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The Composition of the Richardton, Estacado, and Knyahinya Meteorites

BY BRIAN MASON[1] AND H. B. WIIK[2]

THE RICHARDTON METEORITE

On June 30, 1918, at 9.48 P.M. a shower of stones fell over a strip of country some 9 miles by 5 miles, the center (latitude 46° 37′ N., longitude 102° 16′ W.) being about 20 miles south of Richardton, North Dakota. The total number of stones recovered is not known but was probably of the order of one hundred; the total weight was about 200 pounds. The circumstances of the fall and chemical and mineralogical composition of the meteorite were described by Quirke (1919). The largest stone recovered weighed 8.34 kilograms; it is illustrated as figure 1 in Quirke's paper, and was later acquired by the American Museum of Natural History.

The Richardton meteorite is a typical olivine-bronzite chondrite, but the analysis published by Quirke is inconsistent with this, showing too high a content of FeO. In addition it reports 4.34 per cent of Fe_2O_3, although the stone is unweathered, and no S, although it contains the normal amount of troilite. In view of these discrepancies, and because this meteorite has been used for numerous determinations of trace elements and rare gases in meteoritic material, we decided to make a new analysis, and for this purpose took a piece from the specimen (No. 662) in the collection of the American Museum of Natural History.

[1] Chairman, Department of Mineralogy, the American Museum of Natural History.

[2] Research Associate, Department of Mineralogy, the American Museum of Natural History.

Mineralogical Composition and Structure

The principal minerals in the Richardton meteorite (as in all olivine-bronzite and olivine-hypersthene chondrites) are olivine and orthopyroxene. Other characteristic minerals are nickel-iron, plagioclase feldspar, and troilite. Minor and accessory minerals include chromite, a phosphate mineral (apatite or merrillite or both), and native copper (in trace amounts). Notes on some of the minerals follow.

Olivine: The refractive indices are $\alpha = 1.667$, $\gamma = 1.705$, indicating a content of 17 mole per cent of the Fe_2SiO_4 component, according to the determinative curve of Poldervaart (1950). By the use of the X-ray method of Yoder and Sahama (1957), the composition was found to be 18 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 $\alpha = 1.671$, $\gamma = 1.681$, indicating a content of 15 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.

Plagioclase: The plagioclase is extremely fine-grained and contains numerous inclusions, so that it is difficult to determine the refractive indices precisely. The mean index is approximately 1.538, indicating a composition about $Ab_{85}An_{15}$.

Nickel-Iron: Both kamacite and taenite are present.

The structure of the meteorite is markedly chondritic. The chondrules are easily seen on a broken surface and are prominent in a thin section (fig. 1); they range in size from about 2 mm. to 0.2 mm. in diameter, most of them being of the order of 1 mm. They show a variety of composition and structure: some consist of numerous idiomorphic olivine crystals in a turbid, almost opaque groundmass; some are ortho-pyroxene, which may be extremely fine-grained with a vague radiating structure, or as thin prisms radiating eccentrically within the chondrule; some appear to consist of alternate prisms of parallelly oriented olivine and orthopyroxene; some are "barred" forms—parallel prisms or laths of olivine separated by turbid, almost opaque material. The chondrules are set in groundmass consisting largely of irregular grains of olivine and orthopyroxene; some of the orthopyroxene grains contain poikilitic inclusions of olivine. The nickel-iron, the troilite, and the chromite are present as irregular grains interstitial to the silicate minerals; in some places the nickel-iron is aggregated into small veinlets.

The density of a piece of this meteorite was determined by measuring

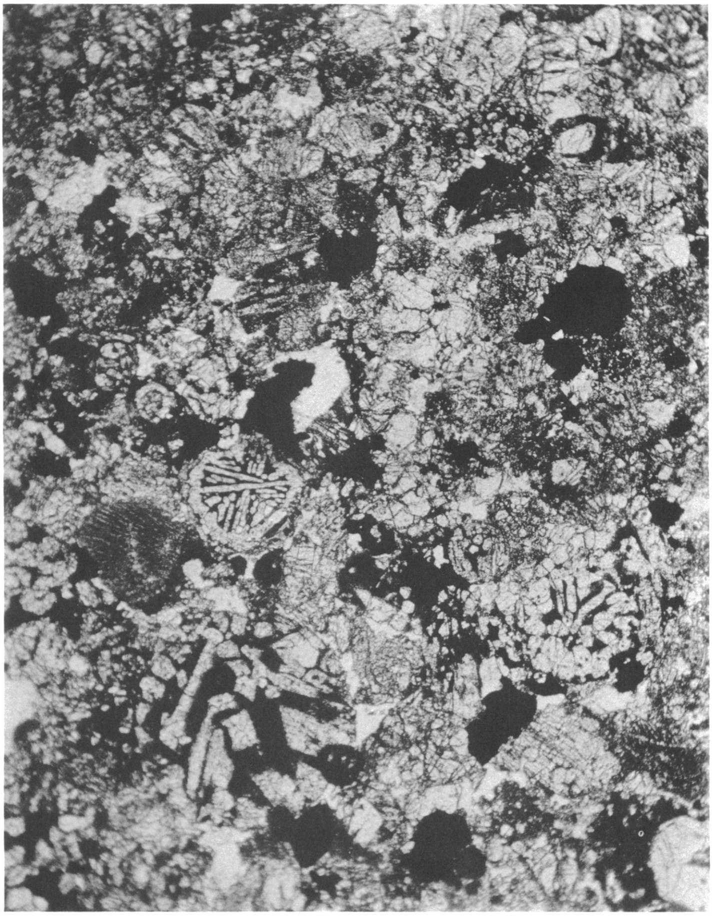

FIG. 1. Photomicrograph of a thin section of the Richardton meteorite, showing chondrules of olivine and orthopyroxene (gray); black is nickel-iron and troilite. × 20.

the apparent loss of weight on suspension in carbon tetrachloride (after evacuation by an oil pump under a bell jar to remove air from the pores) and found to be 3.75.

Chemical Composition

The chemical analysis is given in table 1, in the conventional form expressed as oxides, troilite, and metal; in terms of the individual elements, as determined by analysis, with oxygen to bring the total to 100;

and recalculated as atom percentages with the elimination of H, O, S, and C. 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, and that the H_2O given by the analysis is present as free or combined H_2O. In the Richardton meteorite the first two assumptions are probably valid; the third will not be if small amounts of hydrocarbons are present to provide the hydrogen for the H_2O, as may well be the case.

TABLE 1
CHEMICAL COMPOSITION OF THE RICHARDTON METEORITE

A		B		C	
Fe	18.30	Fe	29.79	Si	31.45
Ni	1.57	Si	16.01	Mg	30.33
Co	0.09	Mg	13.38	Fe	29.41
FeS	6.00	S	2.19	Al	2.85
SiO_2	34.27	Ni	1.57	Na	1.71
TiO_2	0.10	Al	1.40	Ni	1.47
Al_2O_3	2.64	Ca	1.00	Ca	1.38
FeO	9.88	Na	0.71	Cr	0.41
MnO	0.36	Cr	0.38	P	0.41
MgO	22.19	Mn	0.28	Mn	0.28
CaO	1.40	P	0.23	K	0.15
Na_2O	0.96	C	0.21	Co	0.08
K_2O	0.13	K	0.11	Ti	0.07
P_2O_5	0.53	Co	0.09		100.00
H_2O+	0.47	Ti	0.06		
H_2O-	0.00	H	0.05		
Cr_2O_3	0.56	(O	32.52)		
C	0.21		100.00		
	99.66				

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, C, and S

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 the amount of 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 eliminating H, O, S, and C 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 the Richardton meteorite 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 as weight percentages, is given in table 2. The normative composition agrees well with the observed mineral composition. The proportion of olivine to pyroxene agrees with estimates from thin sections and X-ray diffraction patterns. No diopside was seen, but the small amount of this component is probably in solid solution in the bronzite. The ratio of FeO to MgO in the olivine and bronzite, as estimated from the refractive indices of these minerals, is in good agreement with the ratio of FeO to MgO shown by the analysis. Although neither apatite nor merrillite was observed in thin sections, the 1.24 per cent of apatite in the norm could well be present. It would be extremely difficult to recognize in a thin section, as it probably occurs in small grains intimately mixed with pyroxene and olivine.

TABLE 2
NORMATIVE COMPOSITION OF THE RICHARDTON METEORITE

Olivine	37.1
Bronzite	21.2
Diopside	0.8
Albite	8.1
Anorthite	2.5
Orthoclase	0.8
Apatite	1.2
Chromite	0.8
Ilmenite	0.2
Troilite	6.0
Nickel-iron	20.0

TRACE ELEMENTS

Because of its ready availability, material of the Richardton meteorite has been extensively used for trace-element determinations. The data (in parts per million) are as follows:

B: 0.38 (Shima, 1962)
Sc: 9.6, 9.9 (Bate, Potratz, and Huizenga, 1960)
V: 84 (Wiik, unpublished)
Cu: 85 (Wiik, unpublished)

Zn: 65 (Nishimura and Sandell, 1962)
Se: 9.7 (DuFresne, 1960)
Rb: 2.96 (Gast, 1960)
Sr: 10.1 (Gast, 1962)
Te: 2.31 (DuFresne, 1960); 0.73, 0.44, 0.52 (Goles and Anders, 1962)
I: 0.031, 0.021, 0.033 (Goles and Anders, 1962)
Cs: 0.088 (Gast, 1960)
Ba: 3.0, 3.4 (Hamaguchi *et al.,* 1957)
La: 0.32 (Schmitt *et al.*, 1960)
Ce: 0.48 (Schmitt *et al.*, 1960)
Pr: 0.12 (Schmitt *et al.*, 1960)
Nd: 0.61 (Schmitt *et al.*, 1960)
Sm: 0.20 (Schmitt *et al.*, 1960)
Eu: 0.080 (Schmitt *et al.*, 1960)
Gd: 0.34 (Schmitt *et. al.*, 1960)
Tb: 0.053 (Schmitt *et. al.*, 1960)
Dy: 0.34 (Schmitt *et al.*, 1960)
Ho: 0.068 (Schmitt *et al.*, 1960)
Er: 0.21 (Schmitt *et al.*, 1960)
Tm: 0.033 (Schmitt *et al.*, 1960)
Yb: 0.19 (Schmitt *et al.*, 1960)
Lu: 0.033 (Schmitt *et al.*, 1960)
W: 0.13 (Amiruddin and Ehmann, 1962)
Pb: 0.019, 0.091 (Hess and Marshall, 1960)
Th: 0.0364, 0.0396 (Bate, Huizenga and Potratz, 1959)
U: 0.013 (Goles and Anders, 1962)

THE ESTACADO METEORITE

The Estacado meteorite, a large stone weighing originally about 290 kilograms, was found in 1883 near a Quaker colony of that name, some 12 miles south of Hale Center in Hale County, northwest Texas. A bright meteor had been seen in the area in 1882, and it was thought that the meteorite may have fallen at that time. However, the exterior was considerably rusted, and the meteorite may be an old fall. It was acquired by Ward's Natural Science Establishment in 1906 and described in that year by Howard and Davison. Several slices were cut from this stone, and they have been widely distributed, but the largest piece, about 103 kilograms, is now in the Chicago Natural History Museum. A second stone, weighing 122 kilograms, was also found; it was acquired by W. M. Foote, who disposed of it to the American Museum of Natural History in 1912. It is a wedge-shaped mass, approximately 30 cm. by 33 cm. by 50 cm. (fig. 2).

The name "Estacado" is an abbreviation of the Spanish name for that region, the Llano Estacado. The English translation of this name, i.e., Staked Plains, has been applied to this meteorite, and we have seen

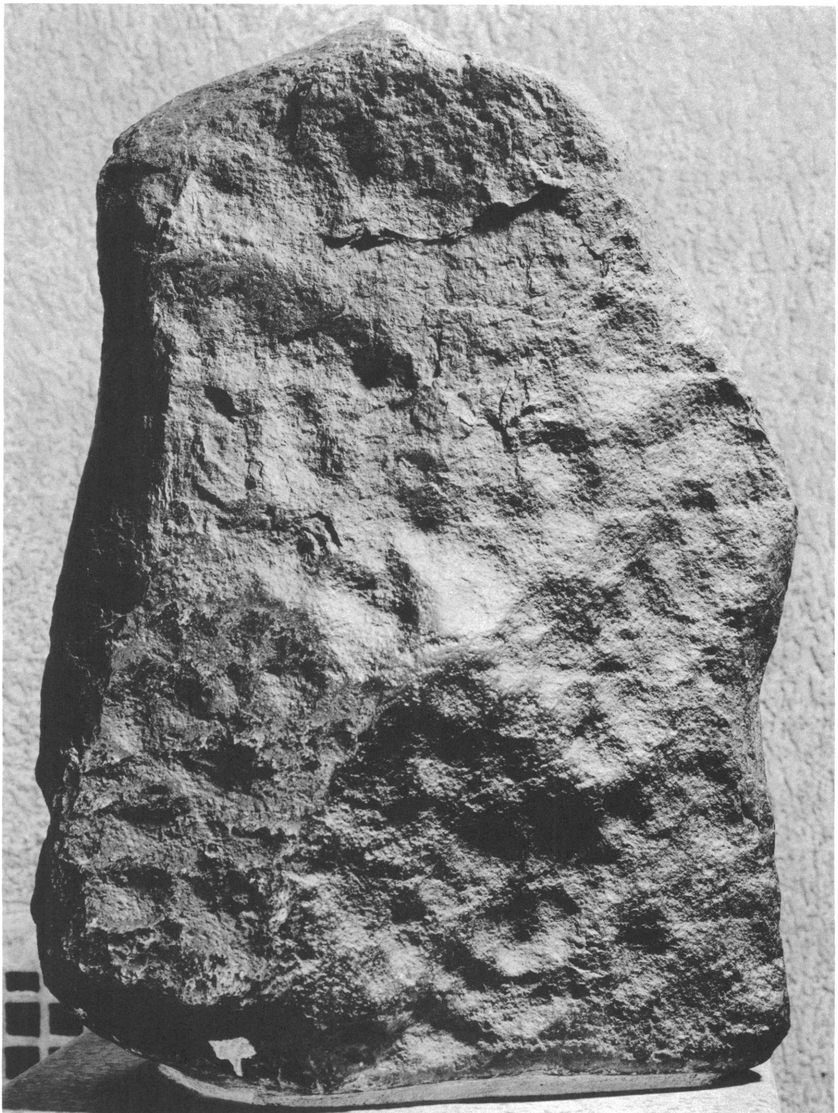

FIG. 2. The Estacado meteorite in the American Museum of Natural History; it weighs 122 kilograms, and the exposed face is 33 cm. by 50 cm.

a specimen labeled "Slaked Plains," evidently as a result of erroneous translation.

Wahl (1950) pointed out that Davison's analysis showed an unusually high alkali content (2.07% Na_2O, 0.32% K_2O), which is inconsistent with the mineralogy and the amounts of other elements present. In spite of this, the analysis was enumerated as a superior one by Urey and Craig (1953). In view of these discrepancies, we decided to reëxamine this meteorite, using a specimen (No. 2176) from the collection of the American Museum of Natural History. This is a piece from the original stone described by Howard and Davison.

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). Ramdohr (personal communication) examined a polished surface of this meteorite and has identified ilmenite, native copper, chalcopyrrhotite, and valleriite in small amounts, and a little secondary pentlandite and limonite. Notes on some of the minerals follow:

Olivine: The refractive indices are $\alpha = 1.669$, $\gamma = 1.707$, indicating a content of 18 mole per cent of the Fe_2SiO_4 component, according to the determinative curve of Poldervaart (1950). By the use of 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 $\alpha = 1.673$, $\gamma = 1.683$, indicating a content of 17 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.

Plagioclase: The refractive indices are $\alpha = 1.532$, $\gamma = 1.540$, corresponding to a composition of $Ab_{92}An_8$. Some of the grains show polysynthetic twinning, which is not commonly observed in plagioclase from chondritic meteorites.

Nickel-Iron: The nickel-iron consists dominantly of kamacite, with minor amounts of taenite and plessitic intergrowths of kamacite and taenite.

The structure of the Estacado meteorite is not markedly chondritic. The chondrules are small, sparse, and poorly defined, and most of the meteorite is an aggregate of xenomorphic grains of olivine, orthopyroxene, and opaque minerals (fig. 3). Estacado is a typical crystalline chondrite, as that term was used in the Rose-Tschermak-Brezina classifica-

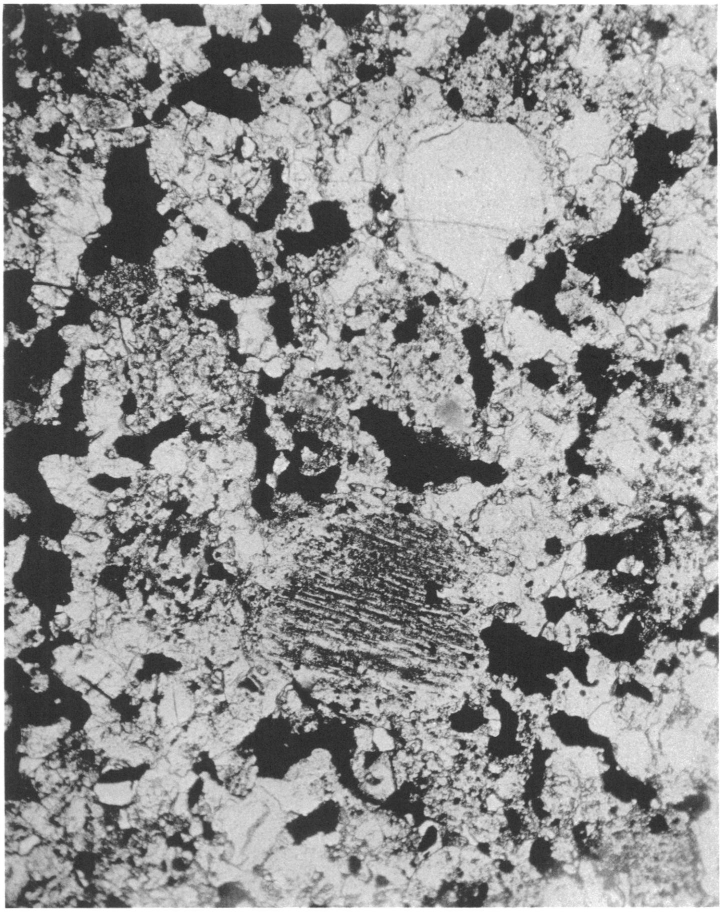

FIG. 3. Photomicrograph of a thin section of the Estacado meteorite, showing olivine and pyroxene (white to gray) and nickel-iron and troilite (black); chondritic structure is poorly developed. × 20.

tion. The chondrules are made up of olivine, of orthopyroxene, or of both these minerals within a single chondrule.

The density of a piece of this stone was determined by measuring the apparent loss of weight on suspension in carbon tetrachloride and was found to be 3.65.

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, S, and C. A discussion of these procedures is given above in the description of the Richardton meteorite. The chemical composition of the Estacado meteorite is similar to that of Richardton, and the mineralogical composition is essentially identical. Both meteorites are typical olivine-bronzite chondrites. The somewhat higher FeO content

TABLE 3
CHEMICAL COMPOSITION OF THE ESTACADO METEORITE

A		B		C	
Fe	14.76	Fe	27.88	Si	33.09
Ni	1.46	Si	16.73	Mg	30.84
Co	0.09	Mg	13.51	Fe	27.72
FeS	5.68	S	2.07	Al	2.79
SiO_2	35.81	Ni	1.46	Ca	1.49
TiO_2	0.11	Al	1.35	Ni	1.38
Al_2O_3	2.56	Ca	1.07	Na	1.24
FeO	12.24	Na	0.51	Cr	0.53
MnO	0.29	Cr	0.49	P	0.39
MgO	22.41	Mn	0.22	Mn	0.23
CaO	1.50	P	0.21	K	0.14
Na_2O	0.69	C	0.18	Co	0.08
K_2O	0.12	K	0.10	Ti	0.08
P_2O_5	0.50	Co	0.09		100.00
H_2O+	0.00	Ti	0.07		
H_2O-	0.00	(O	34.06)		
Cr_2O_3	0.72		100.00		
C	0.18				
	99.12				

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, C, and S

(12.24%) of Estacado compared to Richardton (9.88%) is probably the result of a small amount of weathering of the metal phase in the former.

The normative mineral composition, expressed in weight percentages, is given in table 4. The observed mineral composition corresponds well with that calculated as the norm. Keil (1962), by planimetric analysis of a polished surface, obtained 16.02 per cent of nickel-iron, 5.23 per cent of troilite, 0.53 per cent of chromite, and 78.22 per cent of silicates, in good agreement with the norm. The proportion of olivine to pyroxene agrees 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 bronzite. The ratio of FeO to MgO in the olivine and pyroxene, as estimated from the refractive indices of these minerals, is somewhat lower than the ratio of FeO to MgO in the analysis. As mentioned above, a small amount of the FeO shown in the analysis is secondary, produced by weathering of the metal phase, and is not combined in the silicate phases. Normative feldspar is 10.04 per cent, probably somewhat higher than the actual amount, as some of the Al_2O_3 calculated as feldspar will be in the pyroxene. This is confirmed

TABLE 4
NORMATIVE COMPOSITION OF THE ESTACADO METEORITE

Olivine	36.0
Bronzite	27.6
Diopside	0.5
Albite	5.8
Anorthite	3.5
Orthoclase	0.7
Apatite	1.2
Chromite	1.1
Ilmenite	0.2
Troilite	5.7
Nickel-iron	16.3

by the composition of the plagioclase, which is close to albite, indicating that comparatively little of the calcium is combined as feldspar, most of it evidently going into pyroxene. It is interesting to note that normative chromite is about twice that found by Keil; evidently a good part of the Cr_2O_3 in the analysis is combined in the silicate phases, probably the pyroxene. A recent analysis of orthopyroxene from the Kesen meteorite (Miyashiro, 1962) confirms this.

THE KNYAHINYA METEORITE

On June 9, 1866, a few minutes before 5 P.M., a shower of more than 1000 stones of the total weight of some 500 kilograms (the largest weighing about 293 kilograms) fell over an area of 15 by 5 kilometers centered on the village of Knyahinya (latitude 48° 58′ N., longitude 22° 31′ E.). At that time this locality was administratively within the Kingdom of Hungary. It has since had a checkered history. After World War I it was in Czechoslovakia until the dismemberment of that country in 1938–1939, when the region was returned to Hungary. At the end of World War II it was annexed by the Russians and is now within the boundaries of the Ukrainian S.S.R. It is situated almost at the point where Poland, Czechoslovakia, and the Soviet Union meet.

The circumstances of the fall were described in considerable detail by Haidinger (1866), and the meteorite was later analyzed by Baumhauer (1872). A considerable amount of literature was published on it during the nineteenth century, which is listed by Wülfing (1897). He also enumerates the location at that time of specimens of the fall. It is extremely widely distributed, Wülfing enumerating some 97 collections that possess material. The major part, including the 293-kilogram stone, is in the Naturhistorisches Museum in Vienna.

Kokta (1937) published a new analysis of Knyahinya, differing very greatly from that of Baumhauer. Wahl (1950) pointed out a number of doubtful figures in the analyses of both Kokta and Baumhauer. Urey and Craig (1953) included Kokta's analysis in their list of superior analyses of chondrites and rejected that by Baumhauer. Because of the doubtful figures, and the discrepancies between the two analyses, we decided to reëxamine this meteorite and selected a specimen (No. 1068) from the collection of the American Museum of Natural History for this purpose.

Mineralogical Composition and Structure

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

Olivine: The refractive indices are $\alpha = 1.683$, $\gamma = 1.719$, indicating a content of 25 mole per cent of the Fe_2SiO_4 component, according to the determinative curve of Poldervaart (1950). By the use of the X-ray method of Yoder and Sahama (1957), the composition was found to be 26 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 $\alpha = 1.678$, $\gamma = 1.688$, indicating a content of 21 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 hypersthene.

Plagioclase: The refractive indices are $\alpha = 1.532$, $\gamma = 1.539$, corresponding to a composition of $Ab_{92}An_8$.

Nickel-Iron: Both kamacite and taenite are present, as individual xenomorphic grains between the silicate minerals and also as plessitic intergrowth.

The structure of the Knyahinya meteorite is highly chondritic. A cut

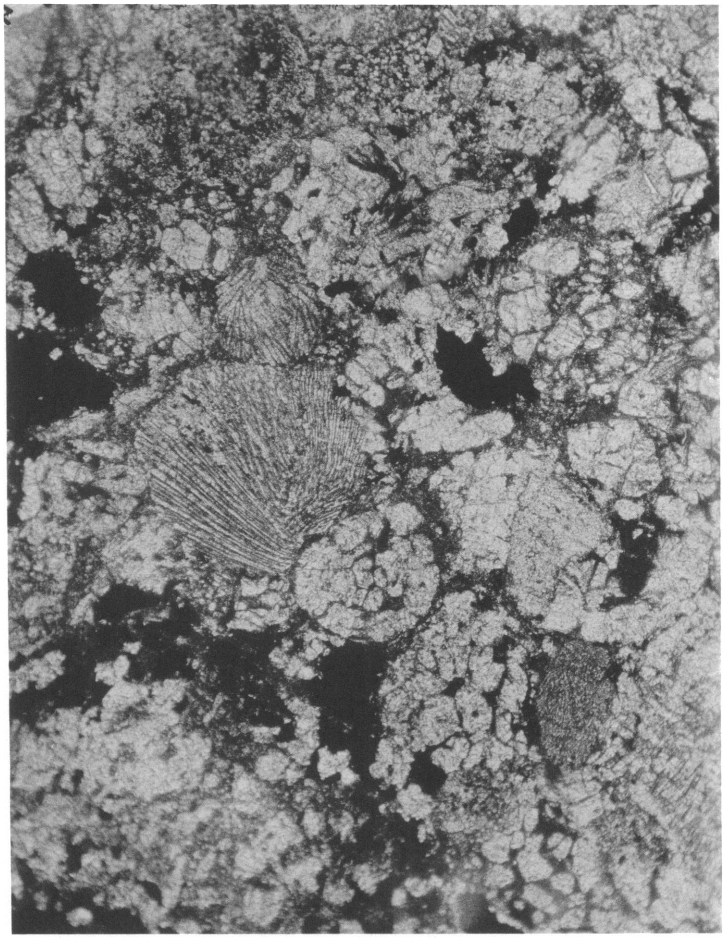

FIG. 4. Photomicrograph of a thin section of the Knyahinya meteorite, showing chondrules of orthopyroxene (gray, radiating) and olivine (gray, granular); black is nickel-iron and troilite. $\times$ 20.

surface shows that it consists of an aggregate of chondrules ranging in diameter from about 3 mm. downward. A thin section (fig. 4) shows that the chondrules are varied in composition and structure. Some consist of numerous idiomorphic olivine crystals in a turbid, almost opaque groundmass; others are made up of lath-like olivine in optical continuity, with interstitial orthopyroxene; in chondrules consisting entirely of orthopyroxene, this mineral is usually present as thin laths radiating eccentrically, although in some it is finely granular. The chondrules are separated by a groundmass consisting largely of small grains of olivine and orthopyroxene, although the boundaries of the chondrules are not always sharp; they sometimes merge imperceptibly with the groundmass. Plagioclase is present as small irregular patches interstitial to the other minerals. The nickel-iron, troilite, and chromite are present as irregular grains.

TABLE 5
CHEMICAL COMPOSITION OF THE KNYAHINYA METEORITE

A		B		C	
Fe	3.36	Fe	20.15	Si	37.38
Ni	1.04	Si	19.02	Mg	34.34
Co	0.05	Mg	15.14	Fe	19.91
FeS	6.33	S	2.31	Al	2.74
SiO_2	40.72	Al	1.34	Na	1.90
TiO_2	0.10	Ca	1.12	Ca	1.54
Al_2O_3	2.54	Ni	1.04	Ni	0.98
FeO	16.44	Na	0.79	Cr	0.47
MnO	0.30	Cr	0.45	Mn	0.23
MgO	25.11	C	0.34	P	0.24
CaO	1.57	Mn	0.23	K	0.15
Na_2O	1.06	P	0.14	Ti	0.07
K_2O	0.14	K	0.11	Co	0.05
P_2O_5	0.31	Ti	0.06		100.00
H_2O+	0.27	Co	0.05		
H_2O-	0.05	H	0.04		
Cr_2O_3	0.65	(O	37.67)		
C	0.34		100.00		
	100.38				

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, C, and S

The density of a piece of this stone was determined by measuring the apparent loss of weight on suspension in carbon tetrachloride and was found to be 3.49.

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, S, C, and H. A discussion of these procedures is given above in the description of the Richardton meteorite. The Knyahinya meteorite is a typical olivine-hyperstene chondrite, similar to Mocs, New Concord, and Chateau-Renard (Mason and Wiik, 1961). It belongs to the low-iron (L) group of Urey and Craig (1953).

Of the two previous analyses, that of Baumhauer (1872) agrees quite well with the present one; that of Kokta (1937) is quite different. A possible explanation for Kokta's analysis is that the specimen he had was not Knyahinya at all; his analysis appears to be of a high-iron, olivine-bronzite chondrite.

TABLE 6
NORMATIVE COMPOSITION OF THE KNYAHINYA METEORITE

Olivine	49.3
Hypersthene	23.1
Diopside	3.3
Albite	9.0
Anorthite	1.7
Orthoclase	0.8
Chromite	1.0
Apatite	0.7
Ilmenite	0.2
Troilite	6.3
Nickel-iron	4.5

The normative mineral composition, expressed as weight percentages, is given in table 6. The observed mineral composition corresponds well with that calculated as the norm. Keil (1962), by planimetric analysis of a polished surface, obtained 4.73 per cent of nickel-iron, 6.17 per cent of troilite, 0.20 per cent of chromite, and 88.90 per cent of silicates, in good agreement with the norm. The proportion of olivine to pyroxene agrees 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. The ratio of FeO to MgO in the olivine and pyroxene, as estimated from the refraction indices of these minerals, is in good agreement with the ratio of FeO to MgO in the chemical analysis. Normative feldspar is 11.51 per cent, probably somewhat higher than the actual amount, as some of the Al_2O_3 calculated as feldspar will be in the pyroxene. This is supported by the actual composition (An_8) compared to the calculated composition (An_{25}). Evidently a considerable part of the calcium calculated as plagioclase is actually in the pyroxene, whereby the plagioclase is less calcic than indicated by the norm calculation. Normative chromite is much greater than the amount actually present, according to Keil. As pointed out above in the discussion of the Estacado meteorite, this is due to the incorporation of a considerable part of the chromium in the pyroxene phase, with correspondingly less available for a chromite phase.

ACKNOWLEDGMENTS

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