SMITHSONIAN MISCELLANEOUS COLLECTIONS
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NEW WESTVILLE, PREBLE COUNTY, OHIO, METEORITE

(WITH FOUR PLATES)

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A 4.8-kilogram iron meteorite was found during the summer of 1941 in a field near National Highway 40, about 2 miles east of the Ohio-Indiana State line in Preble County, Ohio, lat. 39°48′ N., long. 84°49′ W. The authors selected for this meteorite the name "New Westville" after the town nearest to the point of discovery.

There is no record of the time of fall; the fact that when the specimen was discovered the outer surface was covered with a thick brown limonitic crust indicates that it is probably an old fall. The meteorite was so weathered that all the external features, the flight markings or "thumbmarks," had been obliterated. The surface was firm and dense, and the alteration appeared to have been confined to the surface, but when the end slice was cut off, it separated into small angular pieces because the products of weathering (brown iron oxide) had penetrated along the intercrystalline boundary zones and weakened the bond between the constituents.

On some of these broken flat surfaces thin scales of taenite were noticed, and it was found possible to separate them mechanically and recover them. It seemed advisable, therefore, to cut a few additional slices and break them apart in order to obtain enough taenite for study.

In plate 1, figure 1, is shown the structure of the New Westville iron, which is a medium-fine octahedrite. Kamacite bands average about 0.5 mm. thick and are often grouped together in a number of thin parallel bands, separated by lamellae of taenite.

Few inclusions of any kind are present; only one troilite mass about one-eighth of an inch in diameter was found. Plessite appears gray and dense and has only partly transformed. The taenite enclosing the plessite often makes a thicker band than the taenite that separates some of the kamacite plates.

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The microstructure of New Westville is fairly typical of the irons of its group, a strongly marked octahedral pattern with abundant taenite and plessite. Much of the taenite is in clear lamellae, and when thicker taenite bodies contain a core darkened because of incomplete transformation there is usually a relatively thick border that is fully transformed and clear.

Plessite is mostly of the light or "normal" type, occurring usually in the form of fields of clear kamacite filled with droplike bodies of taenite, showing complete transformation except around the periphery where there is often a narrow band of imperfectly transformed gamma-alpha aggregate, appearing dark to black with moderate etching. In some fields the minute taenite bodies are spheroidized, in others they are elongated or irregular in form. Occasional fields show more or less banded orientation.

The kamacite rather generally is marked by an acicular gamma-alpha transformation structure, consisting of darkened needles. This structure, resembling the martensitic structure in some low-carbon steels, is found in numerous octahedrites, and exceptionally in hexahedrites (New Baltimore) and nickel-poor ataxites (Primitiva, San Francisco del Mezquital).

Schreibersite appears sparingly, reflecting the low phosphorus content of the iron. It occurs usually in irregular bodies along grain boundaries.

Near the surface of the mass the kamacite has been wholly altered by oxidation into limonite. Farther inward the invasion of hydroxide is incomplete, proceeding along grain boundaries and in plessite fields. In such fields the fine dispersion of taenite particles in kamacite apparently favored the oxidation, which always tends to develop along the interfaces of inclusions of any kind. Many light plessite fields near the surface have been completely oxidized except for the more resistant layer of taenite surrounding them. As alluded to elsewhere in this paper, such bodies of plessite (appearing in section as fields) when broken out of the surrounding limonite appear as bright tetrahedrons of taenite. In some places light plessite fields show only incipient intergranular invasion of hydroxide, kamacite areas being more or less oxidized while taenite particles are unaltered.

No Neumann lines were observed. In a few places there are striations somewhat resembling them, but actually part of the gamma-alpha transformation structure.

Table I contains the analysis of New Westville as well as of several other meteorites of similar chemical compositions. In many respects all these meteorites have similar structures, yet there are certain details which distinguish them from each other. These structural differences must reflect changes that owe their origin to various cooling rates or successive reheatings. It is not known what care was taken in selecting the sample of each meteorite that was analyzed, but the portion of New Westville selected for analytical work was polished on both sides and each was etched and found to be free from inclusions. The structure of the sample definitely represented the average for the meteorite. The analysis of New Westville was made on a sample weighing 12.5 grams.

TABLE 1.—*Comparison of the composition of New Westville with eight similar meteorites*

	1 New Westville	2 Grant	3 Grand Rapids	4 El Capitan	5 Mart	6 Thurlow	7 Cleveland *	8 Duchesne	9 Coopertown
Fe	89.77	88.63	89.80	90.51	89.68	89.17	89.63	89.26	89.59
Ni	9.41	9.35	9.38	9.40	9.20	9.92	8.79	9.20	9.12
Co	.61	.63	.53	.60	.33	1.04	.67	.41	.35
P	.10	.57	.14	.24	.15	.25	.31	.21	.04
S	....	.03	None	Trace	....	.05	.006	.01	.01
Cu	....	....	....	.05	.03	....	.12	....	Trace
Insol ...	.07	....	.03	....	....	....	....	....	....

* Average of three analyses.

No. 1. New Westville. Description in this paper.
2. Grant. E. P. Henderson, Pop. Astron., vol. 42, No. 9, November 1934, and Amer. Journ. Sci., vol. 239, pp. 407-411, 1941.
3. Grand Rapids. E. P. Henderson and S. H. Perry, Ann. Rep. Smithsonian Inst. for 1942, p. 235. (Sep. publ. No. 3714.)
4. El Capitan. E. E. Howell, Amer. Journ. Sci., vol. 50, p. 253, 1895.
5. Mart. Geo. P. Merrill, Proc. Washington Acad. Sci., vol. 2, p. 51, 1900.
6. Thurlow. E. Cohen, Meteoritenkunde, Heft 3, p. 377, 1905.
7. Cleveland. F. A. Genth, Proc. Acad. Nat. Sci. Philadelphia, p. 366, 1886.
8. Duchesne County. H. H. Nininger, Journ. Geol., vol. 37, p. 83, 1929.
9. Coopertown. J. L. Smith, Amer. Journ. Sci., vol. 31, p. 266, 1861.

TABLE 2.—*Comparison of structures of eight meteorites, the analyses of which appear in table 1*

Name of meteorite ...	New Westville	Grant	Grand Rapids	El Capitan	Mart	Thurlow	Cleveland	Coopertown
Length of kamacite...	5-6 cm.	6 cm.	5 cm.	6 cm.	3-5 cm.	4-5 cm.	5 cm.	4 cm.
Width of kamacite....	0.5 mm.	0.8-1 mm.	0.5 mm.	1 mm.	0.5 mm.	0.4-0.6 mm.	1 mm.	3 mm.
Plessite with secondary octahedral pattern	None	None	None	Feebly developed	None	Well developed	Slightly developed	Slight development

As all these meteorites are of similar composition, they can be represented by the line OO′ drawn upon the nickel diagram of Owens and

Sully (fig. 1.). The line OO′ lies wholly within the kamacite-taenite zone at all temperatures below 690°C., and at this temperature some kamacite will separate with a nickel content of 2 percent and be in equilibrium with taenite with a nickel content of 9.3 percent. As the temperature of the melt decreases, the kamacite separating increases slowly in nickel content, the taenite much more rapidly.

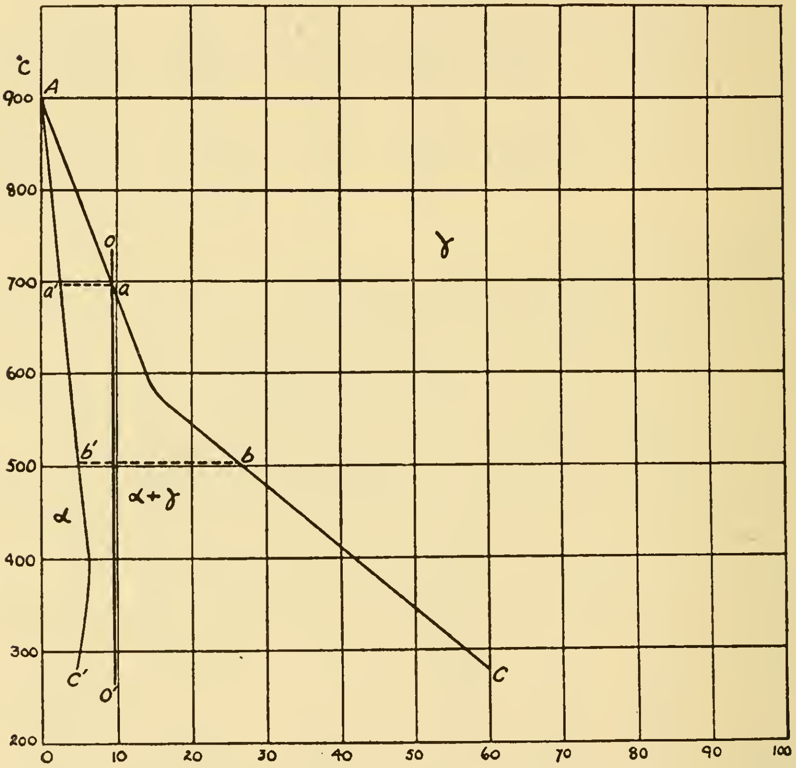

FIG. 1.—Equilibrium diagram of iron and nickel. (Copied from E. A. Owen and A. H. Sully.) The vertical line oo′ represents the composition of the meteorites listed in table 1. *b* represents the composition of the taenite found in the New Westville meteorite.

The kamacite or taenite that first forms at high temperatures will contain much less nickel than that which forms at lower temperatures. If the drop in temperature is very slow, the first products to separate out should be absorbed and converted into the higher nickel-content phases consistent with the temperature levels prevailing. However, if the temperature falls rapidly at times, in all probability the taenite and kamacite deposited around the preexisting particles will have a higher nickel content, and not all the particles formed earlier will be transformed into a uniform product. Since the kamacite line has a very gradual slope, there will be only a slight difference in its composition as the temperature is lowered. Taenite increases rather rapidly in its nickel content as it separates at successively lower temperatures; hence if the taenite forming at lower temperatures precipitates around that which formed at higher temperatures and the two do not come to equilibrium, the thick plates of taenite very likely will not be homogeneous in composition.

From a structural relationship it appears that plessite, which is a mixture of kamacite and taenite, is the last to differentiate from the melt, hence it may contain taenite richer in nickel than the taenite deposited between kamacite plates. A structural study of plessite may give some information on the rates of cooling.

The major differences between these meteorites seem to be confined to the plessite, as this is the last component to form, these variations in plessite probably reflect different rates of cooling at relatively low temperatures.

Reheating is recognized as the cause of changes in the structures of irons, such as the change from a normal hexahedrite structure to a nickel-poor ataxite, or the disruption of the normal octahedral pattern. Such features as diffusion of phosphide and the formation of phosphide eutectics are definite proof of reheating subsequent to the formation of the general pattern for that particular meteorite. Schreibersite, the iron-nickel phosphide, is frequently found in immediate contact with troilite or surrounding it. When such an association is reheated, both of these compounds apparently melt; but whether or not they make a homogeneous solution is unknown to the authors. On cooling, however, neither of these two compounds is soluble in the other, and the schreibersite is rejected at times in droplike particles.[1]

Reheating can modify dense plessite into a form showing partial spheroidization [2] of the taenite. However, the features described above —the normal evidence of reheating—are lacking in all the photomicrographs of the New Westville iron. The type of reheating that caused them produces a change in structure subsequent to the establishment of the primary type for that particular meteorite. Had the material cooled to a point above the temperature where the kamacite and taenite differentiated and a second elevation of temperature then occurred, it is unlikely that any evidence of this type of reheating could be found in the structure of the metals.

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[1] Perry, S. H., The metallography of meteoric iron. U. S. Nat. Mus. Bull. 184, pp. 168-169, pl. 49, fig. 3, 1944.

[2] Idem, p. 194, pl. 74, figs. 3 and 4.

Plessite, which is generally believed to be the last constituent to separate on cooling, may be found to consist of a dense, imperfectly transformed gamma-alpha aggregate. In these plessite areas at times there will be a slight development of a miniature octahedral structure which obviously had formed at a later time than the primary structure of the meteorite, and likely this miniature structure slowly formed at a much lower temperature which was sustained for a very long period of time.

From the phase relationships of taenite and kamacite it is evident that these products have separated largely into their characteristic forms before the plessite solidified. Since, apparently, there are valid reasons for assuming that all kamacite contains about 5.5 percent nickel, and from some of the plessite areas the taenite contains 26-27 percent nickel, it would appear that plessite forms after kamacite has attained its maximum saturation of nickel, and from our present knowledge this indicates a temperature of between 400 and 500°C.

The fact that the dense plessite has a miniature octahedral structure in some meteorites, and not in others of about the same general composition, certainly indicates some differences in their history.

Taenite in New Westville.—Taenite is more resistant to alteration than kamacite, and the weathering agents that penetrated along the octahedral planes had weakened the bond between the taenite and the kamacite. Consequently it was mechanically possible to recover the taenite free from adhering kamacite. Several thin slices taken from one end of the New Westville iron were broken apart to expose the taenite. Excellent recovery of taenite was possible from the plessite areas where the kamacite and taenite made long, narrow bands. By prying apart the kamacite the taenite could be picked loose from the kamacite; sometimes when one end was loosened, with the aid of forceps the taenite could be rolled up like foil.

The polished and etched surface of New Westville shows in the oxidized portions small triangular areas of dark-gray plessite surrounded by an enclosing envelope of taenite. When these slices were broken apart, a number of small, four-sided pyramids were obtained which are completely enclosed by taenite, but when they were broken open the interiors were found to be gray and crumbly. None of these was included in the taenite sample that was analyzed, although to the eye they appear as solid masses of very pure taenite.

Taenite is very elastic and tough, silvery white, and strongly magnetic. The scales are so thin that when placed in water they remain on the surface until they become thoroughly wetted.

The specific gravity was determined by M. Fleischer on the Berman balance in the laboratory of the United States Geological Survey, but accuracy is not claimed for the determination because of the fragmentary nature of the material.

It was somewhat of a surprise to find no phosphorus in the taenite. In spite of the fact that no phosphide inclusions were seen on the etched sections of this iron, and only 0.10 percent phosphorus was found in the analysis, it was expected that some phosphorus would be found dissolved in the taenite since it is a well-known fact that phosphorus is more soluble in gamma iron, which corresponds to taenite, than it is in kamacite. Most of the published analyses of taenite show considerable phosphorus. Vogel[3] proved, by etching specimens with sodium picrate, that taenite often contains phosphides. Perry[4] mentioned that the phosphide content is usually greater along the interface of a taenite body or of the taenite border of a plessite field and decreases inward.

TABLE 3.—*Taenite from New Westville meteorite*

Partial analysis (E. P. Henderson)	Percent	No. of fragments used	*Specific gravity (M. Fleischer)*
Fe	....		
Ni	26.13	2	7.65
Co	.95	2	7.87
P	None	3	7.85
Insol.	.46	3	7.46

Farrington[5] published a series of 22 analyses of taenite which vary in content from 13 to almost 48 percent of nickel. Attempts have been made to assign a chemical formula to taenite, but without success. If the line AC, figure 1, which was given by Owen and Sully, is followed from *a*, where the composition line OO′ for this meteorite intersects it, down to the point *b*, that of the New Westville taenite, it is evident that the composition of taenite is changing constantly.

The majority of the analyses given by Farrington were made on taenite separated from the meteorite by virtue of the slow solubility of taenite in hydrochloric acid. Samples obtained by such a method would appear to be unreliable because there are excellent chances that particles of kamacite completely enclosed in taenite, such as have been mentioned previously in this paper, could be included in

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[3] Vogel, Rudolf, Über die Struktur des Meteoreisens und ihre spezielle Beeinflussung durch Umwandlung und beigemengter Phosphor. Abh. Ges. Wiss. Gottingen, Math.-Phys. Kl., n.s., vol. 12, p. 2, 1927.

[4] Perry, S. H., U. S. Nat. Mus. Bull. 184, 1944.

[5] Farrington, O. C., Meteorites, their structure, composition, and terrestrial relations, p. 134, 1915.

a sample. Chemical analysis on this type of sample would give low nickel values for taenite.

As stated above, one cannot be certain that all taenite in any given meteorite has the same composition. The greater portion recovered from New Westville came from the areas containing alternating plates of kamacite and taenite. Such areas are closely related to plessite. The taenite enclosed in this type of structure may have originally separated at different temperatures, and if so, the composition of the taenite plates would not be identical.

Considering the taenite analyzed from New Westville as likely to be similar to that which forms in meteorites with the compositions given in table 1, the authors made an attempt to trace the temperature of formation using the diagram of Owen and Sully (fig. 1). The composition line OO′ represents this group of meteorites, and at temperatures above 690°C. only a single phase exists, but at 690° some taenite separates which will have a nickel content of slightly more than 9 percent. This taenite is in equilibrium with kamacite containing about 2 percent of nickel. Cooling along the composition line OO′ to slightly above 500°C., taenite with a nickel content of 26.1 percent will form, and this corresponds with that in the New Westville iron. At this temperature the kamacite which is in equilibrium with the taenite will contain about 5 percent nickel. Thus the kamacite has nearly reached its maximum content of nickel.

However, we cannot stop here because the meteorite is still rather hot. Around 500°C. it must be possible for considerable diffusion of the elements to form new phases, and hence it should be possible for a taenite richer in nickel to form at lower temperatures. This holds only if the cooling rate is very slow; if the meteorite rapidly cools below this temperature, it is likely that equilibrium conditions are not attained and areas of dense untransformed plessite will result.

If the dense plessite areas are the last to form, the taenite surrounding them would naturally be richer in nickel. The composition of the taenite from New Westville is indicated by the point *b* on the line AC, and we also noted that the temperature is just above 500°C. If the boundary lines for the two phases are as shown by Owen and Sully, the kamacite has not yet attained its maximum percentage of nickel. Yet the kamacite plates in the specimen measure .5 mm. in thickness. It is difficult to conceive that such sizable inclusions of kamacite as occur in New Westville could still be transforming or absorbing more nickel at this low temperature unless the mass were retained at such temperature for an almost infinite length of time.

The kamacite masses in hexahedrites are the largest available for study, and 23 separate analyses have been published.[6] In five the nickel content is noticeably lower than 5.5 percent—namely, 5.32, 5.30, 5.33, 5.21, and 5.35 percent. There also happen to be five in which the nickel content is noticeably higher than 5.5 percent—namely, 5.77, 5.73, 5.70, 5.78, and 5.79 percent.

If the boundary of the alpha iron (kamacite) is as indicated by Owen and Sully, one would expect that it would not be unusual to find taenite or plessite in hexahedrites, since at temperatures below 400°C. the solubility of nickel is believed to decrease; a composition line drawn vertically representing a nickel content of 5 percent would again enter the two-phase (alpha and gamma) zone just below 400°C. At the temperature slightly above 500°C. corresponding to the composition of the taenite in the New Westville, the kamacite will have a nickel content of nearly 5.0 percent.

Perry [7] found plessite to be present in the Otumpa and Sierra Gorda hexahedrites. He assumed that the occurrence of plessite in Sierra Gorda was due to "rapid cooling from a relatively high range."

Sierra Gorda was found to contain 5.58 percent nickel and .25 percent cobalt, which is about the average value for kamacite. Perry's explanation may be correct; but again if Owen and Sully are right, some plessite can separate below 400°C., since the curve of alpha iron decreases in nickel content as it cools below 400°.

Dense plessite areas filling the space between the kamacite plates probably represent the last metal to transform—the residual portion remaining after the kamacite has separated and formed a skeletal mass of plates.

The following table gives all the meteorites now known to have been discovered in Ohio.

TABLE 4.—*Ohio meteorites*

Name	County	Kind	Latitude N.	Longitude W.
*Anderson	Hamilton	Pallasite	39°10′	84°18′
*Cincinnati	"	Ataxite	39°7′	84°29′
Enon	Clark	Mesosiderite	39°54′	83°57′
Hopewell Mounds	Ross	Med. octahedrite	39°15′	83°0′
*New Concord	Muskingum	Stone	40°2′	81°46′
*New Westville	Preble	Octahedrite	39°48′	84°49′
Pricetown	Highland	Chondrite	39°11′	83°44′
*Wooster	Wayne	Octahedrite	40°50′	81°58′

* Specimens in the U. S. National Museum's collections.

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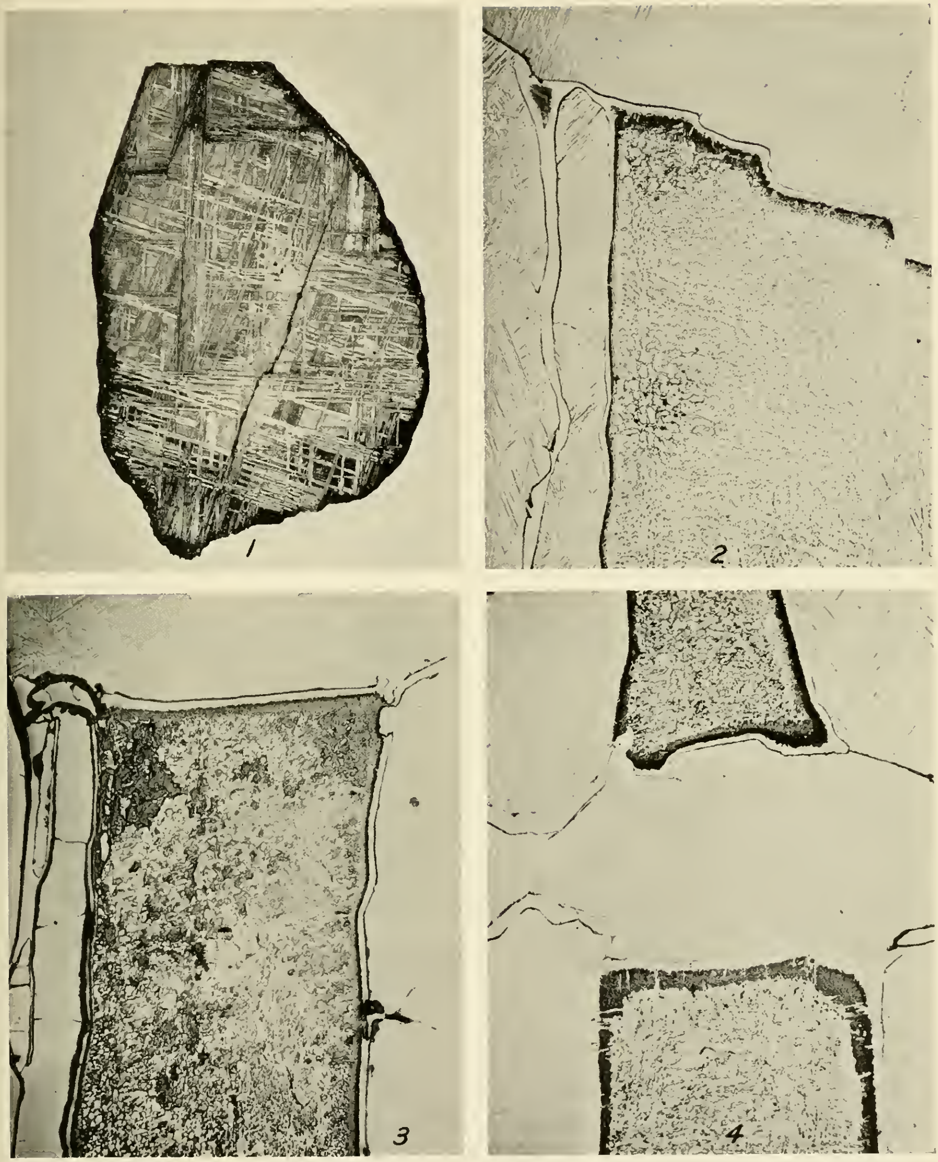
[6] Henderson, E. P., Chilean hexahedrites, Amer. Mineral., vol. 26, p. 546, 1941.

[7] Perry, S. H., U. S. Nat. Mus. Bull. 184, p. 54, 1944.



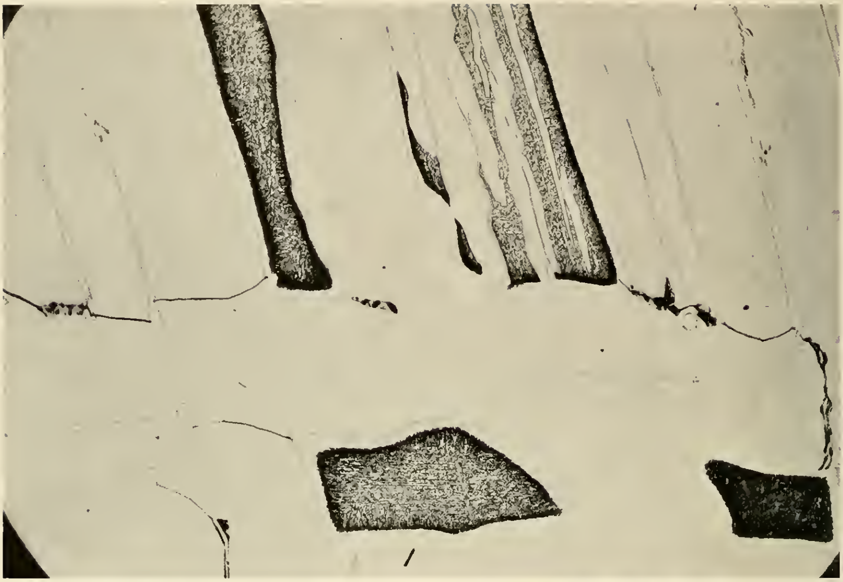
New Westville Meteorite

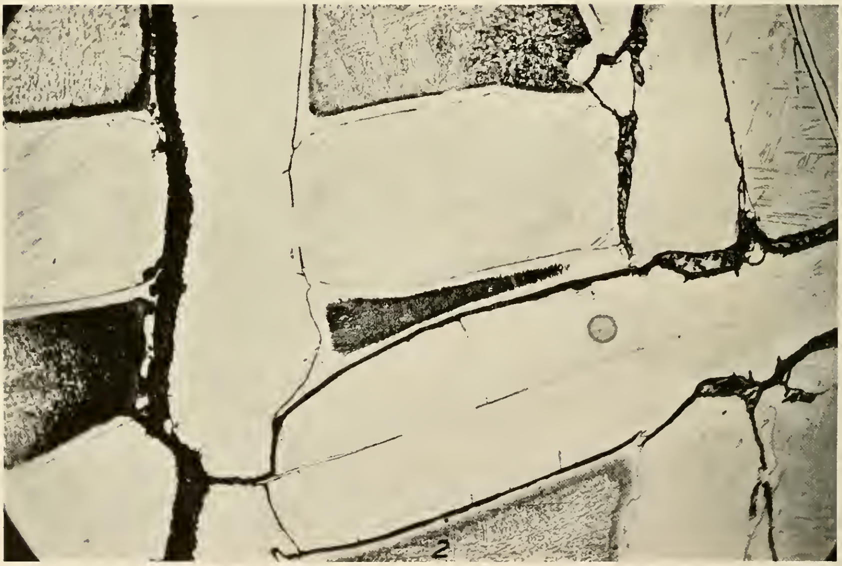
1, slice, light macro-etch, ordinary light. 2/5 natural size.

2, at left, two kamacite bands, showing gamma-alpha transformation figures, separated by a lamella of taenite. At right, a characteristic light plessite field, consisting of spheroidized taenite particles scattered without orientation in a ground of clear kamacite. Near the edges of the field, inside the clear taenite border, a band of varying width darkened because of incomplete transformation. Picral 30 seconds x 50.

3, a plessite field showing intergranular invasion of hydroxide. Kamacite areas are, in part, darkened; taenite is not affected. Picral 30 seconds x 50.

4, two light plessite fields showing (particularly the upper one) some intergranular invasion of hydroxide. Gamma-alpha transformation figures are faintly visible in the kamacite bands. Picral 30 seconds x 50.

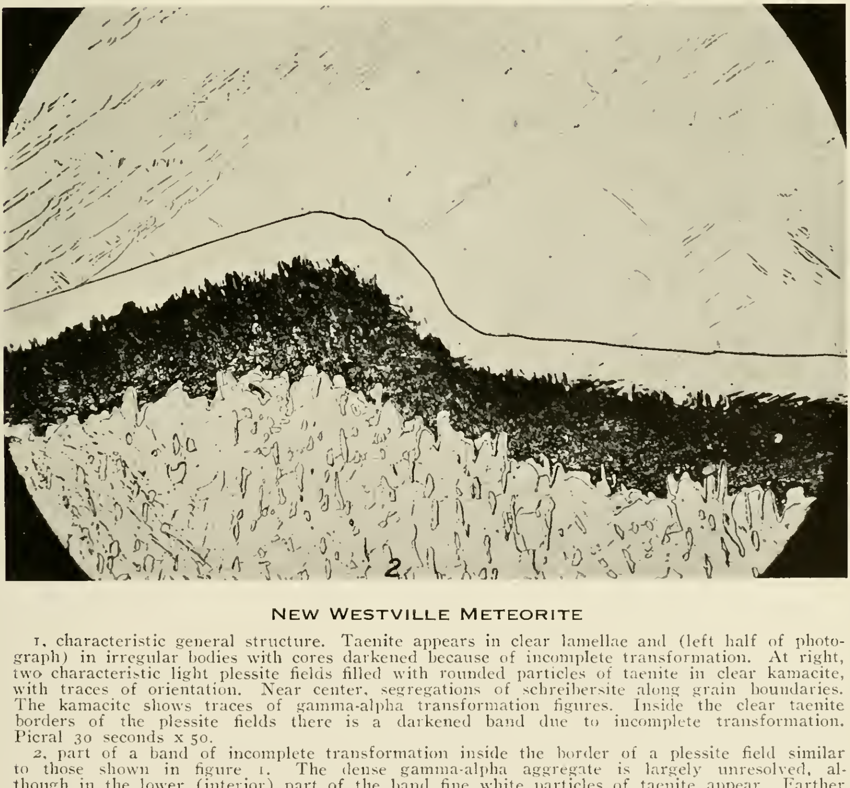




New Westville Meteorite

1, characteristic general structure. Taenite strongly developed, clear and fully transformed in the lamellae and in the borders of the plessite fields. The plessite field in lower center shows orientation; that at the lower right has a dense core unresolved at this magnification. Picral 15 seconds x 50.

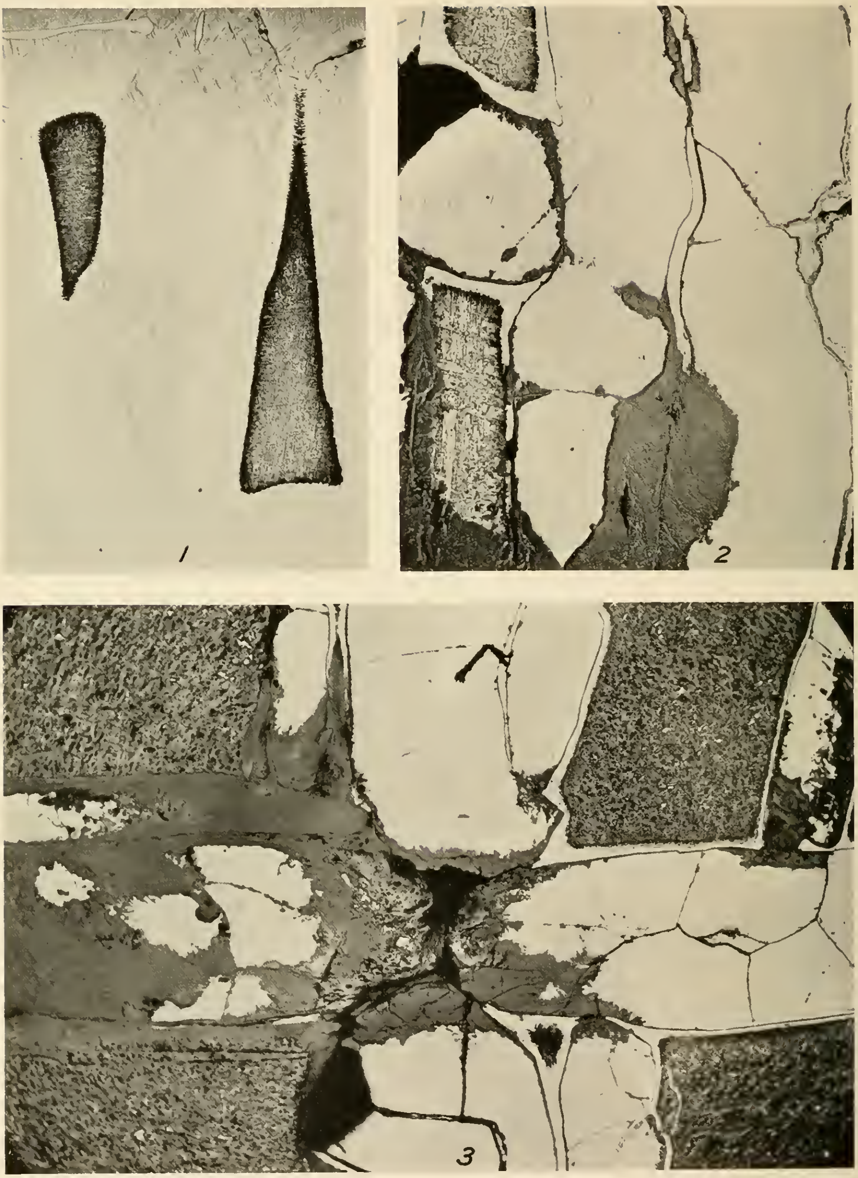
2, general structure similar to figure 1, more strongly etched. Invading hydroxide along interfaces and (at the left) in a plessite field. Picral 30 seconds x 50. (The round spot, right center, is due to a defect in the negative.)



NEW WESTVILLE METEORITE

1, characteristic general structure. Taenite appears in clear lamellae and (left half of photograph) in irregular bodies with cores darkened because of incomplete transformation. At right, two characteristic light plessite fields filled with rounded particles of taenite in clear kamacite, with traces of orientation. Near center, segregations of schreibersite along grain boundaries. The kamacite shows traces of gamma-alpha transformation figures. Inside the clear taenite borders of the plessite fields there is a darkened band due to incomplete transformation. Picral 30 seconds x 50.

2, part of a band of incomplete transformation inside the border of a plessite field similar to those shown in figure 1. The dense gamma-alpha aggregate is largely unresolved, although in the lower (interior) part of the band fine white particles of taenite appear. Farther inward (at bottom) fully transformed taenite has segregated in elongated particles. The kamacite (above) shows gamma-alpha transformation figures. Picral 15 seconds x 367.



New Westville Meteorite

1, wedge-shaped bodies of taenite with cores darkened because of incomplete transformation. At top, a short lamella of taenite (clear) and three small bodies of schreibersite (gray). Picral 30 seconds x 50.

2, an area near edge of slice showing invasion of hydroxide. Taenite is little affected. Picral 30 seconds x 50.

3, an area near edge of slice strongly invaded by hydroxide, proceeding from the left (surface) toward the right (interior) of the mass. At the left two kamacite bands and two plessite fields are almost wholly oxidized. At the right the taenite borders of two plessite fields remain unchanged, the interior of the fields completely oxidized. Picral 30 seconds x 50.