THE WINONA METEORITE.*

ROBERT E. S. HEINEMAN AND L. F. BRADY.

Part I.

L. F. Brady.

In September, 1928, a broken mass of meteoric material of unusual interest was found by Mr. A. J. Townsend, of Flagstaff, in the neighborhood of a small group of pre-historic ruins about five miles northeast of Winona, in northern Arizona. Specimens of the material were shown to Professor Byron Cummings of the University of Arizona, and to the writer, and were recognized as being of meteoric origin.

Apart from the peculiarities of composition and structure described later, the chief interest attached to this meteorite is due to its position when found. The writer visited the site a few days after its discovery and made careful measurements and excavations. The ruins in question are two groups of five or six "houses" each. The pottery fragments and other artifacts show no difference from those of the numerous prehistoric ruins of this area, of which the best known is the Elden Pueblo, excavated by the Smithsonian Institution in 1926.

The meteorite was found enclosed in a rough cist of flat stones, the cover of the cist being ten inches below the level of the ground. The terrain is a fairly level, grassy flat, covered by a scattered growth of "cedars." The position of the cist was one hundred and eighty feet due east of one ruin and two hundred and fifty feet five degrees east of north from the other, but this orientation may well be accidental. The writer's first impression was that the cist was of the nature of a shrine built to contain an object of superstitious reverence, but excavation showed that four broken digging stones had been left on the top of the cist, and Mr. Townsend states that it contained very little soil. As the stones were irregular in shape and as there was no trace of clay to fill the spaces between them, it seems clear that if such a shrine had been built on the surface of the ground and subsequently covered with drifted soil, it would have been completely filled; so that it seems safe to conclude that the meteorite was carefully buried, perhaps at the spot where it was seen to fall.

* Part II published by permission of the Director of the Arizona Bureau of Mines.

The cist was formed of six flat slabs of "malpais" rock as shown in Fig. 1. The one at the bottom, on which the meteorite rested, was considerably smaller than the four sides or the top. Mr. Townsend states that the meteorite, when found, was roughly egg-shaped, but was so cracked that it fell to fragments at once. The largest piece seen by the writer weighed about four pounds, the other pieces ranging from that weight to a few grains. The total weight was fifty-three pounds, of which approximately ten pounds, together with the cist, are in the possession of the Museum of Northern Arizona, at Flagstaff.

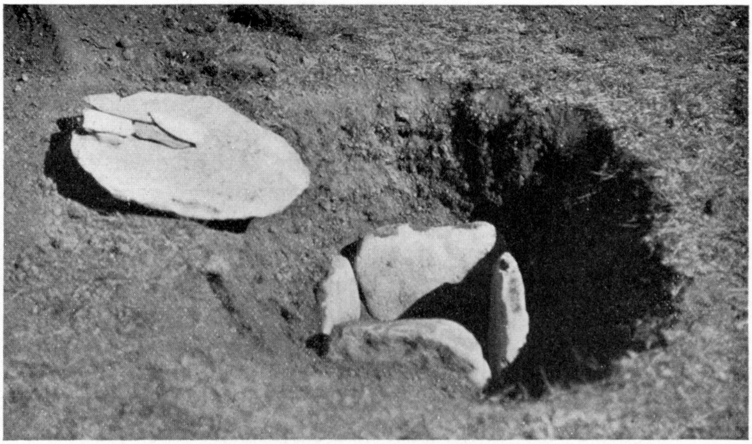

Fig. 1. The cist in which the meteorite was discovered.

Meteorites have been revered and preserved as supernatural objects by primitive man in many parts of the world. Even as late as 1492, in so civilized a country as Alsace, the Ensisheim Iron was for a long time preserved in the village church.[1] The Winona meteorite is the third one found, as far as the writer has been able to learn, that indicates any interest in such objects on the part of the pre-historic inhabitants of the southwestern states. It is true that somewhat vague legends have been reported, as told by Hopis and Navajos, of the fall of the great masses of iron at Meteor Mountain near Winslow, but it is not at all certain that these legends are not of comparatively recent date.

[1] Farrington, O. C., Meteorites, 220, Chicago, 1915.

One of the other meteorites referred to is the Navajo Iron[2] found in 1921, whose existence, according to the Navajos, had been known to them since the first coming of their ancestors to that part of the country. As this stone has certain undoubtedly artificial grooves and marks on its upper surface, and as human bones were found buried beside or under it, it seems probable that it actually struck and killed an Indian child. The second was reported by Dr. J. W. Fewkes of the American Bureau of Ethnology as a seven-pound meteoric iron found in 1922 in the Sun Temple at Mesa Verde "with other miscellaneous rock fragments." In the case of the newly found Winona meteorite there is, of course, no direct evidence that it was seen to fall, but it is difficult to understand why any notice would have been taken of it, otherwise.

MESA RANCH SCHOOL,
MESA, ARIZONA.

PART II.

ROBERT E. S. HEINEMAN.

In September, 1928, a piece of the Winona meteorite was brought into the Arizona Bureau of Mines by Dr. Byron Cummings of the Archaeology Department of the University of Arizona for identification. The general appearance resembled that of a piece of typical limonitic gossan of an ore body with a green stain streaking it in several places. Mr. A. J. Townsend of Flagstaff, who had given the fragment to Dr. Cummings, thought it to be copper ore. A few simple qualitative tests showed an abundance of nickel and no copper. The writer suspected meteoric material, and made a polished surface section which showed nickel-iron particles and pyrrhotite in a field of silicate minerals and limonite or hematite. The nickel-iron, upon etching with nitric acid, gave excellent Widmanstatten figures, thus definitely proving the material to be of meteoric origin. (Fig. 3.)

The writer visited Mr. Townsend at his home near Flagstaff on October fourth and obtained several more fragments of the meteorite ranging in weight from 16 grams to 257 grams. The total amount obtained weighed 1297 grams or 2.8 pounds, and consisted of eleven pieces. Small fragments were broken from all of these pieces to obtain a sample for chemical analysis. The meteorite when found weighed about fifty-three pounds.

[2] Butler, G. M., oral communication.

Ten pounds are in the possession of the Museum of Northern Arizona. Dr. Cummings has the piece before mentioned. It weighs 376 grams.

According to Townsend,[3] the meteorite when found in the cist was a roughly egg-shaped mass which fell to pieces on removal. It was badly decomposed and altered. The color is a dark chocolate brown about $13^{3}l$ on the color chart prepared by Goldwin and Merwin.[4] Due to variations in the mineral

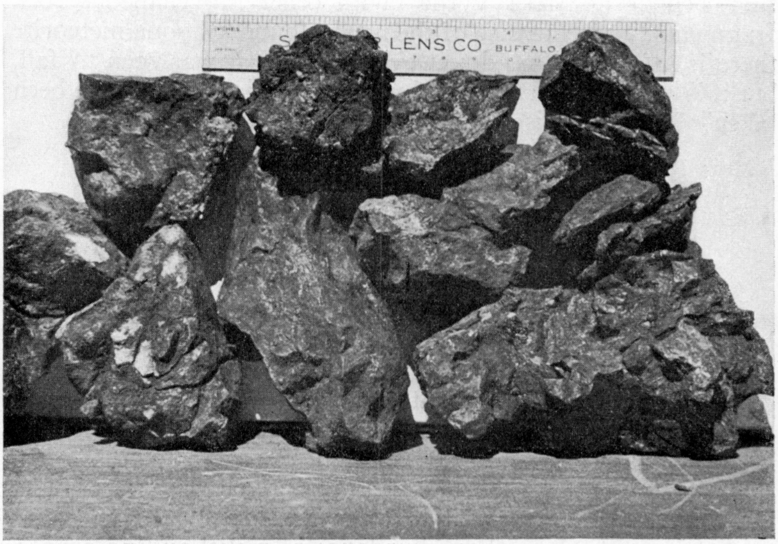

Fig. 2. Parts of Winona meteorite. The cracked surface may be noted on the fragment above the left center.

composition, some portions are lighter than this hue and some darker. Pieces from the center of the mass are in general darker. Pieces from the outside show a lighter color on the surface which had been exposed to weathering influences. This surface is rough and shows irregular cracks which may penetrate as much as a quarter of an inch. (Fig. 2.) Silicate chondri appear on the weathered surface as ochre-colored, crumbly protuberances, varying in size from more than half an inch in diameter down to minute grains. All of the sur-

[3] Oral communication.

[4] Goldwin, M. I., and Merwin H. E., Color chart for the description of sedimentary rocks, Washington, 1928.

faces of the various pieces show stains and streaks of emerald-green zaratite. The cracks noted are not uncommon in decomposed meteorites. The Lampa, Chile stone[5] shows them very well. Farrington believes[6] that these cracks are due to the slow hydration of the interior of the meteorite such as would occur in an arid climate. Water penetrating the meteorite would be held and cause hydration while the surface would dry comparatively soon. Minute cracks would act as wedges and split the meteorite, eventually causing it to become a pile of fragments, as was the case with the Winona stone.

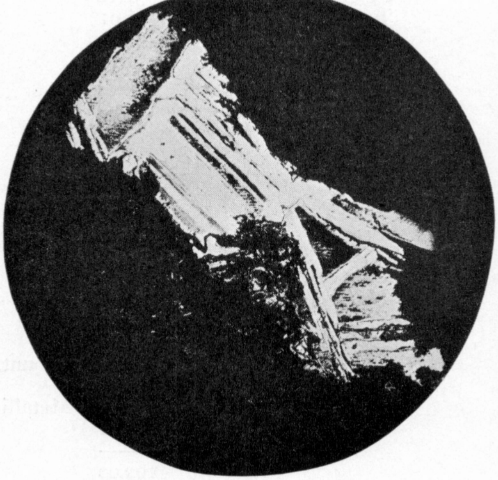

Fig. 3. Etched surface of fragment of nickel-iron, showing Widmanstatten figures. x 8.5.

During the winter of 1928-29, the writer made a chemical analysis of the meteorite. The decomposed condition of the material makes it impossible to classify the meteorite accurately[7] or to give the exact mineral composition. All that may be said at present about classification is that before terrestrial alteration the meteorite was probably a siderolite, Grahamite, number 44 in Brezina's[8] classification. Farrington's[9] quanti-

[5] Howell, Proc. Rochester Academy of Sciences, 1, 93, 1890.
[6] Farrington, O. C., Field Mus. Publications, 1, 290, 1902.
[7] Farrington says "It is understood that analyses of decomposed rocks are not available for classification," Field Mus. Publications 3, 199, 1911.
[8] Proc. Am. Phil. Soc. 53, 211-247, 1904.
[9] Farrington, O. C., Field Mus. Pub. 3, 195-229, 1911.

tative classification may not be used for reasons we have just stated. The great amount of limonite present shows that at one time much more nickel-iron was in the metallic state and it is called a siderolite on that basis.

The specific gravity, which was determined from the eleven pieces by weighing them in air and water, was found to be approximately 3.41. The average specific gravity of meteorites seen to fall is 3.59.[10]

The chemical analysis follows:

SiO_2	19.84	
Al_2O_3	4.09	
Fe_2O_3	32.12	
FeO	16.01	
MgO	12.03	
CaO	1.13	
Na_2O	0.74	
K_2O	0.06	
H_2O-	0.96	
H_2O+	4.80	
TiO_2	0.05	
P	0.00	
S	5.30	
Cr_2O_3	0.17	
NiO	3.86	
CoO	0.33	
MnO	0.06	
ZrO_2	0.00	
BaO	0.00	
CO_2	small amount, not analyzed	
Fe	0.38	Metallic portion
Ni	0.06	Metallic portion
Co	0.01	Metallic portion
	102.00	
Minus O = S	1.17	
Total —	100.83	

The sample was ground in an agate mortar and passed through an 80-mesh screen. The metallic particles, being somewhat malleable, did not pass through the screen and were analyzed separately. In the analysis of most stony meteorites three portions are used—the metallic, the soluble in HCl, and the insoluble in HCl. The SiO_2 and MgO in the soluble portion, with FeO, would represent olivine, while the MgO and SiO_2 in the insoluble portion would be representative of the insoluble silicates. In the analysis of the Winona meteorite, however, this separation was not made for several reasons.

[10] Farrington, O. C., Meteorites, 217, Chicago, 1915.

The high percentage of Fe_2O_3 shows the extreme alteration which has taken place. Because of this alteration, the original mineral composition may not be calculated, as we have stated. Moreover, in the analysis of material for ferrous iron in the presence of a sulphide such as pyrrhotite and ferric oxide, the results are apt to be inaccurate, due to the reduction of the higher oxide.[11] This would again cause a misrepresentation in a mineral content calculation. Also in several portions, the soluble and insoluble parts could not be made to check. On treating with HCl an excess of sulphur remained, which neces-

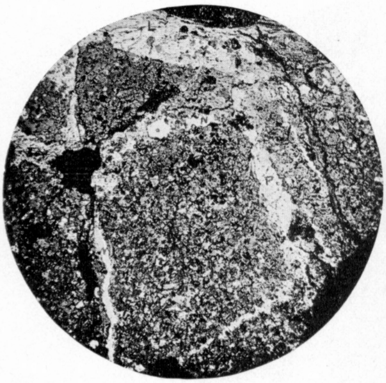

Fig. 4.

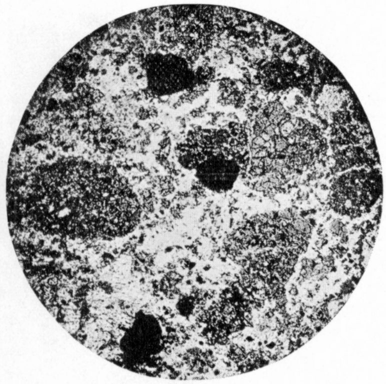

Fig. 5.

Fig. 4. Veins of metallic nickel-iron, pyrrhotite and limonite cutting silicate aggregates. Reflected light. x7. N: nickel-iron; P: pyrrhotite; L.: limonite.

Fig. 5. Rounded aggregates of silicate minerals in a matrix of pyrrhotite and limonite. Reflected light. x 7.

sitated the use of a saturated solution of $KClO_3$ in nitric acid as a solvent. The solubilities of the several silicates appear to vary with the strength of the solutions used as solvents and the length of time exposed to them. These facts would vitiate any results as to mineral composition obtained from the analysis of soluble and insoluble portions. Therefore the insoluble portion was fused with sodium carbonate, combined with the soluble portion, and the analysis made on these combined portions.

Silica, lime, and magnesia were determined by the usual methods. Iron and alumina were weighed as the sesquioxide. Total iron was titrated in a separate portion and alumina

[11] Hillebrand, W. J., U. S. Geol. Survey, Bull. 700, 201, 233, 1919.

obtained by difference. Ferrous iron was titrated after treating with hydrofluoric and sulphuric acids. Sulphur was weighed as barium sulphate in a separate portion. Soda and potash were determined in a separate portion by the J. Lawrence Smith method. Nickel was precipitated and weighed as the oxime. Cobalt was precipitated by nitroso-beta-napthol and blasted to Co_3O_4. Microscopic examination of thin sections under polarized light and of polished sections showed the following minerals to be present: olivine, enstatite, plagioclase (andesine), limonite and hematite, pyrrhotite and metallic nickel-iron.

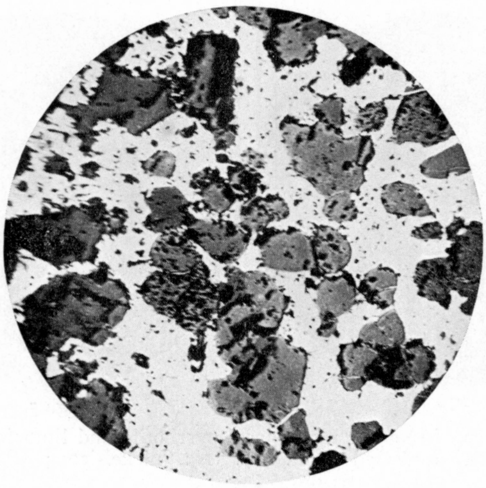

Fig. 6. Silicate chondri (gray) surrounded by pyrrhotite (white). Reflected light. x 58.

The silicate minerals occur in aggregates of a centimeter in diameter down to small individual grains 0.05 mm. in diameter. The aggregates and isolated grains show rounded outlines and may be called chondritic even though none of the radiating textures sometimes seen in chondri were noted. The chondri are in a matrix composed of pyrrhotite and limonite (hematite) with minor amounts of metallic nickel-iron. The limonite is secondary, penetrating cracks and fissures in all of the other minerals present and may be safely said to have been formed later than all of them. It is most certainly an alteration product of the nickel-iron and pyrrhotite and therefore probably contains secondary salts of nickel, cobalt, manganese, and sulphur as well as iron.

The olivine and enstatite were present in about equal portions. The olivine showed typical high relief and cleavage cracks. The enstatite has parallel extinction. A basal section showed typical cleavage and was positive in sign. The plagioclase was not present in large quantity. As seen by the analysis it would not be more than about 4 percent of the whole. It showed albitic twinning under the microscope and was called andesine on the basis of an extinction angle of about 6 degrees on a section normal to Y. The silicate minerals compose at least 50 percent of the whole. The exact amount can not be determined without knowing how much FeO they contain individually and how much FeO is present in the entire mass.

Perhaps the most interesting fact noted in connection with the Winona meteorite is the high percentage of pyrrhotite. The sulphur is 5.30 percent of the whole meteorite. Some of this may be present as secondary sulphate, but since there is a small amount of carbonate occurring as zaratite it is not likely that there is any free sulphate. The composition of the pyrrhotite is not known, except that it does contain more sulphur than troilite, pure FeS. Troilite goes entirely into solution, when treated with dilute HCl, without leaving any residue. When the iron sulphide in the meteorite was treated with dilute HCl, a considerable residue of sulphur remained, showing it to be pyrrhotite. It is noticeably magnetic. In calculating the amount of oxygen to be subtracted from the total of the analysis, to allow for iron sulphide, the pyrrhotite was given the formula Fe_7S_8, which Hillebrand[12] says may be assumed. If calculated as Fe_7S_8 the percentage would be 13.38 of the whole. In polished section the pyrrhotite occurs in veins and masses which in spots completely enclose silicate chondri. This is well seen in Figs. 5 and 6. As far as may be observed in polished section, the pyrrhotite and nickel-iron have been formed contemporaneously and both were in a fluid form later than the silicate minerals. Using the criteria employed in the study of terrestrial ore paragenesis, we assume this to be true since the silicates show rounded and embayed edges.

Mention has been made of zaratite, the nickel carbonate, which causes the green colorations seen on portions of the meteorite. Some of this mineral was isolated and studied. It is a clear emerald green, quite transparent, and glassy. The index of refraction found by the use of oils is 1.595. The

[12] Op. cit. 233.

index of zaratite according to Winchell[13] varies from 1.56 to 1.61 with a specific example given as 1.597. The mineral is isotropic. It is completely soluble with effervescence in dilute HCl.

In closing, it may be said that the two chief points of interest connected with the Winona meteorite are its location when found and the exceedingly high sulphur content. There are

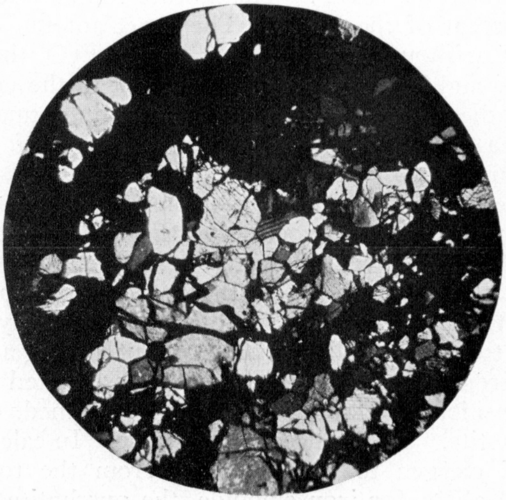

Fig 7. Photomicrograph of silicates. Shows enstatite, olivine and plagioclase. Crossed nicols. x 26.

only two meteorites in Farrington's catalog[14] of 125 stones with which a close comparison may be made. Orgueil runs 13.43 percent FeS and Cabezzo de Mayo 20.57 percent FeS. The average sulphur in stone meteorites is 1.98 percent. Before alteration, it is at least possible, that the Winona may have contained more pyrrhotite than either of these two.

Arizona Bureau of Mines,
Tucson, Arizona.

[13] Winchell, A. N., Elements of Optical Mineralogy, part II, 87, New York, 1927.

[14] Farrington, O. C., Field Mus. Publications 3, 225-228, 1911.