the measured hardness is possibly on the low side of the genuine interior value.

Taenite and plessite cover about 35% by area. Comb and net plessite are present, but more characteristic are massive fields with tempered martensite or optically unresolvable $\alpha + \gamma$ fields. Wide taenite lamellae are also common. They etch yellow, are not cloudy, and are soft (HV 188±10), suggesting annealing and homogenizing.

Schreibersite is common as imperfect Brezina lamellae in dodecahedral directions. They range in size from 50 x 1 mm to 2 x 0.2 mm and are enveloped in 0.8-1.0 mm wide rims of swathing kamacite. Schreibersite also occurs as 20-80 μ wide grain boundary veinlets and as 5-50 μ particles inside the plessite fields substituting for γ-particles of similar sizes. Rhabdites appear locally as 2-6 μ prismatic particles; there are also numerous microrhabdites less than 1 μ across in the matrix. In the strained kamacite adjacent to black taenite wedges, the microrhabdites are particularly common, having profusely decorated the densely spaced slipplanes of the kamacite.

Around the nickel-richest, i.e., the smallest schreibersite particles, an inconspicuous 1-2 μ wide reaction zone with taenite particles is apparent. This zone probably indicates a readjustment of nickel towards lower values in the schreibersite as a result of reheating to about 500° C. This is in line with the partial recrystallization of the kamacite and the annealing of the taenite.

Troilite was not detected as large nodules, but it occurs as scattered 50-1,000 μ lenticular and bar-shaped bodies in the kamacite. It contains 1-10 μ wide daubreelite lamellae. It is recrystallized to 50-200 μ grains, each displaying multiple twinning due to slight plastic deformation. Subangular daubreelite grains, 10-50 μ across, occur locally in the kamacite.

Graphite, carbides and silicates were not present in the sections.

Hraschina's chemical composition is only very inaccurately known. The structure indicates that it is either related to Treysa, Zacatecas (1969) and Sanderson and thus a member of the resolved chemical group IIIB, or related to Elbogen, Carbo and N'Kandhla and then a member of group IID. Whatever its genetical relationship may be, the structure clearly indicates that it has been subjected to cosmic deformation and annealing in a way known to occur in many other iron meteorites, such as Zacatecas (1969), Carbo, Sandtown, Avoca and Roebourne.

Since what can be done with minute near-surface sections is very limited, it is recommended that a section through the interior be made available for metallographic examinations and samples be subjected to chemical analytical and gas analytical work. After all, there are only few iron falls, and Hraschina appears to belong to the more important ones.

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

0.7 g part slice (no. 1043, 12 x 6 x 0.1 mm) mechanically damaged during the separation from the main mass
0.3 g part slice (no. 2825)

Huizopa, Chihuahua, Mexico
28°46'N, 108°32'W

Fine octahedrite, Of. Bandwidth 0.28±0.05 mm. Partly recrystallized. HV 185±15.

Group IVA. 7.90% Ni, 0.38% Co, 0.035% P, 2.3 ppm Ga, 0.12 ppm Ge, 2.8 ppm Ir.

HISTORY

This meteorite was first reported by Prior (1923a: 74) who had acquired a 1.5 kg fragment for the British Museum in 1908. According to letters from the informer, one mass of 108 1/2 kg and four smaller masses of from 5 to 10 kg had been found the year before in a ruin near Huizopa. Huizopa may be found on modern maps as a tiny village in Chihuahua, only 4 km east of the state line to Sonora; it has the coordinates given above. The masses were brought to Chihuahua City for sale as silver ore, but then they were lost sight of, until Nininger (1932a; 1950: 111) performed some detective work during a couple of visits to Mexico in 1929 and 1931. While an 8 kg mass had been acquired for the Instituto Geologico in Mexico City (Haro 1931: 77: "No. 36 Temosachic"), the largest mass had been incorporated, unlabeled, in a pile of ore specimens, also mostly unlabeled, in the State Mines Exhibit in Chihuahua City. Nininger secured a total of about 40 kg from these masses for exchange (personal communication). The fate of the other three small masses is unknown.

The large mass was described with photographs of the exterior and with photomacrographs by Nininger (1932a). Some of the figures were again reproduced in Nininger (1933c: figure 5) and Nininger & Nininger (1950: plate 1). Jaeger & Lipschutz (1967b) assumed that the surface of the meteorite still retained marks of aerodynamic ablation;

Figure 894. Huizopa (Tempe no. 55bx). Fine octahedrite of group IVA, related to Gibeon. Severe cracks, now partly filled with terrestrial corrosion products. Black dots indicate shock-melted troilite nodules. Deep-etched. Scale in centimeters. (Courtesy C.B. Moore.)

HUIZOPA – SELECTED CHEMICAL ANALYSES

Huizopa is evidently one of the better analyzed meteorites. Many other trace elements have been determined, thus As, Sb, Mo, Ag, In and Pd by Smales et al. (1967) and Pd and Au by Goldberg et al. (1951). Hawley's platinum value above includes all platinum metals.

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Hawley in Nininger 1932a	7.90	0.37	0.04		600	470	350					
Hawley 1939	7.90											9.6
Lovering et al. 1957	7.81	0.38				233	135		2.8	<1		
Nichiporuk & Brown 1965											2.5	4.4
Wasson 1967a	7.94								2.28	0.122	3.0	
Smales et al. 1967					390	304	154	<1	2.02	0.19		
Lewis & Moore 1971	7.94	0.38	0.03	60								

they were not able to conclude whether the observed recrystallization was atmospheric or preatmospheric. Schultz & Hintenberger (1967) determined the amount of occluded noble gases, while Voshage (1967) by the $^{40}K/^{41}K$ method found an exposure age of 430±90 million years.

COLLECTIONS

Chihuahua City (about 65 kg of the 108 1/2 kg mass), Mexico City (6.3 kg of an 8 kg mass), New York (3,571 g), Amherst (2,930 g), Washington (2,790 g), London (2,676 g), Ann Arbor (2,100 g), Tempe (1,875 g), Los Angeles (1,206 g), Chicago (303 g), Yale (294 g), Harvard (204 g), St. Louis (167 g). Most of the slices come from the 108 1/2 g mass, cut by Nininger about 1932.

DESCRIPTION

Huizopa appears to have been a shower of which at least five masses were recovered. The extreme dimensions of the 108 kg mass were, according to Nininger (1932a), 65 x 35 x 18 cm. The shape was irregular crescent-like with numerous 2-5 cm pits, and with occasional basin-like depressions up to 3 cm deep and 9.5 cm in diameter.

The 8 kg (now 6.3 kg) mass in Mexico City has the average dimensions 21 x 15 x 7 cm and is irregularly lens-shaped. It is covered with 2-5 cm pits, some of which appear to be weathered regmaglypts. There is no obvious fracture to indicate where it broke loose from the main mass. Fusion crusts are not preserved on any of the masses; on the contrary, most of the surfaces are covered with 0.5-2 mm thick oxide crusts. However, locally on sections up to 1 mm wide α_2 zones may be detected. It, thus, appears that the masses have been exposed to terrestrial weathering for a considerable period, resulting in an average loss of 1-3 mm of the surfaces and a significantly modified ablation relief. Several of the masses have been hammered and chiseled, and flattened areas from this treatment are common. The damage seems to be very superficial and not associated with reheating.

Etched sections display a fine Widmanstätten pattern of slightly distorted, long ($\frac{L}{W} \sim 25$) kamacite lamellae with a width of 0.28±0.05 mm. Characteristic of the larger slices, as, e.g., Tempe No. 55bx and U.S.N.M. No. 871, are the discontinuous fracture lines which zigzag along octahedral planes from the surface to the center of the mass. It is most likely that they date back to a remote, preatmospheric event which deformed and somewhat fissured the main mass. Upon entering the Earth's atmosphere the deceleration forces were sufficient to fragment the mass along some of these fissures, thus producing a shower. The remaining fractures are now, of course, filled with terrestrial corrosion products.

The kamacite is beset with Neumann bands which are locally bent and distorted. In one place, at least, heavy cold-deformation is present in the form of a 1 mm wide and 10 cm long zone in which the Neumann bands and other linear elements are intensely folded and sheared. Lenticular deformation bands, similar to those observed in some

Figure 895. Huizopa (Tempe no. 55bx). The meteorite shows severely distorted Neumann bands and partly recrystallized kamacite lamellae. In the center a daubreelite crystal. Etched. Scale bar 400 μ.

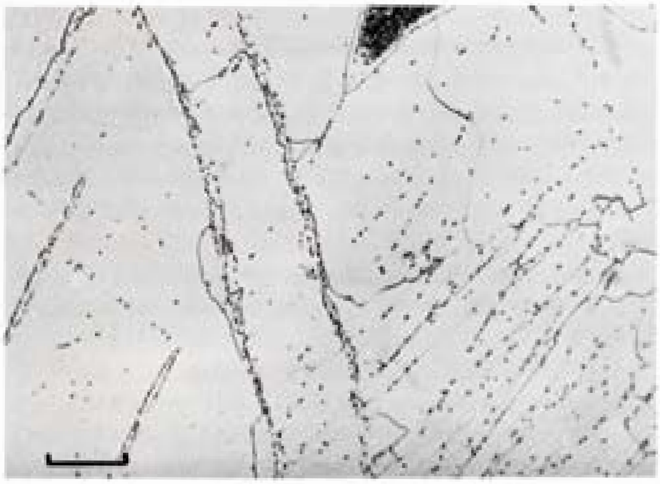

Figure 896. Huizopa (Tempe no. 55bx). Annealed kamacite with numerous γ-particles, particularly along former Neumann bands, and with incipient recrystallization. Etched. Scale bar 20 μ.

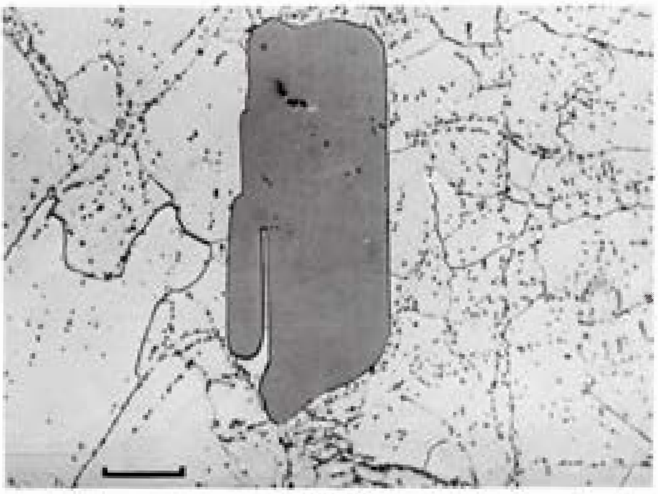

Figure 897. Huizopa (Tempe no. 55bx). A daubreelite crystal which is unaffected by the shock-annealing because it was not associated with troilite. Concentric growth rings in recrystallized kamacite. Etched. Scale bar 20 μ.

Campo del Cielo specimens, are numerous. The effects are probably preatmospheric.

The Neumann bands are heavily decorated with 0.5 μ granular precipitates which appear to be taenite. About 50% by area of the sections studied are recrystallized to more or less elongated ferrite grains, generally 20-100 μ in size. The recrystallization is especially pronounced around the sulfide inclusions, but occurs everywhere, in single grains or in clusters of grains that have often grown preferentially along Neumann band directions. Although the previously existing Neumann bands still appear to be present inside the recrystallized units, this is not so. Only the double rows of fine precipitates have been preserved, and it is these that, at low magnification, give the false impression of Neumann bands. The hardness ranges from 170 to 200, reflecting the varying degree of cold-working and recrystallization.

Plessite covers about 40% by area, partly as comb and net plessite, partly as duplex $\alpha + \gamma$ fields, which are resolvable better than in most meteorites of group IVA. It appears that the annealing that led to recrystallization of part of the alpha phase and to precipitation upon the Neumann bands, simultaneously spheroidized the duplex $\alpha + \gamma$ fields somewhat, producing widely spaced 0.5-20 μ taenite grains in a polycrystalline kamacite. The cellular plessite, which appears to be characteristic of IVA irons, is also present.

Phosphides were not observed and are probably not present under any form, in harmony with the analytical data.

Troilite is common as 0.5-5 mm irregular rhombic to lenticular nodules. They occur with a frequency of about one per 4 cm^2 and usually contain 10-20% daubreelite lamellae. Daubreelite is further present as scattered 10-80 μ angular blebs in the kamacite without associated troilite. The troilite nodules have been micromelted, probably due to shock, and they have dissolved part of the surrounding metal and intruded and partially dissolved the fragmented daubreelite lamellae. Rapid solidification of the melt has led to eutectic sulfide-metal mixtures with a grain size of 1-5 μ, in which the dispersed daubreelite grains are embedded.

Huizopa is structurally a complex meteorite. It may be assumed that, after the initial cooling period, it closely resembled Charlotte, Gibeon and other phosphide-poor IVA meteorites. Later a shock with severe deformation and associated relaxation heat led to point melting of the troilite, recrystallization of part of the metal and precipitation upon the Neumann bands. Finally, the deceleration in the atmosphere resulted in some further distortion of the linear structure elements and complete fissuring along some of the already present fissures. La Grange appears to be a meteorite with a somewhat similar story.

Specimen in the U.S. National Museum in Washington:
2,790 g slice (no. 871, 29 x 17 x 0.8 cm)

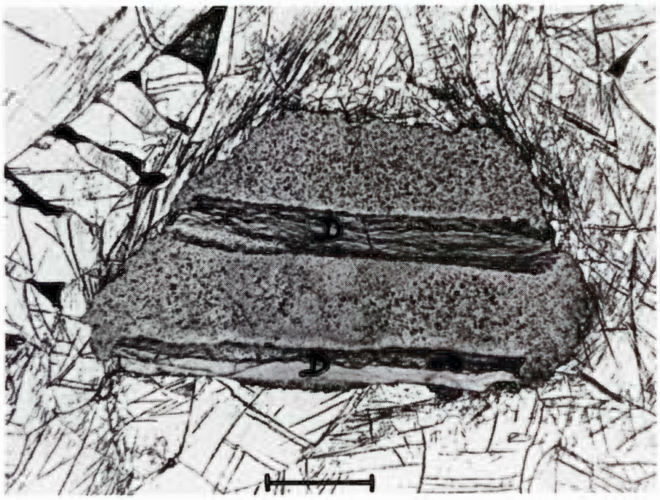

Figure 898. Huizopa (Tempe no. 55bx). Troilite-daubreelite nodule which is shock-affected, but no more than the original lamellar disposition of the daubreelite (D) can be seen. Etched. Scale bar 400 μ.

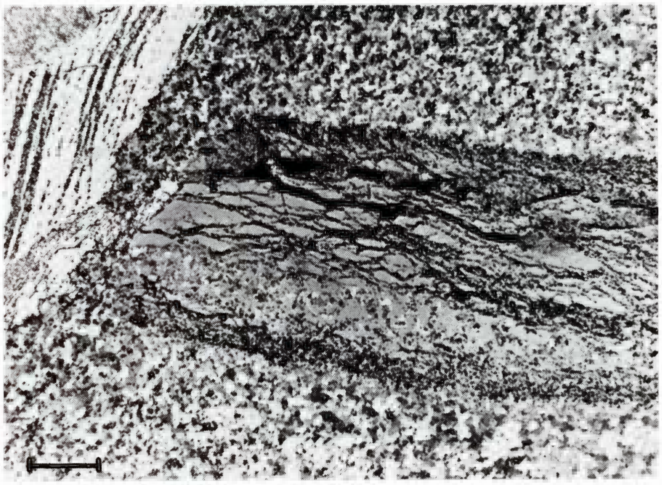

Figure 899. Huizopa. Detail of Figure 898. Shock-melted troilite (above and below) has shattered and penetrated the daubreelite lamella. Etched. Crossed polars. Scale bar 50 μ.

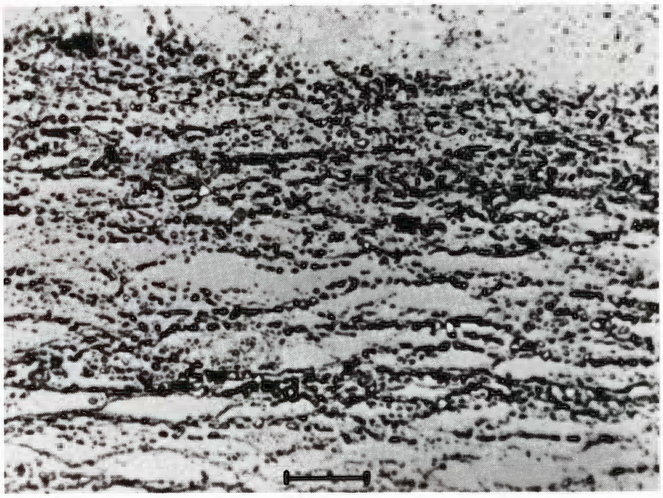

Figure 900. Huizopa. Detail of Figure 898. The shock-melted troilite (above) has penetrated a shattered daubreelite lamella. Dark spots are small pits left when eutectic iron particles were removed by etching. Etched. Slightly crossed polars. Scale bar 20 μ.

Ider, Alabama, U.S.A.

34°41'N, 85°39'W; 475 m

Medium octahedrite, Om. Bandwidth 1.20±0.20 mm. ϵ-structure. HV 285±20.

Group IIIA. About 8.2% Ni, 0.2% P, 20 ppm Ga, 40 ppm Ge, 2.8 ppm Ir. Severely corroded.

HISTORY

An extremely weathered mass of about 140 kg was plowed up in 1959 by Hoyt Frazierville in a cotton field 3 km southeast of Ider, De Kalb County. The exact location was, according to a letter from the owner of the farm, G.M. Wootten, in the southeast quarter of the southwest fourth of Section 12, Township 4, Range 9; and the corresponding coordinates are given above. The field had been plowed each year for more than 10 years without detecting the meteorite, in spite of the fact that the soil was nowhere more than 50 or 60 cm thick. The meteorite was put on an improvised sled and pulled to the farmhouse, where two sledge hammers were broken before the finders succeeded in splitting the corroded mass. Many pieces were carried away as curios, before E.P. Henderson secured the remainder for the U.S. National Museum in 1961, mainly in form of kilogram-sized fragments. A preliminary report was presented by Henderson & Clarke (Abstract, Journal of Geophysical Research, Volume 67, 1962: 3564), who discussed the find relative to the underlying sandstone sediments, and suggested that the meteorite might be of interest to nuclear physicists studying long half-lives of certain isotopes because they expected the meteorite to have a very high terrestrial age. Kaye, Shedlovsky & Kohman (Abstract, Transactions American Geophysical Union, Volume 44, No. 1, 1963: 89) reported a low ^{53}Mn/^{10}Be ratio and the absence of ^{59}Ni, ^{26}Al and ^{36}Cl, which supported the theory that Ider was terrestrially very old, possibly more than a million years. Goel & Kohman (1963) found less than 0.4 disintegrations of ^{36}Cl per minute per kg, which again supported this theory. Kaye & Cressy (1965) used the ^{53}Mn/^{10}Be ratio to establish a terrestrial age of 3.1±0.4 million years which puts Ider at the top of the list of terrestrially old iron meteorites. They also gave a refined estimate of the half life of the ^{53}Mn nuclide, $(1.9\pm0.5)\times10^6$ years.

COLLECTIONS

About 100 kg severely oxidized fragments in Washington. London (193 g).

ANALYSES

No analysis has been performed, since it has proven difficult to select proper amounts of representative, unoxidized material. The structural analysis is in such a case very helpful. Based upon the following description the author would expect the unweathered meteorite to contain about 8.2% Ni and 0.2% P, and to belong to group IIIA. After the conclusion of the manuscript, Wasson (letter of April 24, 1970) reported the following results on hand plucked, relatively pure metal: 8.3±1.1% Ni, 20.1 ppm Ga, 40.0 ppm Ge, 2.8 ppm Ir, confirming the previous conclusion.

DESCRIPTION

The irregular weathered fragments are bordered by octahedral faces, indicating that the primary corrosive attack followed the Widmanstätten planes. Sections through various fragments failed to disclose any significant nucleus of unweathered matrix. Corrosion has progressed so far that almost every (111) grain boundary is widened to a conspicuous black oxidized vein. The widest veins are 5 mm thick, but all widths down to 0.05 mm are encountered. In the freshest parts it is clearly observed how corrosion starts by converting a 50-100 μ wide zone of kamacite to "limonite" adjacent to the taenite-plessite and to the phosphides. This is exactly the zones which, in other iron meteorites, have been shown with the microprobe to be depleted in nickel. Also, the subgrain boundaries of the α-phase and the interior of the plessite fields are severely corroded. The matrix itself is corroded in a feathery, moss agate-like pattern, indicating that the original structure was a hatched ϵ-structure of the shocked type. The phases which have been relatively most resistant to corrosion are, as usual, the taenite frames and ribbons and the massive schreibersites. Ider belongs with Sardis, Santa Catharina, Cookeville and a few others to the most corroded meteorites ever recovered, however, still identifiable as to original structure and composition.

Etched sections show a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 15$) kamacite lamellae with a width of 1.20±0.20 mm. Due to the oxidized veinlets, the lamella width may be difficult to measure, but this average is based on the best preserved sections. The kamacite has subgrain boundaries, and it is converted by shock to an indistinctly crosshatched ϵ-structure with a hardness of

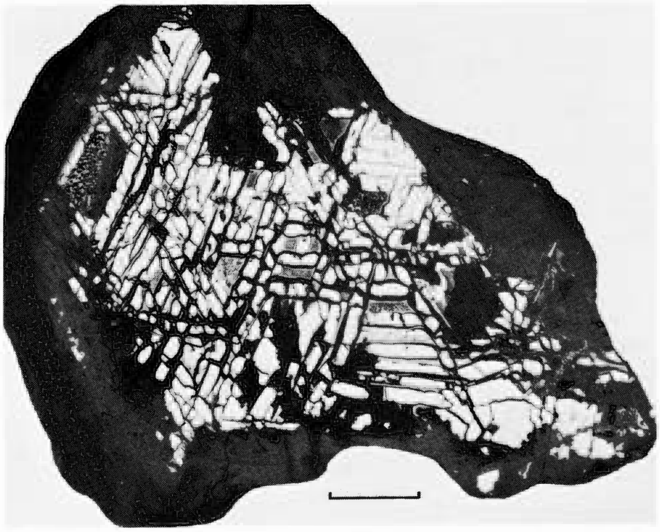

Figure 901. Ider (U.S.N.M. no. 2147). A severely weathered medium octahedrite of group IIIA. Etched. Scale bar 10 mm. S.I. neg. M-1366.

285±20. (The metastable, hardened, kamacite phase has survived 3.1 million years under terrestrial conditions.) Plessite covers about 30% by area in the form of comb and net plessite and as acicular and poorly resolvable duplex fields. The interior of several high-nickel fields is decomposed to martensitic platelets, but no cosmic or terrestrial annealing is observed.

Schreibersite is present as 30-90 μ wide grain boundary precipitates, and as an occasional larger crystal, e.g., 1 x 0.15 mm. No rhabdites were observed. Apparently due to corrosion the schreibersite is optically isotropic. The bulk phosphorus content of the meteorite is estimated to be 0.2%. Reichenbach lamellae are present as 20 x 0.2 mm or 10 x 0.1 mm straight lamellae with irregular sacks and deposits of 0.5-1 mm schreibersite. They are enveloped in ragged rims of 0.5-1 mm swathing kamacite. The troilite of the lamellae is not preserved in any of the sections; it appears that it originally was present in a fine eutectic mixture with iron. Troilite plus iron in such a form would corrode more rapidly than monocrystalline troilite.

Ider has been listed as a coarse octahedrite (e.g., Hey 1966). According to this examination Ider is a shock-hardened medium octahedrite with ϵ-structure and Reichenbach lamellae. It is related to, e.g., Cumpas, Kayakent and Thunda and is a normal member of the chemical group IIIA.

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

About 100 kg weathered fragments (no. 2147)
About 1 kg polished sections, embedded in plastic (no. 2147)

Ilimaes (pallasite). See Imilac (in the Supplement)

Ilimaes, Atacama, Chile
About 26°10′S, 70°20′W

Medium octahedrite, Om. Bandwidth 1.10±0.15 mm. ϵ-structure. HV 275±30.

Group IIIA. 8.10% Ni, about 0.3% P, 21.6 ppm Ga, 43.3 ppm Ge, 0.17 ppm Ir (average of analyses for Ilimaes and Chañaral, which are here recorded as fragments of the same fall).

HISTORY

In the 1860s a mass of 51.7 kg was brought to Heidelberg by Herman Schneider, a student from Valparaiso. It was purchased, in 1870, for the Vienna collection by Tschermak, who gave an eminent description (1872b), accompanied by lithographs of the exterior and of etched sections. Reichenbach lamellae were prominent and described as troilite parallel to the cube faces $(100)_\gamma$. Spencer (1951) questioned, however, whether this was true; he believed he had evidence for orientations parallel to the rhombic dodecahedron $(110)_\gamma$.

Brezina (1885: 212; 1896: 278) did not accept Ilimaes as a separate fall but united it with Juncal with which it certainly has many similarities. However, a minute examination reveals significant structural differences, and also the trace element concentrations are sufficiently different to distinguish between Ilimaes and Juncal.

Fletcher (1889: 260) tried to pinpoint the locality, but in vain. The place of discovery is only known in very vague terms as "Atacama Desert" with the approximate coordinates 26°S, 70°W. Even the name may be a misspelling of another similar Spanish name. Wülfing (1897: 157) also

Figure 902. Ilimaes (Vienna). The convex side of the main mass is covered with distinct regmaglypts, which are modified by corrosion pits. Scale bar approximately 5 cm. (Lithograph from Tschermak 1872b).

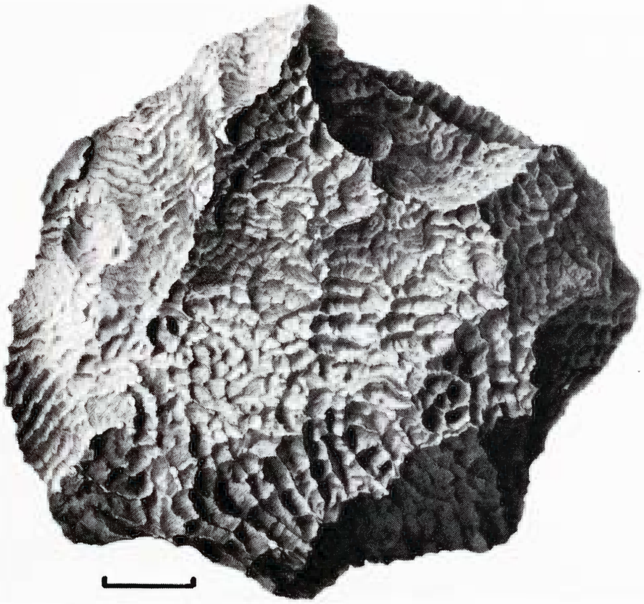

Figure 903. Ilimaes. The main mass from the concave side. Shallow original regmaglypts are severely altered and superimposed by sharp corrosion pits. developed during long exposure to the Atacama salt desert. Scale bar approximately 5 cm. (Lithograph from Tschermak 1872b.)

accepted the iron as a separate meteorite and gave several references to the literature.

Somewhat later, another iron meteorite, Chañaral, was acquired by Ward and described as a medium octahedrite (1906). This iron has been assumed to be similar to Merceditas and Ilimaes (Hey 1966: 97). As shown by Schaudy & Wasson (1971) and supported by the present study, Chañaral is similar to Ilimaes but is distinctly different from Merceditas.

Thus, Chañaral's place of discovery may give more accurate information of the region from which Ilimaes actually came.

COLLECTIONS

Vienna (50.8 kg main mass, three slices totaling 392 g), Harvard (237 g), Yale (172 g), Amherst (140 g), London (39 g), Calcutta (3.7 g).

DESCRIPTION

The mass is shield-shaped with the average dimensions 33 x 32 x 11 cm. Seen from above, it is approximately five-sided; seen from the side, one face is convex, the opposite slightly concave.

The convex surface is well-preserved and exhibits typical regmaglypts, 3-5 cm across, with softly rounded ridges in between. Due to weathering, the fusion crust and a small portion of the heat-affected α_2 zone have been removed. The surface is densely pock-marked by 3-5 mm wide, but shallow pits, and the Widmanstätten grid is distinctly developed by etching.

The opposite concave surface is more corroded, but former large and shallow regmaglypts may be suspected. The present surface is roughly indented by 5-8 mm wide pits, that are usually arranged in irregular rows meeting along very sharp ridges and crests. The pattern closely resembles that of Filomena, Iquique, Maria Elena and other irons from the Atacama environment and clearly testifies that the Ilimaes iron came from that part of Chile.

In two places hemispherical cavities, 25 and 40 mm in diameter, indicate where troilite nodules ablated away during the atmospheric flight. Subsequent corrosion has only slightly changed the morphology.

It appears that Ilimaes still roughly displays its aerodynamical shield shape from the atmospheric flight, only slightly modified by terrestrial corrosion. More has been dissolved from the concave side (about 5 mm) than from the convex side (about 1 mm).

Etched sections display a medium Widmanstätten structure of straight, long $(\frac{L}{W} \sim 30)$ kamacite lamellae with a width of 1.10±0.15 mm. The kamacite displays hatched structures rich in contrast and suggestive of shock-hardening. In accordance with this view the microhardness is high, 275±30. Subboundaries are common, sparsely decorated with less than 0.5 μ precipitates.

Taenite and plessite cover 35-40% by area, mainly as fields that repeat the bulk Widmanstätten structure on a 25 times finer scale. This plessite type is also very well developed in, e.g., Narraburra, Kouga Mountains and Bear Creek. The α-platelets of these fields are 30-50 μ wide and often nearly extend across the entire width of the field. The intercalated retained taenite forms concave wedges and islands which are decomposed to martensitic structures.

Comb and net plessite are also present, and dense fields with martensitic or unresolvable duplex structures occur everywhere. A fully developed field may exhibit a yellow-cloudy taenite rim (HV 380±50) that stands in marked contrast to the adjacent brown martensitic zone (HV 450±30). Farther inwards the martensite that follows is developed parallel to the bulk Widmanstätten structure (HV 400±30) and duplex unresolvable $\alpha + \gamma$ mixtures (HV 300±50). Finally come duplex structures in which the γ-component is clearly visible as 1-2 μ vermicular particles (HV 245±30). Dense grids of slipplanes parallel to $(111)_\gamma$ are sometimes visible in the cloudy taenite rims.

Schreibersite is common and occurs as irregular skeleton crystals and lamellae up to 10 x 0.4 or 4 x 0.6 mm in

Figure 904. Ilimaes (Vienna). Medium octahedrite with prominent Reichenbach lamellae of chromite and troilite. Deep-etched. Scale bar approximately 2 cm. (From Tschermak 1872b.) See also Figure 162A.

ILIMAES – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Schaudy & Wasson 1971	8.20								21.2	43.3	0.17	

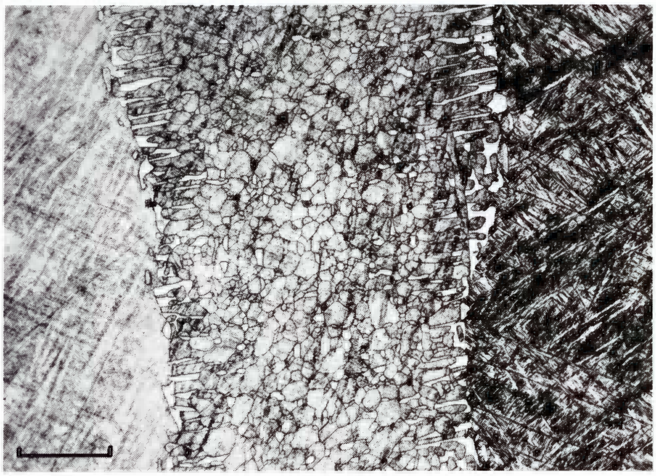

Figure 905. Ilimaes (Brit. Mus. no. 67450). Net plessite in center between two kamacite lamellae with different shades of shock-hatched ϵ, due to orientation shift. Etched. Scale bar 300 μ.

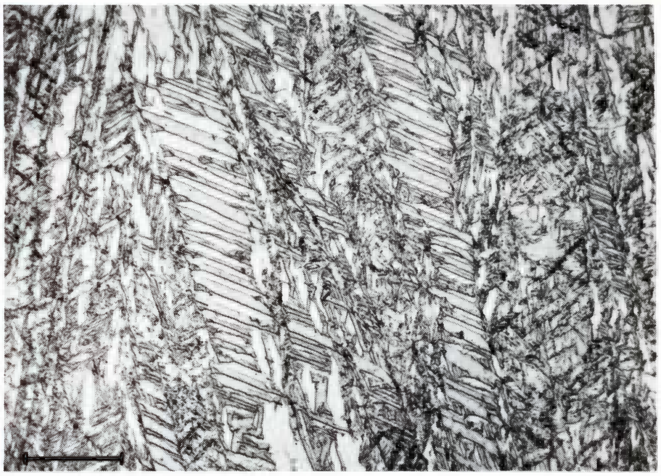

Figure 906. Ilimaes (Brit. Mus. no. 67450). Shock-hatched kamacite in a kamacite lamella. Compare Figures 103 and 907. Etched. Oil immersion. Scale bar 20 μ.

size. They appear to be imperfect Brezina lamellae parallel to $(110)_\gamma$, and they are enveloped in 0.5-1.5 mm wide rims of swathing kamacite. Schreibersite is also common as 20-100 μ wide grain boundary veinlets and as 2-25 μ particles inside the plessite fields. Most characteristic are the island arcs, formed by rows of angular 5-20 μ phosphides situated 10-20 μ outside the $\alpha - \gamma$ phase boundaries. Rhabdites were not detected. The bulk phosphorus content is estimated to be 0.30±0.05%.

Troilite occurs as 2-4 cm nodules and as Reichenbach lamellae that are typically 30 x 10 x 0.1 mm in size and are mutually perpendicular to each other. They occur with a

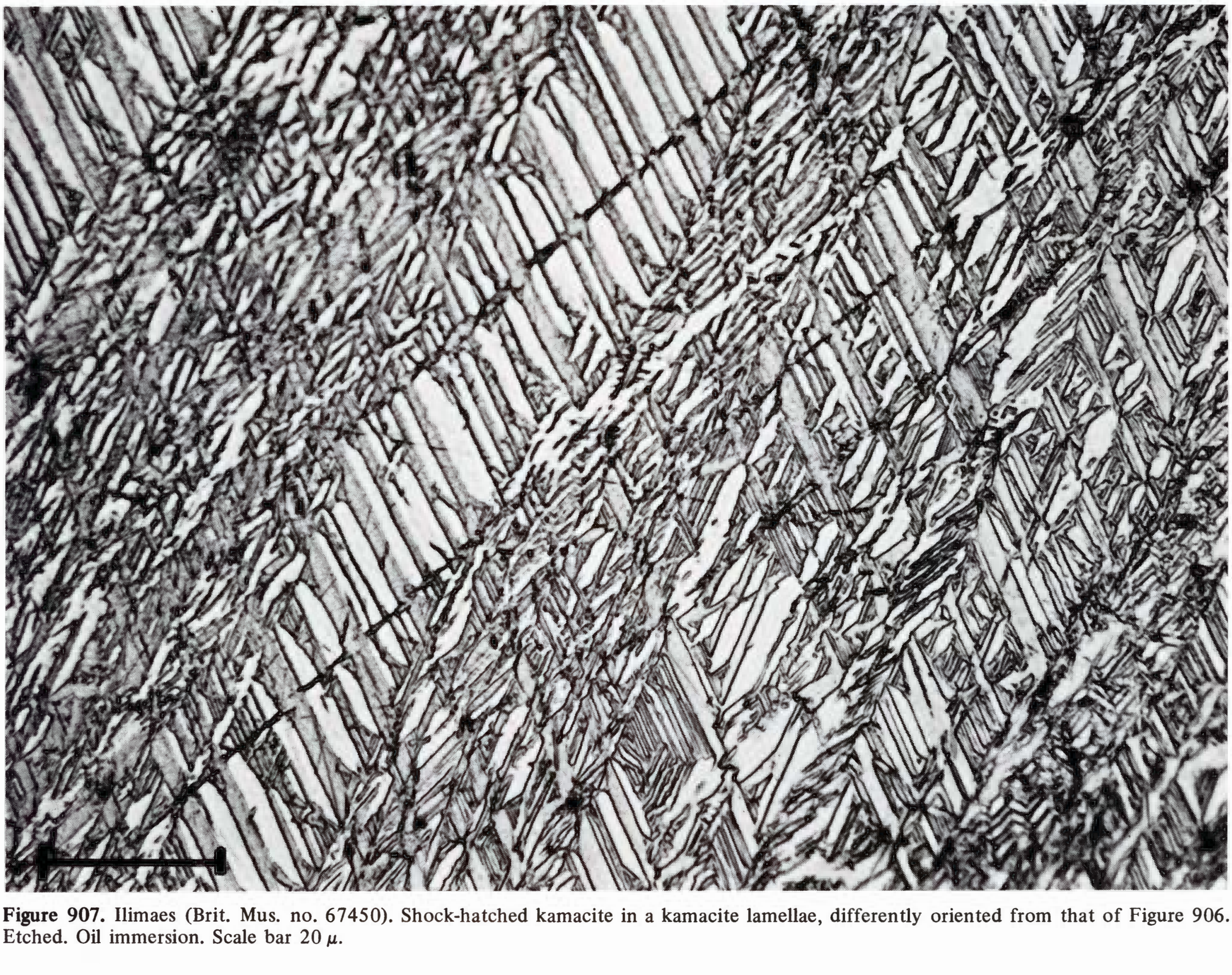

Figure 907. Ilimaes (Brit. Mus. no. 67450). Shock-hatched kamacite in a kamacite lamellae, differently oriented from that of Figure 906. Etched. Oil immersion. Scale bar 20 μ.

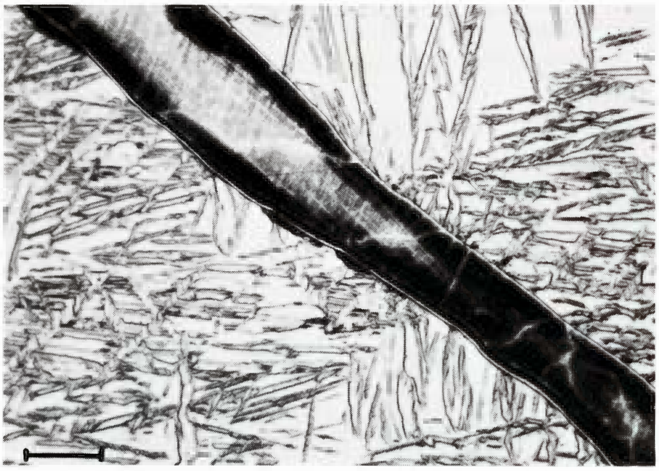

Figure 908. Ilimaes. (Brit. Mus. no. 67450). Taenite lamella with deformation grid and cloudy rim zones. Shocked kamacite on either side. Etched. Oil immersion. Scale bar 10 μ.

frequency of about one per 10 cm² section and completely cut across all other structural elements. They consist of troilite that has subsequently nucleated minor blebs of schreibersite and a 1-1.5 mm wide rim of swathing kamacite.

Unfortunately, no uncorroded Reichenbach lamella was available for examination. It appears, however, that troilite is not the primary mineral of the lamellae as hitherto assumed. There are indications of very thin chromite lamellae along the central parts, so that it is these chromite lamellae that have determined the crystallography and subsequent nucleation sequence. When similar Reichenbach lamellae were examined on much better and larger polished sections of Thule, Cape York, Kouga Mountains, Juncal, Kayakent and Augusta County, a central chromite lamella was invariably detected. It was also seen in Chañaral, although on a minor scale.

Carlsbergite, graphite, carbides and silicates are not present.

Ilimaes is a shock-hardened medium octahedrite which is closely related to Juncal, Kayakent, Cumpas and Franceville, all of the resolved chemical group IIIA. A detailed comparison with Chañaral fails to disclose any differences. Considering the proximity of the finds, it is, therefore, concluded that Chañaral is a part of the Ilimaes fall.

Ilimaes (Chañaral), Atacama, Chile

About 26°10'S, 70°20'W

Medium octahedrite, Om. Bandwidth 1.10±0.15 mm. ε-structure. (HV 225±25).

Group IIIA. 8.00% Ni, 22.0 ppm Ga, 43.2 ppm Ge, 0.17 ppm Ir.

It is here concluded that Chañaral is a fragment of Ilimaes.

HISTORY

During a visit to the coast of Chile in the spring of 1905, H.A. Ward (1906) saw in the School of Mines, Santiago, a hitherto unrecorded iron meteorite of 1,207 g. It had been found in 1884 by Roberto Budge in the Atacama Desert, a short distance inland from the port of Chañaral. It had consequently been called by this name and was now announced as a new meteorite, with a photograph of the exterior, a good description, and a poor analysis (5.37% Ni).

Ward noted that the place of discovery was very near to the locality given in the same publication for the pallasite Ilimaes, and he gave the approximate coordinates 26°30'S, 70°15'W and also stated that the finder had said that the place was about 12 leagues (Chilean leagues each of 4.51 km, i.e., 54 km) south or southwest of Taltal. It must be assumed that the medium octahedrite Ilimaes was found in the same region as the pallasite Ilimaes, and consequently we have Ward's indication that Chañaral was found near the Ilimaes (Om) mass. As we shall see below, the structure, composition and state of corrosion all tally very well for these two irons so that there is no doubt that they are two fragments of the same fall. Schaudy & Wasson (1971) recently arrived at a similar conclusion.

COLLECTIONS

School of Mines, Santiago (main mass of about 1.2 kg), Chicago (10 g).

DESCRIPTION

According to Ward (1906) the 1.2 kg mass "is in the shape of a sickle, with a main arm 5 cm wide, tapering thence along its curve to a sharp point. Its length across the curve is 12.7 cm, and vertically 7.8 cm. Its average thickness is 3.5 cm."

On one side the surface is covered by regmaglypts about 1 cm in diameter. The opposite side is apparently corroded somewhat more, displaying densely spaced circular pits of the typical Atacama variety, as seen upon, e.g., Ilimaes, Maria Elena and Filomena.

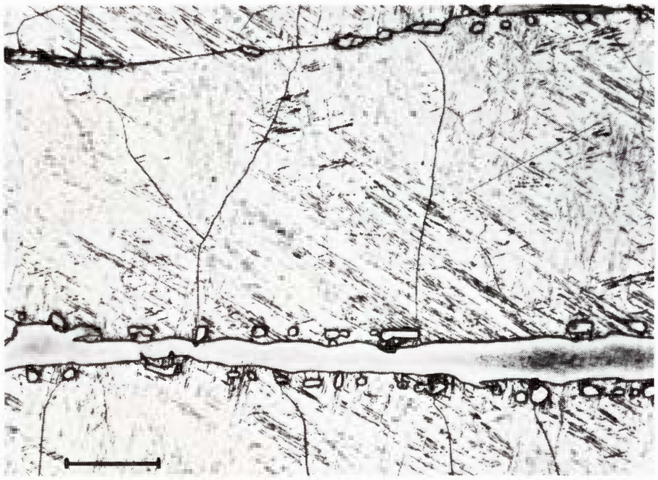

Figure 909. Ilimaes. The Chañaral mass (Chicago no. 939). Above, a grain boundary with phosphides and taenite particles. Below, a taenite lamella with island arcs of phosphides. Shock-hatched kamacite. Etched. Scale bar 200 μ.

For the present study, Dr. E. Olsen kindly loaned me H.A. Ward's original sample, evidently hacksawed in Santiago by himself, and so far the only material distributed (Me 939, 20 x 15 x 8 mm, 10 g). The etched section clearly indicates that the Atacama corrosion has taken its toll. The α_2 zone is penetrated by sharp-edged pits and in many places completely removed. This part of the mass has on the average lost 2 mm by weathering. The α_2 zone is composed of serrated, unequilibrated grains, 10-40 μ across, and the hardness is 186±8 (hardness curve type I).

The Chañaral fragment exhibits a medium Widmanstätten pattern of straight, long ($\frac{L}{W} \sim 25$) kamacite lamellae with a width of 1.10±0.15 mm. Subboundaries with less than 0.5 μ precipitates are common but obscured by an overlapping hatched ϵ-structure, indicative of shock-hardening.

Taenite and plessite cover about 30% by area, mainly as dense fields with martensitic and unresolvable duplex interiors. The Narraburra plessite type, with concave taenite islands, is likewise common.

Schreibersite occurs as 20-100 μ wide grain boundary veinlets and as characteristic island arcs. The individual particles are subangular, 10-20 μ across and situated 5-20 μ outside the $\alpha - \gamma$-phase boundaries.

Troilite occurs as a 1 x 0.2 mm bleb, which is deposited upon a primary 1 x 0.08 mm straight chromite lamella. The troilite contains daubreelite lamellae; one of these is 20 μ thick and along its entire length in contact with the chromite backbone. The troilite is not shock-melted but recrystallized to an aggregate of 5-30 μ grains. The chromite-troilite-daubreelite aggregate has nucleated small particles of schreibersite, and all is enveloped in swathing kamacite.

Carlsbergite, graphite, carbides and silicates were not detected.

The specimen is small, and the ratio of exterior surface to interior mass is large. Therefore, it has been significantly annealed by the atmospheric flight. The ϵ-structure is thus softened by recovery to 225±25, and in the nickel- and phosphorus-depleted zones adjacent to schreibersite incip-

Figure 911. Ilimaes. Chañaral (Chicago no. 939). Shock-hatched and slightly annealed kamacite with indistinct precipitates. Etched. Oil immersion. Scale bar 20 μ.

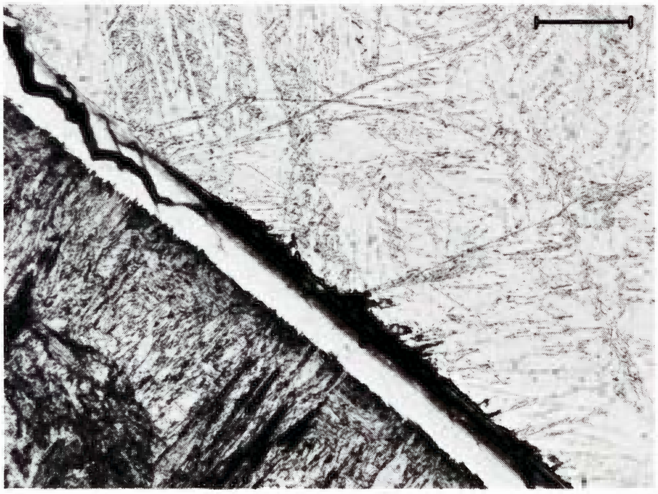

Figure 910. Ilimaes. Chañaral (Chicago no. 939). Plessite field with martensitic interior. Corrosion along taenite-kamacite interface and along crystallographic planes in the taenite rim. Etched. Oil immersion. Scale bar 20 μ.

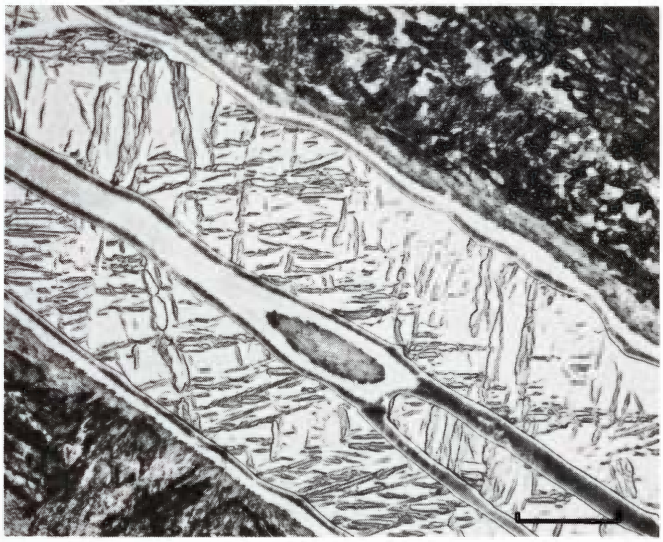

Figure 912. Ilimaes. Chañaral (Chicago no. 939). Two plessite fields with unresolvable duplex interiors. A forked taenite lamella with cloudy rims. Shock-hatched kamacite in between. Etched. Oil immersion. Scale bar 20 μ.

ILIMAES (CHAÑARAL) – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
Reference	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Schaudy & Wasson 1971	8.00								22.0	43.2	0.17	