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The Hyperstheme Achondrites

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INTRODUCTION

The hypersthene achondrites comprise a small group of meteorites, eight in all (table 1), of notably uniform chemical and mineralogical composition. They are remarkable in being made up almost entirely of a single mineral, the orthorhombic pyroxene hypersthene. In spite of this uniformity of composition, their place in meteorite systematics has been the subject of controversy and confusion. Rose (1863) believed that the Shalka meteorite was made up of olivine and "shepardite" (actually orthopyroxene) and considered it as the sole member of a special class, calling it "shalkite." Tschermak (1883) pointed out that Shalka consisted essentially of orthopyroxene and contained no olivine. He therefore discarded the term "shalkite," and proposed the term "diogenite" for hypersthene achondrites, of which he recognized Shalka, Manegaon, and Ibbenbühren. However, Brezina (1895) included these meteorites in the chladnites, a term Tschermak had reserved for the enstatite achondrites. Brezina also introduced a new class, the rodites, for the Roda meteorite, which he described as consisting of bronzite and olivine, with a brecciated structure. However, as can be seen from the chemical and mineralogical composition, Roda is essentially identical with the other hypersthene achondrites, the olivine being present in accessory amounts. The Ellemeet meteorite was later classified as a rodite.

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Thus, for this small group of eight meteorites no fewer than four classes have been created—shalkite, diogenite, chladnite, and rodite—a fact that has served to confuse rather than to clarify their classification, and under these circumstances the simple descriptive term "hypersthene achondrite" seems preferable.

NOTES ON THE INDIVIDUAL METEORITES

The hypersthene achondrites are enumerated in table 1. Notes on the individual meteorites follow:

ELLEMEET: This meteorite fell near Ellemeet (latitude 51° 45′ N., longitude 4° E.) on the island of Schouwen, The Netherlands, at 11.30 A.M. on August 28, 1925. At least two stones fell; the only one that has been preserved weighed 970 grams and was broken into five pieces on impact. It was described by Nieuwenkamp (1927). Most of the material is in the Mineralogical Institute of Utrecht University.

TABLE 1
THE HYPERSTHENE ACHONDRITES

	Date of Fall	Weight, in Kilograms
Ellemeet (The Netherlands)	8/28/1925	1.5
Garland (United States)	1950	0.1
Ibbenbühren (Germany)	7/16/1870	2
Johnstown (United States)	7/6/1924	40
Manegaon (India)	6/29/1843	0.04
Roda (Spain)	1871	0.4
Shalka (India)	11/30/1850	4
Tatahouine (Tunisia)	7/27/1931	12

GARLAND: This meteorite fell near Garland (latitude 41° 41′ N., longitude 112° 08′ W.) in Box Elder County, Utah, in the summer of 1950. A single stone, weighing 102 grams, is preserved in the United States National Museum of the Smithsonian Institution.

IBBENBÜHREN: This meteorite fell near the village of Ibbenbühren (latitude 52° 17′ N., longitude 7° 42′ E.) in northwestern Germany about 2 P.M. on June 17, 1870. A stone weighing about 2 kilograms was recovered, most of which is preserved in the University of Berlin. It was described by Rath (1872).

JOHNSTOWN: The meteorite, the largest in size of all the hypersthene achondrites, fell as a shower of stones near Johnstown (latitude 42° 20′ N., longitude 104° 54′ W.), in Weld County, Colorado, at 4.20 P.M. on July 6, 1924. One stone fell beside a church at which a funeral service was being held, and was considered by some a sinister omen. At least 26 stones were recovered, from an elliptically strewn field some 10 miles long and 2 miles wide, elongated in a north-northeast direction (individual stones show increasing size from south-southwest to north-northeast). The total weight was 40 kilograms, the largest stone (somewhat fragmented) weighing 23.5 kilograms. Material of this meteorite has been widely distributed; the largest stone is in the collection of the American Museum of Natural History. The meteorite was described by Hovey (1925), with supplemental notes by Merrill and Shannon.

MANEGAON: This meteorite fell at Manegaon (latitude 20° 58′ N., longitude 76° 06′ E.), in the Deccan region of India, at 3.30 P.M. on June 29, 1843. A single stone was seen to fall. It was broken up and only a small amount has been preserved—32 grams in Calcutta (Geological Survey of India) and 12 grams in the British Museum. The meteorite was described by Story-Maskelyne (1870).

RODA: This meteorite fell near Roda (latitude 42° 18′ N., longitude 0° 33′ E.), in the province of Huesca, Spain, in the spring of 1871. One stone, weighing about 400 grams, was recovered. Small pieces of this have been widely distributed, the largest fragment being one of 125 grams in the Museum National d'Histoire Naturelle in Paris. It was originally described by Pisani and Daubrée (1874) and reëxamined by Lacroix (1925). Although it has been made the type for a special class, the rodites, it does not differ essentially from the other hypersthene achondrites.

SHALKA: This meteorite fell at Saluka (latitude 26° 06′ N., longitude 87° 18′ E.), near Calcutta in West Bengal, at 4.30 P.M. on November 30, 1850. A stone said to measure 3 feet across fell and broke in pieces, but only a few kilograms were preserved, this being widely distributed in collections. About 2 kilograms is in the collection of the Geological Survey of India in Calcutta, and a little more than 1 kilogram is in the British Museum, London. This meteorite was investigated by several authorities in the last century, the best account being that of Foullon (1888).

TATAHOUINE: This meteorite fell near the village of Tatahouine (latitude 32° 57′ N., longitude 10° 25′ E.), in southern Tunisia, at 1.30 A.M. on July 27, 1931. It broke up into innumerable small fragments, the total weight recovered being about 12 kilograms. Most of this is preserved in the Museum National d'Histoire Naturelle in Paris. It was described by Lacroix (1932).

A consideration of the data on time and place of fall fails to show any regular pattern which might indicate a common extraterrestrial origin for this very homogeneous group of meteorites. However, the numbers are so small that it is most unlikely they would supply statistically valid data of this sort.

MINERALOGICAL COMPOSITION

These meteorites are made up almost entirely of hypersthene, with other minerals present only in accessory or trace amounts. These minerals (not all of which are necessarily present in any one meteorite) are plagioclase feldspar (bytownite), olivine, chromite, troilite, and nickel-iron.

The composition of the hypersthene is remarkably uniform, judging from the refractive indices (measured in sodium light, at a controlled temperature, in oils checked on a refractometer). The results were as follows:

	α	γ	Mole Per Cent $FeSiO_3$
Ellemeet	1.684	1.695	26
Garland	1.683	1.694	25
Ibbenbühren	1.684	1.695	26
Johnstown	1.685	1.696	27
Manegaon	1.683	1.694	25
Roda	1.685	1.696	27
Shalka	1.684	1.695	26
Tatahouine	1.683	1.694	25

These results show that the orthopyroxene is remarkably uniform in composition throughout, corresponding to 26 ± 1 mole per cent $FeSiO_3$, according to the data of Kuno (1954). This is in the composition range of hypersthene, as this term is used for meteoritic orthopyroxene. The chemical analyses of these meteorites do not show the same uniformity, $Fe/Fe+Mg$ (mole per cent) ranging from 23 for Johnstown to 33 for Manegaon. However, small errors in FeO and MgO in these analyses, especially if in opposite directions, can result in considerable errors in the calculated $Fe/Fe+Mg$. The optical data on the orthopyroxene is good evidence for a remarkable uniformity of composition within this group of achondrites.

During the course of this investigation a comprehensive analysis of a carefully purified sample of the hypersthene from the Johnstown meteorite was made for me by Mr. H. Haramura, at the Geological Institute of the University of Tokyo. This analysis is presented in table 2, together with a published analysis of the hypersthene from the Tatahouine meteorite. These analyses show some interesting features. One is the presence of a noteworthy amount of chromium combined in the pyroxene. The presence of chromium in the pyroxene of the Shalka meteorite was remarked upon by Foullon (1888), when he found that the total chromium in the bulk analysis of the meteorite considerably exceeded the amount present as chromite. In the hypersthene achondrites (and in the chondrites) chromium is partitioned between the pyroxene phase and the chromite. The analysis of the Tatahouine pyroxene shows no nickel. At my request Mr. Haramura made a careful analysis for nickel in the Johnstown pryoxene and found 0.001 per cent, i.e., 10 parts per thousand. This is about 100 times less than is present in terrestrial orthopyroxene. The nickel-iron in Johnstown contains 2.8 per cent of Ni (Shannon, *in* Hovey, 1925).

TABLE 2
Analyses of Hypersthene from Hypersthene Achondrites

	1	2
SiO_2	53.63	54.94
TiO_2	0.21	0.19
Al_2O_3	0.33	0.62
FeO	15.66	14.35
MnO	0.50	0.26
MgO	27.23	27.42
CaO	1.39	0.75
Na_2O	0.13	—
H_2O+	0.41	0.06
H_2O-	0.00	0.08
P_2O_5	0.08	None
NiO	0.001	None
Cr_2O_3	0.81	0.35
	100.38	99.02

1 Johnstown, unpublished
2 Tatahouine; Lacroix (1932)

Another interesting feature of the analysis of the Johnstown pyroxene is the presence of 1.39 per cent of CaO. Microscopical examination shows that this pyroxene contains narrow exsolution lamellae with oblique extinction, probably parallel to (100). These exsolution lamellae are probably diopside, and their presence indicates that the pyroxene originally crystallized at a temperature above the diopside-hypersthene solvus. When the position of the solvus is precisely known, this should provide a temperature of crystallization for the pyroxene of the Johnstown meteorite. I have observed similar exsolution lamellae in the hypersthene from the Ibbenbühren, Manegaon, and Roda meteorites, but not in that from other meteorites of this group. Analyses of Ibbenbühren, Johnstown, Manegaon, and Roda all show more than 1 per cent of CaO, those of the other meteorites less than 1 per cent of CaO. Evidently, for the conditions under which these meteorites crystallized, 1 per cent of CaO is about the maximum that can be held in solid solution in the orthopyroxene.

Notes on the remaining minerals follow:

PLAGIOCLASE: This has been found in accessory amounts in Ibbenbühren, Johnstown, Manegaon, Roda, and Shalka. In all of them it appears to have the same composition, the refractive indices $\alpha = 1.570$, $\gamma = 1.579$ corresponding to $Ab_{15}An_{85}$, i.e., bytownite. Merrill and Shannon (*in* Hovey, 1925) estimated that the Johnstown meteorite contained about 0.7 per cent of plagioclase.

OLIVINE: This mineral is present in accessory amounts in Ellemeet and Roda. In Ellemeet its refractive indices are $\alpha = 1.689$, $\gamma = 1.726$, corresponding to 28 mole per cent Fe_2SiO_4, according to the determinative curve of Poldervaart (1950). In Roda its indices are $\alpha = 1.687$, $\gamma = 1.724$, corresponding to 27 mole per cent Fe_2SiO_4. It is interesting to note that when the chemical analyses of the hypersthene achondrites are recalculated into normative minerals, olivine always appears in the norm, although this mineral is usually absent. The reason is that Al_2O_3 and the corresponding amount of CaO are calculated as anorthite in the norm, whereas they are largely or entirely present in the orthopyroxene.

CHROMITE: Chromite, in amounts of 2 per cent or less, is present in most of the hypersthene achondrites, as black microscopic grains, usually translucent red-brown in thin section. Foullon (1888) analyzed a very small sample (17 milligrams) of chromite from the Shalka meteorite; his analysis, for which he claimed no great precision, was Cr_2O_3, 56.82 per cent; Al_2O_3, 11.36 per cent; FeO, 26.14 per cent; MgO, 5.68 per cent.

TROILITE: This mineral is present in accessory amounts in most of these meteorites, usually less than 1 per cent, although 1.73 per cent is recorded in the analysis of Roda.

NICKEL-IRON: A small amount of metal phase is present in some of the hypersthene achondrites. Merrill and Shannon (*in* Hovey, 1925) extracted 0.35 per cent of metal from Johnstown and analyzed it, with the following results: Fe, 96.78 per cent; Ni, 2.80 per cent; Co, 0.35 per cent; S, 0.66 per cent; P, trace. Lacroix (1932) recorded 0.79 per cent of metal in Tatahouine, as thin plates on the surfaces of the pyroxene grains, and states that it was quite free from nickel.

Tschermak (1885) mentioned that he had observed an accessory mineral in the Ibbenbühren meteorite which he tentatively identified as tridymite. The occurrence of tridymite is not inconsistent with the

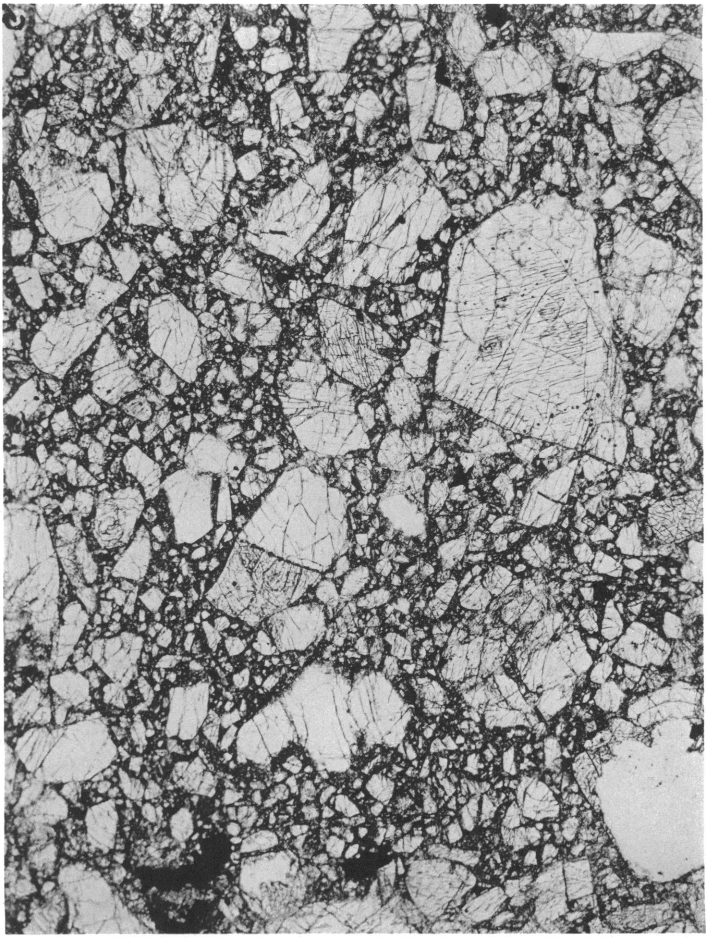

FIG. 1. Photomicrograph of a thin section of the Johnstown meteorite, showing angular fragments of hypersthene in a groundmass of crushed hypersthene. × 10.

mineralogy of Ibbenbühren. However, a careful search of a small sample failed to show any tridymite, and it is possible that the mineral seen by Tschermak was actually plagioclase feldspar.

STRUCTURE

The hypersthene achondrites, besides showing a remarkable uniformity of mineralogical and chemical composition, also resemble one another closely in their internal structure. All except Tatahouine show a crushed and brecciated structure, with large angular fragments of hypersthene in a groundmass of crushed and broken hypersthene (fig. 1). In Johnstown some of the large fragments are up to 50 mm. across. Evidently the material crystallized originally as an aggregate of large crystals of hypersthene which were crushed and broken by intense mechanical deformation. Many of the pyroxene fragments show undulose extinction in thin section, evidently the result of strain. Tatahouine is exceptional in not showing this crushing. It seems to have consisted of a friable aggregate of large crystals which broke up into innumerable fragments in the atmosphere or on impact. However, many thin sections of Tatahouine have a patchy or flamboyant appearance when viewed between crossed Nicols, especially along cleavage directions in the hypersthene. Lacroix (1932) described this in detail and ascribed it to a recrystallization of the hypersthene. However, these recrystallized parts show a consistently higher birefringence than the original hypersthene. It appears more probable that the recrystallized parts consist of clinohypersthene. Possibly this patchy distribution of clinohypersthene within the hypersthene is the result of mechanical deformation under considerable confining pressure, a mode of formation demonstrated experimentally for enstatite by Turner, Heard, and Griggs (1960). If this explanation is correct, the structural differences between Tatahouine and the other hypersthene achondrites merely reflect the confining pressure under which mechanical deformation took place, rather than completely different conditions.

Chemical Composition

The chemical analyses of the hypersthene achondrites are given in table 3. These analyses show a notable degree of uniformity, although not so great as would be expected from the uniformity of their mineralogical composition. Some of the analyses lack some components which are certainly present, and some are deficient in other respects. It is difficult to account for the 0.87 per cent of SO_3 reported in the analysis of Johnstown, since the meteorite contains no sulphate mineral. As mentioned in the discussion of the mineralogical composition, recalculation of these analyses into normative mineral composition always gives some olivine, to as much as 22 per cent in Roda. However, olivine is absent in all except Roda and Ellemeet, and in these is present in small amount only. The olivine appears in the norm as a result of the abstraction of Al_2O_3 and the corresponding amount of CaO as normative plagioclase, whereas all or most of these components are combined in pyroxene.

Because of its availability, the Johnstown meteorite has been extensively

TABLE 3

CHEMICAL ANALYSES OF THE HYPERSTHENE ACHONDRITES

	1	2	3	4	5	6	7
SiO_2	53.63	54.47	50.31	53.63	50.38	52.51	54.94
Al_2O_3	—	1.06	2.35	—	2.86	0.66	0.62
Cr_2O_3	1.82	—	—	0.70	0.64	1.25	0.35
FeO	18.95	17.15	14.05	20.81	14.91	16.81	15.30
MnO	1.35	0.28	0.40	—	0.22	—	0.26
MgO	25.65	26.12	26.88	23.32	27.10	28.35	27.42
CaO	—	1.39	2.63	1.50	1.42	0.89	0.76
FeS	—	—	1.17	0.55	1.73	0.39	0.35
	101.40	100.47	97.79	100.51	99.26	100.86	100.00
D	3.41	3.405	3.411	—	3.37	—	3.404

1 Ellemeet (Nieuwenkamp, 1927); also S, 0.42%
2 Ibbenbühren (Rath, 1872)
3 Johnstown (Hovey, 1925); also chromite, 1.50%; SO_3, 0.87%; Na_2O, 0.33%; K_2O, 0.10%; nickel-iron, 0.88%
4 Manegaon (Story-Maskelyne, 1870)
5 Roda (Lacroix, 1925); also Na_2O, 0.38%; K_2O, 0.31%; H_2O+, 0.33%; H_2O-, 0.17%; P_2O_5, 0.04%
6 Shalka (Foullon, 1888); also Na_2O, 0.22%
7 Tatahouine (Lacroix, 1932); also H_2O+, 0.06%; H_2O-, 0.08%

used in trace element investigations. The following results have been reported (in parts per million):

K: 10 (Kirsten, Krankowsky, and Zahringer, 1963)
Sc: 14 (Pinson, Ahrens, and Franck, 1953); 17 (Bate, Potratz, and Huizenga, 1960); 14.0 (Schmitt, 1962)
Cr: 3200 (Bate, Potratz, and Huizenga, 1960)
Zn: 3 (Nishimura and Sandell, 1962)
Se: 0.007 (Schindewolf, 1960)
Rb: 0.105 (Webster, Morgan, and Smales, 1957); 0.04 (Cabell and Smales, 1957)
Sr: 2.07 (Webster, Morgan, and Smales, 1957); 3(Pinson, Ahrens, and Franck, 1953)
Y: 1.22 (Schmitt, 1962)
Zr: 30 (Pinson, Ahrens, and Franck, 1953)
Te: 0.007 (Schindewolf, 1960)
Cs: 0.007 (Cabell and Smales, 1957)
Ba: 5 (Pinson, Ahrens, and Franck, 1953)
La: 0.044 (Schmitt, 1962)
Sm: 0.080 (Schmitt, 1962)
Eu: 0.0089 (Schmitt, 1962)
Dy: 0.14 (Schmitt, 1962)
Ho: 0.036 (Schmitt, 1962)

Er: 0.14 (Schmitt, 1962)
Tm: 0.021 (Schmitt, 1962)
Yb: 0.15 (Schmitt, 1962)
Lu: 0.033 (Schmitt, 1962)
Ta: 0.008 (Atkins and Smales, 1960)
W: 0.006 (Amiruddin and Ehmann, 1962)
Ir: 0.008 (Rushbrook and Ehmann, 1962)
Th: 0.0059 (Bate, Huizenga, and Potratz, 1959)
U: 0.0022 (König and Wänke, 1959)

Schmitt (1962) has determined a number of trace elements in Shalka with the following results (in parts per million): Sc, 9.8; Y, 0.22; La, 0.015; Ce, 3.9; Pr, 0.0062; Nd, 0.64; Sm, 0.0103; Eu, 0.004; Ho, 0.0046; Er, 0.021; Tm, 0.0037; Yb, 0.024; Lu, 0.0058; U, 3.0.

DISCUSSION

It has been shown that the hypersthene achondrites make up a notably homogeneous group of meteorites. It remains to examine their possible relationships to other meteorite groups, and to see what deductions as to their history can be made from the available data.

The obvious comparison is with the enstatite achondrites, with which these meteorites have sometimes been included as a single class of chladnites. However, while it is true that both the enstatite achondrites and the hypersthene chondrites consist essentially of orthopyroxene, the fact remains that they do not form a continuous series, being separated by a marked chemical hiatus. The enstatite achondrites are practically iron-free, whereas the hypersthene achondrites contain 15 per cent to 20 per cent of combined FeO, and no meteorites of intermediate composition are known. This situation is analogous to the composition gap between the enstatite chondrites and the bronzite and hypersthene chondrites (Mason, 1962). In spite of a mineralogical similarity, there is no close or continuous relationship between the enstatite and the hypersthene achondrites.

Actually, the hypersthene achondrites are most closely related to the pyroxene-plagioclase achondrites. The latter consist of calcic plagioclase and pyroxene which is either hypersthene or pigeonite (or both in varying proportions). Some of the pryoxene-plagioclase achondrites such as Frankfort have similar chemical composition to the hypersthene achondrites, except for higher CaO and Al_2O_3—in other words, they differ by having appreciable plagioclase along with the pyroxene. This is understandable in terms of crystallization of an orthopyroxene-plagioclase melt; if the initial phase to crystallize is orthopyroxene, the composition of the melt will change toward the orthopyroxene-plagioclase cotectic, and on reaching the cotectic, plagioclase will crystallize along with the orthopyroxene.

It is more difficult to visualize the origin of the postulated orthopyroxene-plagioclase melt. However, if from a melt of chondritic composition a considerable amount of nickel-iron and olivine were removed, the residual melt would approximate that required (Mason, 1962). On this view the hypersthene achondrites are the intermediate product in a sequence pallasites-hypersthene achondrites-pyroxene plagioclase achondrites. The sequence is a logical one in terms of the fractional crystallization of a chondritic melt; the circumstances under which it might have taken place are less well understood.

At this point the interpretation of the structure of these meteorites is highly significant. For a petrologist familiar with terrestrial rocks, the hypersthene achondrites present obvious analogies to terrestrial hypersthenites. These are usually interpreted as cumulates of hypersthene crystals separated from a magma by gravitational or tectonic forces. A similar process may well have operated in a large asteroidal or small planetary body in the solar system. It appears that the hypersthene achondrites represent samples of a hypersthenite shell within such a body. Their brecciated and cataclastic structure is most readily interpreted as the result of a catastrophic breakup which projected them as fragments into orbits which eventually brought some of them within the sphere of attraction of the earth.

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REFERENCES

Amiruddin, A., and W. D. Ehmann
1962. Tungsten abundances in meteoritic and terrestrial materials. Geochim. et Cosmochim. Acta, vol. 26, pp. 1011–1022.

ATKINS, D. H. F., AND A. A. SMALES
1960. The determination of tantalum and tungsten in rocks and meteorites by neutron activation analysis. Geochim. et Cosmochim. Acta, vol. 22, pp. 462–478.
BATE, G. L., J. R. HUIZENGA, AND H. A. POTRATZ
1959. Thorium in stone meteorites by neutron activation analysis. Geochim. et Cosmochim. Acta, vol. 16, pp. 88–100.
BATE, G. L., H. A. POTRATZ, AND J. R. HUIZENGA
1960. Scandium, chromium and europium in stone meteorites by simultaneous neutron activation analysis. Geochim. et Cosmochim. Acta, vol. 18, pp. 101–107.
BREZINA, A.
1895. Die Meteoritensammlung des k. k. naturhistorischen Hofmuseums am 1 Mai 1895. Ann. K. K. Naturhist. Hofmus., Vienna, vol. 10, pp. 231–370.
CABELL, M. J., AND A. A. SMALES
1957. The determination of rubidium and caesium in rocks, minerals and meteorites by neutron-activation analysis. Analyst, vol. 82, pp. 390–406.
FOULLON, H. B. VON
1888. Untersuchung der Meteorsteine von Shalka und Manbhoom. Ann. K. K. Naturhist. Hofmus., Vienna, vol. 3, pp. 195–208.
HOVEY, E. O.
1925. A new meteoric stone from Johnstown, Weld County, Colorado. Amer. Mus. Novitates, no. 203, 13 pp.
KIRSTEN, T., D. KRANKOWSKY, AND J. ZAHRINGER
1963. Edelgas und Kalium-Bestimmungen an einer grösseren Zahl von Steinmeteoriten. Geochim. et Cosmochim. Acta, vol. 27, pp. 13–42.
KÖNIG, H., AND A. WÄNKE
1959. Uranbestimmung an Steinmeteoriten mittels Neutronaktivierung über die Xenon-Isotope 133 und 135. Zeitschr. Naturforsch., vol. 14a, pp. 866–869.
KUNO, H.
1954. Study of orthopyroxenes from volcanic rocks. Amer. Min., vol. 39, pp. 30–46.
LACROIX, A.
1925. La météorite de Roda. Compt. Rendus Acad. Sci. Paris, vol. 180, pp. 89–93.
1932. La météorite (diogénite) de Tataouine, Tunisie (27 juin 1931). Bull. Soc. Française Min., vol. 55, pp. 101–122.
MASON, B.
1962. Meteorites. New York, John Wiley and Sons, 274 pp.
NIEUWENKAMP, W.
1927. De meteoorsteen van Ellemeet. Verslag K. Akad. Wetensch. Amsterdam, vol. 36, pp. 625–628.
NISHIMURA, M., AND E. B. SANDELL
1962. Zinc in meteorites. Minneapolis, University of Minnesota, Final Report NSF-G9910, 51 pp.
PINSON, W. H., L. H. AHRENS, AND M. L. FRANCK
1953. The abundances of Li, Se, Sr, Ba, and Zr in chondrites and some

ultramafic rocks. Geochim. et Cosmochim. Acta, vol. 4, pp. 251–260.

PISANI, F., and G. A. DAUBRÉE
1874. Analyse d'une météorite tombée dans la province de Huesca, en Espagne. Compt. Rendus Acad. Sci. Paris, vol. 79, pp. 1507–1511.

POLDERVAART, A.
1950. Correlation of physical properties and chemical composition in the plagioclase, olivine and orthopyroxene series. Amer. Min., vol. 35, pp. 1067–1079.

RATH, G. VOM
1872. Über den Meteoriten von Ibbenbühren (Westphalen), gefallen am 17 juni 1870. Monatsber. Akad. Wiss. Berlin, pp. 27–36.

ROSE, G.
1863. Beschreibung und Eintheilung der Meteoriten auf Grund der Sammlung in mineralogischen Museum zu Berlin. Phys. Abhandl. Akad. Wiss. Berlin, pp. 23–161.

RUSHBROOK, P. R., AND W. D. EHMANN
1962. Iridium in stone meteorites by neutron activation analysis. Geochim. et Cosmochim. Acta, vol. 26, pp. 649–658.

SCHINDEWOLF, U.
1960. Selenium and tellurium content of stony meteorites by neutron activation. Geochim. et Cosmochim. Acta, vol. 19, pp. 134–138.

SCHMITT, R.
1962. A program of research for the determination of rare-earth elemental abundances in meteorites. San Diego, California, General Atomic, General Dynamics Corp., Report GA-3411, pp. 1–76.

STORY-MASKELYNE, N.
1870. On the mineral constituents of meteorites. Phil. Trans. Roy. Soc. London, vol. 160, pp. 189–214.

TSCHERMAK, G.
1883. Beitrag zur Classification der Meteoriten. Sitzber. Akad. Wiss. Wien, Math.-Nat. Kl., vol. 88, div. 1, pp. 347–371.
1885. Die mikroskopische Beschaffenheit der Meteoriten erläutert durch photographische Abbildungen. Stuttgart, Schweizerbart'sche Verlags, 24 pp.

TURNER, F. J., H. HEARD, AND D. T. GRIGGS
1960. Experimental deformation of enstatite and accompanying inversion to clinoenstatite. Proc. Internatl. Geol. Congr., XXI Session, vol. 18, pp. 399–408.

WEBSTER, R. K., J. W. MORGAN, AND A. A. SMALES
1957. Some recent Harwell analytical work on geochronology. Trans. Amer. Geophys. Union, vol. 38, pp. 543–546.