

Santa Rosa, Boyacá, Colombia

5°55'N, 72°59'W; 2,750 m

Anomalous. Polycrystalline iron with cohenite and graphite. Shock-reheated. HV 200±10.

Anomalous. 6.74% Ni, 0.51% Co, 0.36% P, 0.19% C, 0.3% S, 52 ppm Ga, 222 ppm Ge, 0.07 ppm Ir.

Numerous specimens which were recovered in early days have been artificially reheated to about 1000° C, and are often labeled Rasgata.

HISTORY

The very involved history of this interesting meteorite shower has been clarified recently by Buchwald & Wasson (1968). The following informations and deductions are condensed from their paper. The main mass of 612.5 kg (No. 1) was discovered in 1810 on a hill named Tocavita about a mile east of the main square of Santa Rosa de Viterbo, a small town in the Andes Mountains 175 km northeast of Bogotá. Two small individuals of 681 g (No. 2) and 561 g (No. 3) and several unspecified fragments, collectively named No. 4, were found in the following years on the same hill. Two larger individuals of 41 kg (No. 5) and 22 kg (No. 6) were obtained from a miner in a village, 125 km farther south in the region of Rasgata; but these are, no doubt, transported fragments. Humboldt (1823) announced the discovery, and Rivero & Boussingault (1824a, b) described and analyzed the specimens. Partsch (1843: 128) and Wöhler & Partsch (1852) also examined the material and presented lithographs of etched sections. Many other examinations appeared, but the confusion was considerable, because (i) it was not recognized that several wrought iron specimens were included in collections as authentic material; (ii) it was not realized that a large part of the material received in Europe had been artificially

reheated with the result that the structure had become very anomalous; and (iii) the chemical analyses of the nineteenth century were generally accredited with a much too high precision when, in fact, they were of a highly vacillating quality. Cohen (1905: 54, 272), who published a very thorough study, thus worked only with artificially heat-treated material without knowing it himself.

Ward (1907), in an attempt to clear up the mess, made an adventurous journey to the disputed place, Santa Rosa, and purchased the 612 kg main mass which at that time had been exhibited for a generation as a beloved item on a pillar at the market place. While he was not allowed to export the whole meteorite, he did secure a 150 kg endpiece which was later cut and distributed (Figure 1529). Ward gave a photograph of the main mass and Codazzi (1925: 33) gave one of a Rasgata specimen (No. 5 or 6), now in the National Museum at Bogotá. Ramirez (1949) gave a summary of the history and geography of the problem as seen in Colombia. He identified the locality, as did Ward, as

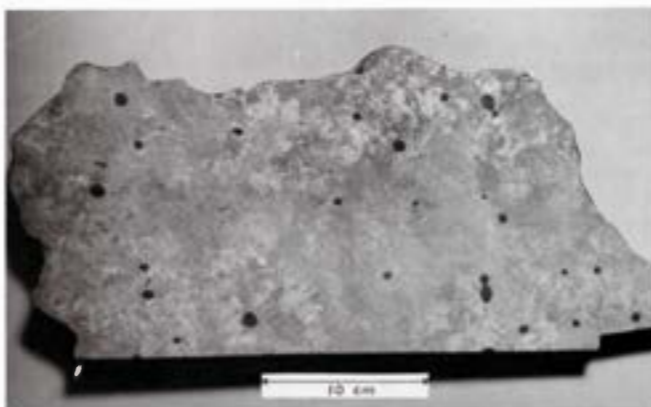


Figure 1530. Santa Rosa (U.S.N.M. no. 460). One of the slices from Figure 1529. The structure consists of more than 100 individual grains, originally austenite, now transformed to an indistinct Widmanstätten pattern. The troilite cylinders are cut almost perpendicular to their long direction.

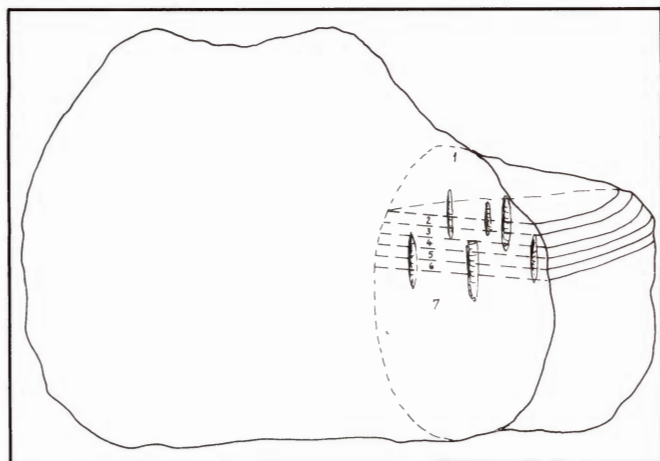


Figure 1529. Santa Rosa. Sketch of the 612.5 kg main mass with reconstruction of the sectioning done by Ward in 1906. No. 1 of 14 kg is in Harvard and no. 7 of 98 kg in Chicago. The five parallel plates, 2-6, were about 40 x 17 x 1 cm and weighed 3-4 kg each; four of these are now in Denver, New York (American Museum), New York (City College) and Washington (U.S.N.M. no. 460). The sketch also shows the orientation of the troilite cylinders.

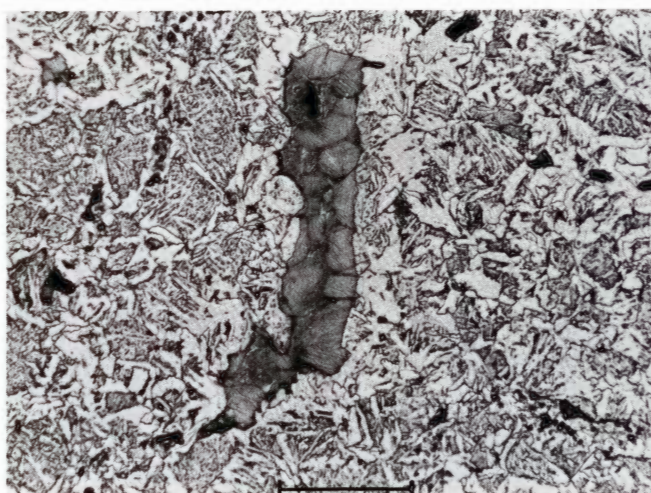


Figure 1531. Santa Rosa (Vienna no. A212). Artificially altered Santa Rosa sample, called Rasgata. Thorough reheating to about 1000° C has fused the schreibersite (center) and transformed the kamacite to a ferritic-bainitic grain mosaic. Etched. Scale bar 300 μ.

the somewhat elevated terrain 1-2 km east of the main square which is now the property of the Jesuit Novitiate in Colombia.

"On this property and in the surrounding territory since 1810 until the present day, several meteorites, both large and small, have been found buried in the ground. These meteorites are to be found mostly in private collections of Colombia."

The two largest specimens recovered in recent years (No. 7 of 38.4 kg found in 1926, and No. 8 of 100.5 kg found in 1942, 10-15 km east of Santa Rosa) are now in Bogotá. Quite recently a mass, No. 9 of 8 kg, has been recorded as being in the Jesuit Monastery at Santa Rosa (Ramirez, personal communication).

Thus, Santa Rosa is an important shower, totaling at least 825 kg and apparently covering an area 10-15 km long. Only the first found, small masses, Nos. 2-6, appear to have been reheated artificially; but these were the very masses which were more or less distributed in the nineteenth century and which caused the confusion. A very small amount of material, labeled Tocavita, has been treated separately under the entry Salt River (Tocavita), page 1048.

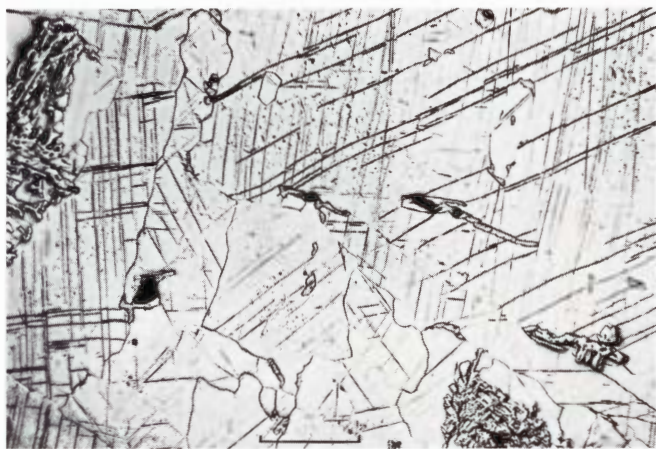


Figure 1532. Santa Rosa (Tempe no. 103b). A sample from the 38.4 kg mass. Recrystallized kamacite with distorted Neumann bands. Palmate cohenite crystals in relief. Etched. Scale bar 400 μ . See also Figure 141.

Chackett et al. (1953), Schaeffer & Fisher (1960), Fisher & Schaeffer (1960) and Bauer (1963) presented data on helium and other noble gas isotopes. The cosmic ray exposure age estimates ranged from 120-260 million years. Fisher (1965) chose Santa Rosa as an example of a gas-tight meteorite and showed that the large variations in the ratio of radiogenic ^{40}Ar to primordial ^{40}K must cast considerable doubt on the $^{40}\text{Ar}/^{40}\text{K}$ method of establishing an "age" for any meteorite. Buchwald & Wasson (1968) examined a large number of specimens from various collections, presented new analyses and numerous photomicrographs of both authentic material and — for comparison — of artificially reheated specimens in Vienna, London and Berlin and of pseudometeorites labeled Santa Rosa.

COLLECTIONS

Bogotá, National Museum (about 460 kg of No. 1, used as an anvil 1817-1824), Bogotá, Instituto Geofísico (No. 8 of 100.5 kg, No. 7 of 38 kg), Chicago (98.2 kg of No. 1; 1,811 g of No. 1), Harvard (14.25 kg of No. 1), Santa Rosa, Jesuit Monastery (No. 9 of 8 kg), New York (6.65 kg of No. 1), Washington (5.71 kg, specified below), New York

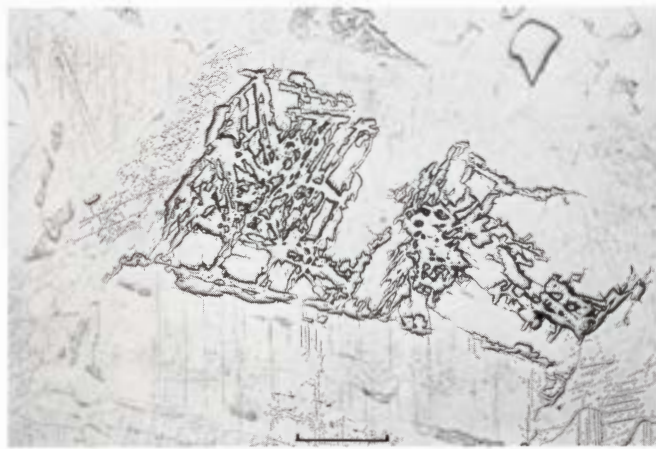


Figure 1533. Santa Rosa (U.S.N.M. no. 1673, from the 38.4 kg mass). A large palmate cohenite crystal with fingers parallel to the Widmanstätten directions. Etched. Scale bar 400 μ . (Perry 1950: volume 7.)

SANTA ROSA — SELECTED CHEMICAL ANALYSES

References	percentage			C	S	Cr	Cu	ppm Zn	Ga	Ge	Ir	Pt
	Ni	Co	P									
Wöhler & Partsch 1852	6.71	0.25	0.35									
Sjöström in Cohen 1898a	6.61	0.71	0.32	1900	600		150					
Lovering et al. 1957		0.48				60	121		49	167		
Dyakonova & Charitonova 1963	6.78	0.66	0.40				100					
Smales et al. 1967					9	60	143	13	54.5	221		
Buchwald & Wasson 1968	6.63								50.6	222	0.07	
Lewis & Moore 1971	6.95	0.45	0.38	1850								

Sjöström's results are the average of two analyses made on "Santa Rosa" and "Rašgata" material, respectively.

City College (3.46 kg of No. 1), Denver (3.46 kg of No. 1), Calcutta (2.0 kg), Tübingen (2.0 kg), Rio de Janeiro (1.6 kg), London (946 g of No. 1; 630 g), Vienna (about 1.2 kg), Tempe (1.2 kg), Paris (about 1.2 kg), Berlin (about 1.2 kg), Madrid (400 g of No. 1), Bonn (280 g), Vatican (250 g), Copenhagen (103 g of No. 7; 17.5 g), Prague (125 g), Sydney (111 g of No. 7), Canberra (98 g), Yale (69 g), Moscow (67 g), Ottawa (47 g), Strasbourg (14 g).

DESCRIPTION

The 612 kg main mass, which for some years served as an anvil in Santa Rosa, measured 77 x 49 x 45 cm (Ward 1907). It is covered with regmaglypts, 3-7 cm across and 1-2 cm deep, over a large part of its surface; and the fusion crust of magnetite plus wüstite is preserved in numerous places, albeit in a somewhat corroded state. As expected, the regmaglypts on the smaller individuals are smaller; e.g., they are 10-20 mm in diameter on No. 7, of 38 kg, which has the average dimensions of 30 x 20 x 15 cm. As often is the case, the regmaglypts have a diameter which averages one tenth of the diameter of the mass itself. The well developed regmaglypts on the individual specimens prove that the meteorite burst high in the atmosphere. In several places there are cylindrical pits, 4-10 mm in diameter, from troilite that partly burned out from the ablatational heat. In a few places a plastically distorted structure may be noted on near-surface sections; this is probably the remainder of metallic bridges that were broken by tensile-torsional forces when the meteorite ruptured in the atmosphere; compare Glorieta Mountain. A 1.0-2.0 mm thick heat-affected zone is present on most sections. In the exterior 50% the phosphides are micromelted, and the graphite and cohenite have formed martensitic-bainitic nests. Even ledeburitic melts are present locally. The hardness of the α_2 zone is unusually high, 270 ± 15 , presumably because it is rich in dissolved carbon.

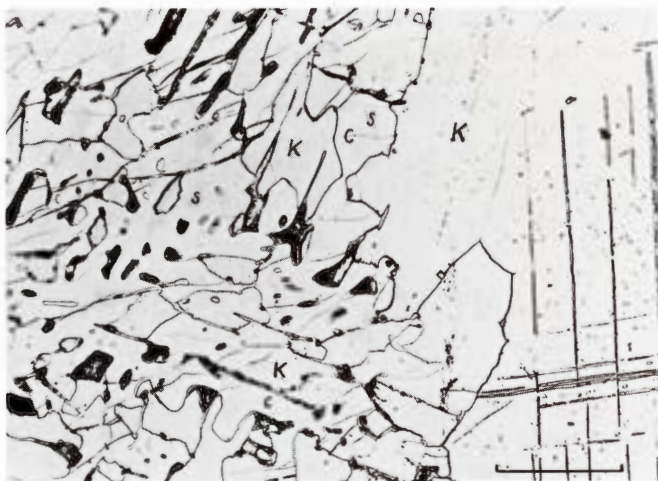


Figure 1534. Santa Rosa. Detail of Figure 1532. The serrated cohenite crystal (C) has grown around schreibersite grains (S), kamacite (K) and taenite (black). The taenite lamellae are "fossil remains" of the parent taenite and are themselves decomposed by annealing. Etched. Scale bar 100 μ .

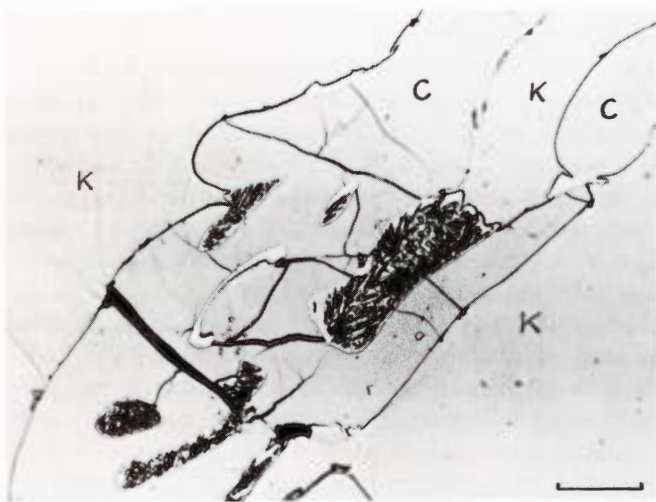


Figure 1535. Santa Rosa (Tempe no. 103b). Cohenite (C) with decomposed duplex plesite inclusions (dark) and with taenite lamellae (white). Kamacite (K) on either side. Etched. Scale bar 20 μ .

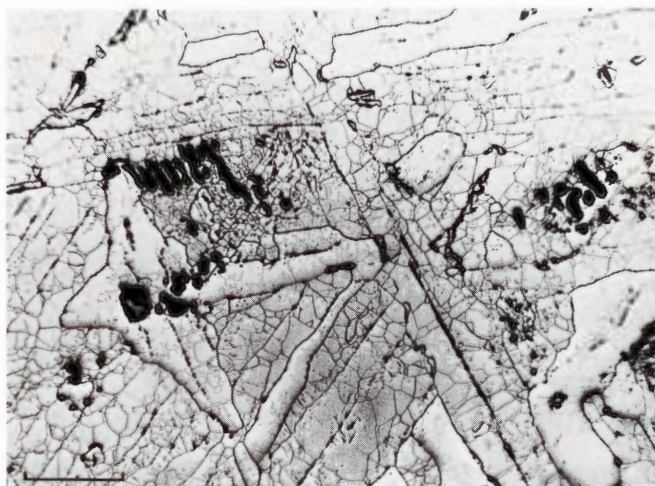


Figure 1536. Santa Rosa (Tempe no. 103a, probably from the 612 kg main mass). Indistinct Widmanstätten structure showing annealing effects. Original cohenite crystals are decomposed to graphite that forms irregular cakes and clusters (black), sometimes with a cliftonitic morphology. Several schreibersite crystals are also present, e.g., in upper left corner. Etched. Scale bar 400 μ .

Etched sections are anomalous in displaying no clearly identifiable Widmanstätten structure. At high temperature the metal was evidently a polycrystalline aggregate of austenite (taenite) grains, each 2-5 cm across and slightly elongated. Several of the grains show twinning. The grain boundaries are marked by a seam of discontinuous phosphide precipitates which are about 50 μ wide and surrounded by a 0.2-0.5 mm wide border of kamacite. The presence of parallel – somewhat flattened – cylinders of troilite is very characteristic. These occur with a frequency of about one per 20 cm². Point counting indicates 1.3 volume % FeS, or 0.29% S. The individual troilite bodies seem to be shaped as belemnites or small cigars, typically 4-10 mm thick and 4-6 cm long and tapering to a point at both ends. High magnification reveals the troilite to be a

polycrystalline mosaic of 1-10 μ thick grains with 10-15% of daubreelite distributed evenly as 2-5 μ wide melted drops. The hardness is 235 ± 10 . The discontinuous 50-200 μ wide schreibersite rims originally present are shattered and partially dispersed as 2-100 μ fragments which show incipient melting. Extending from some nodules there are 5-100 μ wide cracks partially filled with troilite-daubreelite melts and now cemented together by corrosion products. The troilite-daubreelite-schreibersite assemblages suggest a high-intensity shock with point melting of the shock-absorbing troilite. Similar, fully melted troilite-daubreelite assemblages have been described herein from, e.g., Zacatecas, Bingera and Holland's Store. It may be noted that the troilite is, for all practical purposes, graphite-free although graphite occurs in large amounts in other places.

While the above observations are true for all masses, there are some surprising microstructural differences. At least there are such differences between the 612 kg main mass and the 38 kg mass (No. 7) — differences which do not appear to be due to artificial reheating. These microstructures were described in their extreme form by Buchwald & Wasson (1968) on basis of the Tempe specimens Nos. 103a and 103b.

The 38 kg mass shows indistinct kamacite lamellae which are oriented within each original γ -grain in a Widmanstätten structure. The bandwidth ranges irregularly from 0.1-0.5 mm. Neumann bands are common, and the hardness is 202 ± 10 . Taenite and plessite fields of the accepted forms are absent. Phosphides occur abundantly as 2-50 μ wide grain boundary veins and as 1-8 μ thick rhabdites. Some of the larger schreibersite crystals display continuous cohenite rims, 20 μ thick.

The 612 kg mass also shows indistinct kamacite lamellae, but because of the finely disseminated graphite in the grain boundaries, the etching picture is somewhat more contrast-rich. The Neumann bands are decorated along both edges with 0.5-1 μ phosphides, or they are resorbed and

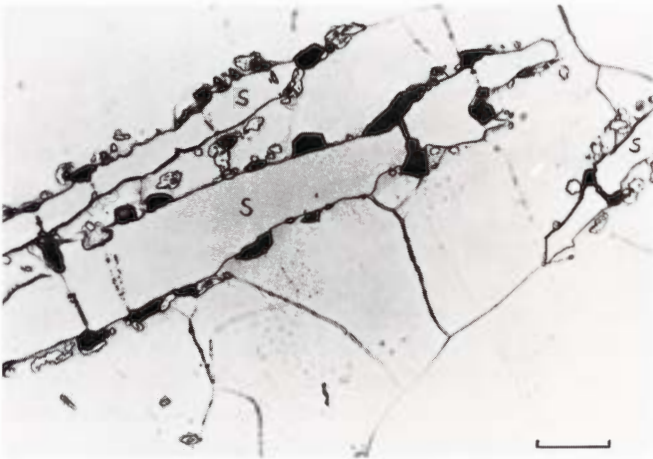


Figure 1537. Santa Rosa (Tempe no. 103a). Three schreibersite crystals (S) showing annealing effects. They have segregated fine amoeba-like γ -particles along their periphery. Pits from corrosion and imperfect polishing are shown black. The interpretation is different from that previously given (Buchwald & Wasson 1968: plate 11). Etched. Scale bar 20 μ .

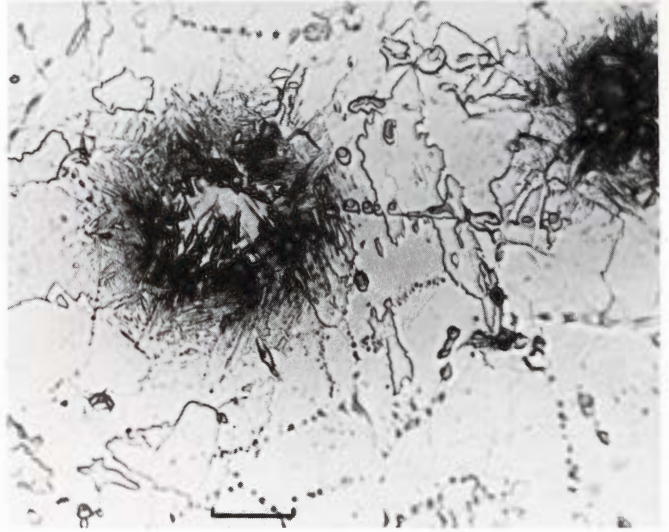


Figure 1538. Santa Rosa (Tempe no. 103a). Three graphite crystals that happened to be situated in the heat-affected α_2 zone. Two were fully, the one at right, partly, dissolved in the austenite. Upon cooling, martensitic-bainitic zones (black) formed around retained high-carbon austenite. Etched. Scale bar 20 μ .

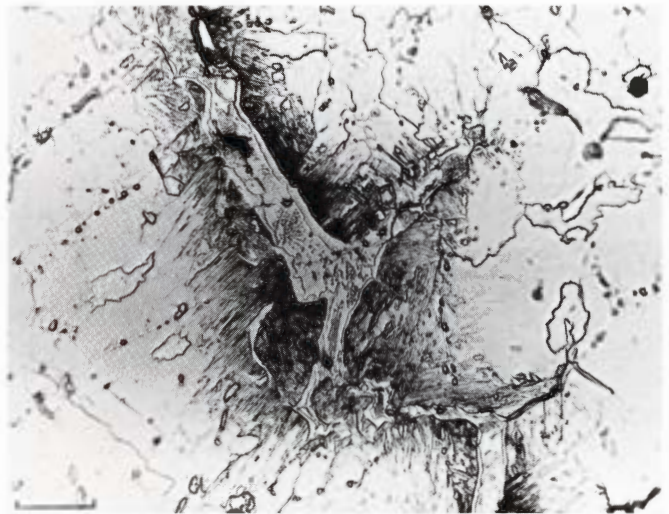


Figure 1539. Santa Rosa (Tempe no. 103a). Graphite-schreibersite aggregate that fused in the atmosphere and solidified to a steadite eutectic, with bainitic-martensitic rim zones. Etched. Scale bar 20 μ .

substituted by dense networks of subboundaries. Few meteorites display so many and such sensitized subboundaries as this Santa Rosa specimen. The hardness is 198 ± 10 , insignificantly softer than the 38 kg mass. The phosphides are heat-altered showing a rim of tiny detached taenite blebs, 0.5-5 μ thick. They are shown on Figures 11 and 12 (Buchwald & Wasson 1968) where they were erroneously identified as retained cohenite.

The 38 kg mass contains numerous, conspicuous, palmate cohenite bodies, 0.2-1.5 mm in diameter; but little graphite is present. The cohenite is not pure but rather oriented intergrowths of cohenite and taenite, plessite, kamacite and schreibersite. The hardness ranges correspondingly from 1,200 for the purest form to 950 for the mixed parts. Also, smaller carbides, 1-10 μ across, are widely

disseminated through the matrix and appear to be haxonite; compare Anoka.

The 612 kg mass has no cohenite but has, instead, corresponding amounts of graphite – often exactly in the places where cohenite was previously situated. The graphite is developed as cliftonite crystals, 10-50 μ across, or as clusters of clifonitic units, or as irregular grain boundary precipitates.

It appears that the (examined part of the) main mass represents a more altered structure than the 38 kg mass. The cohenite is decomposed to graphite, the Neumann bands are decorated, numerous subboundaries and partial recrystallization are introduced, and the phosphides display rounded edges and detached taenite islands. These structural alterations seem to have required temperatures around 500-550° C for several days. There is, of course, the remote possibility that the alterations took place when the large mass served as an anvil during the extended period 1817 to 1824. Ward expressly stated (1907: 5) that he removed his 150 kg piece from that end which had been smoothed down due to the battering of the smith's sledge hammer. However, it appears unlikely that an anvil should be 500° C warm in its massive parts for any extended period. Further, it can be stated that all sections were taken at least 12 cm from the anvil face.

One alternative, then, is to accept that the meteorite, while inside its parent body or circling in cosmos, suffered a rather thorough cohenite decomposition at one end while next to nothing happened at the other end, less than 100 cm away. A third alternative is that the deceleration and rupturing in the atmosphere were so violent that some of the masses were reheated. Such effects can be observed in, e.g., some specimens of the Campo del Cielo, Canyon Diablo, Henbury and Gibeon meteorites, but appear to be associated only with very large showers or with crater-producing meteorites. Finally, a fourth alternative is provided by the hypothesis that the shock event that produced the troilite melts was highly attenuated in some parts of the body and heated these selectively while steep temperature gradients occurred around them.



Figure 1540. Santa Rosa. A Rasgata sample (Brit. Mus. no. 35185). Typical artificially reheated structure with concave schreibersite melts and bainitic kamacite matrix. Etched. Scale bar 100 μ .

While it is difficult at present to reach a definitive conclusion, I am inclined to prefer the fourth alternative as the one which seems to explain the observations best. In this connection it should be pointed out that meteorites, such as Forsyth County and Holland's Store which are chemically very different from Santa Rosa, have apparently suffered similar late inhomogeneous reheatings; and the explanation would seem to be analogous.

The cohenite and graphite are intimately associated with taenite, kamacite and schreibersite in oriented intergrowths that suggest the previous existence of plessite fields. Each original austenite grain, 2-5 cm in diameter, may be assumed to have decomposed to a Widmanstätten structure with a bandwidth of 0.1-0.2 mm. In between the kamacite lamellae, the residual austenite fields slowly, by diffusion, became enriched in carbon. Still later, the austenite decomposed to intricate intergrowths of cohenite, taenite, kamacite and schreibersite. Finally, at a late stage

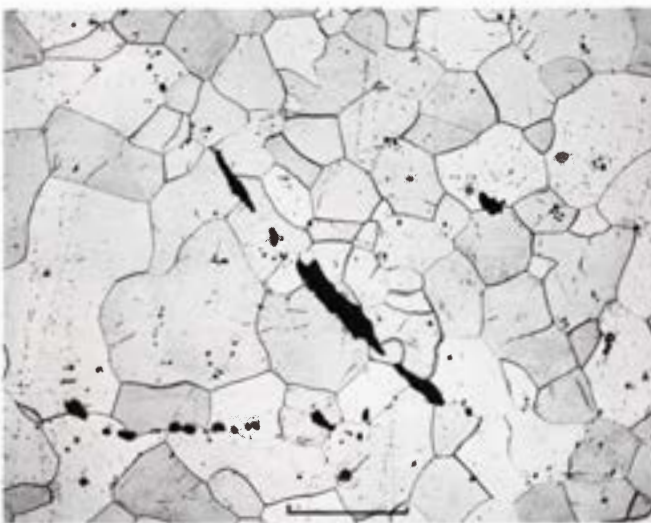


Figure 1541. Pseudometeorite. A sample (Chicago no. 1156, of 95 g) which was for 150 years considered to be a genuine Santa Rosa specimen (see, e.g., Horback & Olsen 1965: 291). It is wrought iron with equiaxed ferrite grains and black slag inclusions. Etched. Scale bar 200 μ . (Perry 1950: volume 5.)

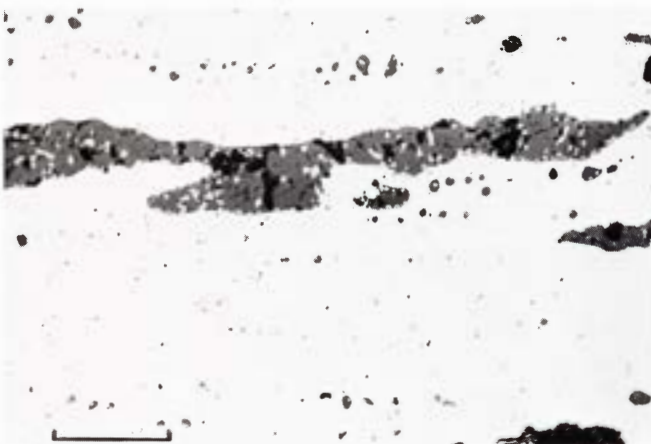


Figure 1542. Pseudometeorite. The same as Figure 1541, a typical wrought iron with elongated slag inclusions. Polished. Scale bar 200 μ . (Perry 1950: volume 5.)

which did not influence all of the meteorite equally, the cohenite further decomposed to graphite and kamacite. That the graphite is, in fact, a very late product may be seen from its lining of sometimes very small phosphides, only 20 μ thick, which must themselves have precipitated below about 500° C.

If the above description appears confusing it is partly because Santa Rosa is an intriguing meteorite, which does not easily surrender to interpretation. Also, chemically, it is rather unique, having only Chihuahua City as its near relative. Farther away stand Bendego and Saint Francois County.

With respect to the many pseudometeorites and artificially reheated specimens often labeled Rasgata, I refer to the description and figures in Buchwald & Wasson (1968).

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

632	g endpiece (no. 1392, 7 x 4 x 3 cm)	} from the 38 kg specimen
40	g slice (no. 1673, 8.5 x 5 x 0.1 cm)	
440	g part slice (no. 361, 16 x 6 x 0.8 cm)	} from the main mass, via Ward's Natural Science Establishment
645	g slice (no. 457, 18 x 10 x 0.8 cm)	
3,810	g part slice (no. 460, 41 x 17 x 0.9 cm)	
83	g irregular fragment (no. 673, 5 x 3 x 2)	
16.5	g part slice (no. 3045, 7 x 1.5 x 0.2 cm)	
9	g part slice (no. 3046, 7 x 1.5 x 0.1 cm)	} Reheated artificially.
228	g part slice (no. 3047, 6 x 4 x 1.5 cm)	

Santiago Papasquiario, Durango, Mexico

Approximately 24½°N, 106°W

A taxite. Equiaxial, recrystallized kamacite grains, 0.1 mm in diameter, with dispersed taenite particles, 0.01 mm in diameter. HV 153±6.

Anomalous, but slightly related to group IVA. 7.50% Ni, 0.38% Co, 0.01% P, 0.57 ppm Ga, 0.040 ppm Ge, 4.0 ppm Ir.

HISTORY

A mass of 130 kg (287 pounds) was found in 1958 by Jose Silva when he was chopping wood in the mountainous, sparsely populated regions of western Durango. The meteorite was brought to scientific knowledge when it was purchased in 1964 for the collection of Arizona State University. The only information Silva imparted as to the circumstances of finding was that the mass lay on top of the ground in a place which was stated to be 143 km southwest of Santiago Papasquiario by dirt road. The corresponding coordinates are given above. The reported locality is more than 100 km distant from other Mexican meteorites.

The meteorite was described by Buchwald & Moore (1968). The information in Hey (1966) as to weight,

coordinates and structure is only preparatory and insufficient. The meteorite was examined by Tackett et al. (1970) for its reaction to an electrolytic solution in a potentiostatic experiment.

COLLECTIONS

Tempe (about 128 kg), Washington (1,176 g), Copenhagen (155 g), London (141 g).

DESCRIPTION

The average dimensions before cutting were 50 x 30 x 20 cm, and the weight was 130 kg. The mass is an entire lenticular monolith from which only a few small fragments have been removed with a hacksaw by the finder. The meteorite is rusty and partly covered by light ochre colored crusts, probably of caliche as is so frequently seen on irons found under arid conditions. No rough handling, such as heavy hammering or artificial reheating, has taken place.

The meteorite is rounded and does not exhibit distinct regmaglypts. On the topside a few flat depressions 25 cm in diameter and 1-2 cm deep may be observed. On the underside is a series of rough depressions, typically 8 x 6 cm in aperture and 2-4 cm deep. It appears that the present sculpture is mainly the result of terrestrial corrosion.

No fusion crust and no heat-affected α_2 zone could be detected on sections. This is further confirmation of the observation above: at least 2, and probably 5 mm, have been removed by terrestrial weathering over most of the surface. The corrosion has attacked the meteorite evenly but superficially. No deep cracks or fissures filled with corrosion products are present.

The mass was cut with a bandsaw and with carborundum wheels. The sections are extremely homogeneous, like steel, but do contain scattered sulfide-inclusions, generally

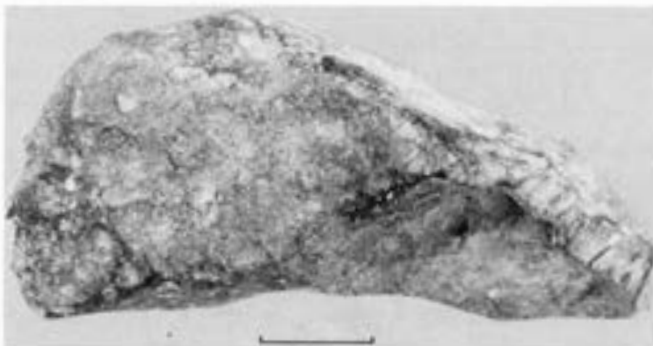


Figure 1543. Santiago Papasquiario (Tempe no. 721). The main mass of 130 kg at a time when only a few small slices (left) had been removed. Scale bar approximately 10 cm. (Courtesy C.B. Moore.)

SANTIAGO PAPANASQUIARIO – SELECTED CHEMICAL ANALYSES

References	percentage			C	S	Cr	Cu	ppm				Pt
	Ni	Co	P					Zn	Ga	Ge	Ir	
Buchwald & Moore 1968	7.51	0.38	0.01	27	215							
Schaudy et al. 1972	7.48							0.573	0.040	4.0		

1-5 mm across. During the wet cutting a wedge-shaped cavity, 15 x 15 x 10 mm in size, was encountered. It has not been possible to determine which material, if any, filled this hole before cutting. The hole does not appear to be connected with the surface or associated with weathering.

The macro- and microstructure are highly unusual for an iron meteorite. No trace of Widmanstätten pattern can be detected. Normally a 7.5% Ni iron would exhibit some degree of Widmanstätten array. Instead, the structure is homogeneously fine-grained, exhibiting equiaxial ferrite grains 50-150 μ in diameter in which a second phase, about 10 μ in diameter, is evenly dispersed. The ferrite is homogeneous, without Neumann bands and without rhabdites. The grain boundaries are in a state of imperfect equilibrium and arrested grain growth. In numerous places it may be seen that 20-50 μ ferrite grains have coalesced to larger units. The microhardness is 153 ± 6 , corresponding to well annealed recrystallized kamacite.

The dispersed phase covers about 5% by area, mostly in the form of irregular, rounded globules 1-15 μ across. They occur with an average frequency of 1300 per mm^2 . The

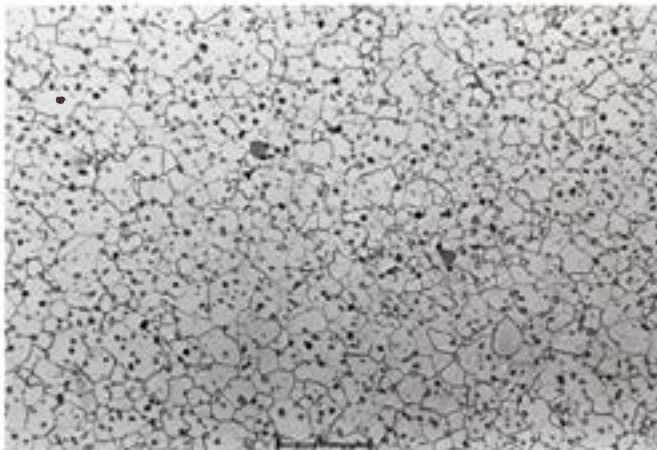


Figure 1544. Santiago Papasquiaro (Tempe no. 721). Recrystallized kamacite matrix with occasional daubreelite grains (black). Etched. Scale bar 200 μ .

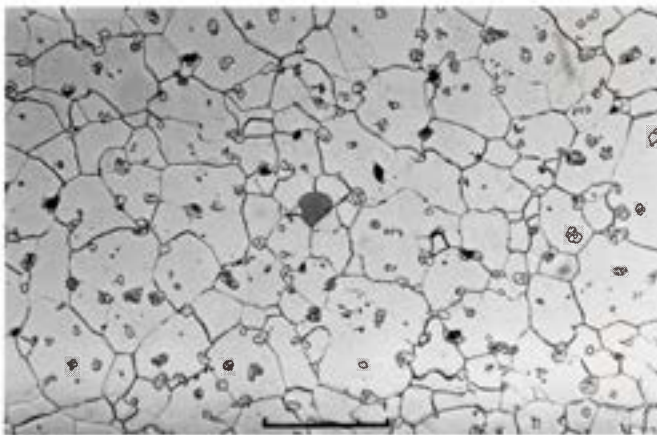


Figure 1545. Santiago Papasquiaro (Copenhagen no. 1972, 339). A daubreelite crystal at the center. Recrystallized kamacite and amoeba-like taenite particles. No phosphides. Etched. Scale bar 100 μ .

smaller ones are massive and rounded to lenticular, while the larger ones are irregular, with reentrant angles and with internal "windows" of ferrite, 0.4-2 μ across. Optical examination alone suggests that the dispersed phase is austenite (taenite), however, of an unusual morphology and distribution. A somewhat similar morphology is present in Hammond, Juromenha, Washington County and a few other iron meteorites.

Electron microprobe examination confirmed that the amoeba-shaped particles were taenite. Analysis of 10 different particles yielded an average composition of 29.7% Ni, 70.0% Fe, 0.3% Co and 0.01% P. The range in nickel was from 28.0 to 30.7% when care was taken to sample the massive parts of the taenite particles. A more casual probing of the taenite particles led to a wider range, from 16.8 to 30.7% Ni, but these lower values are misleading since they are influenced by the numerous small windows of kamacite in the taenite particles.

With the microprobe the ferritic matrix was found to have the following composition: 6.80% Ni, 92.6% Fe, 0.5% Co, and 0.01% P. No phosphides were observed in either the kamacite or taenite, and this tallies well with the low analytical values for phosphorus.

The anomalous microstructure can thus be described as an aggregate of recrystallized kamacite grains with 6.8% Ni, in which a large number of annealed taenite particles with about 30% Ni occur. The phosphorus content of about 0.01% is the lowest ever recorded in an iron meteorite.

Troilite occurs as a few scattered inclusions, e.g., 5 x 2 mm and 1 x 1 mm in size. A single, almost cylindrical inclusion is located near the surface. It is corroded but had apparently been 25 mm long and 8 mm in diameter. All troilite is converted by shock melting to polycrystalline aggregates, 2-10 μ in diameter. The associated daubreelite is brecciated and dispersed through the troilite.

Daubreelite is also common in the kamacite phase as irregular bluish grains, 1-50 μ across. It is isotropic under crossed Nicols and shows no fracturing. It is normally

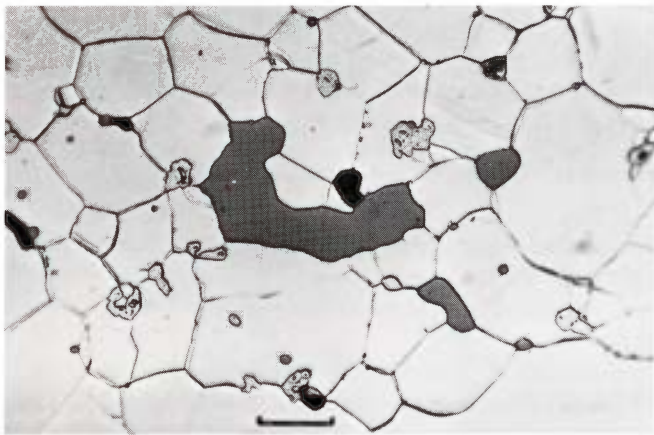


Figure 1546. Santiago Papasquiaro (Copenhagen no. 1972, 339). Daubreelite crystals (dark) and cavernous amoebae of taenite in recrystallized kamacite. Black denotes pits from imperfect sample preparation. Etched. Scale bar 20 μ .

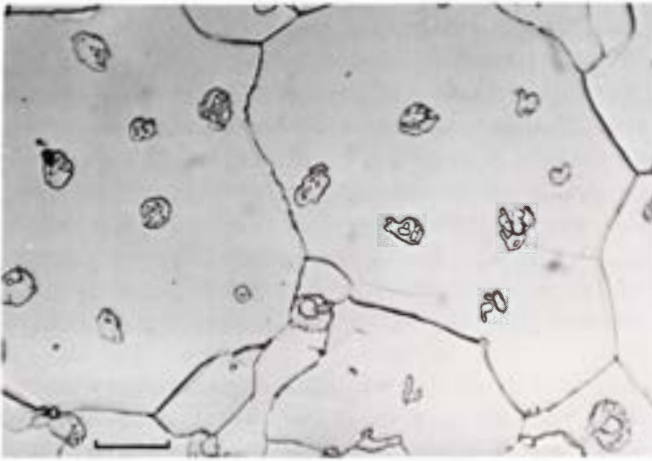


Figure 1547. Santiago Papasquiario (Copenhagen no. 1972, 339). Detail showing the cavernous unequilibrated taenite particles. Grain growth on part of the kamacite has resulted in many taenite particles being now situated entirely within the kamacite grains. Etched. Scale bar 20 μ .

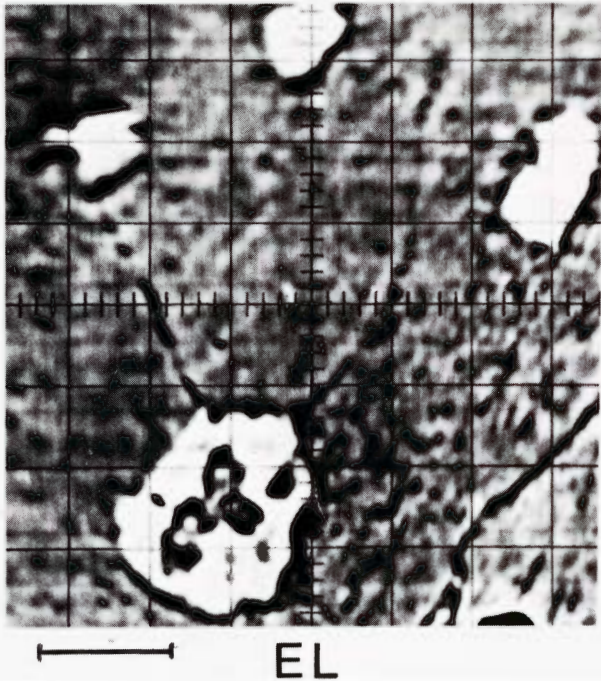


Figure 1548. Santiago Papasquiario (Copenhagen no. 1972, 339). X-ray scanning picture of four taenite particles showing their irregular outlines and kamacite-filled cavities. Scale bar 10 μ .

surrounded by ferrite or located in the grain boundaries out of touch with the taenite phase.

No traces of carbides, graphite and silicates were detected.

Terrestrial weathering has formed an oxide shale 0.1-1 mm thick. In this there still remain undissolved parts of the high-nickel taenite phase. In fact, the morphology of this phase is easily studied here against the background of the dark limonite. In places the ferrite grain boundaries are preserved in the limonite. This indicates that a narrow zone

along the grain boundaries is electrochemically more noble than the grain interior, a somewhat unexpected phenomenon. In other meteorites the grain boundaries are the first to become transformed by terrestrial weathering, presumably due to nickel depletion and a general accumulation of such foreign atoms as are unable to be accommodated in the ferrite lattice.

The chemical composition and the structure of Santiago Papasquiario are unique. There are, of course, other iron meteorites with 7.5% Ni, but none of them contain as little gallium, germanium and phosphorus. Some of the closest in chemical composition are such irons as Obernkirchen, Social Circle and Maria Elena, which are all fine octahedrites belonging to the resolved chemical group IVA. The microstructures of Maria Elena and Smithland in particular have certain similarities with Santiago Papasquiario. Maria Elena, which is clearly a fine octahedrite, shows polycrystalline ferrite and taenite lamellae under decomposition to ragged amoeba-shaped particles, not very different from those in Santiago Papasquiario. Maria Elena has shock-melted troilite, and it also has a significant population of small daubreelite particles in the kamacite. Smithland also exhibits a polycrystalline kamacite matrix with scattered taenite particles, but since Smithland has been artificially reheated it is not quite clear what is the original structure and what is artificial.

While Maria Elena, thus, has much in common with Santiago Papasquiario, this on the other hand is closely related to Obernkirchen, Social Circle and Gibeon. Thus there is some corroboration for the theory that Santiago Papasquiario was originally a fine octahedrite like the others but that a separate and extreme heat treatment – probably in association with a cosmic shock event – completely recrystallized the kamacite and spheroidized the taenite. Equilibrium conditions were apparently not reached, since the interphase area is rather large, and the taenite particles are ragged and have internal kamacite.

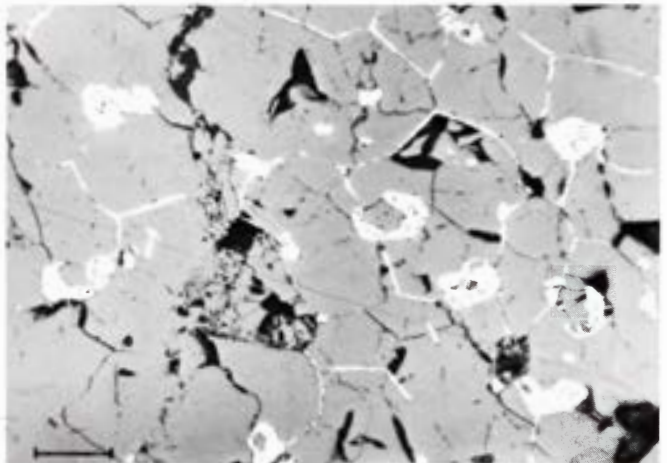


Figure 1549. Santiago Papasquiario (Copenhagen no. 1972, 339). Near-surface section. Corrosion has selectively transformed the kamacite to limonite (gray), while the taenite particles survive for a while. Polished. Scale bar 20 μ .

Before the microstructure of Santiago Papasquiaro was examined in detail and before adequate chemical analyses became available, the mass was hard to accept as being of meteoritic origin. Without a close examination it could be mistaken more easily than any other iron meteorite for an artificial product.

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

1176 g part slice (no. 2603)

São Julião de Moreira, Minho, Portugal

41°45'58"N, 8°35'1"W

Coarsest octahedrite, Ogg. Bandwidth 6±2 mm, and 5 cm grains. Neumann bands. HV 188±12.

Group IIB. About 6.4% Ni, 0.47% Co, 0.9% P, 46 ppm Ga, 107 ppm Ge, 0.012 ppm Ir.

HISTORY

A weathered mass was found at a depth of 1.2 m on a disintegrating granite bedrock in São Julião de Moreira, near Ponte do Lima. It was described by Ben-Saude (1888) who also gave a photomicrograph and several sketches of the microstructure. He furnished the coordinates quoted above. According to Teixeira (1968a), who studied the early history, the mass was found in 1877 when a new vineyard was laid out. The meteorite was enclosed in a muddy shell, impregnated with rust, and was itself covered with a limonitic crust several centimeters thick. Fragments were easily detached from it with hammer and chisel, so before it reached Lisbon in 1883 some 40-50 kg had been lost. Therefore, its original weight is very uncertain but may have been about 160 kg as noted by Ben-Saude (1888). The mass was sold to Brezina in Vienna about 1889. He distributed most of the presently known material. Cohen (1889; 1900b) described and analyzed the meteorite; he proved that schreibersite was a well defined mineral with the composition of (Fe, Ni, Co)₃ P. Previous authors had ascribed various other formulas to schreibersite or, at least, had not been able to prove unambiguously that the composition was stoichiometric. Böggild (1927) examined

the rhabdites. Marvin (1963) identified akaganeite, goethite and magnetite in the corrosion products.

Hintenberger & Wänke (1964) determined the helium and neon isotopes. Vilcsek & Wänke (1963) found a cosmic ray exposure age of 270±100 million years by the ³⁶Cl/³⁹A method. Chang & Wänke (1969), however, revised this value to 33±10 million years, and also estimated the terrestrial age to be very high – 770,000 years – mainly based on the low concentrations of ³⁶Cl and ¹⁰Be.

COLLECTIONS

Vienna (3,050 g and 1,500 g), Lisbon (3 kg; Teixeira 1968a), Chicago (2,727 g), Washington (2,150 g), New York (2,065 g), Budapest (1,465 g), Oslo (1,122 g), Bally (1,097 g), Moscow (three different collections, totaling 940 g), London (875 g), Stockholm (828 g), Harvard (811 g), Bonn (695 g), Leningrad (695 g), Copenhagen (563 g), Sarajevo (493 g), Paris (393 g), Prague (304 g), Helsinki (283 g), Sydney (283 g), Strasbourg (272 g), Dresden (275 g), Riga (232 g), Tempe (182 g). Small sections are in numerous other collections. Cohen (1900b: 389) received 20 kg of weathered fragments from Brezina in Vienna and isolated 1 kg of schreibersite from this material. This, added to the known specimens, still only adds up to about 50 kg. It is probable that the remainder of the original mass consists only of corroded fragments of little value which are stored in some basement.

DESCRIPTION

According to Ben-Saude (1888) the mass had a spheroidal shape with an approximate diameter of 34 cm. Today no large, single section appears to remain. Most material in collections is irregular fragments or slices weighing a few kilograms or less. Possibly the mass was weathered so badly that it broke apart along grain boundaries and schreibersite and troilite inclusions when it was cut. The cutting seems to have been performed in Germany – possibly by Krantz or Stürtz in Bonn – around the year 1900, but no record was found to confirm this supposition. Anyway, what is left is weathered fragments which only occasionally exhibit the original surface. On specimen No. 3052 the fusion crust is preserved, albeit in a limonitized state, at the bottom of a regmaglypt. It forms

SÃO JULIÃO DE MOREIRA – SELECTED CHEMICAL ANALYSES

By point counting I have estimated the bulk phosphorus content to be 0.9%, of which 85% is present as large schreibersite crystals. These contain about 15% Ni and 0.43% Co (Cohen 1900b). The value of 6.1% Ni was obtained on metal free of large schreibersite inclusions. We

may arrive at the true bulk nickel value of 6.4% by a recalculation, taking into account the significant amount of nickel that is bound in the large number of schreibersite inclusions.

References	percentage			ppm								
	Ni	Co	P	C	S	Cr	Cu	Zn	Ga	Ge	Ir	Pt
Lovering et al. 1957		0.47				1.5	79		35	73		
Smales et al. 1967						6.4	90		37	94		
Wasson 1969	6.1								46.2	107	0.012	
Crocket 1972											0.0093	2.9



Figure 1550. São Julião (U.S.N.M.). A coarsest octahedrite of group IIB. Troilite, at left and right, with a coarse eutectic of schreibersite in between. Terrestrial limonite in the grain boundaries. Deep-etched. Scale bar 20 mm. S.I. neg. 550a.

whirlpool structures of concentric, dendritic metal with occasional dispersed globules of magnetite. The fusion crust has significant amounts of low-melting, interdendritic phosphide because the meteorite is so rich in schreibersite. Under the fusion crust is a 0.3 mm wide α_2 zone with a hardness of 180 ± 10 . Then follows an annealed transition zone with a minimum of 160 ± 5 , and finally comes the unaffected interior with a hardness of 188 ± 12 . On most other sections the heat-affected α_2 zone is totally removed by weathering, in harmony with a high terrestrial age.

Etched sections reveal a confusing mixture of Widmanstätten structure and irregular kamacite grains with wide ribbons of schreibersite. Only a few sections are large enough to exhibit the two structural types simultaneously; but by examining a number of sections, the investigator may note that the overall structure is identical to that of Sikhote-Alin, Ainsworth and other group IIB irons. The bandwidth of the Widmanstätten structure is estimated to be 6 ± 2 mm and the individual lamellae may reach a length of 40 mm. Squeezed between the lamellae is an occasional taenite ribbon or an open-meshed comb plessite field, up to 2 x 2 mm in size.

The irregular kamacite areas are normally developed around schreibersite or around troilite/schreibersite inclusions and may best be interpreted as extremely wide zones of swathing kamacite. The combined kamacite plus inclusions attain sizes of 5-10 cm in diameter, often with the schreibersite forming millimeter-wide winding ribbons and rosettes in the center. Some textures closely resemble iron-phosphide eutectics, except that they are extremely coarse-grained. With a bulk composition of 6.4% Ni and 0.9% P it is just possible for some residual phosphorus-rich liquid to have remained at as low a temperature as 1000°C (Buchwald 1966; Doan & Goldstein 1970). Figure 1528 gives a good impression of such a residual liquid pocket and its subsequent decomposition to schreibersite and metal in the ratio about 1:2.

The schreibersite is extremely pure with no associated troilite, daubreelite, chromite or cohenite. It is now somewhat brecciated and surrounded by terrestrial oxides in 10-100 μ wide zones. Its microhardness is 890 ± 20 . Cohen (1900b) reported a Mohs hardness of 6 1/2, in good harmony with this determination. He also found the schreibersite of this meteorite to be very homogeneous with respect to Co, Ni and P: 0.43% Co, 14.5% Ni, 15.8% P. In addition it contained 0.03% Cu.

Schreibersite further occurs as 0.1-1 mm wide grain boundary veins, along which corrosion has been extremely active. Rhabdites locally attain large dimensions, as 4 x 4 x 0.01 mm platelets or as 0.1 mm thick prisms. Microscopic rhabdites, 0.5-2 μ across, are more common. They occur as a cloud through most of the matrix — except in 100-500 μ wide zones around the large schreibersite crystals. Neumann bands are well developed; they are 1-3 μ wide in the rhabdite-crowded matrix but increase in width to 10 μ in precipitate-free kamacite. The bulk phosphorus content is estimated to be 0.9%, of which 0.75% is bound in the large schreibersite inclusions that cover 4.5-5% by area.

Troilite is present as monocrystalline nodules ranging from 0.5-10 mm in diameter and normally enveloped in 0.2-1 mm wide schreibersite rims. No daubreelite is present, and no visible plastic deformation or shock melting have occurred. At one point in the surface (No. 3052) some ablation-melted troilite is still preserved as fine-grained dendritic veinlets that penetrate the underlying brecciated troilite. The troilite also displays some pentlandite veining, but it is otherwise little altered by the weathering.

São Julião is a coarsest octahedrite which is closely related to Sikhote-Alin, Ainsworth and several other irons of group IIB. It is among the most phosphorus-rich meteorites we know of, being surpassed by La Primitiva, Tombigbee, Soper and a few others.

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

- 162 g part slice (no. 267, 6.5 x 4.5 x 0.7 cm)
- 661 g part slice (no. 314, 14 x 7.5 x 0.9 cm)
- 302 g part slice (no. 1501, 7 x 5 x 1.8 cm)
- 116 g irregular fragment (no. 1501, 4 x 3 x 3 cm)
- 270 g part slice (no. 1674, 7.5 x 5.5 x 0.7 cm)
- 415 g part slice (no. 3049, 11 x 8 x 0.9 cm)
- 140 g endpiece (no. 3052, 5 x 4 x 1.3 cm)
- 65 g small part slices (nos. 2131, 3048, 3050)

Saotome. See Shirahagi

Sardis, Georgia, U.S.A.

$32^\circ 56' 56''\text{N}, 81^\circ 51' 54''\text{W}; 70\text{ m}$

Coarse octahedrite, Og. Bandwidth 2.5 ± 0.8 mm. Neumann bands. HV 205 ± 15 .

Group I. 6.63% Ni, 0.47% Co, 0.24% P, 94 ppm Ga, 400 ppm Ge, 1.3 ppm Ir.

HISTORY

A weathered mass of about 800 kg was found 10 km west-southwest of Sardis near Beaverdam Creek in the northern part of Jenkins County, only 200 m from the Burke County line. Although the cotton field had been under cultivation since 1890, the meteorite was not discovered until 1940 when a boy fouled his plow in such a manner as to cause him to investigate the obstruction. In 1941 the mass was recovered and sent to the U.S. National Museum where it was examined by Henderson & Cooke (1942). It was an entire mass when received, but it rapidly started to disintegrate; and at the present time the mass has completely fallen apart – forming gravel and fragments ranging from grams to a few kilograms. However, several large polished sections, 10-15 cm across, have been preserved by embedding them in transparent two-component plastic. Non-embedded fragments continue to corrode under normal, dry museum conditions (relative humidity: 25-55%, seasonal variations).

Buddhue (1944; 1957) analyzed the oxides and noted the relatively high proportion of FeO to Fe₂O₃ which was ascribed to a large, additional but imperfect, oxidation since the mass was excavated. Henderson & Furcron (1957) reviewed the case and reprinted the figures (from Henderson & Cooke 1942). While Buddhue believed the observed chlorine to be due to cosmic lawrencite, Henderson and Furcron pointed to the possibility that it had been introduced by cutting in the laboratory by chlorine-bearing tap water. The chlorine is, I believe, much more probably a

result of ground water contamination during exposure to the terrestrial environment for thousands of years.

Goles & Anders (1962) determined iodine, tellurium and uranium in a troilite nodule. It is possible that their results are biased as a result of terrestrial contamination. From ¹⁴C determinations, Kohman & Goel (1963) estimated the terrestrial age to be above 10,000 years. Goel & Kohman (1963) found a bulk chlorine content of 0.022% and a low activity of ³⁶Cl (half life 310,000 years), which again indicated a high terrestrial age. Marshall & Feitknecht (1964) reported on the isotopic composition of lead and included Sardis in their study. Begemann (1965) examined the composition of the noble gases of both a troilite nodule and of the metallic matrix.

In the original publication by Henderson & Cooke (1942) the coordinates suffered a grave printing error, which has been carried over in all later descriptions. The correct coordinate set is given above.

COLLECTIONS

Washington (several hundred kilograms of weathered fragments; 5 kg embedded slices), Copenhagen (1,000 g), Chicago (800 g), Calcutta (800 g), Perth (700 g), Moscow (400 g), Los Angeles (286 g), London (192 g).

DESCRIPTION

The original dimensions were 82 x 70 x 40 cm, and the mass was roughly lenticular in shape. It was surrounded by at least 10 kg of weathered fragments and it was itself



Figure 1551. Sardis (U.S.N.M. no. 1381). The main mass of 800 kg as recovered and before it started to disintegrate in the museum. Scale bar approximately 10 cm. S.I. neg. 34602.

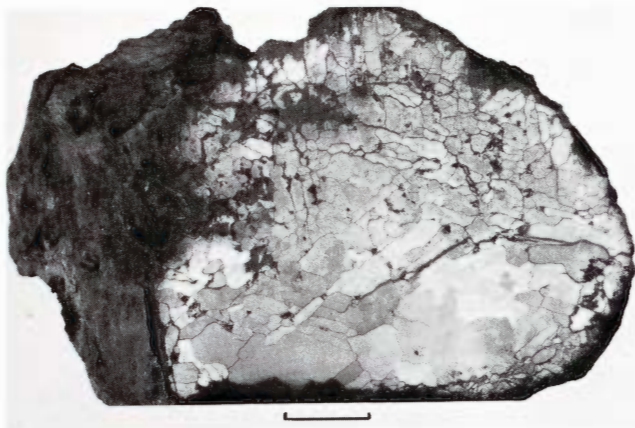


Figure 1552. Sardis (U.S.N.M. no. 1381). Corroded fragment showing the coarse Widmanstätten structure and secondary grain growth in the lower part. Deep-etched. Scale bar 20 mm. S.I. neg. 34602B.

SARDIS – SELECTED CHEMICAL ANALYSES

References	percentage			C	S	Cr	Cu	ppm					
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt	
Henderson & Cooke 1942	6.69	0.47	0.24										
Wasson 1970, per. comm.	6.58								93.7	400	1.3		

encrusted with soil particles which were cemented together by terrestrial corrosion products. No fusion crust could be identified (Henderson & Cooke 1942).

It appears that, at the time of its recovery, the entire mass was crisscrossed by corroded grain boundaries and that the disintegration in the museum took place along these boundaries upon exposure to the new environment. Individual fragments are enveloped by 0.5-5 mm thick, limonitic crusts which, of course, were mainly already formed while buried in the soil.

Etched sections display a coarse Widmanstätten structure of irregular, short ($\frac{l}{w} \sim 10$) kamacite lamellae with a width of 2.5 ± 0.8 mm. The narrowest lamellae are associated with cohenite-rich patches. Late grain growth has locally eliminated the former, straight lamellae boundaries and created almost equiaxial kamacite grains, 10-30 mm in diameter. Within these there are undissolved remnants of oriented taenite and plessite fields, indicating that the parent mass was a single austenite crystal, larger than 25 cm in diameter (size of the largest sections prepared). The kamacite is rich in subboundaries decorated with 1-2 μ phosphides. It has Neumann bands and a hardness of 205 ± 15 .

Taenite and plessite occupy 1-2% by area, mainly as comb plessite and as taenite ribbons with martensitic or pearlitic interiors. The martensite is frequently a beautifully developed, feathery-acicular, high-nickel, high-carbon product with a hardness of 370 ± 25 . The pearlitic fields have parallel 0.5 μ wide taenite lamellae with a somewhat lower hardness, except where the kamacite component is selectively oxidized.

Schreibersite is common as, e.g., 30 x 1 or 5 x 5 mm skeleton crystals. They are enveloped in 0.1-0.4 mm wide rims of cohenite followed by 2-4 mm of swathing kamacite. Schreibersite is further common as 20-100 μ wide grain boundary veins and as 5-20 μ rhabdites.

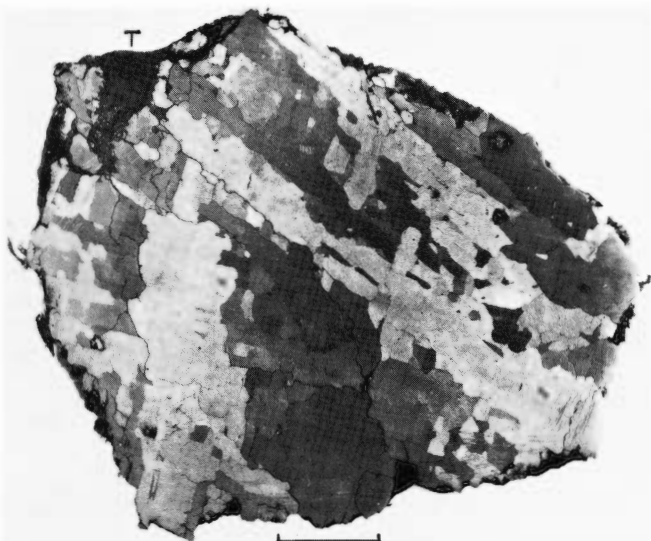


Figure 1553. Sardis (Copenhagen no. 1961, 556). A coarse octahedrite of group I. At T, a troilite-graphite inclusion, somewhat damaged by terrestrial weathering. Deep-etched. Scale bar 20 mm.

Cohenite dominates some sections but is absent in others. It normally occurs as 3 x 0.6 mm rounded or rosette-like grains aligned centrally in the kamacite lamellae and covering, e.g., 8 x 6 cm sections. In these areas rhabdite prisms are scarce. The cohenite contains the normal, tiny inclusions of kamacite, taenite and schreibersite; and in places it is under decomposition to kamacite and graphite lamellae. Its hardness is normal, 1075 ± 25 .

Troilite is common as lenticular nodules, ranging from 1 x 1 to 6 x 2 cm in size. They have served as nucleation sites for 0.5 mm thick rims of schreibersite followed by 0.1-0.4 mm of cohenite. The troilite contains 5-15% of parallel daubreelite lamellae and accessory amounts of graphite sheaves, normally located at the rim. Some of the troilite nodules display interesting mixtures of shock-melted, microcrystalline parts and passive blocks which show only subparallel, undulatory extinction from plastic deformation. The shock-melted parts have solidified to 1-5 μ grains, and the melt has invaded the surrounding minerals – particularly the daubreelite which may be completely disintegrated and dispersed as 1-5 μ rounded droplets. The adjacent, passive blocks still contain unmelted daubreelite lamellae, albeit significant shear displacements and distortions have taken place. The microhardness of the troilite is 265 ± 20 .

The corrosion is violent. Even subboundaries are attacked; the minute phosphide precipitates located here are clearly seen to survive for a while. The nickel-depleted kamacite zones adjacent to phosphides and taenite are particularly strongly oxidized, but the kamacite of the plessite areas is also corroded. The troilite is partly converted to pentlandite.

Sardis is an extremely weathered, coarse octahedrite which structurally resembles Cosby's Creek, Cranbourne and Jenny's Creek. Chemically, it is a normal member of group I.

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

About 5 kg part slices, embedded in plastic (no. 1381, each about 15 x 10 x 1 cm in size and ranging from 0.5-2 kg in weight)
Several hundred kilograms of weathered fragments and gravel.

Sarepta, Stalingrad Oblast, Russia

Approximately 48°20'N, 45°E; 50 m

Coarse octahedrite, Og. Bandwidth 2.2 ± 0.5 mm. Neumann bands. HV 185 ± 10 .

Group I. 6.82% Ni, 0.43% Co, 0.17% P, 100 ppm Ga, 457 ppm Ge, 3.4 ppm Ir.

HISTORY

A mass of 13.4 kg (32 Funt 58 Zolotnik; each Funt equals 408 g) was found in 1854 on the Kalmuck Steppe on the right bank of the Volga, about 30 miles southeast of Sarepta. The corresponding coordinates are given above.

The town itself has, as have other towns in the district, now changed its name. Sarepta is now Krasnoarmeysk (Times Atlas 1957: plate 45). The meteorite was briefly mentioned by Auerbach (1854) and then fully described with excellent figures of the exterior and of etched slices by Haidinger (1862) who found it to be very similar to Magura. Rose (1864a: 58) briefly described the major specimens in Berlin. Reichenbach (1862a: 155) noted the heat-affected rim zone. References to several other notes on the meteorite are collected in Wülfing (1897: 309). Zavaritsky & Kvasha (1952: 45) discussed the metallographical structure and gave a drawing; they stated that the main mass was in Berlin. However, this is incorrect, since Sarepta was already cut and thoroughly distributed a hundred years ago; several casts were prepared before the cutting (Haidinger 1862).

COLLECTIONS

Berlin (1.96 kg), Paris (973 g), Vienna (751 g), Moscow (739 g), Stuttgart (632 g), Würzburg (488 g), Harvard (446 g), Chicago (286 g), London (283 g), Washington (253 g), Tübingen (336 g), Amherst (203 g), Strasbourg (119 g), New York (95 g), Dresden (89 g), Stockholm (80 g), Budapest (77 g), Calcutta (60 g), Bonn (47 g), Dorpat (41 g), Leningrad (21 g), Göttingen (20 g).

DESCRIPTION

The mass had the average dimensions of 20 x 19 x 10 cm and exhibited a surprisingly large difference between the two opposite sides. As may be seen on the larger, preserved specimens and on models extant, one surface was smoothly ablated to a slightly convex, spherical surface while the opposite side showed an intricate system of grooves, ears and pits of which the largest was 6 cm in diameter and 4 cm deep. Paper-thin fusion crusts cover most of the surface, particularly in the depressions; and sections perpendicular to the surfaces clearly show that a 1-3 mm thick, heat-affected α_2 zone is preserved everywhere. So the morphology must be due to ablation rather than to terrestrial corrosion. Some of the centimeter-sized pits are due to ablational burning out of troilite nodules and some of the grooves, to a similar removal of cohenite and schreibersite. Sarepta evidently was a fine example of stabilized flight in which the domed part was the front side.

Sarepta is cut almost entirely into slices and provides an excellent example of the variation range within a small group I iron, only 20 cm in size. The specimens in Vienna, Moscow, Berlin, Harvard and Amherst are rich in cohenite and show a coarse Widmanstätten structure of straight, long

($\frac{l}{w} \sim 10$) kamacite lamellae with a width of 2.2 ± 0.5 mm. Other specimens, e.g., in Berlin and Washington, show only few cohenite crystals and no marked Widmanstätten structure. The kamacite forms bulky, almost equiaxial grains, 5-15 mm in diameter, and the specimens strongly resemble Seeläsgen. Such variation is not unrecorded from the group I meteorites; Magura, Odessa, Canyon Diablo and Toluca are all good examples, and it seems to be the rule rather than the exception that these large differences in carbon content — and therefore structure also — occur within a few centimeters distance.

The kamacite is rich in subboundaries, and undecorated Neumann bands are common. The hardness is 185 ± 10 . Taenite and plessite cover less than 1% in the cohenite-free parts, but perhaps 2% in the cohenite-rich parts. The taenite ribbons often tarnish upon etching and exhibit hardnesses of 400 ± 20 . In the heat-affected rim zone the hardness falls below 200, and the taenite becomes enveloped in 10-20 μ wide martensitic-bainitic zones due to carbon diffusing out from the taenite. Acicular plessite with 1-5 μ wide kamacite platelets is common in the cohenite-free specimens.

Schreibersite occurs as skeleton crystals up to 20 x 10 x 2 mm in size, but 20-80 μ wide grain boundary precipitates are more common. Occasionally, with a little taenite, they form the remnants of a typical plessite field, proving that they are very late precipitates. Rhabdites occur as 5-20 μ thick tetragonal prisms in the cohenite-free parts but are smaller and less conspicuous in the cohenite-rich parts.

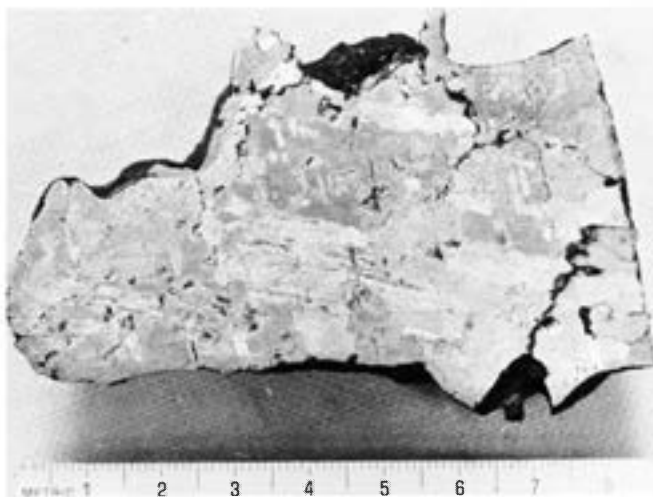


Figure 1554. Sarepta (Harvard no. 216). A coarse octahedrite of group I. Well-preserved fusion crust and regmaglypts. Occasional cohenite crystals (black). Deep-etched. Ruler in centimeters.

SAREPTA – SELECTED CHEMICAL ANALYSES

References	percentage			C	S	Cr	Cu	ppm				
	Ni	Co	P					Zn	Ga	Ge	Ir	Pt
Dyakonova & Charitonova 1963	7.08	0.43	0.17				200					
Wasson 1970a	6.55								99.9	457	3.4	

Troilite was reported as 10-15 mm nodules by Rose (1864a: 59, 138) and must have been present in several places on the surface as indicated by the surface morphology.

The cohenite was observed by Reichenbach (1861: 487), who called it "lamprit;" but both he and later observers (Rose 1864a: 54; Zavaritsky & Kvasha 1952: 46) supposed it was schreibersite. The cohenite typically forms 6 x 3 x 0.6 mm elongated, branched, rounded bodies with reentrant portions and with minute inclusions of kamacite, taenite and schreibersite. It is somewhat brecciated and has a hardness of 1140±25. Cohenite also forms 0.1-0.2 mm thick rims around the schreibersite skeleton crystals; it does not appear to be under decomposition to graphite.

The heated α_2 zone is 2.0-2.5 mm thick below the domed front face, and micromelted phosphides are present to half that depth. The hardness is 182±20 in the α_2 zone but decreases to 150±5 at the transition to the unaffected interior (hardness curve type II). Laminated, metallic fusion crusts are common while the covering oxidic fusion crusts have apparently weathered away. The metallic fusion crusts are composed of dendritic layers – each 20-50 μ thick – that build up to a thickness of 200, or even 400 μ . They have a dendritic armspacing of 1-5 μ and a cell size of 5-20 μ ; and the hardness is 350±20. While the inner layer is intimately intergrown with the underlying matrix – and probably for a major part was formed in situ – the following layers represent successive deposits which were ablated in the vicinity and swept to their present place. This is seen by the intricate discordant succession of the layers and by their varying content of interdendritic sulfide and phosphide.

Sarepta shows several fissures along mineral-filled grain boundaries. At least some of these must have been preatmospheric, since in places the α_2 zone stops abruptly at a fissure running subparallel to the surface. If the grain boundary had not been open in such a place, the heat penetration would have been smooth. We thus have indirect evidence here – as in other irons – that several of the internal fissures go far back in time, probably to the date when the mass was dislodged from its parent body. The fissures are weathered, but otherwise the meteorite is little altered.

Sarepta is a coarse octahedrite which is closely related to Seeläsgen, Burgavli, Cosby's Creek and Magura. It is a very well-preserved, oriented fall.

SAVANNAH – SELECTED CHEMICAL ANALYSES

Whitfield (in Merrill 1923c) presented an analysis performed on severely oxidized material. It indicates, however, about 8.0% Ni and 0.14% P. He also found

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

123 g irregularly broken fragment (no. 455, 4 x 4 x 2 cm)
19 g polished section (no. 3053, 4 x 3 x 0.2 cm)
101 g part slice (no. 3054, 4 x 3.5 x 1 cm)
10 g shavings and fragments (nos. 1134, 3370)

Savannah, Tennessee, U.S.A.

35° 15' N, 88° 11' W; 120 m

Medium octahedrite, Om. Bandwidth 1.20±0.15 mm. e-structure. HV 355±25.

Group IIIA. 7.99% Ni, about 0.14% P, 21.1 ppm Ga, 44.2 ppm Ge, 0.6 ppm Ir.

HISTORY

A weathered mass of about 60 kg was found by C.D. Wright and M.W. Spencer while they were working on the highway between Savannah and Cerro Gordo, in Hardin County. The place was about four miles northeast of Savannah in the Tennessee River Valley, and the corresponding coordinates are given above. The iron was sent to the U.S. National Museum where it was described by Merrill (1923c) who also presented two photographs of a large, polished and etched slice.

COLLECTIONS

Washington (26.8 kg half mass and 524 g fragments), Geological Survey of Tennessee, Nashville (about 30 kg half mass).

DESCRIPTION

Merrill (1923c) stated that the maximum dimensions of the dumbbell-shaped mass were 143.5 x 25.5 x 16.5 cm and that it weighed some 60 kg. The given dimensions must be due to a printing error as, from the preserved half mass in Washington and from the known weight, it can be inferred that the maximum dimensions were 43.5 x 25.5 x 16.5 cm. The mass is weathered and the iron is exfoliating in several places along the corroded Widmanstätten boundaries. Surprisingly enough, the loss of metal is hardly more than 1 mm on the average. This may be stated with confidence because the heat-affected α_2 zone is preserved in many places; the original regmaglypts, 2-3 cm in diameter, are also present locally. The peculiar dumbbell shape is thus not a result of weathering, as believed by Merrill, but a

0.11% Cl. The chlorine has, no doubt, been introduced by percolating ground water during a long terrestrial exposure.

Reference	percentage			C	S	Cr	Cu	ppm				Pt
	Ni	Co	P					Zn	Ga	Ge	Ir	
Scott et al. 1973	7.99								21.1	44.2	0.6	

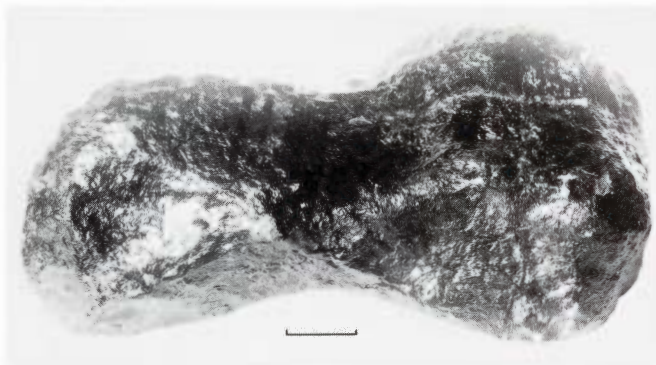


Figure 1555. Savannah (U.S.N.M. no. 706). The dumbbell-shaped mass before it was cut lengthwise. Although corroded, it may be estimated that on the average less than 1 mm has been lost. Scale bar approximately 5 cm. S.I. neg. 25000.

result of ablation in the air of a mass which probably already roughly had the dumbbell shape.

Etched sections reveal a medium Widmanstätten structure of straight, long ($\frac{l}{w} \sim 25$) kamacite lamellae with a width of 1.20 ± 0.15 mm. Savannah belongs to the very few medium octahedrites that are known to be composed of more than one parent taenite crystal. Each of the two dumbbell ends of Savannah constitute a parent taenite crystal about 25 cm in diameter, and they meet along a curved boundary at the constriction midway between the two ends. Upon the original cooling, the boundary was the first to transform to kamacite, partly because troilite was present there as 0.5 mm wide, nucleating bodies. Therefore, the grain boundary is now a 1-1.5 mm wide kamacite ribbon with inclusions of troilite. Each of the two taenite crystals transformed independently to a medium Widmanstätten structure which is not in twin position. The grain boundary is probably a low angle boundary. It is interesting to note that in each grain the Widmanstätten growth occurred in one direction – only in the 3-4 cm wide zone adjacent to the grain boundary – and that the lamella width there is only about half of what it is otherwise. Farther away the normal Widmanstätten pattern sets in. Similar growth “laws” are described on page 590 under Gibeon where the fine structure somewhat hinders the observations, however.

The position of the grain boundary at the dumbbell’s constriction is natural if we accept the dumbbell shape as dating back to the parent environment when the grain growth took place. In that case any original, polycrystalline aggregate – by homogenizing and grain growth in the austenite phase (at 1200° - 1000° C?) – would end up as two crystals with the grain boundary located at the neck between the larger ends. This implies that Savannah in its present shape more or less precisely retains the shape it had on its parent body: a small, metallic raisin in an unknown (unpreserved), nonmetallic matrix.

The kamacite has subboundaries decorated with 0.5μ phosphides. It displays a shock-hardened, hatched ϵ -structure with occasional Neumann bands which have a hardness

of 355 ± 25 , one of the hardest ever recorded. Taenite and plessite cover about 35% by area, particularly as comb and net plessite. A full plessite field may have a tarnished taenite rim (HV 375 ± 25), followed by a yellow martensite (HV 480 ± 30). Then follows darker martensite varieties and duplex, poorly resolvable $\alpha + \gamma$ mixtures (HV 410 ± 30). The net and comb plessite have hardnesses identical to the kamacite lamellae. It will be noted that the taenite and plessite hardnesses are also extremely high, except in the reheated rim zone where they drop to about 225 ± 25 . The α_2 of the kamacite lamellae is 210 ± 15 (hardness curve type I).

Schreibersite occurs as 20 - 60μ wide grain boundary veins and as 5 - 40μ blebs inside the plessite. Rhabdites are not present. Troilite occurs as 0.5 - 2 mm nodules and rhombs; a total of 12 were observed on a 480 cm^2 section. They frequently have euhedric chromite inclusions, 0.1 - 0.5 mm in diameter. The troilite is unmelted, although the metallic matrix exhibits a high degree of shock hardening. The troilite does have martensitic-lenticular twins, indicating mild plastic deformation only.

Savannah appears to be a normal medium octahedrite related to, e.g., Billings, Dexter, Iron Creek and Morito. Chemically, it is a normal member of group IIIA. Its peculiar interest lies in its normality while simultaneously consisting of two parent austenite crystals. Since it is proved here that its exterior shape is not due to weathering, and since the only grain boundary present is located at the constriction on the dumbbell-shaped mass, it is concluded that Savannah’s present shape reflects to a significant degree its original shape in its parent surroundings. If this interpretation – of Savannah as a small iron-raisin in a silicate matrix – is correct, it further suggests that at least some meteorites may survive the very long, cosmic sojourn and the brief, atmospheric passage with a minimum loss of mass, quite in contrast to the predicted heavy losses from space erosion and atmospheric ablation.

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

- 26.8 kg half mass, cut lengthwise through the dumbbell (no. 706, $44 \times 13 \times 9$ cm)
- 413 g weathered fragments (no. 706)
- 111 g part slice (no. 706, $9 \times 4 \times 0.6$ cm)

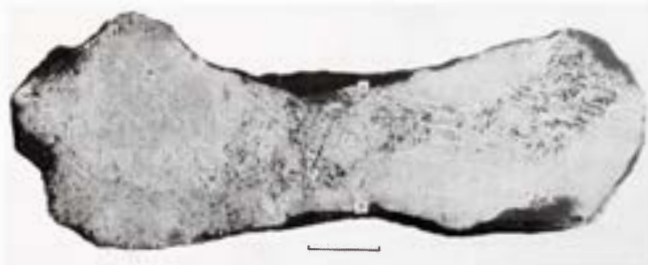


Figure 1556. Savannah (U.S.N.M. no. 706). Section through Figure 1555. Medium octahedrite of group IIIA. Note the band of swathing kamacite, A-A, that separates two precursor taenite crystals. Deep-etched. Scale bar 50 mm. S.I. neg. 24940a.