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The Composition of the Forest City, Tennasilm, Weston, and Geidam Meteorites

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THE FOREST CITY METEORITE

This meteorite fell as a shower of stones at 5.15 P.M. on May 2, 1890, over an area 1 mile wide and 2 miles long, centered at latitude 43° 20′ N., longitude 93° 45′ W., about 11 miles northwest of the town of Forest City, Winnebago County, Iowa. Two large stones, weighing 34 kilograms and 30 kilograms, and thousands of smaller ones ranging from 5 kilograms down to a few grams, were recovered; the total weight was about 122 kilograms. The largest stone is in the collection of the American Museum; it is roughly rectangular in form, some 35 cm. by 35 cm. by 16 cm. (fig. 1). The second large stone is in the University of Minnesota. Material from the meteorite is widely distributed in collections. The Chicago Natural History Museum has more than 700 complete stones, with a total weight of 22 kilograms, and Yale University has about 1000 stones, with a total weight of nearly 30 kilograms.

The Forest City meteorite was described by Kunz (1890), and there are numerous references to it in the more recent literature. Material of this meteorite has been extensively used in recent years for trace-element determinations. Since it is a typical olivine-bronzite chondrite, we de-

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cided to make a chemical and mineralogical analysis of it, selecting for this purpose a stone (No. 2405) from the collection of the American Museum of Natural History.

Mineralogical Composition and Structure

The principal minerals in the Forest City meteorite are olivine and orthopyroxene. Other characteristic minerals are nickel-iron, plagioclase

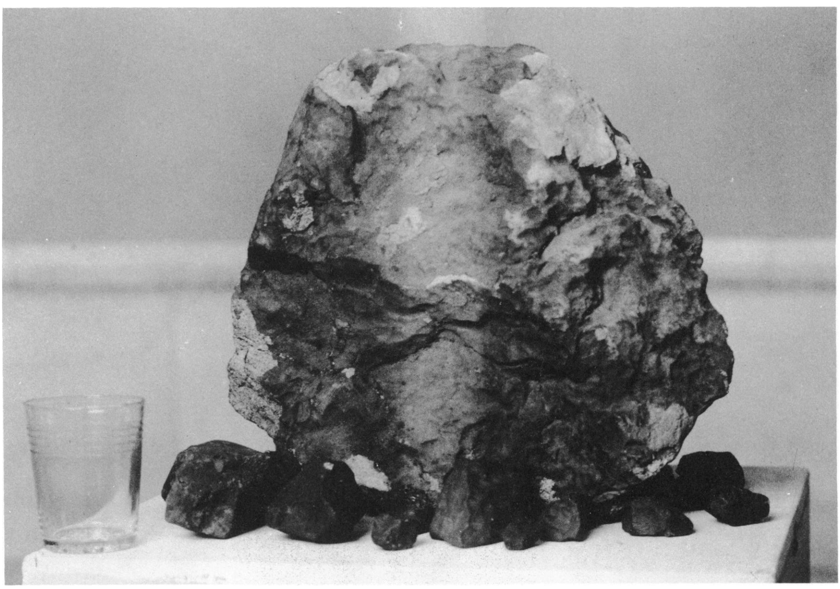

Fig. 1. The largest stone of the Forest City meteorite, together with some of the smaller stones.

feldspar, and troilite. Minor and accessory minerals include chromite, a phosphate mineral (apatite or merrillite, or both), ilmenite, and native copper (in trace amounts). Notes on some of the minerals follow.

Olivine: The refractive indices are $\alpha = 1.674$, $\gamma = 1.708$, indicating a content of 19 mole per cent of the Fe_2SiO_4 component, according to the determinative curve of Poldervaart (1950). By the X-ray method of Yoder and Sahama (1957) the composition was found to be 19 mole per cent of the Fe_2SiO_4 component. The olivine peaks on the diffractometer chart are sharp and well defined, indicating olivine of uniform composition. Keil and Fredriksson (1964), by microprobe analysis, report 18.4 mole per cent Fe_2SiO_4 in the olivine.

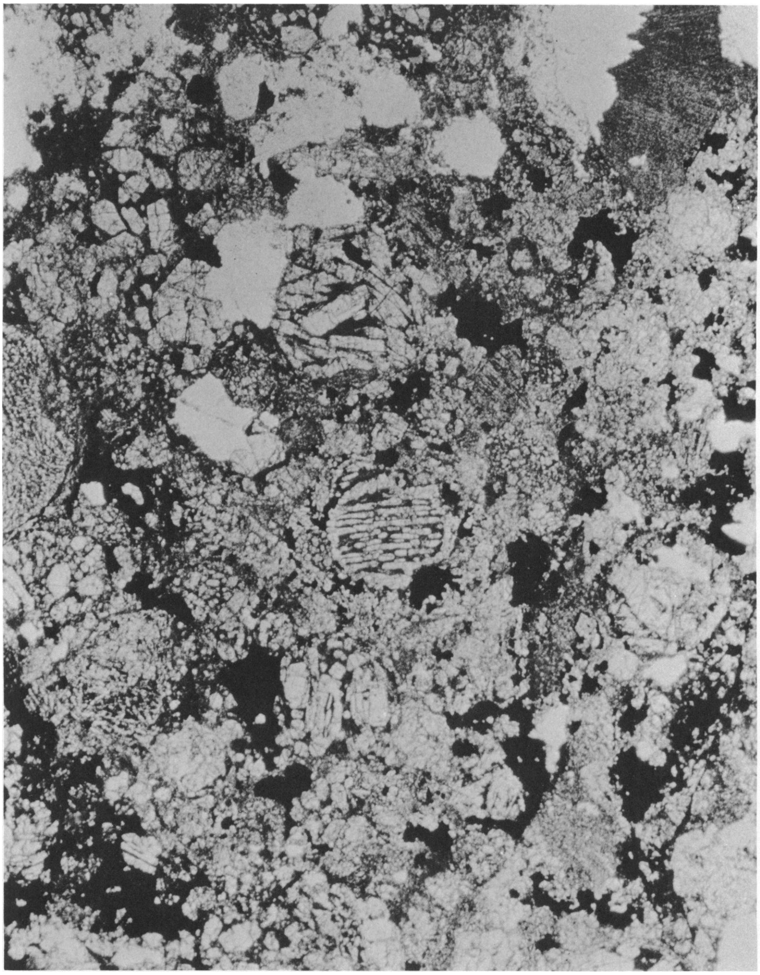

FIG. 2. Photomicrograph of a thin section of the Forest City meteorite, showing chondrules of olivine and pyroxene (gray); black is nickel-iron and troilite, white holes in the section. The diameter of the barred chondrule in the center is 0.5 mm.

ORTHOPYROXENE: The refractive indices are $\alpha = 1.673$, $\gamma = 1.683$, indicating a content of 16 mole per cent of the $FeSiO_3$ component, according to the determinative curve of Kuno (1954). Keil and Fredriksson (1964) report the Fe/Fe+Mg mole percentage of the orthopyroxene to be 16.0. In terms of the conventional subdivision of meteoritic orthopyroxene, this falls in the composition range of bronzite. The acid-in-

TABLE 1
CHEMICAL COMPOSITION OF THE FOREST CITY METEORITE

A		B		C	
Fe	16.21	Fe	27.20	Si	33.46
Ni	1.65	Si	17.31	Mg	31.80
Co	0.10	Mg	14.24	Fe	26.45
FeS	5.21	S	1.90	Al	2.22
SiO_2	37.06	Ni	1.65	Na	1.74
TiO_2	0.15	Ca	1.24	Ca	1.70
Al_2O_3	2.09	Al	1.11	Ni	1.52
FeO	9.89	Na	0.73	Cr	0.38
MnO	0.28	Cr	0.37	P	0.26
MgO	23.62	Mn	0.22	Mn	0.21
CaO	1.75	P	0.15	Ti	0.10
Na_2O	0.99	Co	0.10	Co	0.09
K_2O	0.07	Ti	0.09	K	0.07
P_2O_5	0.34	K	0.06		100.00
H_2O+	0.39	H	0.04		
H_2O-	0.00	(O	33.59)		
Cr_2O_3	0.54		100.00		
	100.34				

A Chemical analysis expressed as nickel-iron, troilite, and oxides
B Chemical analysis expressed as elements, with oxygen added to make 100 per cent
C Chemical analysis expressed as atom percentages, with the elimination of H, O, and S

soluble concentrate of orthopyroxene and plagioclase also contains some fine-grained material tentatively identified as clinobronzite.

PLAGIOCLASE: The plagioclase feldspar is fine grained and turbid, and only a mean refractive index, 1.536, could be measured; this corresponds to a composition about An_{10}.

NICKEL-IRON: Both kamacite and taenite are present.

Forest City is a markedly chondritic meteorite, the chondrules ranging from 0.3 mm. to 2 mm. in diameter (fig. 2). The chondrules are made up of olivine and pyroxene and show a variety of internal structure. Many of the olivine chondrules consist of numerous idiomorphic olivine crystals in a turbid groundmass of lower refractive index and low birefringence, possibly plagioclase. Barred olivine chondrules, the bars consisting of this same turbid material, are occasionally seen. The pyroxene chondrules are usually much finer grained than the olivine chondrules and appear to be made up of a large number of very thin plates. The nickel-iron and the troilite seem to be confined to the groundmass between the chondrules.

The density of a piece of Forest City was determined by measuring the apparent loss of weight on suspension in carbon tetrachloride (after evacuation under a bell jar by an oil pump to remove air) and found to be 3.72.

Chemical Composition

The chemical analysis is given in table 1, in the conventional form expressed as metal, troilite, and oxides; in terms of the individual elements as determined by analysis, with oxygen added to bring the total to 100; and recalculated in atom percentages with the elimination of H, O, and S. The conventional form of presenting meteorite analyses involves certain assumptions, for example, that all S is present as FeS, that Fe in excess of free metal and FeS is present as ferrous iron, that all Ni and Co are present in the metal phase. These assumptions are probably valid for the Forest City meteorite.

TABLE 2
Normative Composition of the Forest City Meteorite

Olivine	35.3
Bronzite	25.2
Diopside	4.3
Albite	8.4
Anorthite	1.0
Orthoclase	0.4
Apatite	0.8
Chromite	0.8
Ilmenite	0.3
Troilite	5.2
Nickel-iron	18.0

The second procedure for expressing the analysis reflects more closely the results actually obtained by the analysis. In effect, the chemical analysis determines the amounts of the different elements, except oxygen, no readily applicable method for this element being available. The results obtained are then recast in the conventional form with the assumptions outlined above.

The expression of the analysis as atom percentages after the elimination of H, O, S (and C, if present) was used by one of us (Wiik, 1956) for comparing analyses of different types of chondrites. Such a procedure in effect distinguishes non-volatile elements from those likely to be lost or gained during heating in extraterrestrial environments. The figures for

Forest City show that its composition is closely similar to Wiik's group of chondrites with 15–19 per cent of metallic iron. These are the olivine-bronzite chondrites of Prior's classification (1920), and they belong to the high-iron (H) group of Urey and Craig (1953).

The normative mineral composition, expressed in weight percentages, is given in table 2. The observed mineral composition, determined by point-counting a polished surface, is: nickel-iron, 18.2 per cent; troilite, 5.4 per cent; chromite, 0.6 per cent; silicates, 75.8 per cent, which corresponds well to that calculated as the norm. The proportion of olivine to pyroxene agrees with estimates from thin sections and X-ray diffraction patterns.

Many determinations of minor and trace elements have been made on material of the Forest City meteorite. The following list of published figures (all in parts per million) is probably incomplete:

Sc, 8.9 (Bate *et al.,* 1960); Ti, 660 (Moore and Brown, 1962); V, 78 (Wiik, unpublished); Cr, 2000 (Bate *et al.,* 1960); Mn, 2250 (Moore and Brown, 1962); Cu, 86 (Wiik, unpublished); Ge, 4.45 (Shima, 1964); Se, 8.6 (Schindewolf, 1960); Rb, 2.71 (Gast, 1962), 2.88 (Smales *et al.,* 1964); Sr, 10.2 (Gast, 1962); Ru, 0.14 (Wiik, 1965); Rh, 0.21 (Schindewolf and Wahlgren, 1960), 0.14 (Wiik, 1965); Pd, 0.76 (Wiik, 1965); Ag, 0.13 (Schindewolf and Wahlgren, 1960); In, 0.0010 (Schindewolf and Wahlgren, 1960); Sn, 0.08 (Shima, 1964); Te, 0.46 (Schindewolf, 1960); Cs, 0.102 (Smales *et al.,* 1964); Ba, 3.3 (Reed *et al.,* 1960), 4 (Moore and Brown, 1963); Eu, 0.073 (Bate *et al.,* 1960); Ta, 0.023 (Atkins and Smales, 1960), 0.027 (Ehmann, 1965); W, 0.18 (Amiruddin and Ehmann, 1962); Os, 0.16 (Wiik, 1965); Ir, 0.57, 0.50 (Rushbrook and Ehmann, 1962), 0.44 (Wiik, 1965); Pt, 0.98 (Wiik, 1965); Au, 0.28 (Wiik, 1965); Pb, 0.4 (Patterson, 1955); Th, 0.2 (Patterson, 1955), 0.0387 (Bate *et al.,* 1959); U, 0.06 (Patterson, 1955), 0.0103 (König and Wänke, 1959), 0.0099 (Hamaguchi *et al.,* 1957), 0.015 (Reed *et al.,* 1960).

THE TENNASILM METEORITE

This meteorite fell on June 28, 1872, near the village of Tennasilm in Estonia. The circumstances of the fall and the recovery of the material were described by Schilling (1882), who made a chemical analysis and identified the minerals. A single stone weighing about 28 kilograms was found some days after the observation of the fall. The coordinates of this find, which are marked on a map by Grewingk (1878), are latitude 58° 49′ N., longitude 25° 27′ E., not latitude 58° 2′ N., longitude 26° 57′ E., as given in the Prior-Hey catalogue (1953) and Krinov (1960). The stone was broken up by gypsies, and pieces were acquired by local peasants (it was believed to be a good protection against animal sickness). However, Schilling succeeded in recovering most of the pieces, from which he was able to reconstruct the original form and weight.

Wülfing (1897) was able to account for about 23 kilograms of this meteorite, of which more than 12 kilograms were still in Schilling's possession. Small amounts are widely distributed in collections. Major portions are some 4 kilograms in the Yale University collection, 3 kilograms in the collection of the Estonian Academy of Sciences, 3.5 kilograms in the Naturhistorisches Museum in Vienna, and 1 kilogram in the United States National Museum, Smithsonian Institution, Washington. The American Museum of Natural History has three pieces, with a total weight of 179 grams; material from one of these pieces (No. 3893) was used in this investigation.

Mineralogical Composition and Structure

The principal minerals in the Tennasilm meteorite are olivine and pyroxene. Other characteristic minerals are nickel-iron, plagioclase, feldspar, and troilite. Minor and accessory minerals include chromite and a phosphate mineral (apatite or merrillite, or both). Notes on some of the minerals follow.

Olivine: The refractive indices are $\alpha = 1.680$, $\gamma = 1.715$, indicating a content of 23 mole per cent of the Fe_2SiO_4 component, according to the determinative curve of Poldervaart (1950). This was confirmed by the X-ray method of Yoder and Sahama (1957), which gave the same composition. The olivine peaks on the diffractometer chart are sharp and well defined, indicating olivine of uniform composition.

Pyroxene: Much of the pyroxene is orthopyroxene, although some polysynthetically twinned clinopyroxene is also present. The refractive indices of the orthopyroxene are $\alpha = 1.677$, $\gamma = 1.688$, indicating a content of 20 mole per cent of the $FeSiO_3$ component, according to the determinative curve of Kuno (1954). In terms of the conventional subdivision of meteoritic orthopyroxene, this falls in the composition range of hypersthene. The indices of the clinopyroxene are similar to, or a little lower than, those of the orthopyroxene. The clinopyroxene is either clinohypersthene or pigeonite, the exact classification depending upon the chemical composition.

Plagioclase: Much of the plagioclase (isolated from an acid-insoluble residue of the meteorite by density separation) is very fine grained and turbid, which makes refractive index determinations difficult. On the most suitable grains, $\alpha = 1.531$, $\gamma = 1.539$, corresponding to albite with composition about An_7.

The structure of Tennasilm is markedly chondritic, the chondrules ranging in diameter from about 0.4 mm. up to 2 mm. (fig. 3). The chon-

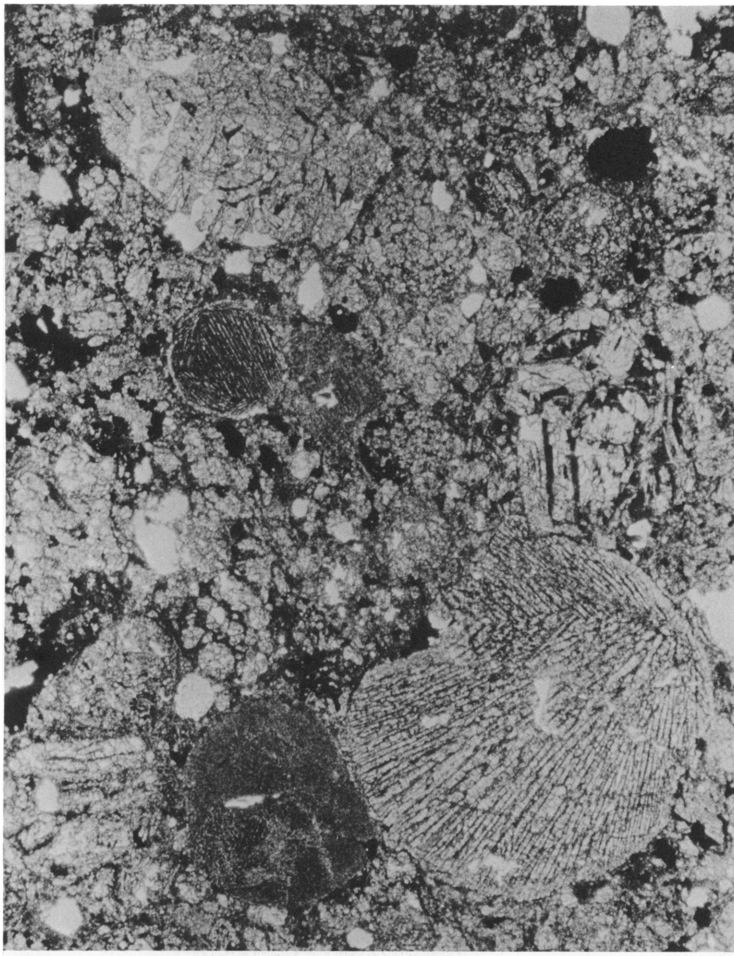

FIG 3. Photomicrograph of a thin section of the Tennasilm meteorite, showing chondrules of olivine and pyroxene (gray); black is nickel-iron and troilite, white holes in the section. The diameter of the largest chondrule is 2 mm.

drules are made up of olivine and pyroxene and show a variety of internal structure. Barred olivine chondrules are not uncommon, the bars consisting of turbid material which appears to be isotropic. Chondrules consisting of idiomorphic olivine crystals in this turbid groundmass are also common. The pyroxene chondrules usually show the typical eccentric radiating structure. The nickel-iron and troilite are virtually confined to

TABLE 3
CHEMICAL COMPOSITION OF THE TENNASILM METEORITE

A		B		C	
Fe	9.24	Fe	21.69	Si	36.52
Ni	1.13	Si	18.74	Mg	33.61
Co	0.06	Mg	14.94	Fe	21.25
FeS	6.33	S	2.31	Al	2.54
SiO_2	40.13	Ca	1.42	Ca	1.95
TiO_2	0.15	Al	1.25	Na	1.91
Al_2O_3	2.37	Ni	1.13	Ni	1.06
FeO	10.85	Na	0.80	Cr	0.38
MnO	0.31	Cr	0.37	P	0.31
MgO	24.77	Mn	0.24	Mn	0.24
CaO	2.00	P	0.17	Ti	0.10
Na_2O	1.08	Ti	0.09	K	0.08
K_2O	0.07	K	0.06	Co	0.05
P_2O_5	0.40	Co	0.06		100.00
H_2O+	0.51	H	0.06		
H_2O-	0.03	(O	36.67)		
Cr_2O_3	0.54		100.00		
	99.97				

A Chemical analysis expressed as nickel-iron, troilite, and oxides
B Chemical analysis expressed as elements, with oxygen added to make 100 per cent
C Chemical analysis expressed as atom percentages, with elimination of H, O, and S

the areas between the chondrules, and some of the chondrules are partly mantled with grains of nickel-iron.

The density of this meteorite, determined as described for Forest City, is 3.56.

CHEMICAL COMPOSITION

The chemical analysis is given in table 3, in the conventional form expressed as metal, troilite, and oxides; in terms of the individual elements as determined by analysis, with oxygen added to bring the total to 100; and recalculated in atom percentages, with the elimination of O, H, and S. A discussion of these procedures is given under the description of the Forest City meteorite.

The composition of the Tennasilm meteorite shows that it is an olivine-hypersthene chondrite in Prior's (1920) classification. The total iron content, 21.69 per cent, is that of a low-iron (L) group chondrite of Urey and Craig (1953). Tennasilm is noteworthy in having a somewhat lower FeO and higher Fe content than most olivine-hypersthene chondrites.

The normative mineral composition, expressed as weight percentagets, is given in table 4. The actual mineral composition, obtained by point-counting a polished surface, is nickel-iron, 11.1 per cent; troilite, 4.0 per cent; chromite, 0.5 per cent; and silicates, 84.4 per cent. This is in good agreement with the norm. The proportion of olivine to pyroxene is consistent with estimates from thin sections and X-ray diffraction patterns. No diopside was seen, but the small amount of this component is presumably in solid solution in the hypersthene and clinohypersthene.

TABLE 4
NORMATIVE COMPOSITION OF THE TENNASILM METEORITE

Olivine	36.2
Hypersthene	28.7
Diopside	4.7
Albite	9.1
Anorthite	1.4
Orthoclase	0.4
Chromite	0.8
Apatite	0.9
Ilmenite	0.3
Troilite	6.3
Nickel-iron	10.4

THE WESTON METEORITE

The Weston meteorite fell near Weston, Connecticut, at 6.30 A.M. on December 14, 1807. A shower of stones fell along a zone about 10 miles long. The largest stone weighed about 90 kilograms, and the total weight was probably about 135 kilograms. The phenomena of the fall and the nature of the meteorite were carefully described by Silliman and Kingsley of Yale College (1809). This occurrence was noteworthy; it is the oldest recorded meteorite fall within the United States and came at a time when the reality of such occurrences was still not generally accepted. As Farrington (1915, p. 12) remarked: "Especial interest attaches to the circumstances of this fall on account of the fact that the possibility of such an occurrence was at that time scarcely believed and the general opinion was expressed by the President of the United States, Thomas Jefferson, in the remark that it was easier to believe that Yankee professors would lie than to believe that stones would fall from Heaven. Subsequent evidence has, however, left no doubt that the Yankee professors (Profs. Silliman and Kingsley of Yale), as well as other historians of the fall, were describing a real occurrence."

Silliman and Kingsley commented on the difficulties they experi-

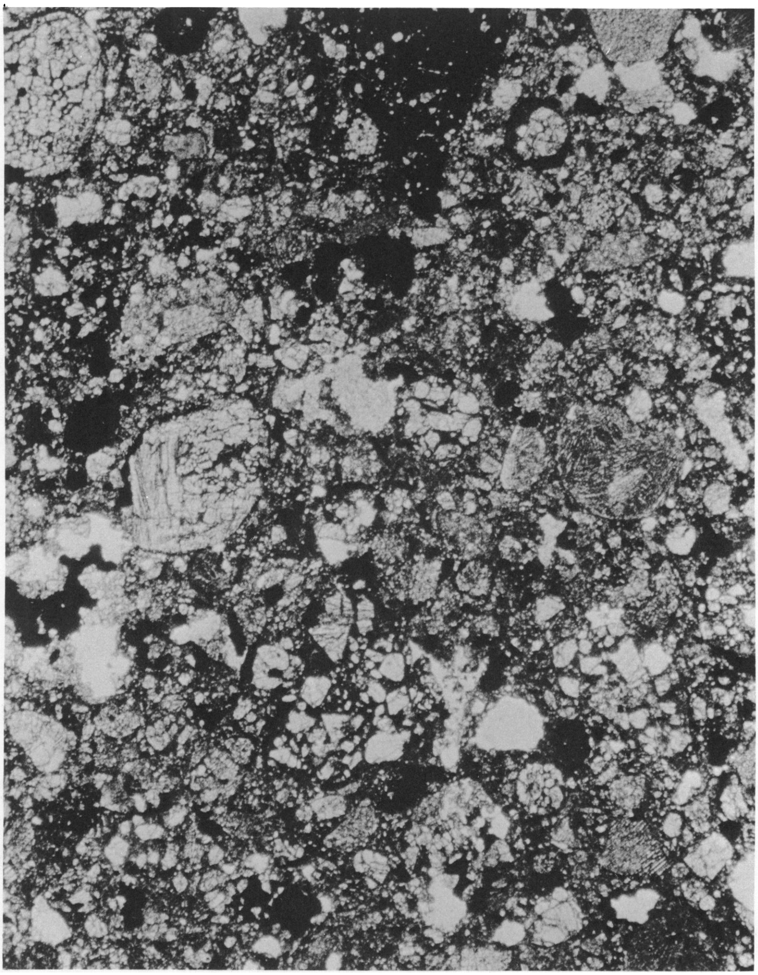

FIG. 4. Photomicrograph of a thin section of the Weston meteorite, showing chondrules of olivine and pyroxene (gray); black is nickel-iron and troilite, white holes in the section. The chondrules are approximately 0.5 mm. in diameter.

enced in retrieving pieces of the meteorite. Most of the stones were shattered on impact or broken up by their discoverers, and the pieces were carried off by souvenir hunters. "Strongly impressed with the idea that these stones contained gold and silver, they subjected them to all the tortures of ancient alchemy, and the goldsmith's crucible, the forge, and the blacksmith's anvil, were employed, in vain, to elicit riches which existed

TABLE 5
CHEMICAL COMPOSITION OF THE WESTON METEORITE

A		B		C	
Fe	14.87	Fe	26.90	Si	33.61
Ni	1.54	Si	17.09	Mg	31.27
Co	0.11	Mg	13.77	Fe	26.59
FeS	5.31	S	1.94	Al	2.41
SiO_2	36.59	Ni	1.54	Ca	1.75
TiO_2	0.13	Ca	1.27	Na	1.69
Al_2O_3	2.23	Al	1.18	Ni	1.45
FeO	11.14	Na	0.71	Cr	0.38
MnO	0.32	Cr	0.36	Mn	0.25
MgO	22.84	Mn	0.25	P	0.24
CaO	1.78	P	0.14	K	0.17
Na_2O	0.95	K	0.12	Co	0.10
K_2O	0.14	Co	0.11	Ti	0.09
P_2O_5	0.32	H	0.11		100.00
H_2O+	0.98	Ti	0.10		
H_2O-	0.10	(O	34.41)		
Cr_2O_3	0.52		100.00		
	99.87				

A Chemical analysis expressed as nickel-iron, troilite, and oxides
B Chemical analysis expressed as elements, with oxygen added to make 100 per cent
C Chemical analysis expressed as atom percentages, with the elimination of O, H, and S

only in the imagination. . . . Indeed, we found it very difficult to obtain a sufficient supply of specimens of the various stones, an object which was at length accomplished principally by importunity and purchase." The major part of this historic meteorite that has survived is still at Yale University—one stone weighing 15 kilograms, and fragments weighing 230 grams. Apparently the only other institution with as much as a kilogram is the British Museum (Natural History), whose catalogue lists 1060 grams of this meteorite.

It is curious that little original work has been done on this meteorite since the description of Silliman and Kingsley a century and a half ago. On this account we decided to reanalyze the meteorite, using for the purpose a specimen (No. 353) in the collection of the American Museum of Natural History.

MINERALOGICAL COMPOSITION AND STRUCTURE

The minerals identified in the meteorite are olivine, orthopyroxene, plagioclase, nickel-iron, and chromite; a phosphate mineral (apatite or merrillite, or both) is present in accessory amounts. Notes on the silicate minerals follow.

OLIVINE: The refractive indices are α = 1.673, γ = 1.706, indicating a content of 18 mole per cent of the Fe_2SiO_4 component, according to the determinative curve of Poldervaart (1950). By the X-ray method of Yoder and Sahama (1957), the composition was found to be 19 mole per cent of the Fe_2SiO_4 component. The olivine peaks on the diffractometer chart are sharp and well defined, indicating olivine of uniform composition.

ORTHOPYROXENE: The refractive indices are α = 1.673, γ = 1.683, indicating a content of 16 mole per cent of the $FeSiO_3$ component, according to the determinative curve of Kuno (1954). In terms of the conventional division of meteoritic orthopyroxenes, this falls in the composition range of bronzite.

PLAGIOCLASE: The refractive indices are α = 1.532, γ = 1.540, corresponding to a composition of An_9.

The structure of Weston is highly chondritic, the chondrules ranging in diameter from 0.2 mm. to 2 mm. (fig. 4). Chondrules are made up of olivine or pyroxene, or both, and a wide variety of structures is seen in them. The common form of olivine chondrule consists of a closely packed aggregate of idiomorphic olivine crystals. Pyroxene chondrules frequently show the characteristic eccentric radiating structure of thin plates. Sometimes, however, a pyroxene chondrule is made up of an aggregate of two or three crystals, and these occasionally show poikilitically enclosed olivine crystals. Other pyroxene chondrules contain thin laths of olivine in parallel orientation. The nickel-iron and troilite is virtually confined to the groundmass between the chondrules.

The density of the Weston meteorite, determined as described under Forest City, is 3.66.

CHEMICAL COMPOSITION

The chemical analysis is given in table 5, in the conventional form expressed as metal, troilite, and oxides; in terms of the individual elements as determined by analysis, with oxygen added to bring the total to 100; and recalculated in atom percentages with the elimination of O, H, and S. A discussion of these procedures is given under the description of the Forest City meteorite.

The composition of the Weston meteorite shows that it is an olivine-bronzite chondrite in Prior's (1920) classification. The total iron, 26.90 per cent, is that of a high-iron (H) group chondrite of Urey and Craig (1953).

The normative mineral composition, expressed as weight percentages, is given in table 6. The actual mineral composition, obtained by point-counting a polished surface, is nickel-iron, 16.8 per cent; troilite, 4.2 per cent; chromite, 0.1 per cent; and silicates, 78.9 per cent. This is consistent with the calculated norm. Measured troilite is a little lower than the calculated figure, probably because a considerable amount of the troilite is finely dispersed and thus tends to be underestimated in the point-counting. Observed chromite is much lower than calculated chromite, mainly because most of the chromium is evidently combined in the pyroxene. The proportion of olivine to pyroxene is consistent with estimates from thin sections and X-ray diffraction patterns. No diopside was seen, but the small amount of this component is presumably in solid solution in the orthopyroxene.

TABLE 6
Normative Composition of the Weston Meteorite

Olivine	37.3
Bronzite	23.2
Diopside	4.3
Albite	8.0
Anorthite	1.4
Orthoclase	0.8
Apatite	0.7
Chromite	0.8
Ilmenite	0.2
Troilite	5.3
Nickel-iron	16.5

THE GEIDAM METEORITE

The Geidam meteorite was briefly described by MacLeod and Walls (1960). Their account of the fall reads as follows: "The Geidam meteorite fell at a village called Garau in the Zajibiri Village Unit of Geidam District, Bornu Province on 6th July, 1950. The stone was recovered by the District Head of Geidam and later presented to the Geological Survey by the Waziri of Bornu for safe keeping.

"The stone had been broken when received and is roughly tabular in form with a thickness between 2 and 2¼ in. and a maximum length and breadth of 5 in. and 2¼ in. . . . The weight is 725 gm."

We received a small piece of this meteorite from the Geological Survey of Nigeria and decided to make a chemical and mineralogical analysis of it.

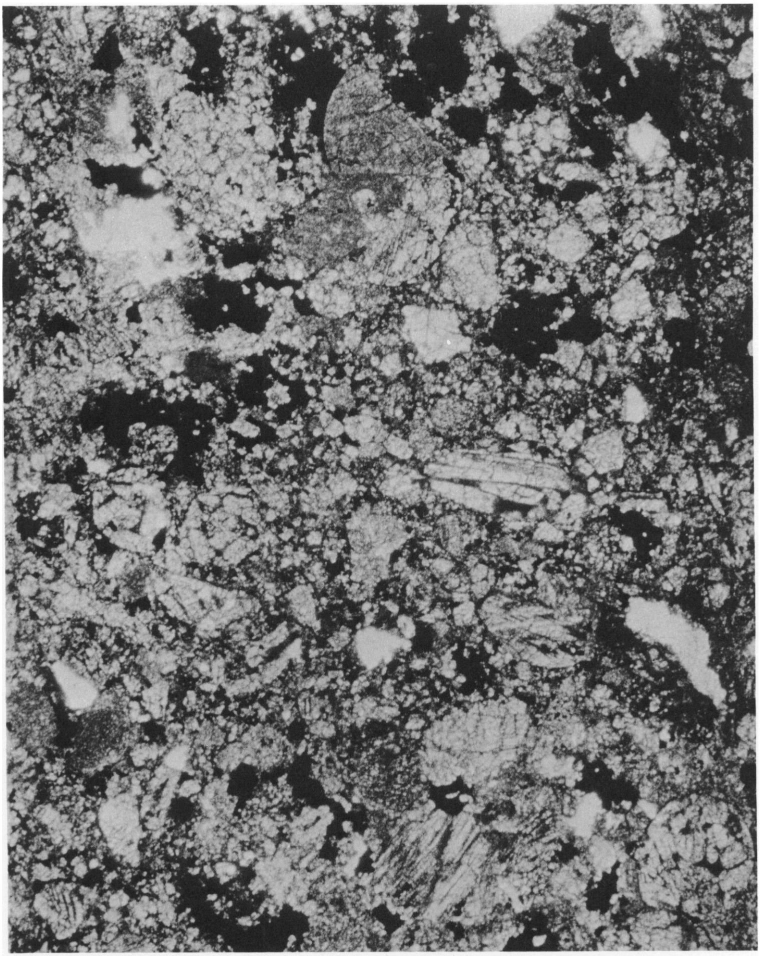

FIG. 5. Photomicrograph of a thin section of the Geidam meteorite, showing chondrules of olivine and pyroxene (gray); black is nickel-iron and troilite, white holes in the section. The chondrules are approximately 0.5 mm. in diameter.

MINERALOGICAL COMPOSITION AND STRUCTURE

The major minerals in the meteorite are olivine, orthopyroxene, nickel-iron, plagioclase, and troilite. Minor minerals, present in amounts less than 1 per cent, include chromite and a phosphate mineral (apatite or merrillite, or both). Notes on the silicate minerals follow.

OLIVINE: The refractive indices are $\alpha = 1.670$, $\gamma = 1.708$, indicating

TABLE 7
CHEMICAL COMPOSITION OF THE GEIDAM METEORITE

A		B		C	
Fe	15.68	Fe	27.20	Si	32.87
Ni	1.69	Si	17.12	Mg	32.16
Co	0.13	Mg	14.50	Fe	26.28
FeS	4.63	S	1.70	Al	2.76
SiO_2	36.62	Ni	1.69	Ca	1.66
TiO_2	0.13	Al	1.38	Na	1.58
Al_2O_3	2.62	Ca	1.25	Ni	1.55
FeO	11.04	Na	0.68	Cr	0.37
MnO	0.32	Cr	0.35	P	0.24
MgO	24.04	Mn	0.25	Mn	0.24
CaO	1.75	P	0.14	Co	0.12
Na_2O	0.91	Co	0.13	Ti	0.09
K_2O	0.07	Ti	0.08	K	0.08
P_2O_5	0.31	K	0.06		100.00
H_2O+	0.57	H	0.06		
H_2O-	0.00	(O	33.41)		
Cr_2O_3	0.51		100.00		
	101.02				

A Chemical analysis expressed as nickel-iron, troilite, and oxides
B Chemical analysis expressed as elements, with oxygen added to make 100 per cent
C Chemical analysis expressed as atom percentages, with the elimination of O, H, and S

a content of 19 mole per cent of the Fe_2SiO_4 component, according to the determinative curve of Poldervaart (1950). This has been confirmed by the X-ray method of Yoder and Sahama (1957). The olivine peaks on the diffractometer chart are sharp and well defined, indicating olivine of uniform composition.

ORTHOPYROXENE: The indices are $\alpha = 1.673$, $\gamma = 1.683$, indicating a content of 16 mole per cent of the $FeSiO_3$ component, according to the determinative curve of Kuno (1954). In terms of the conventional subdivision of meteoritic orthopyroxene, this falls in the composition range of bronzite. A few grains of polysynthetically twinned pyroxene, presumably clinohypersthene, were observed in the acid-insoluble concentrate of pyroxene and plagioclase.

PLAGIOCLASE: The plagioclase is very fine grained and turbid from inclusions, and only a mean refractive index of 1.536 could be measured, indicating a composition about An_{10}.

The structure of the Geidam meteorite (fig. 5) is quite chondritic, although many of the chondrules are rather small, about 0.5 mm. in diameter. Some excellent examples of barred olivine chondrules can be observed, the bars consisting of gray to black, almost opaque material. Pyroxene chondrules with the characteristic eccentric radiating structure are common. The nickel-iron and troilite are distributed in irregular grains between the chondrules.

The density of this meteorite, determined as described for Forest City, is 3.75.

Chemical Composition

The chemical analysis is given in table 7, in the conventional form expressed as metal, troilite, and oxides; in terms of the individual elements as determined by analysis, with oxygen added to bring the total to 100; and recalculated in atom percentages, with the elimination of O, H, and S. A discussion of these procedures is given under the description of the Forest City meteorite.

TABLE 8
Normative Composition of the Geidam Meteorite

Olivine	40.8
Bronzite	21.6
Diopside	3.1
Albite	7.7
Anorthite	2.8
Orthoclase	0.4
Apatite	0.7
Chromite	0.8
Ilmenite	0.2
Troilite	4.6
Nickel-iron	17.5

The composition of the Geidam meteorite shows that it is an olivine-bronzite chondrite in Prior's (1920) classification. The total iron content, 27.20 per cent, is that of a chondrite of the high-iron (H) group of Urey and Craig (1953). Geidam is noteworthy in having a somewhat higher FeO content than most unweathered olivine-bronzite chondrites.

The normative mineral composition, expressed as weight percentages, is given in table 8. The actual mineral composition, obtained by point-counting a polished surface, is nickel-iron, 17.1 per cent; troilite, 4.5 per cent; chromite, 0.2 per cent; and silicates, 78.2 per cent. This is in good agreement with the norm. The proportion of olivine to pyroxene is consistent with estimates from thin sections and X-ray diffraction patterns. No diopside was seen, but the small amount of this component is presumably in solid solution in the orthopyroxene.

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