micrographs clearly show how different lamellae, all of the same hardness, 290±15, etch in various shadings. The ϵ-structure responds to etching in much the same way as Neumann bands in less shocked meteorites. The effects are mainly due to different orientation of the kamacite lamellae.

Taenite and plessite cover about 35% by area, mostly as comb and net plessite and as dark-etching fields. A typical dark, rhombic field will exhibit a tarnished taenite edge (HV 350±20) followed by a light-etching martensitic transition zone (HV 450±20). Then follow a brown-etching martensite – developed parallel to the bulk Widmanstätten structure (HV 510) – and than a darker etching, but similar, martensite (HV 425±25). Finally come duplex interiors of $\alpha + \gamma$ – first fine-grained (HV 350±10) and then coarse-grained, approaching net plessitic development (HV 295±15).

Schreibersite is common as hieroglyphic or rosette-shaped crystals, typically 5 x 0.5 mm in size. They are monocrystalline but somewhat brecciated. Point counting of a typical area (57 cm^2) resulted in an average of 0.25% P as visible phosphides. Since phosphorus is also present in microscopic phosphides and in solid solution the P-determination by Moore seems to be a better bulk value than mine, which was obtained on a small portion of shavings. The schreibersite has a 1-1.5 mm wide rim of swathing kamacite. Schreibersite is also common as 20-50 μ wide grain boundary precipitates and as 2-20 μ thick blebs in the plessite fields, but island-arcs are absent. Rhabdites are numerous, but very small, generally 0.5-1 μ across. They are best identified in the exterior heat-affected α_2 zone where they are micromelted. Around several of the martensitic, dark-etching fields there are numerous slipplanes decorated by less than 0.5 μ wide phosphides; compare Thule, Welland and others.

Troilite was not observed on sections totaling 400 cm^2, however, it is present, as noted above in the discussion of the crust.

Treysa is a medium octahedrite that resembles Ilinskaya Stanitza, Grant and several other irons of group IIIA-IIIB. It is a little anomalous in its detailed Ni-Ga-Ge ratios, and also in its P-Ir ratio.

Specimen in the U.S. National Museum in Washington:
195 g part slice (no. 1881, 10.5 x 8 x 0.3 cm)

Tucson, Arizona, U.S.A.

Approximately 31°48′N, 110°48′W

Polycrystalline ataxite with flow pattern of olivine inclusions. HV 225±20.

Anomalous. 9.53% Ni, 0.45% Co, 0.09% P, 0.21% Cr, 0.8% Si, 0.94 ppm Ga, 0.05 ppm Ge, 2.1 ppm Ir.

The Ring mass is the best preserved. The Carleton mass has been significantly reheated artificially.

HISTORY

When first reported in scientific literature, by Velasco (1850) and LeConte (1852), the two Tucson iron meteorites had already been known to the local population of the then Spanish-Mexican southern Arizona for some time. The remarkable irons, which at one time were both in use as anvils, are now in the Smithsonian Institution, Washington. The ring-shaped Irwin-Ainsa mass weighs 621.5 kg, while the ear-shaped Carleton mass weighs 282 kg. The original weights are unknown but may be estimated to have been about 635 kg and 287 kg (about 1,400 pounds and 635 pounds), respectively; see page 1241. Previous estimates for the original masses are 688 kg and 287 kg (Hey 1966).

Much has been written about these meteorites, but it is only fair to say that very little more is known of the circumstances and place of discovery now than in 1850. Excellent reviews have been presented by Fletcher (1890b), Wülfing (1897: 367), Cohen (1900e; 1905), Farrington (1915: 460) and McGough (1943; 1944) to which the reader must refer for detailed information. Here I shall only quote and discuss a few of the original reports, as these are felt to be pertinent to the history of the masses and to contain valuable information as to the sites and dates of discovery. Numerous other reports exist, but in my opinion they are based upon second- and third-hand information and, consequently, best omitted. Some, e.g., the contributions by Santiago Ainsa, appear unreliable and are apparently improved upon to draw attention to the Ainsa family.

The first record is the following, which was originally in Spanish and consequently unnoticed for a long time.

> Between the presidio of Tucson and Tubac is a mountain range called Sierra de la Madera and (a pass called) Puerto de los Muchachos. In it are several enormous masses of native iron, and many have rolled to the foot of the said sierra. One of the masses, of a moderate size, was transported to Tucson and has stood for many years in the plaza of the said presidio. (Velasco 1850.)

Tubac – until 1751 an Indian village – is believed to have been the first permanent white settlement in Arizona; it was made a presidio (i.e., the site of a garrison) by the Spanish after the Pima Indian revolt in 1751. The Indian

Figure 1798. Tucson. The Ring specimen, or Irwin-Ainsa mass, now weighing 621.5 kg, in the old exhibition rooms of the Smithsonian Institution. (To the left, the Casas Grandes mass, to the right a Canyon Diablo mass). S.I. neg. 15720.

Figure 1799. Tucson. The Ring specimen, to the left, and the ear-shaped Carleton mass to the right (no. 1389; 282 kg). Arrangement from the 1940s in the old exhibition rooms of the Smithsonian Institution. S.I. neg. 42752.

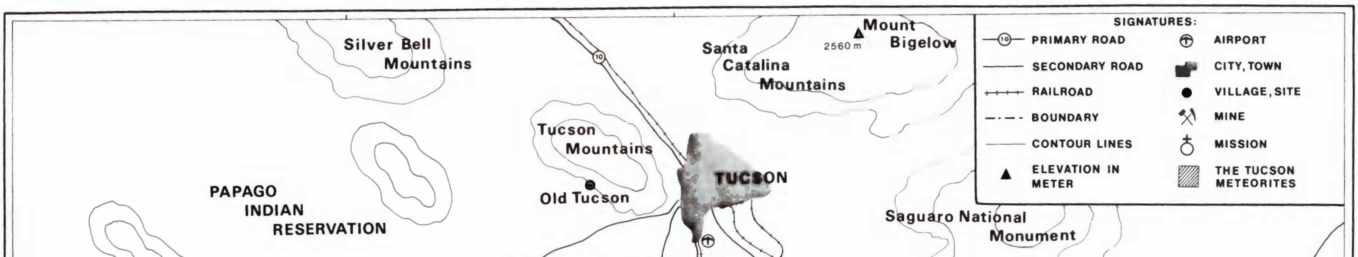

Figure 1800. Tucson. Map sketch compiled on the basis of the reports discussed in the text.

adobe village of Tucson was created a walled presidio as late as 1776, and does not date from 1560 as believed by Fletcher (1890b). In 1821 when Mexico became independent from Spain, this walled town continued to be the military headquarters of the province of Sonora. It appears, therefore, that the masses may have been known by the white settlers since the last half of the eighteenth century. In a country where everything would have to be transported by mule or wagon train over difficult or nonexistent trails, it must have been considered extremely fortunate that such heavy irons could be obtained relatively easily for the blacksmith's use.

When permanent white settlements were first created, Spanish Jesuit missionaries had already been active in the Santa Cruz Valley for three generations, where they had founded the missions of Guébavi (1685), Tumacacori (1691) and San Xavier del Bac (1692). These missions had an important bearing on the mining history of Southern Arizona because the Jesuit fathers conducted mining operations with a considerable force of men – mostly converted Indians – in connection with their missionary work. The remains of the considerable workings can still be seen near the mission ruins. They named, e.g., the old Salero and Montosa mines (argentiferous lead and copper ores) in the Santa Rita Mountains near the supposed places of discovery of the Tucson meteorites. However, it is unknown whether the Jesuits or the Papago and Pima Indians actually knew of the meteorites.

The first report to become widely known in the United States was by LeConte (1852).

> In February 1851, while in Tucson in Sonora, I saw two large masses of iron, evidently meteoritic, which were being used as anvils by the two blacksmiths of the town. They were irregular in form and, though embedded in the ground to make them steady for use, they were 3 feet high. I endeavored to have some pieces cut off, and, although a high price was offered, their characteristic indolence could not be overcome; the only answer I could obtain was that the metal was 'muy duro.' These pieces were brought from a valley in a small mountain chain about 40 miles southeast of Tucson, east of the road leading to Tuvaca [i.e., Tubac]; fragments similar to these and of various sizes were said to be abundant. The valley was called Cañada de Hierro, or Iron Valley, on this account.

The three localities, Sierra de la Madera (i.e., the forest-covered mountains), Puerto de los Muchachos (i.e., the pass of the children), and Cañada de Hierro, were not on most maps of the nineteenth century and neither are they to be found on modern maps. Fletcher (1890b: 24), however, succeeded in locating the Puerto de los Muchachos in Stieler's Atlas as a pass running in an easterly direction at the north side of the Santa Rita Mountains. Of the "several enormous masses" only two have ever been found; there are no reports at all of minor fragments having reached collections.

The first report with a sketch of the ring-shaped mass was contributed by Bartlett (1854):

> July 18, 1852. In the afternoon I called to take leave of General Blanco and at the same time to examine a remarkable meteorite which is used as an anvil in the blacksmith's shop. This mass resembles native iron and weighs about 600 pounds. Its greatest length is 5 feet. . . . The annexed drawing gives the appearance of the singular mass. There is another mass within the garrison grounds, of which I did not take a sketch . . .

Bartlett's drawing showed the ring-shaped mass of 635 kg. Because it was partly buried in the ground, so that only 70 cm protruded (not 3 feet as estimated by LeConte; that would have furnished an impractically high anvil), Bartlett assumed the meteorite to have two "legs" and considerably underestimated its mass.

The first person to succeed in chipping off small fragments was Parke (1855):

> February 31 [sic], 1854. Camp in Tucson. The Commandant showed me two specimens of a meteorite found in a canyon of the Santa Rita Mountains, about

Figure 1801. Tucson. A crescent-shaped slice of 737 g from the Carleton mass (U.S.N.M. no. 757). The silicates (black dots) occur very irregularly over the section. Etched. Scale bar 20 mm. S.I. neg. 1334A.

> 25 miles south of Tucson. They are both used as anvils and were lying, one in the presidio and the other in front of the Alcalde's house [i.e., the mayor's house]. The one in the presidio is of a very peculiar form, being annular and somewhat like a signet ring of large dimensions, its exterior diameter being about 3½ feet, the interior about 2 feet, and it weighs near 1200 pounds. By permission of the authorities, our blacksmith undertook to cut off some specimens for us, in which he almost failed, the metal being so tough and hard. By dint of two hours' hard work and the use of a cold chisel of fine temper and a most weighty sledge, we procured a few small clippings sufficient for the purpose of analysis. The fracture is crystalline, resembling that of cast iron.

LeConte, Bartlett and Parke were employed in making surveys of the Mexican-United States boundary along the Gila River, as required by the Treaty of Guadalupe Hidalgo (1848). At this time Tucson was still under Mexican jurisdiction. But with the Gadsden Purchase in 1854, a long strip of the present Arizona and New Mexico was incorporated in the United States so Tucson became American. Under these circumstances it was evidently easier for Parke than for the previous visitors to examine the meteorites and acquire a little material.

The Santa Cruz Valley and the Sonoita Valley were principal Apache war trails, and Tubac was raided on numerous occasions. Therefore, Fort Buchanan was erected in 1856, strategically situated at the head of the Sonoita Creek, about 60 km south-southeast of Tucson. Dr. Irwin, a U.S. Army surgeon, was stationed at Fort Buchanan in 1857 and became interested in the meteorites. Since he had collected minerals for the Smithsonian for some time, he now made an attempt to secure the larger ring-shaped mass for this institution. The ring had evidently been abandoned when the Mexican garrison left the city a few years earlier; Irwin found it lying in one of the side streets and nobody objected when he made a claim to it (Irwin 1863; McGough 1943; 1944). Irwin engaged the Ainsa brothers to transport the mass to Washington, and in 1860-1861 it was taken south as far as Hermosillo, Sonora, where it remained until an opportunity arose for further transport to Guaymas. From there it was shipped to San Francisco, and finally the mass arrived in Washington in late 1863, by way of boat, the new Panama Isthmus railroad and boat again.

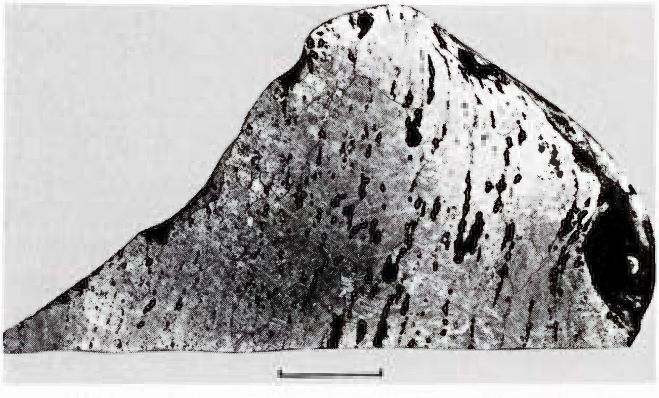
Figure 1802. Tucson (Ring mass) (U.S.N.M. no. 368). The section shows several subparallel streaks of silicate crystals in a polycrystalline ataxite matrix. Etched. Scale bar 10 mm.

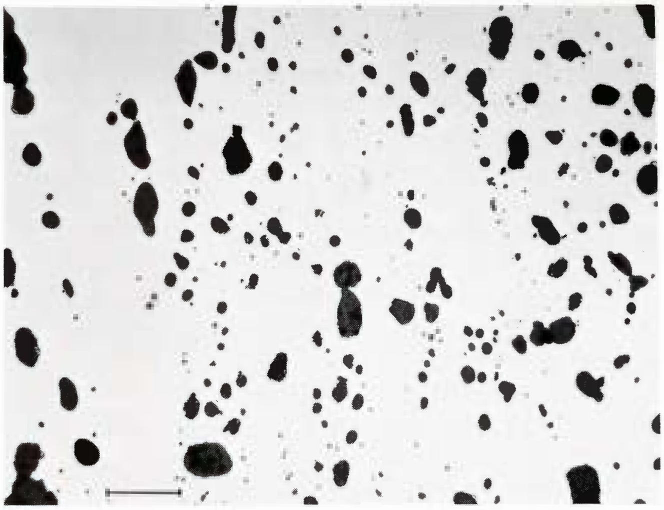
Figure 1803. Tucson (Ring mass) (U.S.N.M. no. 368). Large and small globular silicates, arranged in subparallel rows. Polished. Scale bar 500 μ.

The other mass was still in daily use as an anvil in 1862 when General Carleton obtained it from the owner, Ramon Pacheco, evidently without remuneration at all, much to the owner's dissatisfaction (McGough 1943; 1944). Pacheco – or one of his predecessors in the profession – had discovered the iron on the northwest side of the lower range of the Santa Rita Mountains, southeast of Tucson. The four foot long mass had been transported to the town and set upright in the ground, thus procuring a smooth, flat surface on one end for use as an anvil.

> It was clearly his [i.e., Pacheco's] property, and he was proud of it. This was natural, for where was there a smith, for miles around, who could boast of having an anvil probably discarded by Vulcan himself? Many a pleasant hour had its earthly owner whiled away, thinking of possible thunderbolts ordered for Jupiter, that had been fashioned on its clear-ringing face. (Quotation from the newspaper, Arizona Citizen, January 15, 1876, as rendered by McGough 1944.)

General Carleton had the mass transported by wagon train via Yuma to San Francisco, where it was seen and described by professor Whitney (1863), together with the ring-shaped mass which happened to be in the town at the same time. The "Carleton Iron" was placed in the museum of the Society of California Pioneers, in San Francisco. After the earthquake and fire of 1906, it was removed for safekeeping to the museum of the California State Mining Bureau, also in San Francisco (Linsley 1934). Finally, late in 1941, it was transferred to the Smithsonian Institution, where it has since been a permanent exhibit together with the "Irwin-Ainsa-Iron."

In summarizing, the place of discovery seems to have been a pass, a canyon, or the lower northwestern slopes of the Santa Rita Mountains 20-30 miles south-southeast of Tucson. On modern topographical maps (U.S. Geological Survey – 1:62,500, Sahuarita, Mount Wrightson, and Empire Mountains) interest focuses upon Madera Canyon, Box Canyon and the bajadas north and east of these localities. Only Box Canyon, which lies 30 miles south-southeast of Tucson, is associated with a pass through the Santa Rita range. This leads to Cienega Creek, Sonoita and to the site of the abandoned Fort Buchanan. During an examination of the original maps by Emory (1853), I succeeded in reidentifying Puerto de los Muchachos as a pass about 30 miles south-southeast of Tucson running NW-SE. The pass is also shown in Stieler's Handatlas (1874, Gotha, Justas Perthes, 1:3,700,000), where it appears that the cartographer has based his mapping on Emory's originals. A comparison with the terrain and with modern maps indicates that Velasco's Puerto de los Muchachos, through which Major W.H. Emory and Captain A.W. Whipple of the Boundary Commission, among others, moved in the early 1850s, is identical to Box Canyon. This canyon and the bajadas immediately north and west of it, up to the present Helvetia Mine and Huerfano Butte (1200 m), are, therefore, the most likely discovery sites; they are situated about eight miles east of the road leading from Tucson to Tubac, in accordance with the views presented by Bartlett (1854). Several parties – including myself – have, on one or another occasion, hunted for the masses which supposedly rolled to the foot of the mountain but so far without success. Neither are there any indications of the places from which the two large masses were hauled. Therefore, the coordinates given above must be taken with reservation.

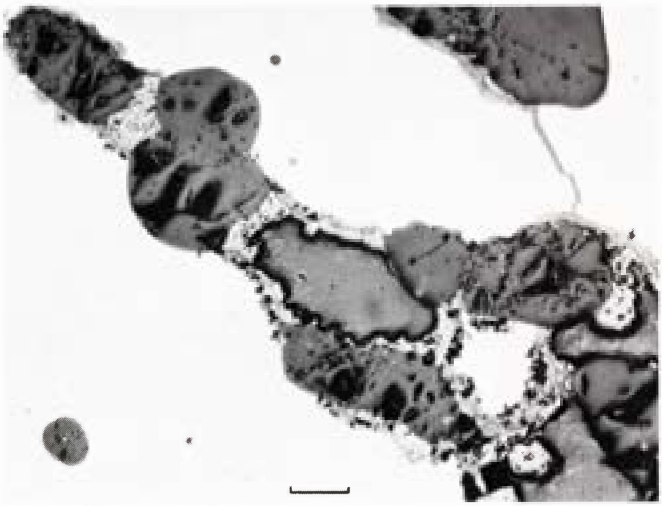

Figure 1804. Tucson (Ring mass). Detail of Figure 1802. A cluster of silicates, composed of olivine, enstatite, diopside and glass. Brezinaite (gray) occurs as rims. Slight terrestrial corrosion along interfaces. Polished. Scale bar 100 µ.

While the military garrison of Tucson probably secured the largest mass during the peaceful period 1790-1822 and placed it in the presidio, the smaller mass was taken possession of by civilian blacksmiths, the last of whom we know by name. The original distance between the masses is entirely unknown. A statement by Irwin (1863) that "the people of Tucson all agree that a shower of these meteorites fell . . . some two hundred years ago" can be dismissed, since the state of corrosion indicates a much higher terrestrial age.

Between 1854 and 1863 small fragments chiseled from the masses were analyzed by Smith (1855), Genth (1855) and Brush (1863). Shepard (1854b) recognized silicate inclusions, which he called "chladnite" (now known as enstatite). Smith (1855) identified olivine and noted the presence of iron chlorides. Genth (1855) inferred from his experiments that the stony matter consisted largely of olivine and of a minor amount of labradorite. Brush (1863) assumed olivine to be the major mineral, too, but he also reported chromite – as Smith (1855) had done. The chromite was not seen but was introduced in the calculations of the analyses in order to account for the surplus of Cr_2O_3. It appears, however, that the surplus of Cr and Si which was repeatedly reported by early authors, e.g., Cohen (1900e), was in fact due to Cr and Si in solid solution in the metal; see below.

Some reports, e.g., by Whitney (1863), Richtofen (quoted by Haidinger, 1863b) and Brezina (1885: 220)

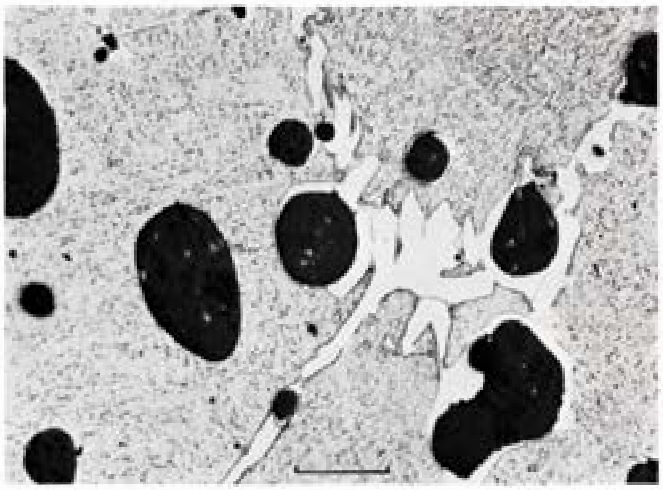

Figure 1805. Tucson (Ring mass) (U.S.N.M. no. 368). Detail of Figure 74. Four precursor taenite grains of different orientation. Swathing kamacite along grain boundaries, with a tendency to Widmanstätten growth. Etched. Scale bar 200 µ.

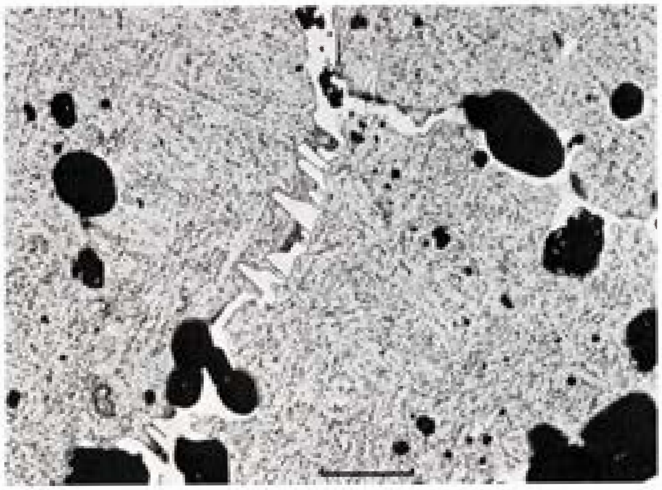

Figure 1806. Tucson (Ring mass) (U.S.N.M. no. 368). Another case of Widmanstätten growth of kamacite from the grain boundaries. Silicate globules occur everywhere (black). Etched. Scale bar 200 µ.

assumed that the two meteorites were quite different in both structure and chemistry. This supposition was proved incorrect by Fletcher (1890b) and Cohen (1900e), both of whom gave detailed descriptions of material from the two masses. Klein (1906: 136) also gave a short description, and he was probably the first to identify the ferrite rims in the metal phase correctly. Berwerth (1914: 1081) noted that his material had been artificially reheated.

Photomacrographs or engravings of the exterior of the two masses have appeared on many occasions, e.g., Bartlett (1854), Haidinger (1863b), Brezina (1896: 296), Hovey (1907), Merrill (1916a: plate 1), Merrill (1943: plate 32), McGough (1943: 1944), Krinov (1960a: figure 94) and Mason (1962a: 34). Photographs of polished sections were presented by Haidinger (1863b), Brezina (1896: plate 9), Perry (1944: plate 20) and Bunch & Fuchs (1969). The last mentioned authors identified a new mineral, brezinaite, Cr_3S_4 with a few percent of iron. Brezinaite is monoclinic and occurs as anhedral, 5-80 μ grains contiguous to the silicate inclusions. Bunch & Fuchs also studied the silicates with the electron microprobe and found olivine of forsterite composition, pure enstatite, aluminous diopside, and pure anorthite. They, and Wai & Wasson (1969), showed that the metal phases were rich in chromium (~ 0.2%) and silicon (~ 0.8%) in solid solution, a feature which is rare among meteorites but is known to occur in the highly reduced enstatite chondrites.

A recent paper by Marchese et al. (1966b) described a 27 g sample allegedly from the Tucson meteorites. It must, however, be a mislabeled specimen of some hexahedrite, possibly a Coahuila sample.

Principal maps of the area were plotted by Emory (1853) and Parke (1855). Modern map compilations are to be found in Saucerman (1942) and Wheat (1959). The exact topography is best studied on the "15 Minute Series" published by the Geological Survey, U.S. Department of the Interior, while information on the mineral deposits of the Santa Rita Mountains has been accumulated by Schrader (1915). Moore & Wilson (1965) have written a bibliography on Arizona's Geology.

COLLECTIONS

Washington (621.6 kg Ring material; 282.7 kg Carleton material), Chicago (1,482 g), Harvard (1,141 g), Tempe (932 g), Vienna (539 g), London (411 g), Amherst (361 g), Calcutta (350 g), Yale (280 g), Philadelphia (193 g), Oxford University (150 g), Paris (103 g), Ann Arbor (70 g), Strasbourg (52 g), Bonn (40 g), Vatican (39 g), Stockholm (38 g), Canberra (36 g), Berlin (29 g), Göttingen (16 g). A 27 g sample in Rome (Millosevich 1928) appears to be a mislabeled hexahedrite. Other mislabelings are known to

TUCSON – SELECTED CHEMICAL ANALYSES

In an old, and otherwise inappropriate analysis, phosphorus was reported as 0.12% (Smith 1855); this together with Moore's value gives 0.09% as an average value. Cohen (1900e) reported lawrencite, but this could not be confirmed in the present study. The chlorine was probably of terrestrial origin, introduced with corrosive waters before the irons were discovered. Sulfur is almost absent, no troilite having ever been seen. The 0.014% S, reported in an analysis by Cohen (1900e), is probably bound in the brezinaite, newly established by Bunch & Fuchs. Tucson is thus also remarkable by being one of the very few iron meteorites devoid of troilite and – almost – of sulfur.

I. Metal Phase

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Lovering et al. 1957		0.46				2360	134		<2	<1		
Moore et al. 1969	9.68	0.43	0.06			2200	140					
Bunch & Fuchs, 1969	9.45					1700						
Wai & Wasson, 1970	9.45					2200			0.941	0.049	2.1	

II. Silicates. Electron microprobe data from Bunch & Fuchs (1969).

	Olivine	Orthopyroxene	Clinopyroxene	Plagioclase	Glass
SiO_2	42.8	59.2	51.0	44.9	52.4
Al_2O_3	<0.03	<0.03	7.3	35.2	28.1
Cr_2O_3	<0.02	<0.02	<0.02	<0.02	<0.02
TiO_2	<0.02	<0.02	0.25	<0.02	<0.02
FeO	0.23	0.27	0.31	<0.02	<0.02
MgO	56.7	39.8	19.1	<0.02	<0.02
CaO	0.11	0.36	21.7	20.2	19.8
MnO	<0.02	<0.02	<0.02	<0.02	<0.02
Na_2O	<0.03	<0.03	<0.03	<0.03	<0.03
K_2O	<0.03	<0.03	<0.03	<0.03	<0.03
Total	99.84	99.63	99.66	100.3	100.3

occur, mainly as a result of the activities of Jackson in the second half of the nineteenth century (Brezina 1896: 273).

DESCRIPTION

The large ring-shaped mass now weighs 621.5 kg and has the following characteristic dimensions:

Maximum exterior diameter	123 cm
Minimum exterior diameter	95 cm
Maximum width of opening	66 cm
Minimum width of opening	57 cm
Width of thickest part of ring	43 cm
Maximum thickness at right angles to plane of ring	25 cm
Minimum circumference of thin part of ring	20 cm

The large opening is asymmetrically located; the 90-100 cm long, narrow part of the ring may be estimated to hold only about 50 kg of the total mass. Some previous owner has made an unsuccessful attempt to divide the meteorite here, as evidenced by a deep chisel scar. Otherwise the mass is only slightly marred by the treatment it has received, except for the flattened surface which was the anvil face. A protuberance, extending irregularly into the ring opening from the massive part – it may be seen in the sketch by Bartlett (1854); also reproduced by Smith (1855) and Burkart (1856) – has been cut off at a later date. On this site there now appears a ground and roughly polished face measuring 15 x 8 cm. In a few other places minor samples have been removed. It is estimated that a total of approximately 15 kg has been removed, so the mass must originally have weighed about 635 kg, or 1,400 pounds.

The ear-shaped mass, which has also been compared to a rusty plowshare or the shoulder blade of a whale, now weighs 282 kg. It is 123 cm long, varies between 38 and 48 cm in width, and between 5 and 13 cm in thickness. One end is provided with two holes drilled in the projecting edge for adding to the convenience of its use as a blacksmith's anvil. Near this flat-hammered surface of about 10 x 3 cm^2, a sickle-shaped cut indicates where perhaps two kilograms measuring 30 x 7 cm has been removed. Farther down the long sharp edge another similar but narrower cut has removed another few kilograms. Additional, minor cuts are also present, so that it may be estimated that a total of 5 kg has been removed. Consequently, the original weight must have been about 287 kg, or 635 pounds.

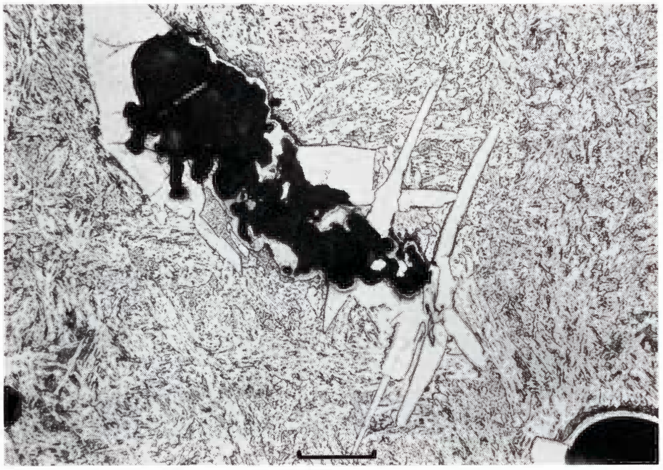

Figure 1807. Tucson (Ring mass) (U.S.N.M. no. 368). An irregular silicate aggregate with swathing kamacite in Widmanstätten growth. Etched. Scale bar 50 μ.

The masses are so different in their exterior shape that they cannot fit together in any way. One is inclined to believe that somewhere in the Tucson area there still remain specimens which, together with the two known specimens, could produce a reasonable parent mass. It is interesting to note that there exists another meteorite, Kokstad-Matatiele, which – although totally different with respect to composition and inclusions – also produced an asymmetrical ring-shaped mass when exposed to the violent deceleration in the atmosphere.

Polished and etched sections through the two masses are in all major respects identical. However, since sections

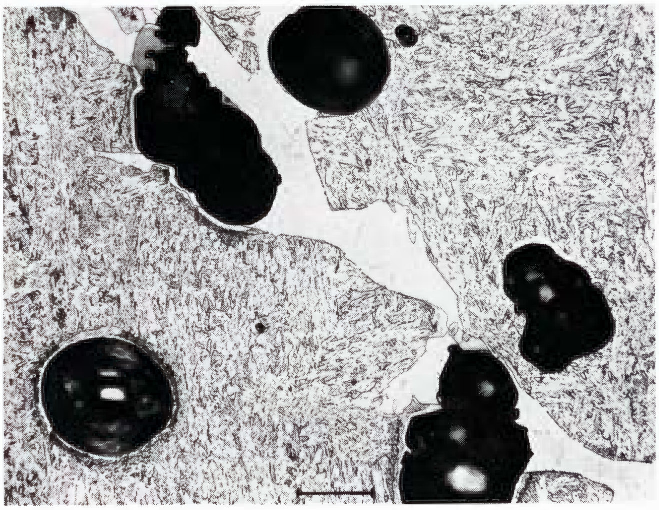

Figure 1808. Tucson (Ring mass) (U.S.N.M. no. 368). Diagonally, a grain boundary with silicates. At the top left, a tiny gray brezinaite crystal precipitated on the silicate. Etched. Scale bar 50 μ.

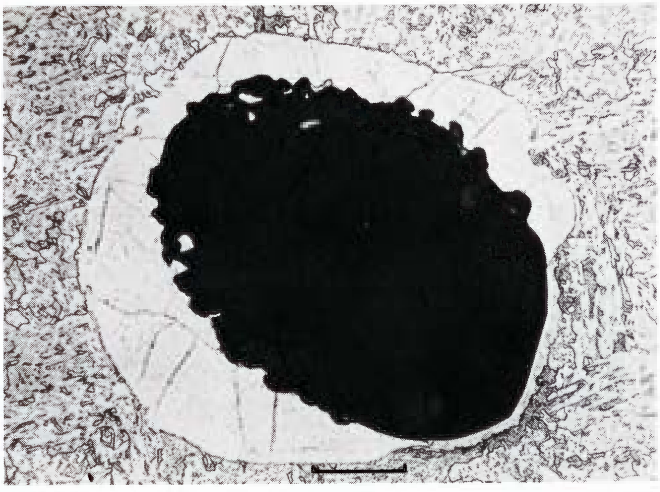

Figure 1809. Tucson (Ring mass) (U.S.N.M. no. 368). The larger silicates are globular or have ragged reentrant edges or combine both forms at once. The rim of swathing kamacite shows several subboundaries. The matrix is indistinctly duplex. Etched. Scale bar 40 μ.

through the Carleton mass show unambiguous evidence of artificial reheating, the descriptions here pertain to specimens from the Irwin-Ainsa-Ring mass, unless otherwise stated.

The sections display an anomalous and heterogeneous mixture of metal and silicate phases. The silicate fraction ranges from 5 to 15 volume percent, with 8% as a fair average estimate. The silicate grains are arranged in subparallel flow structures with 0.5 to 3 mm between individual silicate-rich veins. The flow structures are visible to the naked eye as black lines and were identified on numerous samples, and upon the main masses themselves, on sections up to 200 cm^2 in area. They are probably present throughout the masses, since the samples examined come from many different parts of the surfaces. It appears, moreover, that the flow pattern is roughly parallel to the plane of the Ring and to the long flat faces of the Carleton mass. This would make it easier to understand why the atmospheric breakup produced such odd shapes: the breakup primarily followed the subparallel silicate-rich planes.

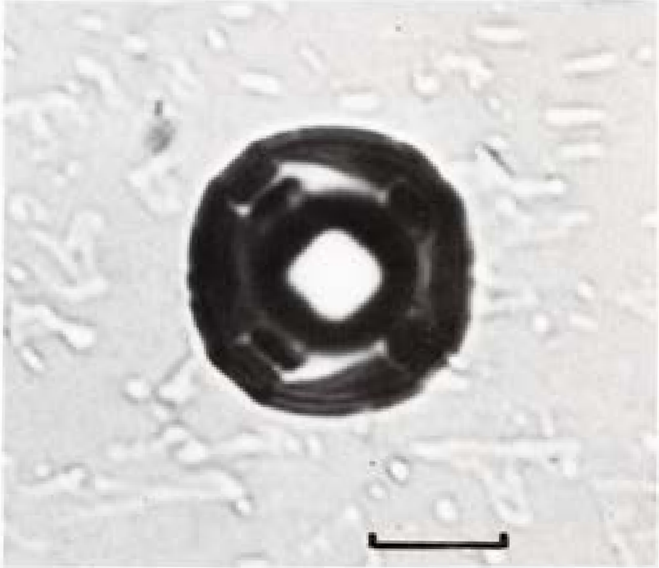

Figure 1810. Tucson (Ring mass) (U.S.N.M. no. 368). The smaller silicates are usually rich in facets that unexpectedly show cubic symmetry. Compare Figure 177B. Unfortunately, at this high magnification not all of the crystal can be in focus at the same time. Polished. Scale bar 5 μ.

Sections perpendicular to the flow lines indicate that the metal occurs in elongated cells 0.5-5 mm across, and that the silicates are concentrated in the walls between adjacent cells. Olivine, of forsterite composition (Cohen 1900e; Bunch & Fuchs 1969), is the most abundant silicate mineral, occurring as rounded crystals, in all sizes from 5 μ to at least 3 mm. Enstatite, aluminium diopside, anorthite and glass occur as accessories adjacent to – or intergrown with – olivine in the elongated veins which are usually 100-500 μ wide. All minerals appear undamaged and undeformed, i.e., the flow structure was due to high temperature events which afterwards allowed time for both the silicates and the metal phase to recrystallize and eliminate all internal flaws.

The interfaces between olivine grains and the metal are highly interesting. In numerous cases, especially pertaining to grains smaller than about 100 μ, the interfaces show unambiguous crystal facets, which is very rare in iron meteorites. The crystallographic faces apparently do not belong to the ortorhombic symmetry of olivine, but rather to the cubic symmetry of austenite, the high temperature phase of iron. It appears that during the "recrystallization" period, when the temperature was above 800° C, and the metal was homogeneous nickel-austenite, the olivine-metal interfaces developed as negative imprints, conditioned by the crystallography of the austenite.

Etching shows that the parent austenite (taenite) was polycrystalline with a grain size range of 1-20 mm, and with an average of 5-8 mm. The austenite grains are undistorted and must have grown to their present equiaxial shapes after the flow pattern had developed. Silicate veins are thus to be found both in the actual grain boundaries and penetrating

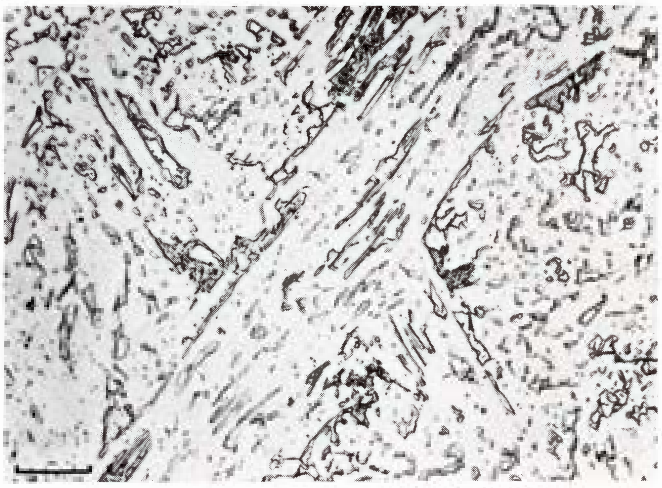

Figure 1811. Tucson (Ring mass) (U.S.N.M. no. 368). Duplex ataxite matrix. The kamacite is subdivided into 1-2 μ cells. The taenite is irregular and inhomogeneous. Etched. Oil immersion. Scale bar 10 μ.

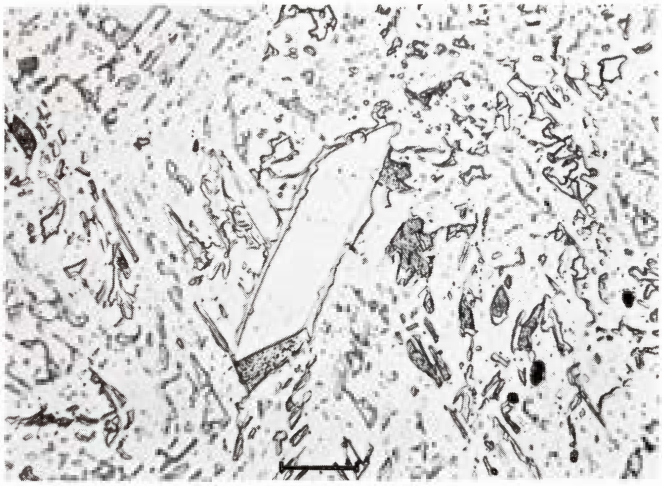

Figure 1812. Tucson (Ring mass) (U.S.N.M. no. 368). In center, one of the few kamacite spindles. The duplex matrix shows a Widmanstätten pattern indistinctly. Etched. Oil immersion. Scale bar 10 μ.

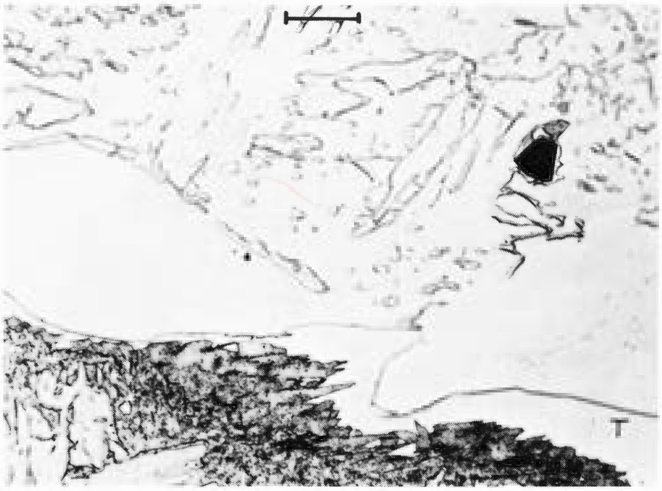

Figure 1813. Tucson (Ring mass) (U.S.N.M. no. 368). Two kamacite spindles in tapered section. Wide taenite rim (T) and transitional martensitic structures. Etched. Oil immersion. Scale bar 10 μ.

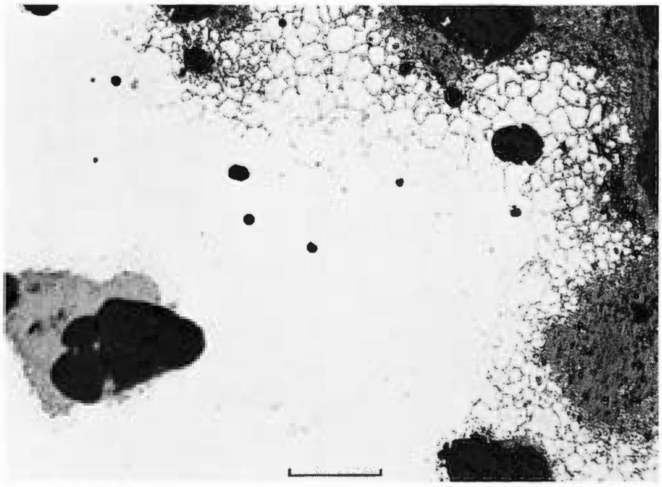

Figure 1814. Tucson (Carleton mass) (U.S.N.M. no. 757). Near-surface section showing globular silicates (dead black), terrestrial corrosion (gray) and high temperature intercrystalline oxidation (gray network). Polished. Scale bar 200 μ.

the grains. The grain boundaries are distinctly visible as 10-40 μ wide kamacite bands in which numerous silicate crystals are situated. The additional silicates, which were left inside the grains by the austenitic grain growth, have nucleated 1-30 μ wide rims of swathing kamacite. The kamacite shows incipient growth towards grain interiors as 10-40 μ wide oriented platelets, similar to the Widmanstätten ferrite of hypo-eutectoid steels. All kamacite has numerous subboundaries and a certain population of almost submicroscopic precipitates. Neumann bands were not detected. Bunch & Fuchs (1969) reported the following composition for the kamacite: 7.5% Ni, 0.78% Si, 0.39% Co, 0.26% Cr (weight percentage, microprobe data).

At low magnification the interior of the austenite grains appear martensitic, with individual grains displaying independent orientations. High magnification (45x objective) reveals a two-phase structure of α and γ. The taenite forms particles which are less than 1 μ wide, densely spaced and oriented in a kamacitic matrix with 1-2 μ cell boundaries. Locally an approach to a plessite field, 20-30 μ wide and with a nickel gradient, is encountered, particularly at grain boundaries or around some small silicates. Bunch & Fuchs recorded the following average composition of the duplex matrix: 10.6% Ni, 0.75% Si, 0.40% Co, 0.23% Cr.

The microhardness of the "martensitic" duplex $\alpha + \gamma$ interior is 225±20. Adjacent to cold-worked surfaces the hardness increases to 300±25. The observed cold deformation is due, to a greater degree, to shear deformation by the atmospheric breakup than to the action of the sledge hammer when the iron was in use as an anvil, judging from the exterior appearance of the examined sections.

Schreibersite is present as minute vermicular bodies, 2-20 μ across, in the grain boundaries, and possibly as almost submicroscopic particles in the duplex $\alpha + \gamma$ structure. Only very insignificant amounts of schreibersite are precipitated upon the silicate. It appears that the bulk phosphorus content is low, below 0.1%, in accordance with the analytical work.

Troilite, daubreelite, chromite, graphite and carbides were not identified. The brezinaite, discovered by Bunch & Fuchs (1969), occurs as 5-100 μ rounded blebs that are nearly always precipitated upon the silicates. It is grayish blue to brown, somewhat depending on the polishing and etching conditions, and it is weakly anisotropic; in appearance and occurrence it is rather similar to troilite and daubreelite.

No fusion crusts and no heat-affected α_2 zones were detected. Unambiguous regmaglypts were not noted. On the contrary, all surfaces are covered with terrestrial corrosion products and selective corrosion of the α-phase has also occurred. It is estimated that, on the average, more than 4 mm has been lost by corrosion.

THE CARLETON MASS

The sections distributed apparently come from the parts of the mass that suffered significant artificial damage. The kamacite is transformed to unequilibrated α_2, and the duplex interiors display blurred outlines and ghost-lines parallel to the worked surfaces. The silicate minerals are brecciated and the brezinaite has reacted with the atmosphere to produce eutectics of iron, nickel, chromium, sulfur and oxygen that penetrate the grain boundaries and fissures as fine-grained, spongy masses. Some high temperature intercrystalline oxidation has also occurred. The terrestrial corrosion products have reacted at high temperature and are decomposed to typical spongy laceworks of metal and oxides. The hardness of the α_2 phase, overlying the imperfectly homogenized $\alpha + \gamma$ matrix, is 265±20, significantly higher than the genuine cosmic structure, due to the rapid cooling under terrestrial conditions. The structural changes indicate peak temperatures of 800-900° C. It is not clear how the bulk of the Carleton mass has been affected, since all samples have been taken near the surface. It is recommended that future discussions on the structures of Tucson be based upon Ring material, or that careful

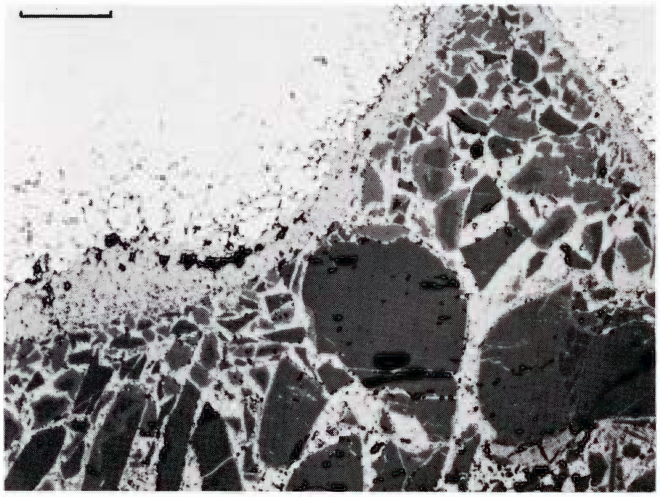

Figure 1815. Tucson (Carleton mass) (U.S.N.M. no. 757). Artificially damaged structure. The silicates are brecciated and recemented by the high temperature oxidation products from forging operations. Compare Figure 24. Polished. Scale bar 100 μ.

Figure 1816. Tucson (Carleton mass). Detail of Figure 1815 showing the edge of the inclusions. High temperature reaction products, comprising oxides, sulfides and glasses, occur at grain boundaries and, partially, within the metallic matrix. Polished. Oil immersion. Scale bar 20 μ.

allowance be made for the reheating effects in the Carleton material.

CONCLUSION

Tucson is an extremely anomalous ataxite displaying a flow pattern of subparallel silicate crystals, mainly olivine. The flow apparently indicates cosmic deformation events at austenitic temperatures, possibly as a result of relative movements of the overburden on the parent body. During this process it appears that the bulk of the low-melting sulfides were squeezed out, leaving only small amounts trapped in the silicate-metal interstices. These remaining sulfides formed brezinaite, Cr_3S_4, rather than FeS, due to the anomalously high chromium content in solid solution in the metal. The cooling from austenitic tempeatures occurred rapidly, compared to most other iron meteorites. This is indicated (i) by the very narrow kamacite grain boundary seams and (ii) by the "martensite" of the grain interiors which probably formed by a two-stage process $\gamma \rightarrow \alpha_2 \rightarrow \alpha + \gamma$, as described by Buchwald (1966). The structure is not that of a finest octahedrite with narrow, homogeneously nucleated α-lamellae as believed by Bunch & Fuchs (1969). These authors have themselves noted that the relatively high calcium content of the olivine indicated rapid cooling. Thus, both structure and chemistry suggest that Tucson was formed by shear-deformation of a metal-silicate mixture, followed by annealing and austenite grain growth (to a size not above 20 mm) and relatively rapid cooling. No appreciable cosmic reheating ever occurred; the Carleton mass was, however, artificially reheated to a significant degree.

Tucson has no close relatives, neither in structure nor in composition. However, the metallic part of Tucson, in particular, does have many points of resemblance with the metal of N'Goureyma; it appears that the two meteorites have had a comparable story and cooling rate.

It has been suggested (Wai & Wasson 1970) that Tucson and Nedagolla are similar in structure. In my opinion, this is not the case, since Nedagolla displays unambiguous evidence of metallic dendrites on a millimeter scale, suggesting rapid cooling from a melt. Such structural elements are absent in Tucson.

With respect to the composition, I will quote Bunch & Fuchs (1969), "The very low iron content of the silicates, the presence of chromium sulfide, significant amounts of silicon in the nickel-iron, and the chalcophile behaviour of vanadium indicate a very high degree of reduction in Tucson, similar to enstatite chondrites and enstatite achondrites."

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

621.5	kg	main mass of Irwin-Ainsa-Signet-Ring mass (no. 368)
160	g	part slice (no. 3116, from the Ring)
282	kg	main mass of Carleton mass (no. 1389)
737	g	slice (no. 757, 28 x 6 x 1 cm; from the Carleton mass)

Tule, pseudometeorite

A small fragment, with no indication of the actual weight, was mentioned by Castillo (1889) as having come from Tule, Balleza, in the state of Chihuahua. The sample was in the collection of the Engineering School in Mexico City, but there was no further information as to its origin, whether it was from one of the large Chupaderos masses or from some other meteorite. Fletcher (1890a: 123, 150) mentioned the fragment but was unable to come to a final conclusion. He preliminarily classified it as a separate meteorite, labeled Tule. Brezina (1896: 365), apparently without examining the sample, listed it as a Toluca fragment, classified Om, a conclusion which was accepted by Prior (1923a) and Hey (1966: 492). A fragment of 8.4 g (Me 955) is listed by Horback & Olsen (1965: 308) as preserved in the Chicago collection. It seems to have been detached from the main fragment on the occasion of one of H.A. Ward's numerous visits to Mexico around 1900.

Haro (1931: 77) gave the weight of the fragment in Mexico City as 49 g. He also added the observation by H.H. Nininger that the meteorite was doubtful. Buchwald (1968c) indicated that Tule was

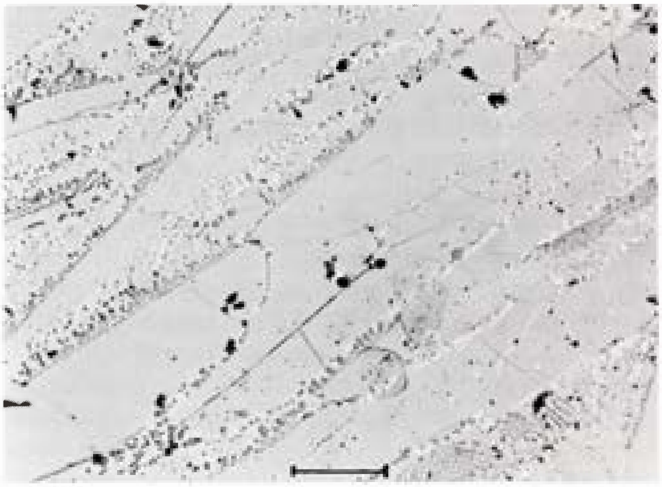

Figure 1817. The pseudo meteorite Tule (Chicago no. 955). Straight and narrow yellow primary bars in a fine-grained eutectic. The main components are iron, phosphorus, carbon and sulfur. Etched. Scale bar 200 μ.

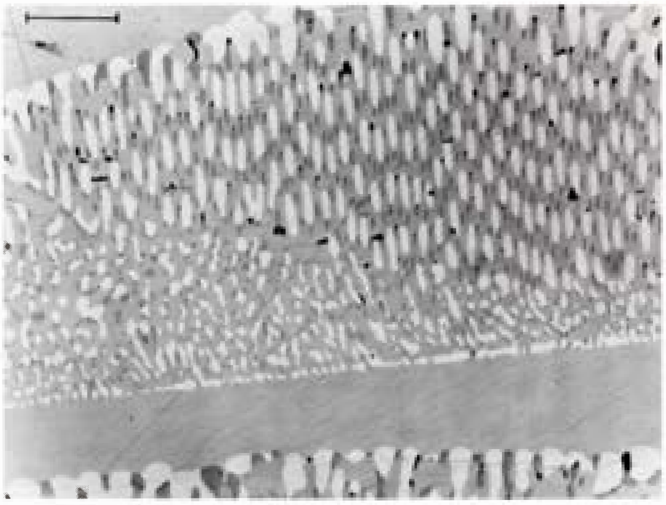

Figure 1818. The pseudo meteorite Tule (Chicago no. 955). Detail of the fine-grained eutectic. It is apparently the result of an artificial casting process, but it was not further examined. Etched. Scale bar 40 μ.

"either a pseudometeorite or a rare type; a microscopic investigation plus an analysis should solve this problem."

COLLECTIONS

Mexico City (49 g), Chicago (8.4 g).

DESCRIPTION

The main fragment in Mexico City is an endpiece measuring 30 x 24 x 15 mm. The small fragment in Chicago measures 16 x 15 x 6 mm and is clearly detached from the first mentioned specimen. Both samples are slightly corroded. Regmaglypts, fusion crust and heat-affected α_2 zones from atmospheric penetration are absent. The samples are attracted by a hand magnet.

Low magnification of an etched section discloses a random arrangement of numerous straight and narrow platelets. Typical sizes are 4-8 mm in length and 50-200 μ in width. Between the platelets is a fine eutectic, composed of yellow, brown and bluish particles, each 0.5-5 μ across. Numerous gasholes, 50-400 μ in diameter are also present. No Widmanstätten structure and no kamacite, taenite, plessite and other accepted meteoritic phases are present.

The structural observations alone would thus strongly indicate a non-meteoritic origin and suggest some artificial casting with iron as the main component and phosphorus, sulfur and carbon as essential alloying elements. Such a material would, in solidifying, develop straight, primary Fe-P dendrites enveloped by a fine-grained Fe-P-C-S eutectic, rich in gasholes.

A check on the electron microprobe confirmed this supposition. Nickel was present only on a level below 0.1%; since nickel has so far been detected on a level above 4% in all accepted iron meteorites, it must be concluded that Tule is a pseudometeorite. It should be omitted from future catalogs.

Tunguska. See Comets, page 9

Turner Mounds. See Hopewell Mounds

Turtle River, Minnesota, U.S.A.

47°36′N, 94°46′W

Medium octahedrite, Om. Bandwidth 1.10±0.20 mm. Recrystallized. HV 160-235.

Group IIIB. 8.80% Ni, about 0.35% P, 20.5 ppm Ga, 41.4 ppm Ge, 0.057 ppm Ir.

The structure was originally a hatched ε-structure, similar to Wonyulgunna, but artificial reheating to about 600° C imperfectly annealed the meteorite.

HISTORY

Slices from a mass of unreported weight were offered for sale by Glenn Huss, Denver, in "Meteorite Catalog and Price Lists of November 25, 1968." The material was described as a medium octahedrite showing heat granulation and with numerous elongated schreibersite inclusions. According to Meteoritical Bulletin, No. 49, 1970, a 22.39 kg mass had been plowed up near Turtle River, Beltrami County, between the years 1953-1958. However, it was first recognized as a meteorite in 1968 when Huss started cutting it. At the time of this writing it appears that a major portion has been converted into polished slices.

COLLECTIONS

Washington, London, Mainz, Copenhagen (745 g).

DESCRIPTION

The size and shape of the 22.4 kg main mass is unreported. From an examination of several cut slices, I would estimate the original dimensions to have been roughly 24 x 18 x 12 cm.

The following is based upon a study of three full slices in Copenhagen and one in the U.S. National Museum.

The mass is weathered and covered by irregularly preserved terrestrial oxides that form a 0.1-1 mm thick crust. Fusion crust and heat-affected α_2 zones were not detected. It appears that Turtle River has lost, on the average, more than 2 mm by corrosion. The corrosive attack penetrates several centimeters into the mass, particularly along kamacite-schreibersite interfaces. The schreibersite crystals are frequently enveloped by 0.1-0.2 mm wide "limonitic" halos. The interior of near-surface duplex plessite fields are likewise severely attacked, resembling the corrosion picture of Richa somewhat. The state of weathering indicates that the meteorite is of considerable terrestrial age.

Etched sections display a medium Widmanstätten structure of straight, long ($\frac{L}{W} \sim 15$) kamacite lamellae with a width of 1.10±0.20 mm. The Widmanstätten pattern appears somewhat confusing, but this is because several additional directions appear as conspicuous 1.0-1.5 mm wide rims of swathing kamacite around the larger schreibersite lamellae. While an unannealed Widmanstätten pattern exhibits a characteristic oriented sheen to the naked eye, Turtle River appears stained and cloudy in an irregular way. High magnification reveals that this is due to imperfect recrystallization, or rather recrystallization without subsequent grain growth. The kamacite has recrystallized to equiaxial 10-50 μ grains that, in detail, are considerably serrated and unequilibrated. In the more nickel- and phosphorus-poor zones adjacent to large schreibersite crystals the recrystallized units are larger, 30-150 μ across, and better equilibrated. On the other hand, in the kamacite adjacent to black taenite wedges, the previous existence of densely spaced decorated slip lines may be suspected; and the recrystallized grains are small, 5-20 μ, evidently pinned by numerous very small precipitates. With an oil immersion objective and a well polished and etched section, the presence of about 0.5 μ particles is disclosed in all parts of the kamacite. These particles may be either taenite or phosphides – or perhaps both. The optical examination alone was not sufficient for a decision.

The microhardness of the kamacite shows an anomalously large range, 160-235. The lowest values occur in the clear kamacite around large phosphides, the highest values being in the dark precipitate-rich areas around black taenite. The range in hardness and structures clearly indicates that the reheating responsible for the recrystallization was of relatively short duration and did not lead to equilibrated structures.

Taenite and plessite cover about 30% by area, mostly as comb and net plessite and massive fields with, originally, martensitic and duplex interiors. Cloudy or tarnished taenite is not present but has given way to clear yellow taenite (HV 270±15). The martensitic interiors are slightly annealed (HV 340±20), and originally duplex interiors display diffuse α - γ interfaces (HV 320±30). The annealing that altered the kamacite, evidently slightly altered the taenite components also.

Schreibersite is abundant, as typically 5 x 1, 3 x 0.3, 8 x 0.5, 4 x 0.9 mm imperfect Brezina lamellae, enveloped in 1.0-1.5 mm wide rims of swathing kamacite. It is also common as 50-100 μ wide grain boundary precipitates and as 5-50 μ blebs inside plessite, substituting for γ-particles of similar size. Rhabdites were not observed, but part of the submicroscopic particles in kamacite, noted above, must be phosphides. The bulk phosphorus content is estimated to be 0.35±0.05%. All phosphides are brecciated and sometimes shear-displaced in successive 5-10 μ steps, apparently due to cosmic deformation. Corrosion penetrates along the breccias, recementing them.

Troilite occurs as nodules and blebs ranging from 50 μ to 14 mm, often with imperfect rims of schreibersite. A few scattered Reichenbach lamellae, 5 x 3 x 0.05 mm, were also noted, with flags and sacks of schreibersite. All troilite was originally monocrystalline with multiple twinning and brecciation from cosmic deformation. The annealing has, however, recrystallized the troilite to 20-150 μ angular blocks, limited in size by the shear fractures and by embedded corrosion products, such as pentlandite.

Chromite occurs as 50-300 μ idiomorphic grains, either singly in the kamacite or having served as nuclei for precipitating troilite or schreibersite.

An unidentified anisotropic nonopaque blackish mineral, possibly a phosphate, occurs as subangular blebs, 100-200 μ across, and as bars, 7 x 0.3 mm, in the kamacite. Like the chromite, these have served as substrates around which troilite and schreibersite could later precipitate.

Carbides, graphite and silicates were not detected.

From the structural observations and the chemical composition, it may be concluded that Turtle River is a medium octahedrite related to, e.g., Wonyulgunna, Bartlett and Cleveland. Turtle River, however, displays an annealed, recrystallized structure which is rather unique and requires a separate discussion.

It has been assumed (Huss 1968, personal communication, and labels attached to samples distributed from his collection) that Turtle River displays genuine cosmic reheating. However, this cannot be the case, since the terrestrial corrosion products have also been altered by the reheating. (i) Along the corroded grain boundaries the

TURTLE RIVER – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
Reference	**Ni**	**Co**	**P**	**C**	**S**	**Cr**	**Cu**	**Zn**	**Ga**	**Ge**	**Ir**	**Pt**
Scott et al. 1973	8.80								20.5	41.4	0.057	

limonite has, at elevated temperatures, decomposed and reacted with the adjacent metal to form 5-50 μ wide zones of lace-like metal-oxide intergrowths. (ii) The interfaces between schreibersite and limonite now consist of 1-2 μ wide creamy-yellow zones, possibly identical to barringerite, erroneously assumed by Buseck (1969) to be a genuine cosmic mineral. Barringerite is, in fact, an artificial high temperature decomposition product of schreibersite. (iii) The troilite recrystallized *after* it was brecciated and partly converted to pentlandite along the fissures. The pentlandite formed during exposure to terrestrial ground waters. (iv) The unequilibrated structures of kamacite and taenite indicate imperfect annealing, suggestive of rapid heating and cooling, different from the more thorough cosmic annealings. (v) Although the terrestrial corrosion is extensive, it has not attacked the grain boundaries of the recrystallized metal. This is a clear indication that recrystallization postdated the corrosion attack and thus was due to artificial reheating.

It is estimated that peak temperatures of about 600° C, applied for about half an hour, would produce the observed changes. It appears that the genuine cosmic structure of Turtle River, before the artificial reheating, displayed shock-hardened hatched ϵ-kamacite with hardnesses of about 300, and that the troilite was monocrystalline with multiple twinning. The taenite was cloudy, and the martensite of the plessite fields was clearly defined. The shear-deformation associated with the cosmic shock event had brecciated the brittle minerals, embedded in the plastic metal. The structure before reheating probably closely resembled that of Wonyulgunna, El Capitan and Bartlett. In certain respects the present structure resembles that of Elbogen, which is also assumed to have had its original ϵ-structure altered by artificial reheating.

Twin City, Georgia, U.S.A.

32°36′N, 82°1′W; 80 m

Polycrystalline, nickel-rich ataxite, D. α-spindles 5±3 μ wide. HV 325±25.

Anomalous. 30.0% Ni, 0.5% Co, 0.34% P, 4.5 ppm Ga, 7.4 ppm Ge, 0.015 ppm Ir.

HISTORY

A mass of 5.1 kg was found in 1955 by Joe L. Drake while he was working for the Emanuel County Highway Department. It was discovered in the sandy soil moved by

Figure 1819. Twin City. Main mass of 5.1 kg with deep, corroded fissures which upon sectioning turn out to follow primary austenite grain boundaries. Scale bar approximately 3 cm.

the road scraper and had probably, at most, been buried a few feet. The location is about one mile north of the one originally reported by Henderson & Furcron (1957); it was found on a NW-SE trending county road 2.3 km N 82° E of St. Paul's Church, and 13 km N 80° E of Twin City, corresponding to the coordinates given above. The meteorite was somewhat damaged by hammering, and some small fragments were apparently lost before it was acquired by the Georgia Geological Survey, where it was described by Henderson & Furcron (1957) who also provided photographs of the exterior and of etched slices. They discussed at length the probable terrestrial age and concluded that Twin City and Lime Creek both might have fallen about the year 1800, being fragments of the same parent body. This is, however, out of the question since both structure and composition of the two ataxites are different in several respects. They mentioned Neumann bands, but since the structure is mainly austenitic this observation is erroneous.

COLLECTIONS

Department of Mines, Mining and Geology, Atlanta (4.5 kg), Washington (182 g), Hugh H. Howard, Atlanta (60 g).

DESCRIPTION

The mass has the average dimensions 19 x 11 x 6 cm. It is irregular with large and small depressions, most of which are primarily due to the atmospheric sculpturing. Small pits and trenches, particularly along the grain boundaries, are due to the removal of troilite by ablational burning in the atmosphere. Although 1-2 mm thick terrestrial oxides cover part of the surface, other parts still have a 0.5-1.2 mm wide heat-affected rim zone, so it is estimated that on the average, only 1-2 mm of the surface has been lost by weathering. However, corrosion penetrates deep into the mass, both along the grain boundaries, thereby facilitating the splitting of the mass, and selectively attacking the kamacite spindles and the swathing kamacite around the schreibersite. Most of the sulfide nodules are, to a large extent, altered to pentlandite. The terrestrial age must run in the thousands of years.

Etched sections reveal a very unusual ataxitic structure. The mass is a polycrystalline aggregate of irregular taenite crystals; at least five individuals ranging from 1 x 1 to 6 x 6 cm in size may be identified. They are separated by schreibersite- and troilite-filled grain boundaries. The troilite is usually 0.1 mm wide but may swell to 1 cm blebs or completely taper out and disappear. The schreibersite is usually 5-25 μ wide and enveloped in 5-25 μ kamacite, now altered to limonite by weathering. Each taenite individual is differently oriented and does not appear to be twinned. Since the bulk nickel content is 30%, no Widmanstätten structure would be expected. The vague beginnings are, however, present. Very fine kamacite needles, 5±3 μ wide and 10-250 μ long, occur locally with a frequency of 500 per mm^2, distinctly oriented parallel to the $\{111\}$ planes and apparently homogeneously nucleated. Many of them are altered to limonite by terrestrial weathering. Routine etching with 1% Nital rapidly dissolves them, leaving narrow grooves. Both effects are evidently due to the significant chemical potential between the α- and the γ-phase and the very small proportion of the anodic α-areas.

The taenite matrix, constituting more than 95% of the etched sections, displays a distinct grid parallel to $\{111\}$. The individual planes are only 1-10 μ apart and are particularly prominent where corrosion has been active.

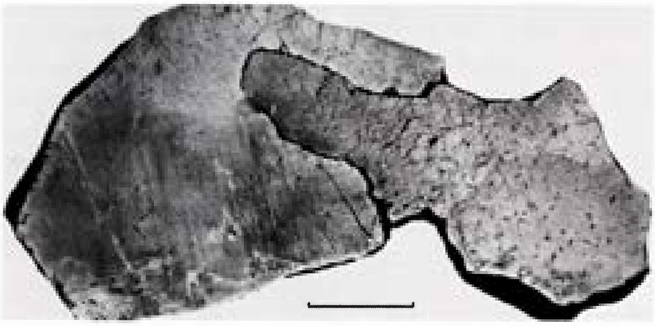

Figure 1820. Twin City (Atlanta). The section is composed of several austenite crystals, of which three (1-3) stand out prominently. Schreibersite, troilite and an unidentified phase (black) occur scattered all over. Deep-etched. Scale bar 20 mm. S.I. neg. 240.

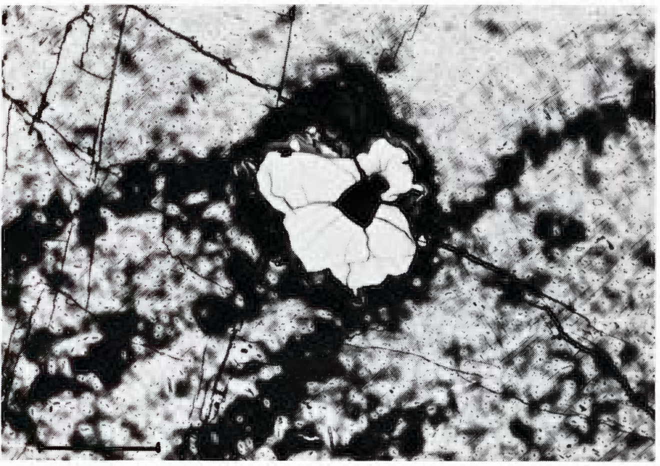

Figure 1821. Twin City (U.S.N.M. no. 1770). An angular silicate(?) crystal (black) at center, surrounded by a wide rim of brecciated schreibersite. Then follows a narrow rim of swathing kamacite, then limonite (gray), and finally the corroded taenite matrix with a dense grid of slip lines. Etched. Scale bar 200 μ.

TWIN CITY – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Henderson & Furcron 1957	29.91	0.51	0.34									
Wasson & Schaudy 1971	30.06								4.54	7.42	0.015	

They would hardly be visible if they were slipplanes as such; but if a chemical potential has been created due to microsegregation, their response to natural etching (corrosion) and laboratory etching (Nital) becomes understandable. It is most likely, then, that the planes have become visible because numerous submicroscopic precipitates of kamacite are located along them. Order hardening to Fe_3Ni is another possibility which is, perhaps, supported by the hardness of 325±25, which is high for a taenite phase. It decreases to 170±10 in the heat-affected rim zone. This zone is a polycrystalline aggregate of austenite grains, 10-50 μ across, and the above mentioned grid has disappeared. Micromelted phosphides are present in the exterior of the zone. The hardness curve is of type 5 and corresponds well to the hardness curve obtained by selecting points in the taenite rims of typical octahedrites as, e.g., Thule and Cape York; it also resembles Freda's curve.

Schreibersite is common as 4 x 0.5, 2 x 0.3 or 0.5 x 0.1 mm angular and branched skeleton crystals. They are monocrystalline but brecciated and have a hardness of 840±30. They are often developed around rounded, gray silicate blebs or around troilite inclusons. Schreibersite is also very common as evenly distributed, rounded precipitates, 0.5-10 μ across, in the taenite.

Troilite is common, both in the grain boundaries and in the grain interiors. The largest bodies observed are 18 x 8 x 6 and 4 x 0.5 x 0.5 mm, but most of the troilite is in the form of 50-300 μ blebs that in one grain occur with a frequency of one per mm^2, in others more sparsely. The troilite is a polycrystalline, shock-altered mosaic of 5-50 μ grains, apparently without daubreelite. Terrestrial corrosion has altered many of the grains to pentlandite in much the same way as in Santa Catharina.

Unidentified rounded gray bodies, ranging from 50 x 20 to 600 x 100 μ in size, are rather common, both alone in the taenite matrix and as inclusions in troilite and schreibersite. They appear to be silicates which have suffered some plastic deformation.

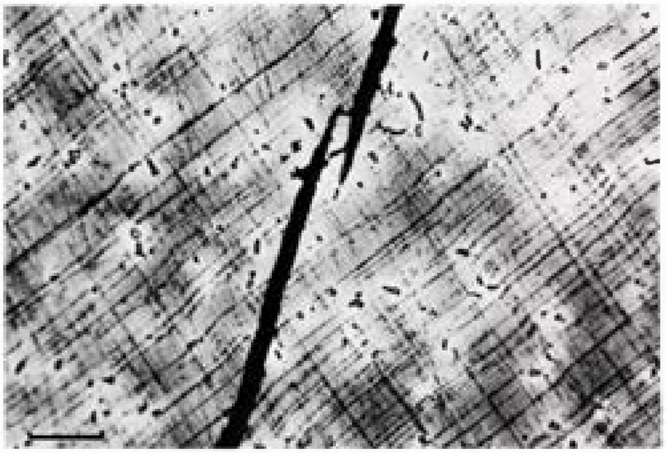

Figure 1822. Twin City (U.S.N.M. no. 1770). Two fissures recemented by terrestrial corrosion products. Fine phosphide particles are disseminated through the taenite which displays a dense grid of distorted slipplanes. Etched. Scale bar 20 μ.

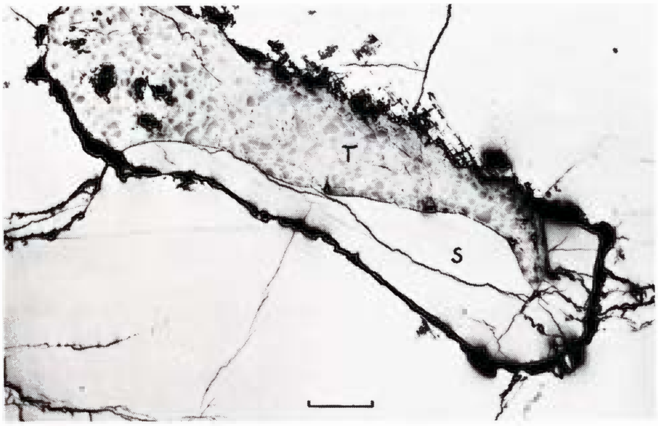

Figure 1824. Twin City (U.S.N.M. no. 1770). In the taenite matrix (white) are corroded fissures (black) and an aggregate of schreibersite (S) and troilite (T). The troilite is partially converted to pentlandite due to corrosion. Polished. Scale bar 100 μ. See also Figure 161.

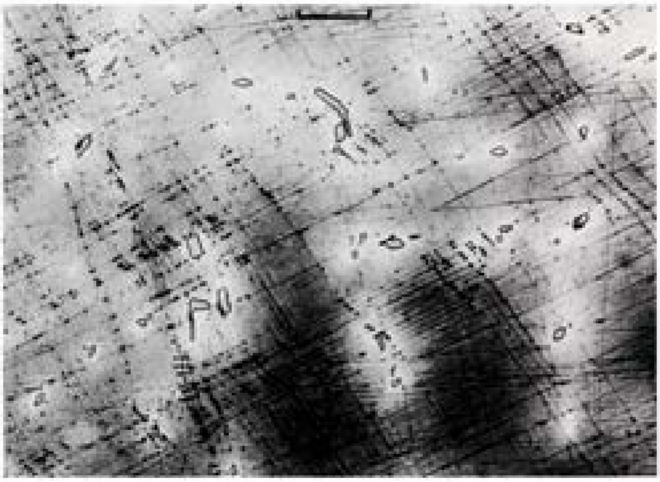

Figure 1823. Twin City (U.S.N.M. no. 1770). The matrix is distorted as evidenced by the bent phosphide particles and the bent slipplanes. These are apparently decorated by small particles (black dots). Etched. Oil immersion. Scale bar 10 μ.

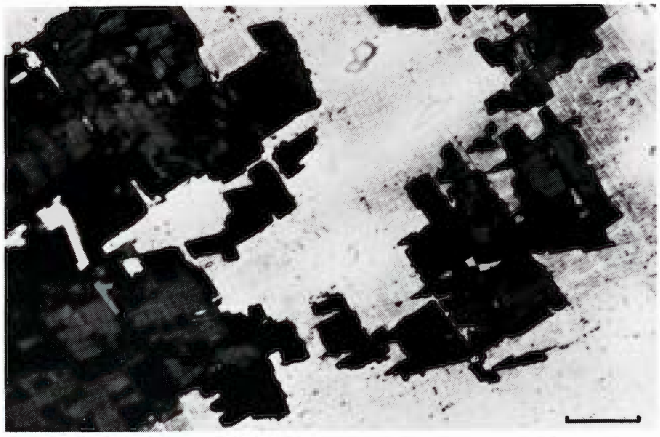

Figure 1825. Twin City (U.S.N.M. no. 1770). The corrosive attack resembles the one described in the taenite phase of Santa Catharina, with corroded units assuming cubic morphology. Their edges are parallel to the grid of slipplanes. Small phosphide particles are indistinctly seen near the center. Etched. Oil immersion. Scale bar 10 μ.

The iron is penetrated by numerous irregular fissures, most of which are filled with corrosion products. Indications of plastic deformation are present – both in the ruptured phosphides and sulfides and in the slight distortion of the Widmanstätten grid. Except for a few hammered places on the surface, the deformation is of preatmospheric origin.

Twin City is an unusual, polycrystalline ataxite. In its structure it resembles Santa Catharina except for its significant content of α-spindles. It is much less weathered than Santa Catharina, preserving the heat-affected rim zones over considerable areas. Its chemical composition resembles Santa Catharina, except for its lower nickel content.

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

109 g slice	(no. 1770, 8 x 5 x 0.4 cm)
38 g slice	(no. 1770, 6 x 3.5 x 0.3 cm)
35 g fragment	(no. 1770, 3.5 x 2.5 x 1.5 cm)

Udei Station, Benue River, Nigeria

7°57'N, 8°5'E

Medium octahedrite, Om, with silicate inclusions. Neumann bands. Group I – Anomalous. About 8.9% Ni, 0.12% P, 62 ppm Ga, 204 ppm Ge, 0.51 ppm Ir.

HISTORY

A meteorite was said to have fallen sometime between January and March 1927, north of the Benue River near Makurdi. The Geological Survey of Nigeria did not learn about the event until 1935, when a mass of 226 pounds (103 kg) was located six miles west of the railway station at Udei and 23 miles north of Makurdi. Residents of the area, and those as far away as 15 miles east of Makurdi, reported seeing and hearing the descent, which took place in the daytime. It was compared to the passage of an express train and was followed by a thud that shook the nearby houses. The meteorite was recovered from a shallow hole, scarcely deeper than its own thickness. Unconfirmed reports exist that a second fragment also fell. The material was classified as a mesosiderite (Macleod & Walls 1958).

Mason (1967a) examined the silicates and concluded that Udei Station was more closely related to the irons with silicate inclusions than to the mesosiderites. A similar conclusion was reached by Powell (1969), who presented the results of a thorough examination of the metal, with a photomicrograph and with microprobe examinations. While nine mesosiderites were estimated to have had an average cooling rate of 0.1° C/10^6 year, Udei Station cooled much more rapidly – 10° C/10^6 year – a rate which is similar to that of typical iron meteorites.

COLLECTIONS

Geological Survey, Kaduna, Nigeria (about 100 kg main mass), London (1 kg), Washington (202 g).

DESCRIPTION

According to Macleod & Walls (1958) who described the main mass and gave photographs of the exterior and of etched sections, the meteorite is roughly a parallelepiped and measures 42 x 35 x 22 cm. Although the surface was dull gray to rusty brown, the authors identified mammillated and striated fusion crusts in the depressions, particularly over the silicates. They noted that the silicates were just below the level of the surrounding iron, suggesting that they had been more readily removed during the meteorite's passage through the atmosphere.

An examination of the samples in Washington confirms the general fresh appearance of the material. Black fusion crust with tiny protuberances and roughly parallel flow lines are preserved, damaged, however, by rough hammering and chiseling during an attempt to detach specimens. Beneath the fusion crusts, 1.5-2.5 mm wide heat-affected α_2 zones are preserved. This information makes it plausible that the actual date of fall was in 1927 near the Benue River as maintained by the local residents.

Etched sections are of an anomalous and very heterogeneous appearance, displaying a mixture of metal, troilite and silicates. The ratio between the components varies in different sections, but the metallic portion always prevails, constituting more than 50% by volume. It appears that the metal was originally a polycrystalline aggregate of taenite grains, about 1 cm in size, and very imperfectly developed because of the numerous silicate and troilite inclusions. During the primary cooling, the taenite decomposed around these nuclei first and thereby formed 0.2-1 mm wide rims of swathing kamacite. Later, a Widmanstätten mechanism transformed the taenite squeezed between the swathing kamacite and produced a medium octahedrite pattern with straight, short $(\frac{L}{W} \sim 6)$ kamacite lamellae with a width of 0.6±0.2 mm. The kamacite displays subboundaries, and Neumann bands from a cosmic shock event are common.

UDEI STATION – SELECTED CHEMICAL ANALYSES

	percentage			ppm								
References	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Macleod & Walls 1958	8.6											
Hey 1966: 495	9.4											
Wasson 1970a	8.83								61.6	204	0.51	

The range in the nickel analyses is probably due to sampling problems of the heterogeneous material.