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THE PARAGOULD METEORITE

SHARAT KUMAR ROY

CHIEF CURATOR, DEPARTMENT OF GEOLOGY

AND

ROBERT KRISS WYANT

CURATOR, ECONOMIC GEOLOGY

At the time of its fall, in 1930, the Paragould meteorite, weighing about 820 pounds,¹ was the largest single stone meteorite ever seen to fall. Since then its reputation as being the largest has suffered a setback. In 1948, a shower of stones, one of which weighed about one ton, fell over a considerable area in Norton County, Kansas, and Furnas County, Nebraska. This one-ton meteorite, known as Norton County, is now the largest known stony meteorite and the largest observed to fall.

Descriptive notes regarding the Paragould meteorite and the phenomena of its fall, published previously by C. C. Wylie and Stuart H. Perry (see Wylie, 1930b, pp. 246–247), have been a valuable aid in the preparation of this paper. The orbit of the meteorite was calculated by H. E. Nelson and W. J. Thomsen (1947), and their work has materially added to our knowledge of it. To these investigators we wish to acknowledge our indebtedness. We are also indebted to Dr. William F. Foshag, Dr. Edward P. Henderson, and Dr. George Switzer, all of the Department of Geology, United States National Museum, for contributing freely of their time in discussing the paper during its preparation and giving us an opportunity to examine a polished surface of Paragould (the smaller individual) and other metamorphosed brecciated stones for comparative studies. To Dr. George Edwards, Enrico Fermi Institute of Nuclear Studies, University of Chicago, we extend our appreciation for his co-operation in the experiments on the effects of heat on the constituent minerals of the meteorite. Finally, we owe deep

¹ When received at the Museum the meteorite weighed 745 pounds, not 820 pounds, as first reported.

gratitude to President Stanley Field, who purchased the main mass of the Paragould meteorite and presented it to the Museum, thus augmenting the Museum's collection with another rare specimen of an observed fall. As indicated by its structure and composition, Paragould is hardly excelled for studies in cosmic metamorphism of meteorites.

PARAGOULD

Paragould, Green County, Arkansas, U.S.A.

Lat. 36° 4' N., Long. 90° 30' W.

Aerolite, monomict brecciated gray chondrite.

Fell February 17, 4:08 A.M. (C.S.T.), 1930.

Weight 745 pounds.

Catalogue number CNHM-ME 2135.

CIRCUMSTANCES OF THE FALL AND FIND

The Paragould meteorite fell about fourteen miles southeast of Paragould, Green County, northeastern Arkansas, at 4:08 A.M., February 17, 1930.

In spite of the early hour, the light and sound that accompanied the fall were seen or heard by many people over vast areas, comprising parts of southern Illinois (East St. Louis), southeastern Missouri (Poplar Bluff), eastern Kansas (Burlingame), western Tennessee (Ripley), and northeastern Arkansas (Beach Grove, Gainsville, and Paragould). The luminous phenomena that appeared in the northeast were said by some witnesses to resemble a ball of fire with a glowing tail. The detonations, followed by a rumble that rolled away toward the southeast [northeast], were compared to an "explosion like a sharp peal of thunder," or "a blast of dynamite" that jarred houses like an earthquake and stampeded livestock. The following quotation (Wylie, 1930b, pp. 387-388) of the description of the phenomena as related by one of the observers may be accepted as a representative one: "Near Gainsville, Arkansas, Marvin Penny, a farmer, was dressing when he heard the crash of an explosion, seemingly right over his house. He was outdoors at once and heard a noise like thunder rolling, as it seemed, to both northeast and southwest, the roll to the northeast being more pronounced and lasting longer. He saw, in spite of the moonlight, a trail 'like the milkmaid's path' extending from about 30° altitude in the southwest through overhead to near the horizon in the northeast. The trail was visible for perhaps five minutes

in the northeast, where it could be seen the longest. The explosion stampeded Mr. Penny's stock."

According to Wylie, who spared no pains in seeking pertinent information from personal interviews and communications with numerous observers of the fall, the meteor came very nearly from the northeast. It then disappeared over a point a few miles west of the city of Paragould, Arkansas. The altitude of disappearance was estimated to be about five miles but the meteor might have burst into two or three pieces at a height of ten miles. Wylie (1940) also gives the height of appearance of Paragould as fifty-two miles.

Two individual meteorites representing the fall of Paragould were recovered. The smaller one was found only a few hours after the fall by Raymond E. Parkinson, a farmer living near Finch, Arkansas. He noticed a short furrow leading to a hole, about thirty-four inches deep, with fresh lumps of soil spattered some thirty feet to the northeast. Apparently the meteorite struck the ground headlong at a slight angle and grazed it a short distance before coming to rest. Ordinarily, the clods would be thrown in the direction of fall; that is, nearly to the south. The anomaly, as later explained by W. R. Heagler, a civil engineer, who examined the hole, was caused by the downhill slope of the ground. The shape of the stone and the position at the instant of striking might have been other contributing factors. The meteorite was found, as would be expected, with the smooth side (apex) down in the hole and the rough side (rear) up. Soon after the discovery, it was removed to Paragould High School, where it was put on display for a time. It was later purchased by Stuart H. Perry, who has since presented it to the United States National Museum (USNM no. 921). At the time of the find, the meteorite weighed eighty pounds and it was supposedly a complete individual, but before it came into Mr. Perry's possession some unknown persons had chipped off about five pounds from one side of the stone. Ironically, the damage has been rewarding; it has exposed the interior structure, which otherwise is hidden by the fusion crust or can only be indistinctly visible on the crust-free surface. Much of the information about the characteristic features of Paragould was obtained from this fractured area and from an adjoining area, which was polished by Mr. Perry before he donated the meteorite to the National Museum.

It was not until March 16, a month later, that the large mass, now in Chicago Natural History Museum, was discovered, about two and one-half miles distant from the smaller one. W. H. Hodges,



FIG. 111. Paragould meteorite (the smaller individual); $\times 0.25$.

a farmer, living a few miles southwest of Finch, noticed a big hole near his home on land belonging to his neighbor, J. H. Fletcher. Scattering clods of dirt were thrown about the hole but chiefly to the south, not northeast, as in the case of the smaller stone. These clods were plentiful at a distance of thirty feet, although some were thrown as far away as 150 feet. The hole measured eight feet in depth, the bottom deviating about a foot to the southwest. This deviation indicates that the meteor was falling nearly to the south, the direction of its travel.

SHAPE, SIZE AND WEIGHT

The smaller individual has too many irregularities to conform to any standard definition of the shape of a mass. Its front side is somewhat broadly rounded and it is roughly ovoidal in cross section cut through its long diameter (fig. 111). The apex occupies the central portion of the broader rounded side, which is light-colored because of total absence of fusion crust and is smooth, with hardly a suggestion of pitting (fig. 111). At the present time it measures about $17 \times 10 \times 9$ inches and weighs $74\frac{1}{2}$ pounds.

The larger individual also has many irregularities, but in general it resembles an oblique pyramid (figs. 112, 113). Some workmen obviously have hammered off approximately twenty pounds from the north, east, and west edges, along the border of the base of the

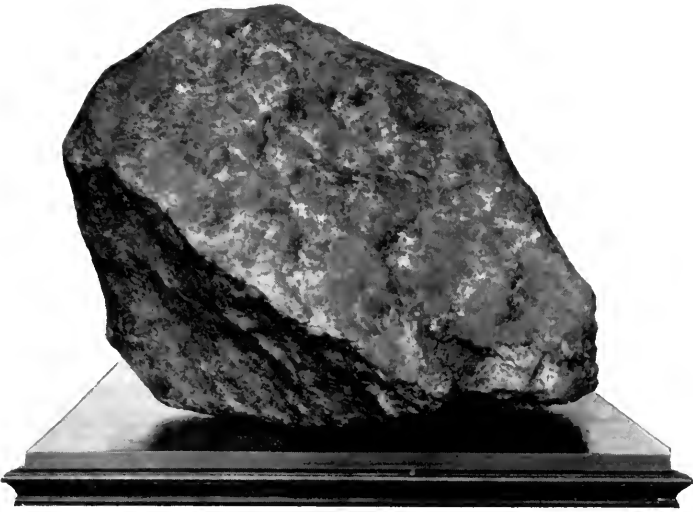


FIG. 112. Paragould meteorite (the larger individual); $\times 0.1$.



FIG. 113. Paragould meteorite (the larger individual); $\times 0.1$.

meteorite to an average height of four inches. The damage does not appear to be the result of impact. There is also an area, a slightly concave triangle, $17 \times 15 \times 23$ inches, one side of which coincides with the boundary of the base. This may be the area where the smaller stone broke away late during the fall. The apex of the meteorite, as shown in the cross sections (fig. 114, A-C), is on the lower left corner, which is rounded and relatively smooth. In its present state, the overall dimensions are: height $21\frac{3}{4}$ inches; length 28 inches; breadth 24 inches. At the time it was received at the Museum, May 29, 1930, it weighed 745 pounds. Since acquiring the meteorite a few fragments weighing 75 grams have been chipped off and used for chemical analysis and thin sections; otherwise it is intact.

CRUST AND SURFACE MARKINGS

Practically the entire surface of the meteorite is coated with fusion crust, which is rough and leathery and has a scale-like semblance (fig. 115). The thickness of the crust varies from a fraction of a millimeter to more than a millimeter. It is thickest at the lateral margins, where the fused materials have dripped from the front and accumulated into incipient slags containing gas cavities. The color of the crust is black mottled with dark gray. Crust-free areas are light gray and smoother.

“Thumb marks” are not as conspicuous or as characteristic as would be expected on a meteorite of this size. Those present are shallow and wide. Some of the marks appear to have coalesced, forming shallower and wider pits. No delicate flight markings or radial pittings have been observed. In fact, the absence of characteristic flight markings make the meteorite appear so much like an ordinary diabase boulder that it could be passed by as an erratic even by the initiated.

The surface is studded with protruding particles of metal and troilite. Megascopically, the latter appear numerous, larger than the metal particles and often drusy. Some of the troilite grains have already oxidized to limonite, leaving scattered reddish brown spots on the surface and contraction cracks.

STRUCTURE

The interior of the meteorite is an intimate mixture of gray and black fragments. It may be pointed out here that neither the gray

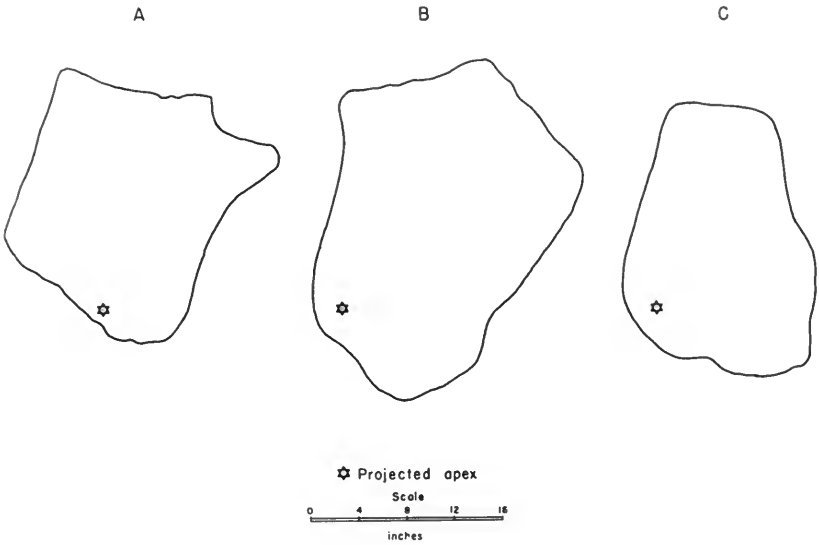


FIG. 114. Cross sections of Paragould meteorite (all sections parallel to base). A, projection 4 inches above base; B, projection 7 inches above base; C, projection 7 inches below apex.

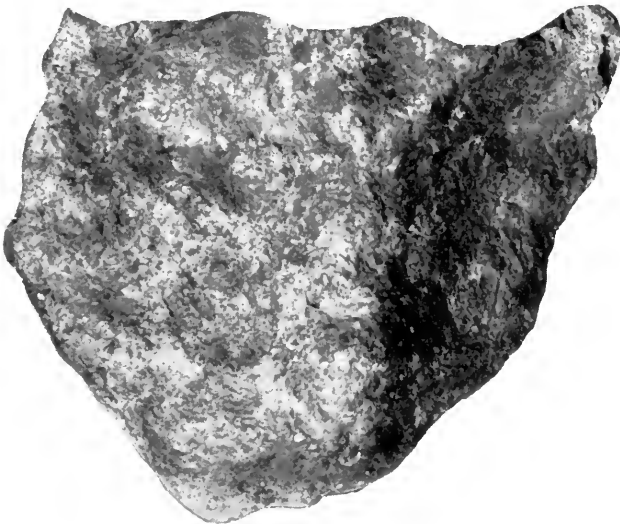


FIG. 115. Portion of surface of Paragould meteorite, showing leathery, scale-like fusion crust; $\times 0.6$.

nor the black fragments are wholly gray or wholly black. The gray may have black veins, and the black, in addition to having black veins, may have gray chondrules and scattered gray specks in the groundmass. These gray specks contain so much fused material that they appear black to the naked eye. It is only in thin sections that the true nature of their color is revealed. In the polished section examined, the gray predominates over the black (fig. 116), but in some of the broken unpolished surfaces this unequal distribution of the two components is not as apparent (fig. 117). All the fragments have a general rounded outline. Angular fragments of both types have been observed, but they do not constitute a common feature.

The stone is hard and compact and it takes an excellent polish. The integration of the black and the gray is complete. There is no line of weakness between the two; one breaks with the other, and both are chondritic. The chondrules are gray, mostly spherical, and of varying size. Because of the contrast of color, they are readily observed in the black fragments.

Black veins, which are numerous, occur both near the margin and in the interior of the stone. They have followed the pattern of the cracks, and hence they are not marked by any orderly arrangement, or by any uniformity of shape. Some are straight, some are curved, others are branching or anastomosing. Still others are swollen at the middle or at the ends. As a rule, the anastomosing veins are the thinnest, from 0.01 to 0.02 millimeters in width, and they generally have a matted appearance.

According to Farrington (1915, p. 88), veins "are apparently produced by the penetration of heat into the fissures of the meteorite during its passage through the atmosphere." He bases his conception of the origin of veins on the similarity in composition between the vein and the substance of meteorites and the resemblance of the vein matter to the crust. Of the cosmic origin of veins, he states: "Earlier writers were inclined to regard the veins of pre-terrestrial origin, but there seems no need to assume this." (loc. cit.).

That veins may be formed by the penetration of heat or by the flowage of fused matter from the surface into the fissures has received wide acceptance. The interior of the meteorites, however, is cold, and these veins cannot be expected to extend far into the bodies from the surface. Thus, veins that have penetrated into the interior and throughout the mass, as in Paragould, Hugoton,

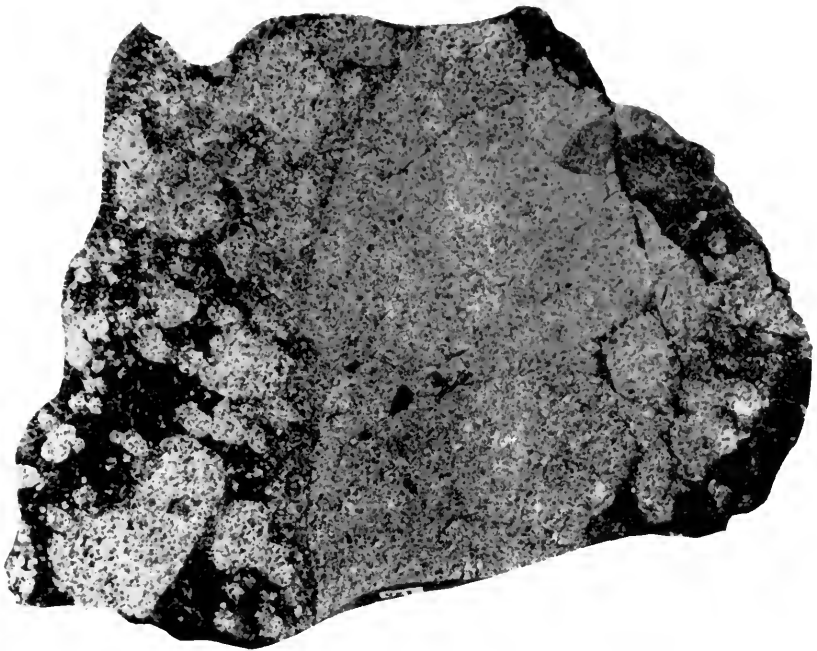


FIG. 116. Polished surface of Paragould meteorite; $\times 0.4$.

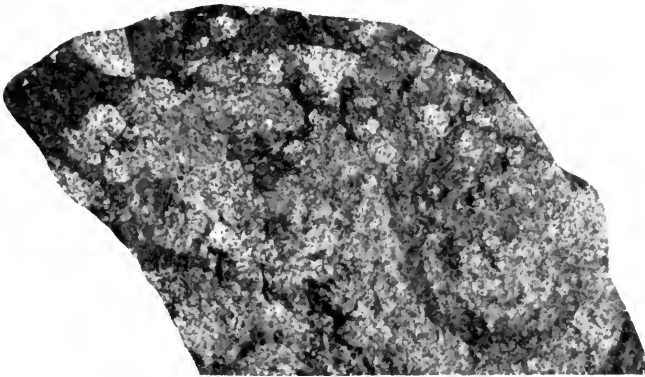


FIG. 117. Broken surface of Paragould meteorite; $\times 0.5$.

Rush, and other polymict and monomict brecciated stones, must have a different origin. A survey of the vein systems in some of these stones and the relationships of the veins to the substance of the matrix, arouses serious doubt that they could have been formed during a few seconds of terrestrial flight of the meteorites.

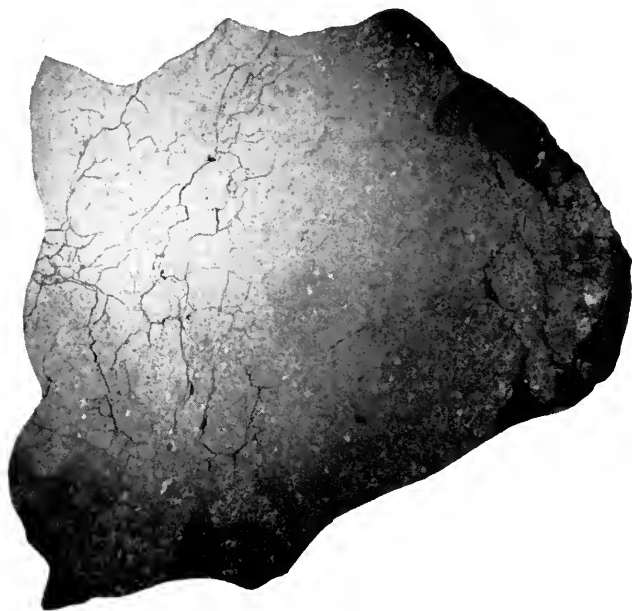


FIG. 118. Paragould meteorite, showing impact cracks; $\times 0.7$.

They rather suggest that they were formed cosmically. It is very likely that there are some metallic veins in this meteorite but none has been observed in the polished section examined.

Besides the black veins, the interior of the meteorite is traversed by narrow, irregular cracks (fig. 118) that appear to have resulted from impact rather than from shock or air pressure during the meteorite's flight.

It has been known and proved experimentally that high temperature blackens the substance of the chondrites, but whether the laboratory technique created conditions similar to those prevailing in the cosmic region is open to question.

In the present study, the blackening of the gray material of the Paragould meteorite was attempted by heating it in a vacuum. This was to eliminate possible oxidation of the specimen.

Two specimens, one unpolished (fig. 119, chip no. 1), the other polished (fig. 120, chip no. 2), each weighing approximately one gram, were used. The specimens were placed in a porcelain boat in a quartz tube. The heavy duty tube furnace was evacuated by a Duo-Seal vacuum pump and attached mercury diffusion pump with a liquid nitrogen cooling trap. The temperature of the furnace was controlled by a Variac rheostat and the temperature measurements were carefully and continually checked by use of a Rubicon potentiometer with attached thermocouple.

Chip no. 1 was first heated for one hour, during which it was examined several times. At temperatures of 700° C. and 900° C. only a minor amount of blackening of the specimen took place, without fusion of any of the constituents, but when it was heated at 1000 C. for another hour the chip appeared lighter in color, due to fusion and spreading of the troilite. This could be clearly seen under fifteen magnifications.

Chip no. 2 was heated directly and continuously to 1000° C. for one hour. No significant changes were observed; the spreading or re-distribution of the troilite was less but more blisters were formed, with the result that the surface of the specimen did not appear as light as chip no. 1 (fig. 119). The difference in behavior of the troilite is attributed to the difference in the surface character of the two; one is rough, with protruding grains of troilite, the other smooth, with grains parallel to the surface.

At no time during the heating period was the melting point of any of the constituents, other than that of troilite, exceeded or even approached. It was also observed that the color and form of the individual gray chondrules were not affected when they were heated to 1000° C.

To summarize the results obtained from this laboratory study:

- (1) Elevation of temperature to 700° C. and 900° C. will produce only minor blackening of the specimen.
- (2) Heating to 1000° C. will cause fusion and re-distribution of disseminated troilite present, but will not cause the silicate constituents to produce veins or any noticeable blackening of the gray matrix.
- (3) It appears that in order to produce any marked blackening or veining, the original gray substance of the chondrites must be heated to temperatures in excess of 1000° C.

Reference has been made to the occurrence of protruding particles of iron and troilite on the surface of the meteorite. These are

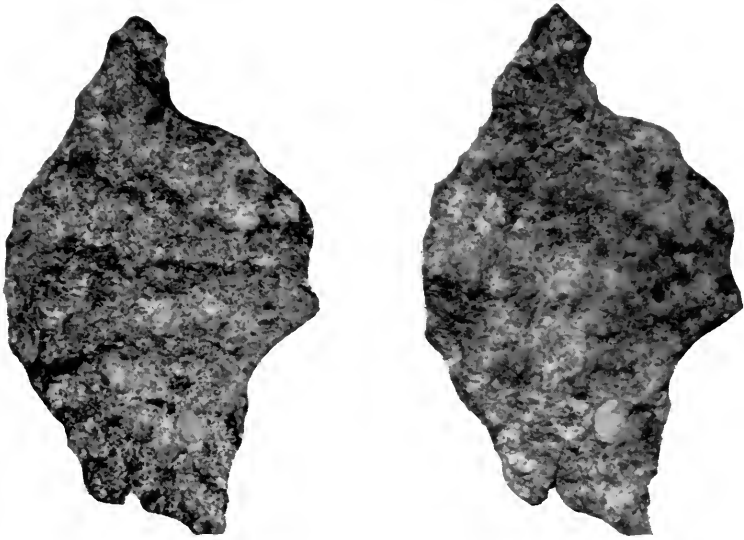


FIG. 119. Chip no. 1. Left, rough surface before heating. Right, after heating to 1000° C. Both $\times 4$.

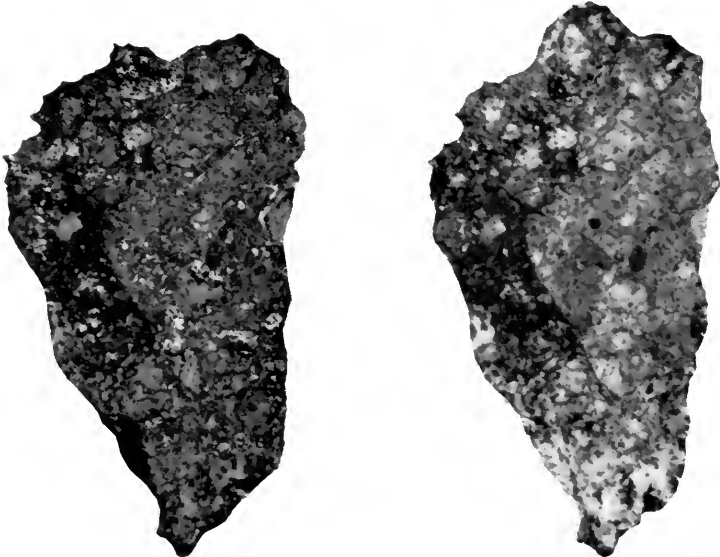


FIG. 120. Chip no. 2. Left, polished surface before heating. Right, after heating to 1000° C. Note troilite "blisters" on polished surface. Both $\times 4$.

clearly seen and readily differentiated in polished sections when properly oriented under reflected light. Some of the troilite nodules and druses are partially encircled by narrow bands of iron. These bands are thought to have formed from traces of iron that had remained soluble in FeS and were rejected when the temperature was lowered. They appear like incipient halos occupying the space formed by the shrinkage of the troilite bodies during their crystallization. In addition to the bands, iron occurs as specks enclosed in troilite. The association of troilite and nickel-iron in the manner stated here cannot be easily accounted for; the two compounds are immiscible and the crystallization temperature of the two is vastly different.

CHEMICAL AND MINERALOGICAL COMPOSITION

The Paragould meteorite has been partially analyzed by K. W. Ray (Wylie, 1930b, p. 391). The following table represents the bulk chemical composition of three samples of the Paragould meteorite as determined in the present study and the average chemical composition of 63 stony meteorites as determined by G. P. Merrill (1930, p. 17):

	I Paragould (gray) Per cent	II Paragould (gray) Per cent	III Paragould (black) Per cent	IV Average of 63 stony meteorites
SiO ₂	39.39	40.39	40.60	38.41
Al ₂ O ₃	2.73	2.58	1.43	2.86
Fe ₂ O ₃	0.43	0.42	0.53	0.92
FeO.....	16.95	17.21	18.45	13.60
MgO.....	24.83	25.51	25.54	23.66
CaO.....	2.00	1.94	1.89	1.88
Na ₂ O.....	1.02	0.93	0.70	0.82
K ₂ O.....	0.13	0.11	0.08	0.16
H ₂ O+.....	0.14	0.16	0.09	0.47
TiO ₂	0.12	0.09	0.10	0.16
Cr ₂ O ₃	0.18	0.14	0.15	0.40
MnO.....	0.34	0.29	0.31	0.23
NiO.....	0.09	0.05	0.07	0.40
CoO.....	0.00	0.00	0.00	0.06
Cl.....	0.00	0.00	0.00	0.03
Fe.....	8.79	7.43	7.21	12.35
Ni.....	0.50	0.37	0.39	1.09
Co.....	0.04	0.03	0.02	0.10
Cu.....	0.01	0.02	trace	0.01
P ₂ O ₅	0.19	0.19	0.10	0.34
P.....	0.02	0.01	0.01	—
S.....	2.04	2.07	1.79	1.89
C.....	0.16	0.10	0.11	0.16
Total.....	100.10	100.04	99.57	100.00

- I. Paragould, gray, CNHM-ME 2135; analyst, R. K. Wyant.
- II. Paragould, gray, USNM 921; analyst, R. K. Wyant.
- III. Paragould, black, USNM 921; analyst, R. K. Wyant.
- IV. G. P. Merrill, Average composition of 63 stony meteorites. Bull. U. S. Nat. Mus., 149, p. 17, 1930.

The normative mineral composition of the Paragould meteorite, as calculated from chemical analysis I, is as follows:

Mineral	Per cent
Feldspar	11.4
Diopside	5.0
Olivine	53.3
Hypersthene and/or iron rich enstatite	15.6
Metal	5.8
Troilite	5.6
Chromite, ilmenite, merrillite	0.9
Total	97.6
Specific gravity	3.47

The most significant feature of the three chemical analyses of the Paragould meteorite is the striking degree of similarity between the gray and black components of the meteorite.

Comparison of the Paragould meteorite analyses with the average chemical composition of 63 stony meteorites shows that the chemical composition of the silicate portion and the troilite content of the Paragould meteorite are about the same as those given for the average stony meteorite. The Paragould meteorite, however, is decidedly low in the percentage of metal (iron, nickel, etc.). Since most analyses of meteorites were made by carefully avoiding visible grains of troilite, it is possible that the troilite content of the average stony meteorite is not truly representative. In that case, the comparison made here is subject to error.

MINERALOGICAL COMPOSITION

Of the silicates, olivine is the most abundant constituent mineral. It occurs both in the groundmass and in the chondrules as minute grains, as fragments, and as euhedral and anhedral crystals. Next in abundance are pyroxene and feldspar. Normative mineral composition gives: olivine 53.3 per cent, pyroxene 20.6 per cent, and feldspar 11.4 per cent. The percentage of feldspar is far in excess of what could be determined petrographically. It may be that much of the feldspar has passed into maskelynite; at least, there is a mineral that answers to the description of maskelynite. It is colorless,

transparent, and semi-vitreous, with index of refraction equal to that of Canada balsam. Between crossed nicols it is, however, not quite isotropic. There may be other individual grains that have completely passed into maskelynite; the history of the meteorite points favorably to such a change.

The pyroxene is practically all enstatite. A neutral-colored mineral which is faintly pleochroic and which exhibits other char-

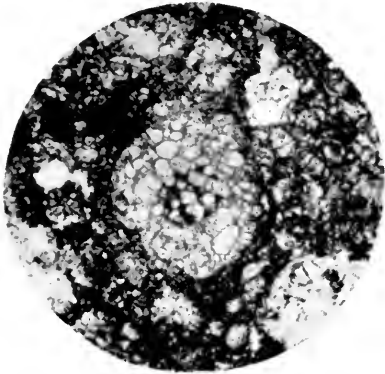


FIG. 121. Olivine chondrule with fused matter at center; ordinary light. Note adjacent metal phases. $\times 24$.

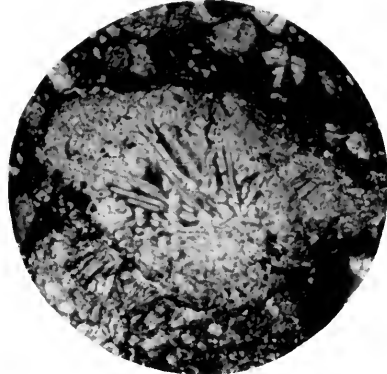


FIG. 122. Olivine chondrule, partially barred and radiating; crossed nicols; $\times 24$.

acteristic features of hypersthene has been observed, but it is optically negative. The mineral may be diopside, although X-ray analysis of the acid insoluble residue showed lines of orthorhombic pyroxene only. Like olivine, the pyroxene occurs both in the groundmass and in the chondrules. In the brecciated groundmass and in areas surrounding the chondrules, dust-like particles of certain minerals are so intimately mixed that none of the constituents could be specifically identified. They may be chiefly olivine and pyroxene.

The chondrules are of the kind found in many other stones. They vary in size and shape and in types (figs. 121-126). Some are composed of olivine, some of pyroxene, others of a mixture of both. All, or practically all, contain fused matter. Some chondrules are fused (fig. 126), yet they are, like the fused matrix, neither vitreous nor wholly isotropic. Whether the chondrules occur in the black or gray matrix, they are structurally and mineralogically the same.

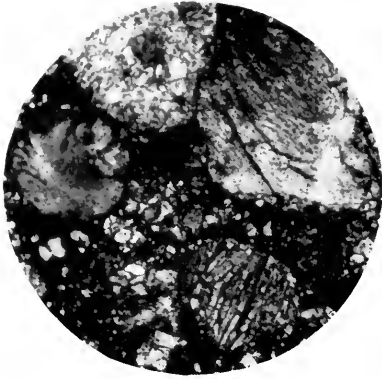


FIG. 123. Olivine (barred and crystalline) and enstatite (fibrous) chondrules within a black groundmass; crossed nicols; $\times 24$.



FIG. 124. Eccentrically radiating enstatite chondrule in black matrix; crossed nicols; $\times 24$.



FIG. 125. Portion of enstatite chondrule with multiple centers of crystallization; crossed nicols; $\times 24$.

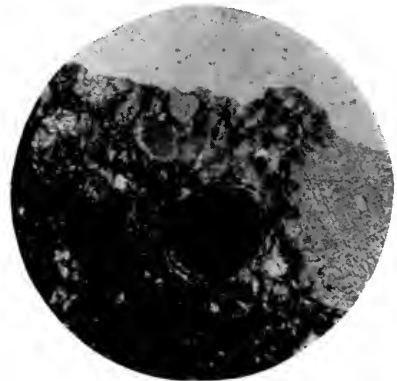


FIG. 126. Thermo-metamorphosed chondrule (black) enclosed in fused and unfused groundmass; ordinary light; $\times 24$.

Between crossed nicols, the chondrules in the black matrix appear brighter and more prominent by contrast.

The accessory minerals shown in the table of normative mineral composition have not been identified. The presence of excess fused matter, in both the gray and the black matrix, has rendered their identification impractical.

COSMIC METAMORPHIC HISTORY

At first sight Paragould appears to be a polymict breccia,¹ composed of two apparently unlike materials, one black, the other gray, but on closer examination it is found that the polymict character is deceptive; the meteorite is actually a monomict breccia,² the black and the gray materials being of the same composition. Further studies indicate that the black material is not foreign to the gray but that it was derived from the latter by thermometamorphism and rapid cooling.

Except for the determination of the composition of the fragments by chemical and petrographic means, brecciated stony meteorites, which have undergone repeated metamorphism, are perhaps best studied on large polished sections. It is on such sections that the characteristic features are more clearly seen and better examined. Were it not for a large polished surface of the Paragould, approximately $9\frac{1}{4} \times 9\frac{1}{2}$ inches (USNM no. 921), which was made available to us for studying the relationship and distribution of the black and gray components, it would have been well nigh impossible to formulate an opinion of the changes it has passed through to attain its present form and structure.

The metamorphic history of Paragould, as can be inferred from the character of its brecciation and the composition of the fragments, appears to be that originally Paragould was a compact homogeneous gray chondrite. It was subsequently subjected to strong external or internal strains, or both, which damaged its mass and filled it with cracks and fragments. Later on, a portion of the mass became heated to well above the melting point so that the molten material was sufficiently fluid to invade and fill the cracks and larger openings between the fragments. It also digested the sharp corners of the gray fragments, imparting to them a general rounded outline. Finally, the molten material solidified as black veins and other semi-glassy irregular areas. The stone might have suffered some further crushing and consolidation after its major metamorphic features were developed. This is indicated by a few small angular fragments of the black material enclosed in the gray matrix. Some of these fragments appear to be isolated; at least, there are no visible connecting veins or passageways through which the black material

¹ As defined by Wahl (1952, p. 91) polymict breccias are those "in which the enclosed fragments are of a foreign material as compared with the surrounding principal mass of the stone."

² Monomict breccias are those "in which the enclosed fragments are of the same material as the surrounding principal mass of the stone." (Wahl, loc. cit.)

might have been injected to account for the presence of the isolated fragments.

The above brief account is an attempt to reconstruct the sequence of the metamorphic history of Paragould. The reconstruction is largely based upon observations made on polished and broken surfaces of the meteorite and on analogy to metamorphism in terrestrial rocks. It is, however, realized that the processes of terrestrial and cosmic metamorphism might not have been the same. Thus, no interpretation of the metamorphic history of a meteorite, bearing stronger evidence than that presented here, could be conclusive or be accepted unreservedly. Nevertheless, we have a meteorite, namely, Paragould, made up of materials of unlike appearance—black and gray—but of the same composition. This is not a case where the black fragments are foreign to the gray matrix; it is one in which the former have been derived from the latter by thermometamorphism. It is also manifest that the injected material upon solidification has formed veins and other irregularly formed bodies, giving the meteorite a mottled appearance, which simulates a polymict breccia. That the Paragould meteorite is a product of metamorphism and that it has passed through more than one cycle of alteration cannot be questioned; whether or not the sequence of its metamorphic history has been correctly interpreted is, of course, open to question.

In an important article, Walter Wahl (1952, pp. 91–117), divides the brecciated stony meteorites into two kinds, and proposes the names, monomict and polymict breccias (see footnotes, p. 299). He further subdivides polymict breccias into “polymict brecciated chondrites, which have undergone metamorphic alterations during their cosmic history” (op. cit., p. 109) and names three meteorites, Plainview, Rush Creek, and Hugoton, as examples. Referring to these meteorites he states (loc. cit.): “We know, however, of a large number of chondrites which do not contain foreign fragments, and are not brecciated in the same way as the stones described above, but which have been altered and metamorphosed after they were formed. In certain cases the stones have evidently, during their cosmic period, been cracked and molten material thereupon injected in cracks. This has solidified in the cracks, forming ‘veins’ which in some cases are quite thin, in others broad, and often branching and spreading into finer veins.” Again (p. 112), in connection with the marble-like structure of the Rush Creek meteorite, he states: “Later on, during its cosmic evolution, it has become heated at one or more times, as a result of which portions have been entirely

molten and the molten mass spread in cracks in the stone, solidifying in the cold portions as glassy veins."

Much of Wahl's interpretation, as quoted here, applies very closely to the cosmic history of Paragould. But the question arises: Can the Paragould meteorite, or any meteorite whose cosmic history is similar to that of Paragould, be classed as a polymict breccia?

As stated earlier, the only major changes that Paragould has undergone during the metamorphism since its brecciation were the re-melting and blackening of a portion of the original gray mass and penetration of the molten black material into that mass. No differences in the chemical or mineralogical composition of the black and gray fragments of the meteorite have been observed.

The term polymict, when applied to brecciated stones, implies that the stones contain fragments, the composition of which is different from that of the groundmass, regardless of whether the differences are due to introduction of foreign materials or to metamorphism *in situ*. Since there have been no changes in the composition of the original material of Paragould by either of these two modes, it is clear that the stone, in spite of its polymict appearance, is not a polymict breccia. Previous to metamorphism it was a monomict breccia and it still is—one that has retained its monomict characters despite metamorphism. It is thus appropriate to call it a monomict brecciated gray chondrite.

Of the Plainview, Rush Creek, and Hugoton, which are classed by Wahl as polymict breccias that have undergone alterations by metamorphism, Hugoton resembles Paragould most closely, especially with regard to the distribution and relationship of the dark and light materials, but the contrast between these two materials in Hugoton, as seen in a polished section (figs. 127, 128), is not nearly as pronounced as that observed in Paragould (fig. 116). The reason for this is that Hugoton, having remained buried for an unknown period of time, has suffered extensive weathering, and limonitization has penetrated so deeply into the interior as to give the stone, in general, a dark, rusty brown color. Perhaps it is for this secondary coloration that the stone has been called a black chondrite (Wahl, 1952, p. 113). But it is not a black chondrite, nor is the brecciation "due to unequal weathering." (H. H. Nininger, *Trans. Kansas Acad. Sci.*, 1936, 39, p. 175.) The lighter areas were originally gray; the darker areas consist of material that was injected into the cracks subsequent to the brecciation of the mass. In general, the stone seems to have had a cosmic history comparable

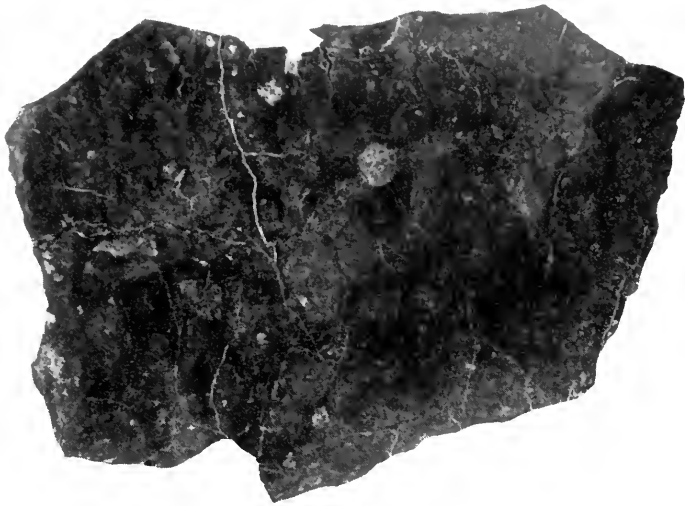


FIG. 127. Polished surface of Hugoton meteorite; direct light photograph. Note large black brecciated and veined areas. $\times 0.5$.



FIG. 128. Polished surface of Hugoton meteorite; reflected light photograph. Small white veins are black in direct light. $\times 0.5$.

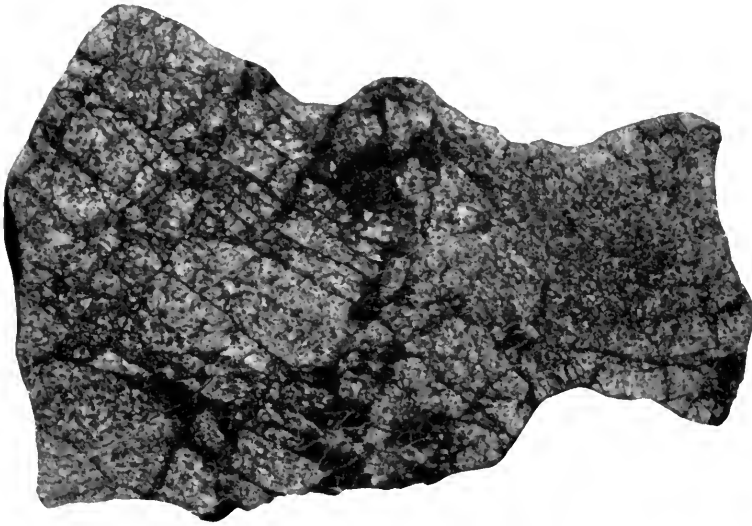


FIG. 129. Polished surface of Walters meteorite. $\times 0.5$.

to that of Paragould. Hugoton may also be a monomict rather than a polymict breccia, but this is a question that cannot be answered with the data presently available. We have at our disposal thin sections of Hugoton prepared from what appears to be chiefly the lighter material but we have none from the darker areas with which to compare for mineralogical differences between the two, if any. In fact, the integration of the black and the gray is so complete and widespread and the boundaries between the two are so indistinct that it is not easy to break a piece separately for sectioning. The manner of integration also indicates that Hugoton has undergone at least one more cycle of heating and reconsolidation than has Paragould. To resort to chemical means to determine the composition of the two areas in Hugoton is likely to be still more unsatisfactory, for oxidation, leaching, and infiltration have been much too active to permit of a reliable analysis. An analysis of Hugoton as a whole, by F. G. Hawley (*Trans. Kansas Acad. Sci.*, 1936, **39**, p. 175), may be consulted in this connection.

It seems that in this particular case, and in cases similar to that of Hugoton, the problem may have to be predicted not on chemistry nor on mineralogy, but chiefly on critical examination of the nature of the distribution and relationship of the darker and lighter material on a polished surface.

To our knowledge, the stone that compares most favorably with Paragould is the Walters meteorite (fig. 129). According to the information received from the United States National Museum, the Walters meteorite fell at Walters, Cotton County, Oklahoma, at 3:45 P.M., July 28, 1941. The meteorite has not yet been described but it shows a striking similarity in the distribution of its black and gray components to the Paragould stone (figs. 116, 129). The cosmic histories of the two were presumably the same.

As in terrestrial rocks, the structure, distribution, and relationships of the various components of meteorites cannot be divorced from the question of origin, for these are factors that may explain the conditions under which the meteorites were formed.

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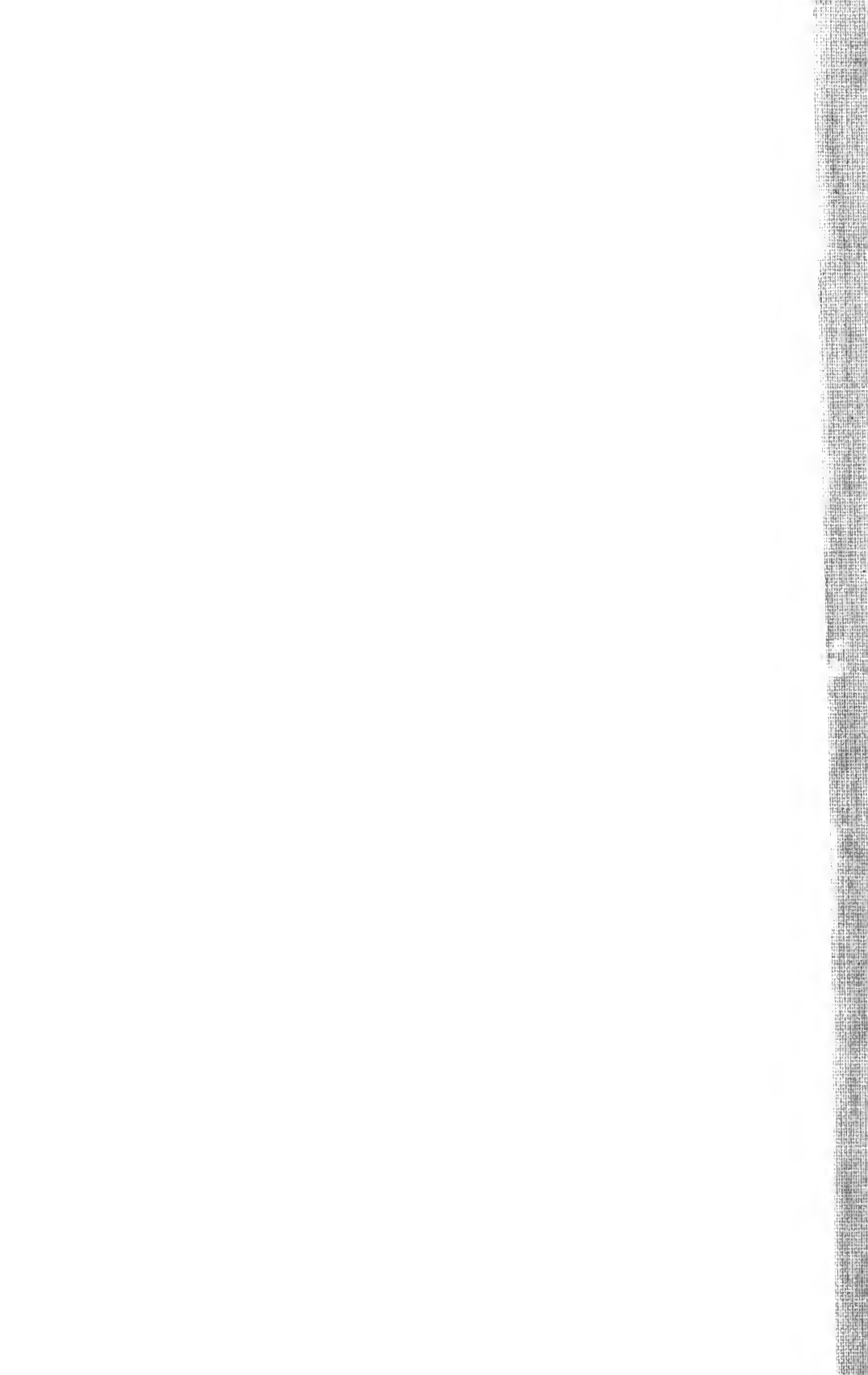
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