

CHAPTER FIVE

Statistical and Historical Notes

If a meteorite is seen and heard to fall and for this reason is detected and collected, it is called a *fall*. A *find* on the contrary is a meteorite which is picked up and identified because of its appearance and composition. Table 19 displays the appropriate characteristics; further details will be found in Table 23.

Table 19. Number of Meteorites, as of January 1, 1972.

	Falls	%	Finds	%	Total	%
Chondrites	574	85.1	456	44.9	1,030	60.9
Achondrites	60	8.9	10	1.0	70	4.1
Stony-Irons	9	1.3	50	4.9	59	3.5
Irons	32	4.7	500	49.2	532	31.5
	<u>675</u>	<u>100.0</u>	<u>1,016</u>	<u>100.0</u>	<u>1,691</u>	<u>100.0</u>

These data do not claim a high degree of accuracy, collected as they are from sources of widely varying authenticity and age. I do, however, believe that they represent an improvement over presently available statistics, particularly when considering stony iron and iron meteorites. Important alterations relative to Hey (1966) are summarized in Appendices 3 and 4, from which it may be seen at a glance that numerous dubious falls, synonyms, pseudometeorites and unsubstantiated reports have been eliminated. The total number of iron meteorites has been reduced from 594 (Hey 1966:xv) to 532, while the total number of iron meteorite falls has been reduced from 43 to 32. The following *falls* have been discredited:

Elbogen, Gundaring, Helt Township, Majorca, Mariaville, Para de Minas, Patos de Minas, Puerto de Arauco, Tandil, Victoria West, Winburg and Calderilla. The reasons are given under the individual descriptions, and it is shown that Tandil is certainly, and Majorca possibly, a pseudometeorite! Eighteen other falls listed as doubtful by Hey, e.g., Deep Springs, Rafrüti and Signal Mountain, have been shown to be finds. On the other hand, it appears that Anaheim, previously labeled a find, is qualified to be included among the falls.

Considerable changes in the Hey data are particularly apparent in the number of *finds*. Seventy-eight iron meteorites (Appendix 3) have been shown to have no right to separate classification. Another nine doubtful irons have been definitely proved to be pseudometeorites (Appendix 4). The reasons for these conclusions are given in the

appropriate places in the book. This "loss of meteorites" is partly counterbalanced by a number of new meteorites, not listed in Hey. These are of two kinds: (i) specimens known for some time, not previously recognized as individual iron meteorites but believed to be samples of well-known meteorites:

New iron meteorites	Weight kg	Previously considered part of
Augusta County	76	Staunton
Babb's Mill,		Babb's Mill,
Blake's Iron	135	Troost's Iron
Bushman Land	3.0	Gibeon
Gay Gulch	0.5	Klondike
Karasburg	11.6	Gibeon
Paneth's Iron	>100 ?	Toluca
Sandtown	9.4	Joe Wright Mountain
Skookum Gulch	15.9	Klondike
Smithsonian Iron	3.6	Coahuila

(ii) specimens recognized after the printing of Hey's catalog (1966), e.g., Juromenha and Zerhamra.

The irons in Appendix 2 are insufficiently known for a variety of reasons. They were (i) recently found, e.g., Aprelskij and Seymchan; (ii) poorly described although found long ago, e.g., Armanty and Barbacena; (iii) never subjected to a close study, either because they were zealously guarded, part of a private collection, or considered too small for a useful study, e.g., Cabin Creek, Hraschina, Cleburne and Albuquerque; (iv) lost before they could be described, e.g., Jalandhar and Lebedinnyi; or (v) thoroughly oxidized, thus preventing classification, e.g., Coldwater, Dorriigo and Lucky Hill.

Evidently iron meteorites of categories (i)-(iii) will eventually find their proper place in the statistics. From my cursory knowledge of the material listed in Appendix 2, I would estimate that about 40% belong in these categories and will eventually attain status of individual well-documented meteorites.

Little can be accomplished with the remaining material, of categories (iv) and (v). Some corroded specimens may be studied and classified, although only little metallic material is left. This was the case with, e.g., Ider, Wolf Creek and Kaalijärv, which were previously considered too corroded for any conclusive work. For the purpose of statistics, the number of iron meteorites in Table 19 is

taken as the 480 well-documented irons in Appendix 1 plus 40% of the 129 insufficiently known irons, listed in Appendix 2.

As is apparent from Tables 10, 19 and 23, the number of meteorites reaching the Earth per year is small. For irons, comprising only 31 falls between 1835 and 1973, the number is in fact so small that meaningful statistical analyses are largely ruled out. The 31 registered falls correspond to one every 4.5 year, or said in a different way: Out of 17 new falls, only one is an iron. Finds of iron meteorites are, however, common because once discovered the samples are not often discarded due to their interesting appearance and density which often makes the finder believe that he has discovered an iron ore or a silver nugget. For examples, the reader is referred to the individual descriptions, such as Augusta County, Billings, Hayden Creek, Jackson County, Seeläsgen and Smithland. While irons are the easiest to recognize among meteorites, achondrites stand at the opposite end of the spectrum: The data in Table 23 indicate that achondrites are similar enough to terrestrial rocks to pass largely undetected, unless found immediately after an observed fall.

Some Statistics on the Frequency of Falls

Although falls have been reported – and partially preserved – since medieval time, e.g., Elbogen and Ensisheim, we will for our purpose limit ourselves to the rather well-documented recent periods. Sorting, for example, the material from 1871 to 1970, and excluding false, unsubstantiated reports, we end with the following number of falls per decade:

1871-80	54	1921-30	71
1881-90	40	1931-40	73
1891-1900	47	1941-50	58
1901-10	54	1951-60	49
1911-20	55	1961-70	48

This makes a total of 549 falls, or 5.5 falls per year, on the average, over the inhabited parts of the Earth. The surface of the Earth is $510 \times 10^6 \text{ km}^2$; of this roughly 30% or $149 \times 10^6 \text{ km}^2$ is land, and of this again roughly $70 \times 10^6 \text{ km}^2$ has a population density above one inhabitant per km^2 . This appears to be the minimum requirement for the reporting of meteorites. By recalculation, we find that the total of 549 falls in a 100-year period corresponds to a frequency of 0.08 falls per year per 10^6 km^2 inhabited surface.

This is, however, a minimum estimate since we know of provinces with far better yields of meteorites. From the World Maps (Buchwald 1968a) it may be readily seen, e.g., that Western Europe, North India and Japan have contributed relatively many more meteorite falls than, e.g., North Europe, South India and Australia. Common factors in countries with a high rate of reported meteorite falls are a high population density and a good education and information level. China makes a surprisingly low figure in the statistics; in spite of a large area and population, only a total of ten meteorites have been reported and examined. Some other factors, such as superstition or entire lack of interest, seems to play a role in connection with meteorite recovery. But China has, of course, remained an enigma to the West in other respects also.

We will choose three widely separated regions for a closer study.

1. A selected, densely populated area of 10^6 km^2 in North India, comprising essentially the Indus and Ganges plains, has in the period 1861-1940 yielded 41 falls: Butsura 1861, Manbhoom 1863, Gopalpur 1865, Supuhee 1865, Pokhra 1866, Khetri 1867, Moti-ka-nagla 1868, Dyalpur 1872, Nagaria 1875, Bhagur 1877, Dandapur

Table 20. The Largest Iron Meteorites

Class	Group	% Ni	Found	Total ton	Total No.	Long axis of dispersion ellipse, km	Largest masses, ton			Smallest masses, kg		
							1	2	3	4	5	
Hoba	D	IVB	16.4	1920	60	1	–	60	–	–	–	–
Cape York	Om	IIIA	7.9	1894	58	>8	>12	30.9	20.1	3.4	1.66	0.29
Campo del Cielo	Og	I	6.7	1803	>30	>20	75	18	4.2	2.0	0.5	0.4
Armanty	O	?	9.1	(1900)	30	1	–	30	–	–	–	–
Chupaderos	Om	IIIB	9.9	(1872)	24.3	>5	40	14.1	6.8	3.3	35	0.1
Sikhote-Alin	Ogg	IIB	5.9	F:1947	>23	>400	2	1.75	1.00	0.70	0.01	0.001
Mundrabilla	Om	Anom	7.5	1911	22	>8	25?	16	6	0.0001	0.10	0.07
Bacubirito	Off	Anom	9.7	1863	22	1	–	22	–	–	–	–
Gibeon	Off	IVA	7.9	1838	21	81	275	0.65	0.60	0.53	11.5	0.20
Mbosi	Om	Anom	8.7	1930	16	1	–	16	–	–	–	–
Willamette	Om	IIIA	7.6	1902	14.1	1	–	14.1	–	–	–	–
Morito	Om	IIIA	7.6	1619	10.1	1	–	16.1	–	–	–	–
Cranbourne	Og	I	7.0	1853	8.5	11	23	3.5	1.5	1.25	24	6.8
Santa Catharina	Anom	Anom	35.3	1875	7.0	>10	0.2	2.56	1.5	0.45	2	1
Bendego	Og	Anom	6.5	1784	5.4	1	–	5.4	–	–	–	–

1878, Haraiya 1878, Andhara 1880, Pirgunje 1882, Chandpur 1885, Bherai 1893, Ambapur Nagla 1895, Bishunpur 1895, Delhi 1897, Gambat 1897, Sindhri 1901, Bholgati 1905, Karkh 1905, Vishnupur 1906, Chainpur 1907, Khohar 1910, Mirzapur 1910, Visuni 1915, Ekh Khera 1916, Rampurhat 1916, Sultanpur 1916, *Garhi Yasin 1917*, Ranchapur 1917, Atarra 1920, Merua 1920, Haripura 1921, Shikarpur 1921, Jajh deh Kot Lalu 1926, Khanpur 1932, *Bahjoi 1934*, and Ramnagar 1940. This corresponds to 0.51 falls per year per 10^6 km². Of the recorded falls, only two were iron meteorites, *Garhi Yasin* and *Bahjoi*. We could extend the statistics over a longer period of time, both before 1860 and after 1940. It appears, however, that the reporting of meteorites was particularly good under the British government; and since we are presently searching for the highest reported frequencies, in India, we will limit ourselves to the period 1861-1940.

2. Japan has between 1827 and 1964 yielded the following 18 meteorites: Yonozu 1837, Kesen 1850, Sone 1866, Otomi 1867, Takenouchi 1880, Fukutomi 1882, Kyushu 1886, Higashi-Koen 1897, Nio 1897, *Okano 1904*, Kijima 1906, Gifu 1909, Tomita 1916, Tane 1918, Kushike 1920, Numakai 1925, Kasamatsu 1938, and Okabe 1958. Of these, one was an iron meteorite; *Okano*. Averaged over Japan's 368,000 km² we find 0.36 falls per year per 10^6 km².

3. Finally, we will examine a small area of

75,000 km², covering the densely populated Po Valley and part of the adjoining Alpine and Apennine Mountains. There were 12 falls between 1750 and 1970: Albareto 1766, Borgo San Donino 1808, Renazzo 1824, Cereseto 1840, Trezano 1856, Alessandria 1860, Motta di Conti 1868, Alfianello 1883, Valdinizza 1903, *Avče 1908*, Vigarano 1910, and Piancaldoli 1968. Of these, one was an iron meteorite, *Avče*. On the average we then have for Northern Italy 0.72 falls per year per 10^6 km². But are we at all allowed to make statistical deductions from such heterogeneous series of data? Note that no falls were recorded between 1910 and 1968.

From the available material it is thus probably hazardous to try to wrest more information. We have, however, learned the same lesson as from the bulk data: that iron meteorites are rare as falls, having provided two out of 41 in India, one out of 18 in Japan, and one out of 12 in North Italy; i.e., on the average, one iron out of 18 falls, while from the bulk data we arrived at one out of 17 falls. We have also deduced a fall frequency for meteorites in general, ranging from 0.36 to 0.72 per year per 10^6 km², corresponding for the Earth as a whole to 182-365 falls per year. If we assume that the Italian data are the best available, we evidently have to expect one fall every day some place on the surface of the Earth. In these statistics we have solely relied upon meteorite falls that left tangible material; i.e., more than 10 grams were collected after each fall. We have also assumed that at least some people were watching day and night so that nothing escaped our notice. If we suppose that the watch was insufficient eight hours a

Table 21. The Smallest Iron Meteorites

	Class	Group	%Ni	Found	Mass grams	Dimensions cm	Shape	Corroded 0-3 (3 = severe corr.)
Wedderburn	D	IIID	23.1	1951	210	5 x 3.6 x 2.6	Ovoid, smooth	1
Freda	D	IIID	23.1	1919	268	4.5 x 4.0 x 3.0	Nose shape, smooth	1
Dehesa	D	?	?	1868	280	5 x 5 x 3	Irregular pyramid	1
Föllinge	Off	IIID	18.1	1932	400	7.4 x 4.5 x 3.0	Ovoid, smooth	1
Linville	D	Anom	16	1882	442	6.5 x 3.8 x 3.5	Cone	Artific. reheat.
Gay Gulch	Opl	Anom	15.1	1901	483	6 x 5 x 4	Ovoid, smooth	1
Kofa	Opl	Anom	18.3	(1917)	490	8 x 7 x 2	Lenticular, smooth	1
Britstown	Opl	IIA	18?	(1910)	544	9 x 6 x 5	Angular, knobby	1
Wathena	H	IIA	5.5	1939	566	8 x 4 x 4	Ovoid, smooth	3
York	Om	IIIA	7.7	1878	835	8.5 x 7.5 x 4	Angular, regmaglypts	2
Maldyak	Om	IIIAB	8.9	1939	992	8 x 6 x 5	Angular	3
Mount Ouray	Om	IID	10.1	1898	1,000	7 x 7 x 6	Spherical, smooth	2
Neptune Mts.	Og	I	7.1	1964	1,070	10 x 6.5 x 5	Angular, regmaglypts	1
Anoka	Of	IIIC	11.8	1961	1,108	12 x 9.5 x 7 (max)	Angular, regmaglypts	1
Avče	H	IIA	5.5	F:1908	1,230	11 x 6 x 5	Crescent, regmaglypts	0
Joel's Iron	Om	IIIAB	8.6	1858	1,323	11 x 7 x 5	Ovoid, regmaglypts	1



Figure 22. A medieval (?) adze blade (535 grams) exhibiting damascene pattern on the polished and etched surface. Microprobe examination indicates that the adze was produced by forging alternating layers of mild steel and meteoritic, probably hexahedritic, material. The adze was excavated in Central Sweden and is in private possession. Scale bar approximately 3 cm.



Figure 23. Examples of worked iron meteorites of known origin. A forged plate of Lenarto, a coldhammered wedge of Bacubirito, a forged finger ring of Gibeon, and a triangular slab of Toluca with the initials AB, probably those of Aristides Brezina. The specimens are now in the Vienna Museum. Scale bar in centimeters.

blacksmiths. Elbogen was apparently exposed to the fire of a medieval blast furnace, but miraculously survived, while Bitburg, Magura and Netschaevo were almost entirely lost.

In Appendix 5, 94 iron meteorites which have been exposed to artificial reheating and working are listed. It is important to note that such reheating may have taken place (Buchwald 1965a; 1968d). Particularly when estimating the effect of cratering impact and of collisional shocks in general, it is necessary to bear in mind that man's curiosity has often led him to reheat the meteorites, without leaving any record of this experiment for future generations. Since the structures which are produced by artificial reheating are deceptively similar to some genuine structures from shock reheating, one has to be extremely careful. Sometimes the artificial reheating effectively destroyed the original cosmic structures, causing great confusion. The classifying term "nickel-poor ataxite" which has been used for generations (Cohen 1903d: 1; Hey 1966: xix)

is, thus, superfluous since the class is very heterogeneous and mainly based upon the erroneous interpretation of damaged hexahedrites (e.g., Chesterville, Cincinnati, Locust Grove and San Francisco del Mezquital) and coarse octahedrites (e.g., Campo del Cielo).

The 94 reheated meteorites constitute no less than 18% of all iron meteorites. This is a surprisingly large percentage and indicates the eagerness and curiosity with which our forefathers utilized the costly material. However, it is not generally accepted that the percentage is so high. Perry (1944: 71), an authority on iron meteorites, thus stated after a thorough examination of many meteorites: "We may fairly conclude that artificial metabolites, though perhaps sometimes produced, are rare."

Often, only a fragment of the whole mass has been reheated. In other cases, one or two masses of a shower have been maltreated, while the remainder has escaped. It is

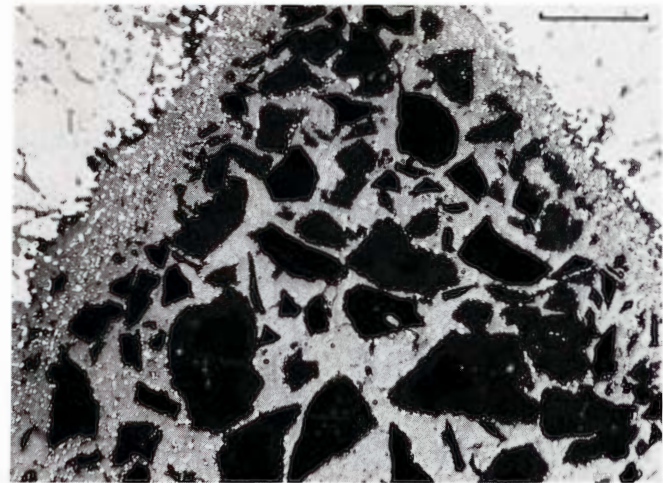


Figure 24. Artificially reheated structure of a near-surface section of the Tucson (Carleton) meteorite, U.S.N.M. no. 757. Decomposed limonitic products (gray), with metal particles (white), and brecciated silicates (black). Polished, unetched. Scale bar 50 μ .

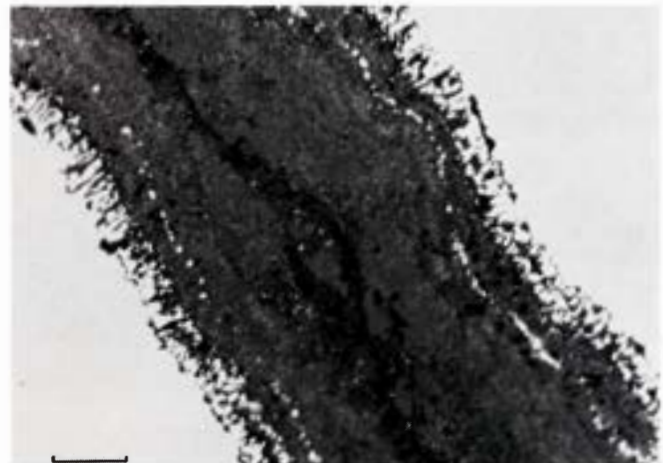


Figure 25. Artificially reheated structure of Ssyromolotovo (Chicago no. 1148). The limonite in a corroded crack has partially decomposed into a lacework pattern, and tiny metallic particles have precipitated within the limonite. Polished, unetched. Scale bar 10 μ .

unusual for museum labels to state that a particular sample has been artificially reheated, so one normally has to detect the damage oneself. In my experience, the damage is best revealed on a near-surface section with corrosion products. The sample is initially examined in the polished state, and the interfaces between the corrosion products and the meteoritic minerals are closely studied. Even brief reheatings above 550-600° C will alter the limonitic products; usually tiny ½-1 μ metallic particles will precipitate in them, and the kamacite-limonite interfaces will acquire a lace-like structure. At 800° C and above, oxidation will create an intercrystalline attack along the austenite grain boundaries. At 900° C and above, the sulfides will react with oxygen and form low-melting quaternary eutectics, such as Fe-Ni-S-O. At 1000° C and above, the phosphides will melt.

On the etched sections, additional information is to be gained. The kamacite matrix will, if heated above 750° C, transform to fine-grained austenite, which upon cooling

will transform to the serrated, unequilibrated α_2 . This structure is, in principle, similar to the heat-affected rim zone from atmospheric flight and may be confused with it. However, proper evaluation of the other components of the structure, the thermal gradient and the depth below the surface will usually allow one to distinguish between the two kinds.

Parallel ghost-lines indicate unidirectional forging and insufficient homogenization, seen in, e.g., samples of

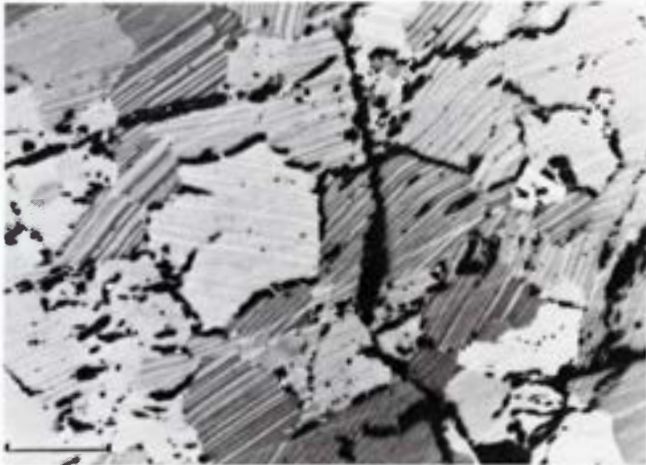


Figure 26. Artificially reheated structure of Yanhuitlan (Tempe no. 129a). Recrystallization and daubreelite exsolution in troilite nodule at 700-800° C. Polished; crossed polars. Scale bar 80 μ.

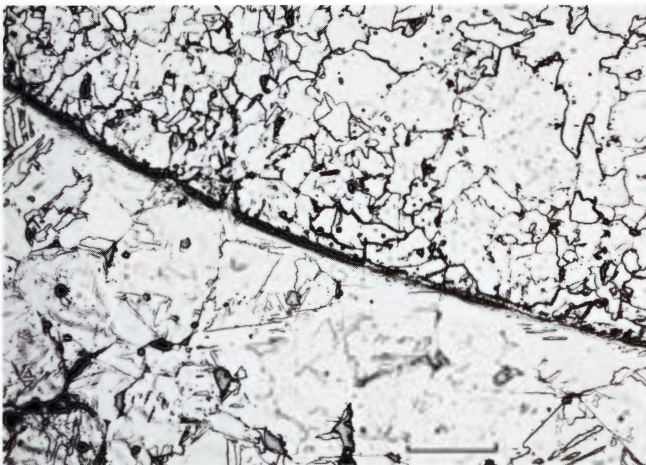


Figure 27A. Artificially reheated structure of Burlington (U.S.N.M. no. 978). Above original kamacite lamella, below original taenite lamella. Both are transformed to unequilibrated α_2 structures due to reheating around 1000° C. Polished, etched. Scale bar 100 μ.

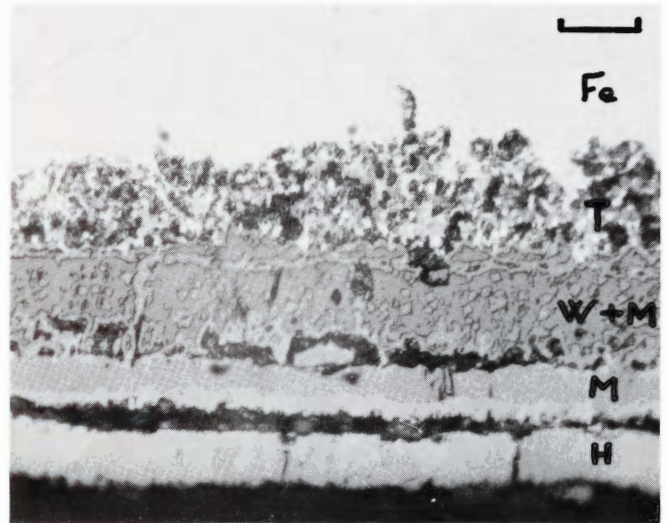


Figure 27B. Artificially reheated sample of Odessa. This particular slice was heated in air to 850° C for 60 minutes, then air cooled. Below an exterior layer of hexagonal hematite, Fe_2O_3 (H), follows cubic magnetite, Fe_3O_4 (M). The next layer, which at 850° was wüstite, FeO, decomposed partially on cooling to magnetite (W+M). The magnetite precipitated as skeleton crystals in grain interiors and as rims along interfaces and grain boundaries. Between the wüstite layer and the unoxidized meteorite there is a transitional layer (T) with fine metallic particles. Except for layers H and T, the zones resemble those of fresh, uncorroded falls. Etched. Crossed polars. Scale bar 20 μ.

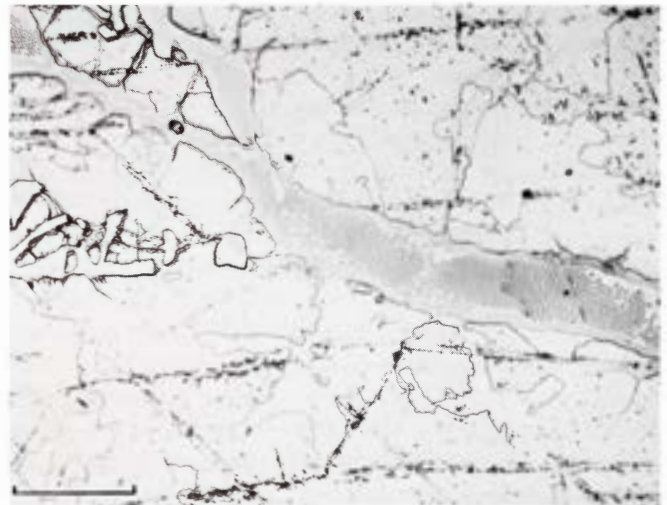


Figure 28. Artificially reheated structure of Toubil River (Moscow no. 2485). Reheating to about 1000° C has melted the schreibersite and caused fine-grained eutectics (spotted vein across the section). The kamacite has been transformed to α_2 , but the reheating was insufficient to dissolve the precipitates along the Neumann bands. Etched. Scale bar 80 μ.

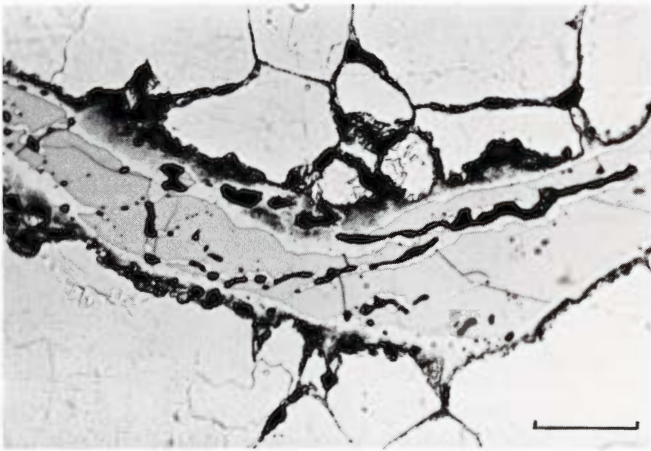


Figure 29. Artificially reheated structure of Rodeo. (Tempe no. 101ax). A central schreibersite vein with 2-10 μ wide, diffuse reaction zones against kamacite, and with spheroidized limonitic inclusions. The kamacite has been transformed to α_2 . Estimated peak temperature 800-900° C. Etched. Scale bar 30 μ .

Campo del Cielo, Prambanan, Babb's Mill (Troost's Iron) and Cacaria. Recovery —i.e., unexpectedly low hardnesses — and incipient recrystallization indicate the mildest damage, from heating to 400-750° C, and these effects, taken alone, are difficult to ascribe definitely to artificial reheating. Again, however, if other features are considered, particularly the corrosion products and the exterior shape and damage, it is usually possible to arrive at a conclusion as to the cause of the anomalous structures and mechanical properties.

Finally, cold-worked meteorites are very common; the damage is normally superficial and adjacent to flat hammered, chiseled and torn surfaces. In several cases it is, however, difficult to distinguish between artificial damage and the deformation that occurred in the atmosphere when — or if — the meteorite fragmented and produced a shower.

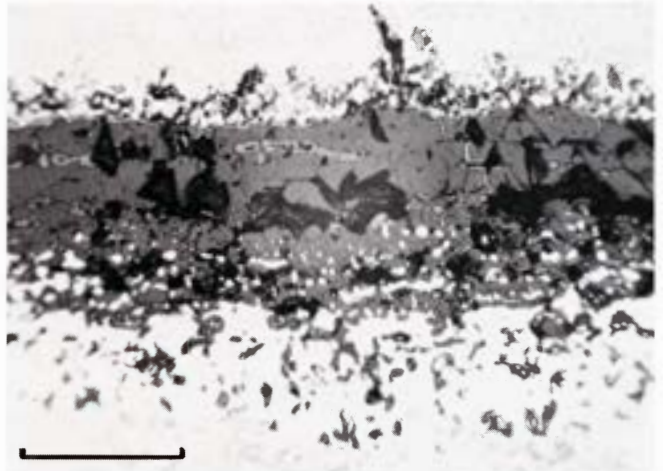


Figure 30. In a laboratory experiment, a small corroded Odessa sample was reheated in the air to 850° C for 60 minutes. The limonite partially decomposed, segregating fine metal globules (white), and the interfaces with kamacite (above) and taenite (below) were altered to lacework structures. The effect was already visible but not very pronounced after 10 minutes at 650° C. Polished. Oil immersion. Scale bar 20 μ .

It is often maintained that distorted Widmanstätten lamellae and other signs of local cold-work are caused by the meteoritic impact with the ground. I have only been able to detect few significant examples of this postulated damage. If cold-work is present it is usually (i) of preterrestrial cosmic origin, (ii) caused by the fragmentation in the atmosphere or (iii) caused by artificial working. In some cases, when large meteorites impacted with high velocities, e.g., Sikhote-Alin, the broken and fragmented masses may be found quite close together in the impact holes, suggesting that the final fragmentation and superficial cold-deformation occurred at the time of impact. This impact deformation is, however, the exception rather than the rule.