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Charles D. and Mary Vaux Walcott
Research Fund

HEXAHEDRITES

(WITH FOUR PLATES)

BY
EDWARD P. HENDERSON
U. S. National Museum
Smithsonian Institution

(PUBLICATION 4601)

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CITY OF WASHINGTON
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INTRODUCTION

Hexahedrites are the simplest of the iron meteorites and a comparatively easy type to recognize, yet many have been incorrectly classified. In several places these irons were found distributed in such a manner that they seem to have fallen as a shower. This investigation of the worldwide distribution of hexahedrites was made to determine how general these local concentrations are. In assembling the geographic data, certain characteristics were noted which could have a bearing on the scatter of these irons.

Acknowledgments.—Because these topics were discussed with many investigators in diverse disciplines over the years, it is difficult to credit specific points to the proper source. The author realizes that some names probably have been overlooked and to them he offers apologies. The following persons have made substantial contributions to this study: H. J. Axon, University of Manchester, Manchester, England; Harrison Brown, California Institution of Technology, Pasadena, Calif.; V. Buchwald, Technical University, Copenhagen, Denmark; Walter Corvello, National Museum, Rio de Janeiro, Brazil; Roy S. Clarke, Jr., U. S. National Museum, Washington, D. C.; M. E. Lipschultz, Goddard Space Flight Center, National Aeronautics and Space Administration, Washington, D. C.; Brian Mason, American Museum of Natural History, New York City; Charles Olivier, formerly of Flower Observatory, University of Pennsylvania, Philadelphia, Pa.; Sharat Roy (deceased), Chicago Museum of Natural History, Chicago, Ill.; Harold Urey, University of California, La Jolla, Calif.; H. Wänke, Max Planck Institute, Mainz, Germany.

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HEXAHEDRITES AND THE NICKEL-IRON SYSTEM

The three types of iron meteorites, hexahedrites, octahedrites, and ataxites, are accounted for by the nickel–iron phase diagram, fig. 1; however, there are no clearly defined separations between the different types. The hexahedrite group is located to the left of the line AB in figure 1. These should consist of a single phase, alpha iron or kamacite. The octahedrites fall in the area between AB and AC and consist of two phases of nickel–iron alloys, kamacite (alpha iron) and taenite (gamma iron). The third group, ataxites, should

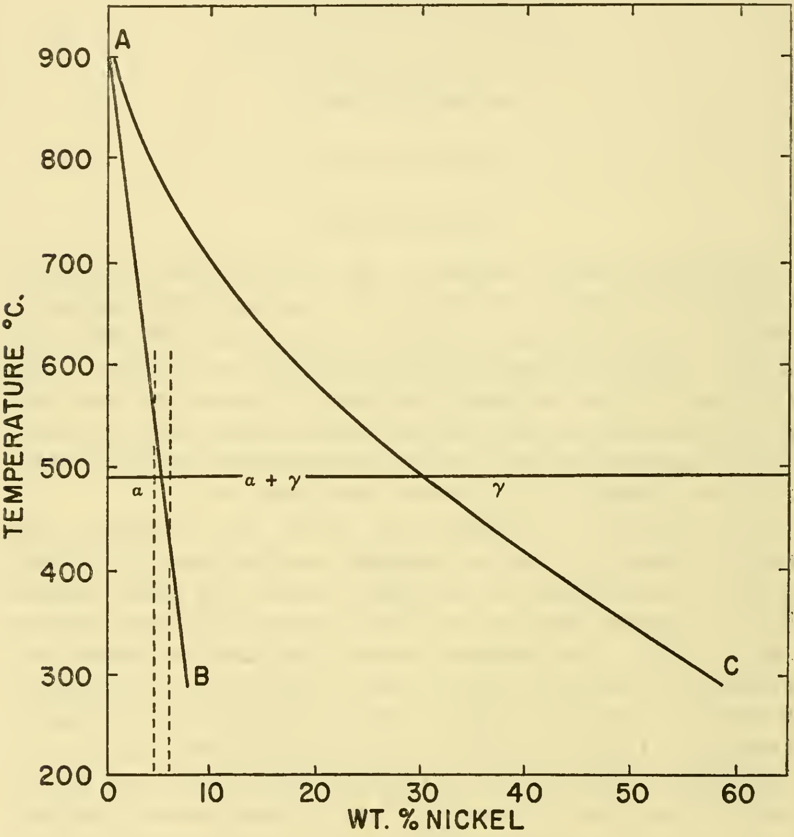

Fig. 1.—Nickel-iron phase diagram. The hexahedrites and nickel-poor ataxites fall into the same area, i.e., left of the line AB and usually within the area defined by the two dotted lines. A hexahedrite should consist of one nickel-iron alloy, kamacite or alpha iron.

occupy the area to the right of AC and chiefly consist of taenite, but usually also contain an appreciable quantity of alpha iron, kamacite.

Meteorites lying along the borderlines of groups are difficult to classify. Thus, any list of hexahedrites compiled by one investigator will contain irons that another compiler might regard as coarse octahedrites.

The Ni–Fe diagram (fig. 1) shows the conditions under which kamacite (alpha iron), the sole constituent of a hexahedrite, forms. The two dotted vertical lines at 5.5 and 6.0 percent Ni define the range within which hexahedrites grade into coarse octahedrites. Thus, no hexahedrite has a nickel value to the right of these dotted lines, and most hexahedrites lie either on or slightly to the left of the 5.5 line.

The different classes of meteorites—hexahedrites, nickel-poor ataxites, octahedrites, and nickel-rich ataxites—do not correspond to the diagram for 1 atmosphere of pressure, as stated by Uhlig (1954) and by Henderson and Perry (1954). According to Uhlig, this is due to the fact that meteorites form under pressures greater than 1 atmosphere.

If a horizontal line is drawn in figure 1 at 490°C., and if it is assumed that no changes take place below this temperature, the modified diagram more faithfully depicts the structures in iron meteorites. Following a 490° line from left to right, the hexahedrites, which consist of one component, lie to the left of the line AB while the octahedrites and nickel-rich ataxites lie between AB and AC.

The chemical composition reported for the hexahedrites and nickel-poor ataxites only represents an average composition of the area selected for analysis and not the entire meteorite. Since the Ni values of hexahedrites range from about 4 to 6 percent, there is no valid chemical reason for continuing the use of the term nickel-poor ataxite. This term should be dropped.

The available analyses of the nickel-rich ataxites, hereafter referred to as ataxites, show nickel values which can be located on the 490° line to the left of where it crosses the AC line. Actually most of the Ni percentages lie nearer to the AB than the AC line. Thus, kamacite should be a common constituent in ataxites, and indeed, kamacite spindles are recognizable in these meteorites. The structures of ataxites are more confused than the structures in the octahedrites and hexahedrites.

An interesting relationship was noted in the range of Ni percentages of the three groups of meteorites. The difference between the lowest and highest nickel value in the hexahedrites is about 2 percent, in octahedrites the range is about 6 percent, while in ataxites it is nearer 18 percent.

DESCRIBED HEXAHEDRITES

Table 1 lists all known hexahedrites as of July 1962, together with their weights and dates of fall or find. Synonyms are not numbered.

TABLE 1.—*List of described hexahedrites.*

	Name	Weight, *kilograms*	Date of discovery	Date of fall
	Angela (see La Primitiva)			
	Aragon, Ga. (see Cedartown)			
1.	Aswan, Egypt	?	1953	
2.	Auburn, Ala.	3.6	1867	
3.	Avče, Italy	1.23		Mar. 31, 1908
4.	Barraba, Australia (Bingara)	1.36	unknown	
5.	Bellsbank, S. Africa	38	1950 (?)	
6.	Bennet Co., S. Dak.	89	1934	
7.	Bingara, N. S. Wales	1.1 & 6.4	1880	
8.	Boguslavka, Siberia	199 & 57		Oct. 18, 1916
9.	Braunau, Czechoslovakia	22 & 17		July 14, 1847
10.	Bruno, Canada	13	1913	
11.	Cedartown, Ga.	11.3	before 1898	
12.	Central Missouri [1]	25	1885	
13.	Chesterville, S. C.	16.5	1848	
14.	Chico Mountain, Tex.	2,000 [2]	before 1915	
15.	Chinguetti, French W. Africa	— [3]	1920	
16.	Cincinnati, Ohio	unknown	1870	
17.	Coahuila, Mexico	1,000	1837	
18.	Corrego do Areado, Brazil	32	1925	
19.	Coya Norte, Chile	17.9	1927	
20.	Edmonton, Canada	7.34	1939	
	El Mocovi (see Otumpa)			
21.	Filomena, Chile	21.1	1941	
	Fort Duncan (see Coahuila)			
22.	Forsyth County, N. C.	17	1891	
	Gressk, Russia (see Hressk)			
23.	Hex River, Africa	60	1882	
24.	Holland's Store, Ga.	12.27	1887	
25.	Hressk, Russia	11.9	1954	
26.	Indian Valley, Va.	14	1887	
27.	Iredell, Tex.	1.5	1898	

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[1] Usually this iron is listed as a coarse octahedrite, but Perry (1944) considered it a granulated hexahedrite. See plate 4.

[2] Sample lost, weight unconfirmed.

[3] Reported as 100 meters long, 45 meters high. These figures probably were intended to be centimeters, not meters.

Table 1.—*Continued*

28. Keen Mt., Va.	6.7	1950	
29. Kendall County, Tex.	21	1887	
30. La Primitiva, Chile	3.1, 4, 1.5, 4.3, 9	1888	
31. Lick Creek, N. C.	1.24	1879	
32. Locust Grove, Ga.	10	1857	
33. Lombard, Mont.	unknown	?	
34. Mayodan, N. C.	16	1950	
35. Mejillones, Chile	—[4]	1875	
Mejillones, Chile	14.5	1905	
36. Murphy, N. C.	8	1889	
37. Mt. Joy, Pa.	385	1887	
38. Navajo, Ariz.	1499 680	1921-1926	
39. Nedagolla, India[5]	4.5		Jan. 23, 1870
40. Negrillos, Chile	28.5	before 1936	
41. Nenntmannsdorf, Saxony	12.5	1872	
42. Okano, Japan	4.74		Apr. 7, 1904
43. Opavo, Czechoslovakia	7.4, 5.8, 1.0, 0.1	1925	
44. Otumpa, Argentina	(15 tons, est.)	1576	
45. Pima County, Ariz.	0.21	before 1947	
46. Pirapora, Brazil[6]	2.56		
47. Puripica, Chile	19	1929	

[4] "A cart would be required for its carriage," G. A. Daubree, Compt. Rend., Acad. Sci. Paris, vol. 81, p. 597, 1875.

[5] Although reported as a nickel-poor ataxite, the analyses show 6.2 and 6.1 percent of Ni. These values are above the Ni content of hexahedrites. This iron, which has exceptionally fine flight markings, obviously fell as an orientated individual. A cross section through its short dimension shows two well-defined heat-altered zones about 2.5-3.0 mm. wide. The metal between these thermally altered zones displays a pattern like that formed when metal is rapidly quenched (Axon, 1962). This structure is visible at low magnifications (6× to 10×); however, at higher magnifications a granular texture is noticeable. Both structures existed before this meteorite entered our atmosphere.

All witnessed falls of hexahedrites (table 2) occurred in the morning. Nedagolla fell at 7 p.m. Meteorites falling in the morning are oncoming ones, thus enter the atmosphere with higher velocities than those which fall in the afternoon hours. Hence, the Nedagolla differs from the witnessed hexahedrite falls not only in its metallography and chemistry, but also in the time of fall.

To combine two interpretations, one from its chemistry and the other from its metallography, to explain its past history, is difficult. The structure, noticeable at low magnifications, is that of a metal which solidified quickly, but the granular texture, visible at higher magnifications, is suggestive of later reheating to about 800°C. Where and when these events took place is unknown, but they happened prior to its fall in 1870. From its chemical composition this iron might represent a melted coarse octahedrite, and it is definitely unlike all other hexahedrites.

[6] The Pirapora, Brazil, iron was reported in private communications from Dr. Walter Curvello, Museum Nacional, Rio de Janeiro. No additional data are available.

Table 1.—*Continued*

48. Quillagua, Chile	78	1938	
49. Richland, Tex.	15.4	1951	
50. Rio Loa, Chile	4	1915	
51. Sakouchi, Japan [7]	4.18	1913	Apr. 13, 1913
52. San Francisco del Mezquital, Mexico	7.5	before 1868	
53. San Martin, Chile	29	before 1924	
54. Scottsville, Ky.	10	1867	
55. Sierra Gorda, Chile	22.0	1898	
56. Sikhote Alin, E. Siberia [8]	(many tons)		Feb. 12, 1947
57. Siratik, W. Africa	—[9]	1716	
58. Smithonia, Ga.[10]	70	1940	
59. Soper, Okla.	3.7	1938	
60. Summitt, Ala.	1	1890	
61. Tandil, Argentina	0.98		1916-1919
62. Tocopilla, Chile	75	1927	
63. Tombigbee, Ala.	43	1859-86	
64. Union, Chile	22	1930	
65. Uwet, Nigeria	54	1903	
66. Villanueva del Fresno, Spain	0.35 [11]	not given	
67. Walker County, Ala.	75	1832	
68. Warialda, N. S. Wales (Bingera)	2.8	1919	
69. Wathena, Kans.	0.56	1939	
70. Yarroweyah, Victoria, Australia	9.5	1903	

[7] Since Kanda (1952) lists the Sakouchi as a hexahedrite, it is included in this list. The information about this meteorite is incomplete and conflicting.

[8] The composition lies along the border between the hexahedrites and the coarse octahedrites. Because there is an absence of a noticeable octahedral arrangement in these specimens, this iron is classified as a hexahedrite.

[9] This meteorite needs restudy. Although a large mass was found, only about 1.7 kg. is known today.

[10] When Roy and Wyant (1950) studied the Smithonia, Ga., iron, they found no Neumann lines, the nickel content below 6 percent, and hence classified it as a nickel-poor ataxite. In a later cut, which penetrated deeper into the meteorite, Henderson and Furcron (1957) observed Neumann lines which established this iron as a normal hexahedrite.

[11] Weight not reported, but was calculated from the dimensions.

METEORITES INCORRECTLY IDENTIFIED AND EXCLUDED FROM THE HEXAHEDRITES

Not included in the foregoing list of hexahedrites are seven specimens incorrectly listed as hexahedrites. These are:

1. Chihuahua City, Mexico. Although this iron was listed by Hey (1953) as a brecciated hexahedrite, Nininger (1931) reported it as having "a fine octahedral crystallization." Also Nininger

published an analysis by F. C. Hawley which reported 6.96 percent Ni. Again in 1950 Nininger classified this iron as a brecciated octahedrite. Goldberg and others (1951) published two nickel determinations, 6.97 and 6.85 percent. Thus, three analyses report values in excess of those for a hexahedrite.

2. Dorofeevka, U.S.S.R. Illustrations of this iron published by Zavaritsky (1954) show both narrow kamacite lamellae and plessite areas. In the text Zavaritsky mentions that this iron resembles a nickel-rich ataxite.

3. Granado, Ariz. Nininger and Nininger (1950) reported this 38-gram iron as a hexahedrite, but H. H. Nininger now regards it as a piece of Canyon Diablo (personal communications).

4. Lake Murray, Carter County, Okla. Classified as a coarse octahedrite. This specimen, weighing 272.7 kg., was found about 1932 but not excavated and recovered until 1952. La Paz considered it an intermediate member between the hexahedrites and octahedrites and proposed the term "hexaoctahedrite." Plate 1 shows a portion of a cut through the Lake Murray meteorite. In several areas wide kamacite bands are arranged in an octahedral pattern. The octahedral structure in other parts of this section is disrupted by the growth of large skeletons of schreibersite inclusions, some measuring more than 6 cm. in length and 4 cm. in width.

5. New Mexico. This 130-gram specimen was found in 1923 at approximately 34°31′ N. and 107° W. Nininger and Nininger (1950) listed it as a hexahedrite and said it had been fashioned into an ax. Obviously man had something to do with this iron. Since the Sandia Mountains, N. Mex., iron has kamacite grains of about this size and shape, H. H. Nininger now regards the New Mexico specimen as a man-worked fragment of the Sandia Mountains iron (personal communications).

6. Sulechow, Poland. Although typed as a hexahedrite by Pokrzywnicki (1959), the Ni value in analysis is within the range of the octahedrites.

7. Western Arkansas. Merrill (1927) reported an analysis with a nickel value within the range of the hexahedrites but did not classify the meteorite. Merrill's published analysis is inconsistent with the structure of this specimen. Also the analysis of the meteorite with which Merrill compared the analysis of the Western Arkansas was proved to be inaccurate. The Western Arkansas, therefore, is definitely not a hexahedrite.

PHENOMENA OF HEXAHEDRITE FALLS

WITNESSED FALLS OF HEXAHEDRITES

The first observed fall of a hexahedrite took place near Braunau, Czechoslovakia, in 1847. Since then, falls of five other hexahedrites have been witnessed. Six of the seven meteorites in table 2 fell north of the Equator in the Eastern Hemisphere, while one (Tandil) fell in the Western Hemisphere south of the Equator (table 2).

Since the two pieces of the Braunau iron, 22 and 17 kg., fell in 1847, two other hexahedrites have been recovered within 100 miles of Braunau (see fig. 7). Perhaps, therefore, the 1847 fall was a shower of hexahedrites.

Table 2.—*Witnessed falls of hexahedrites arranged chronologically.* (The Nedagolla iron, which is not a true hexahedrite, is included for comparison.)

Name	Country	Date of fall and hour	Coordinates	
Braunau	Czechoslovakia	July 14, 1847—3:45 a.m.	56.6° N.	16.3° E.
Nedagolla[1]	India	Jan. 23, 1870—7:00 p.m.	18°41′ N.	83°20′ E.
Okano	Japan	Apr. 7, 1904—6:35 a.m.	35°4′ N.	135°13′ E.
Avče	Italy	Mar. 31, 1908—8:45 a.m.	46° N.	13.5° E.
Boguslavka	Siberia	Oct. 18, 1916—11:47 a.m.	44°33′ N.	131°38′ E.
Tandil	Argentina	Between 1916-1919—?	37°17′ S.	59°6′ E.
Sikhote-Alin	Siberia	Feb. 12, 1947—10:38 a.m.	46°9.6′ N.	134°39.2′ E.

[1] See footnote 5 to table 1.

Another interesting fact about these witnessed falls is that five occurred in the morning, with the Boguslavka iron falling only 13 minutes before noon. The Nedagolla, which has structural features and a chemical composition unlike a hexahedrite, fell in the afternoon. The time of fall of the Tandil iron was not recorded. The fact that these irons, with the possible exception of the Tandil meteorite, fell in the morning may not be a coincidence.

CLUSTERING OF HEXAHEDRITES

The clustered occurrence of hexahedrites was once assumed to be due to transportation by man. Fletcher (1890) concluded that because iron meteorites were useful as anvils and for other purposes, man gathered them for use and later discarded them in places distant from where they fell. This point of view is no longer popular either with those who study meteorites or with archeologists.

In the late 19th century local concentrations of hexahedrites prompted the question, "Are these irons related?" Farrington (1915) said: "Early writers are inclined to group into one fall similar meteorites, even though separated by thousands of miles of distance, but later observations have failed to confirm this view."

Several widely scattered large hexahedrites are known from northern Mexico. Many of these have been sectioned and now are considered to be parts of the Coahuila meteorite. Thus, names given to individual masses, such as Sanchez Estate, Hacienda, Potosi, Fort Duncan, etc., are now relegated to synonomy, and all are collectively known as the Coahuila meteorite. Farrington (1915) accepted the Coahuila group as a shower and said, "In the State of Coahuila, Mexico, numbers of meteoritic irons of a rare class, hexahedrites, are found one or two hundred miles apart. It hardly seems likely that separate falls of these rare meteorites would occur within such a limited area."

Twenty-five hexahedrites have been found since Farrington wrote as he did in 1915. A number of these coincide with some of the geographic groupings noted by earlier writers. Of the new geographic groups found since Farrington's time, the most important is the Chilean group. In general, the places where hexahedrites were found suggest the probability that they fell as showers.

It is assumed that all the Coahuila meteorites come from latitude 28°40′ N. and longitude 102°50′ W., a midpoint in the scatter of those specimens in northern Coahuila. Earlier writers even suggested that some hexahedrites from Virginia, Georgia, and Kentucky were related to the Coahuila irons. Although it is possible that the hexahedrites from these eastern States are part of the Coahuila shower, this study lists them as hexahedrites from southeastern United States (see table 6).

If it is reasonable for Fletcher (1890) to regard the Coahuila irons as a shower, it would seem equally admissable to include some of the hexahedrites found slightly north and east of Coahuila in Texas and toward the Oklahoma border, as part of the same shower. Since the hexahedrites in this portion of Texas are as closely spaced as the hexahedrites in other geographic areas, they are grouped with the irons scattered around Coahuila (see table 5).

MECHANISM FOR SCATTERING METEORITES

The above distribution of hexahedrites would be accounted for if two or more large hexahedrites approached the earth on essentially parallel trajectories. Under these circumstances the second or third masses to enter our atmosphere and fall would scatter pieces in different places from those where the first or second one fell. Thus, the distance between the strewn fields would depend upon the interval that separated the arrival of the individual masses into the atmosphere and upon the trajectories along which they were traveling. For meteorites to approach the earth in such a manner probably would require the fragmentation of a larger object relatively close to the earth. Any mass fragmenting far out in space would scatter, and thus few pieces would have parallel orbits.

Many spectacular fireballs have been tracked across North America, and from some of them meteorites have fallen. Since the distance traversed by some fireballs exceeds the distance over which clustered hexahedrites have been found scattered, a few of these events will be briefly reviewed.

When Smith (1877) described the Rochester fireball of 1876, he may have considered a mechanism similar to that described above when he wrote:

> The Bolide made its appearance about 9 o'clock p.m., December 21, 1876, and was of extraordinary magnificence. It passed eastward over the States of Kansas, Missouri, Illinois, Indiana, Ohio, and parts of Pennsylvania and New York. Although no observations were made in the last two mentioned states, still Professor Kirwood is doubtless correct in defining this as its course. At Bloomington, its elevation was 15 degrees. According to the calculations, the length of its observed track was from 1000 to 1100 miles, one of the longest on record. Its height is supposed to have been 38 miles above the place where the small fragments fell from it.

The Canadian fireball of February 9, 1913, which was named Cyrillid by O'Keefe (1961), also made an unusually long streak across the country. Detonations were heard all the way from Toronto, Ontario, to Towanda, Pa., a distance of 200 miles. If more observations had been collected immediately after its passage, this distance possibly would have been extended. O'Keefe quotes observers as saying, "Before the astonishment aroused by the first meteor had subsided, other bodies were seen coming from the northwest, emerging from precisely the same place as the first one. Onward they moved, at the same deliberate pace, in twos or threes or fours, with trails streaming behind."

The Pasamonte meteorite, which fell March 24, 1933, also made a brilliant display over several states. Nininger (1934) interviewed observers in the area from near Wichita, Kan., to New Mexico, where the specimens were recovered. This fireball was seen for approximately 400 miles, but the objects known to have fallen from it are confined to a distance of about 4 miles.

The three foregoing events happened within 57 years, and in two cases the observed flights extended 1,000 to 1,100 miles and about 400 miles, respectively. Witnesses of the 1913 fireball reported that more than one object was seen moving through the sky. Meteorites are usually considered to be single objects when they enter our atmosphere, but it appears on the basis of the 1913 observation that several objects can enter the atmosphere at slightly different times and along the same trajectory. If more than one object was involved in the 1913 fireball, probably some were higher in the sky than others, although all appeared to be moving on the same or only slightly different trajectories.

Before leaving the subject of fireballs, some comments seem necessary on recurring meteor showers that appear from year to year. Elliott (1804) wrote about the November 12, 1799, display as follows:

> November 12, 1799, about three o'clock a.m., I was called up to see the shooting stars. The phenomenon was grand and awful, the whole heavens appeared as if illuminated by sky rockets, which disappeared only by the light of the sun after daybreak. The meteors which appeared at any one instant as numerous as stars, flew in all possible directions except from the earth towards which they are inclined more or less, and some of them descended perpendicularly over the vessel we were in. So that I was in constant expectation of their falling among us. We were in latitude 25° N. and SE. of Kay Largo near the edge of the Gulph Stream. I have since been informed that the phenomenon extended over a large proportion of the West India Islands and as far north of Mary's in latitude 30°42′, when it appeared as brilliant as with us off Cape Florida.[1]

Although it is frequently stated that meteorites do not fall from reappearing meteor showers, such as the Leonid showers in November, this may be incorrect, for the records show that from 1800 to the present time (January 1963), 43 meteorites have fallen in November. The greatest number of meteorites to fall on any day in November is 5, and this number fell on the 12th day of the month. Thus, until more information is available, we cannot be sure that these recurring meteor showers do not bring an occasional meteorite. However, one phenomenal shower like that observed in 1799 could have delivered most of these hexahedrites.

Between 1800 and mid-1962, 218 meteorites fell and were recovered in August, September, October, and November. The distribution of these falls is shown in figure 2 by listing the year and the day of the month on which the fall occurred.[2] The Bali, West

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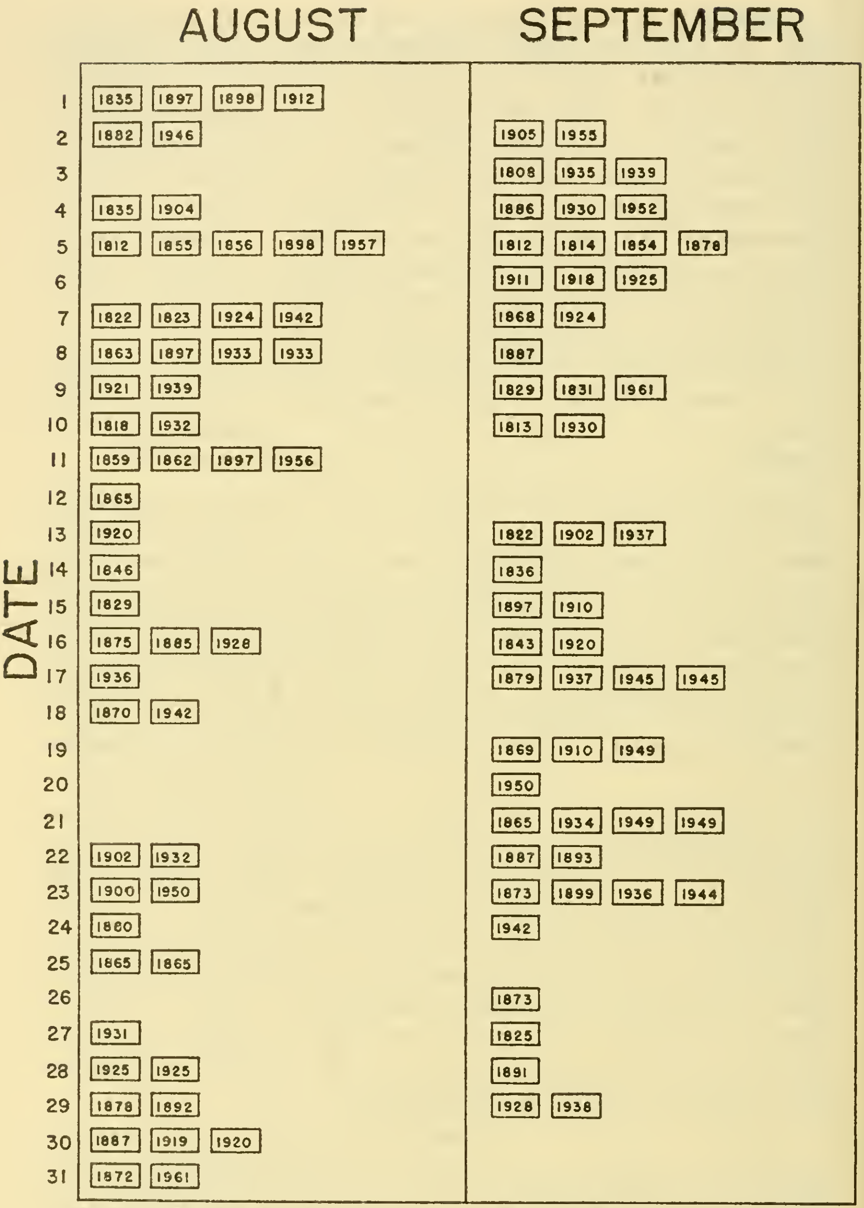
[1] Humboldt, the German naturalist, who was in South America in 1799, also observed this meteor display.

[2] Seventeen falls were reported by year and month, but the day was not given.

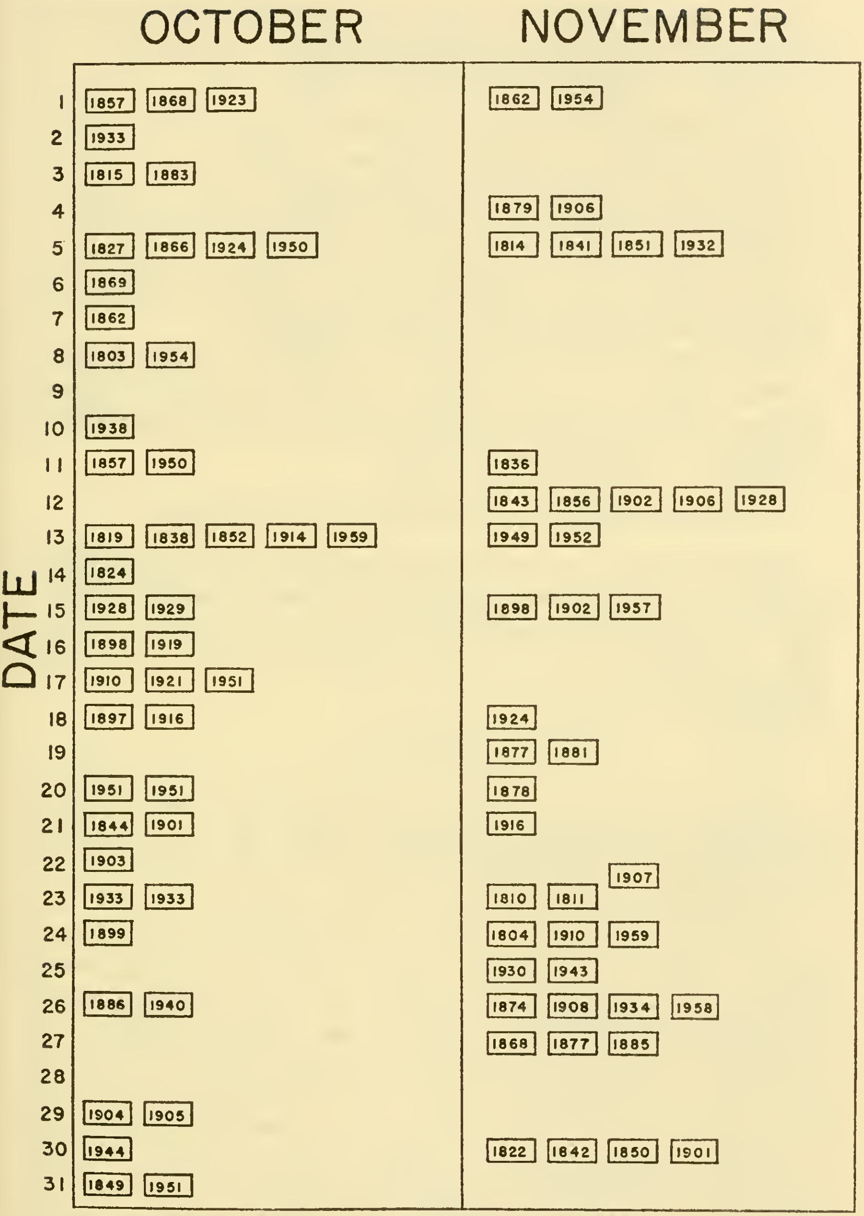


DATE	AUGUST					SEPTEMBER			
1	1835	1897	1898	1912					
2	1882	1946				1905	1955		
3						1808	1935	1939	
4	1835	1904				1886	1930	1952	
5	1812	1855	1856	1898	1957	1812	1814	1854	1878
6						1911	1918	1925	
7	1822	1823	1924	1942		1868	1924		
8	1863	1897	1933	1933		1887			
9	1921	1939				1829	1831	1961	
10	1818	1932				1813	1930		
11	1859	1862	1897	1956					
12	1865								
13	1920					1822	1902	1937	
14	1846					1836			
15	1829					1897	1910		
16	1875	1885	1928			1843	1920		
17	1936					1879	1937	1945	1945
18	1870	1942							
19						1869	1910	1949	
20						1950			
21						1865	1934	1949	1949
22	1902	1932				1887	1893		
23	1900	1950				1873	1899	1936	1944
24	1860					1942			
25	1865	1865							
26						1873			
27	1931					1825			
28	1925	1925				1891			
29	1878	1892				1928	1938		
30	1887	1919	1920						
31	1872	1961							

NO DATE : 1810,1826,1837,1856,1949,1950.

NO DATE: 1843,1875,1907,1930,1930,1933.

FIG. 2A.—Meteorite falls by day of month.



DATE	OCTOBER	NOVEMBER
1	1857, 1868, 1923	1862, 1954
2	1933	
3	1815, 1883	
4		1879, 1906
5	1827, 1866, 1924, 1950	1814, 1841, 1851, 1932
6	1869	
7	1862	
8	1803, 1954	
9		
10	1938	
11	1857, 1950	1836
12		1843, 1856, 1902, 1906, 1928
13	1819, 1838, 1852, 1914, 1959	1949, 1952
14	1824	
15	1928, 1929	1898, 1902, 1957
16	1898, 1919	
17	1910, 1921, 1951	
18	1897, 1916	1924
19		1877, 1881
20	1951, 1951	1878
21	1844, 1901	1916
22	1903	1907
23	1933, 1933	1810, 1811
24	1899	1804, 1910, 1959
25		1930, 1943
26	1886, 1940	1874, 1908, 1934, 1958
27		1868, 1877, 1885
28		
29	1904, 1905	
30	1944	1822, 1842, 1850, 1901
31	1849, 1951	

NO DATE: 1918, 1930, 1951.

NO DATE: 1833, 1959.

FIG. 2B.—Meteorite falls by day of month (continued).

Africa, meteorite fell in the morning hours of either the 22d or 23d of November 1907, hence is shown midway between these dates.

An inspection of figure 2 shows the following:

1. The falls are not uniformly dispersed through these 122 days. Actually, on 32 days no meteorite falls were reported.

2. The longest gap without falls is the 6th to 10th of November, the interval which precedes the reappearance of the Leonid showers.

3. The greatest number of meteorites to fall on any date is 5, and this number fell on each of three days—August 5, October 13, and November 12 (see table 3B for detailed listing).

If the witnessed meteorite falls are grouped into 10-day intervals between August 1 and November 30 (table 3A), the maximum number of falls, 23, occurs between August 1 and 9; the minimum number is 8, between November 1 and 9.

GEOGRAPHICAL ANALYSIS OF HEXAHEDRITES

The next step is to examine the distribution of the hexahedrites listed in table 1 to determine whether their scatter suggests random falls or a shower. The hexahedrites from the different continents have been plotted on maps, and their groupings will be discussed by geographic areas.

NORTH AMERICA

The irons from this continent group themselves into two or possibly three areas, with two stragglers located outside the main geographic concentrations. The stragglers, which occur in western United States, are discussed at the end of the section on North America.

Western North America.—The four hexahedrites from the northwestern portion of the United States and from part of nearby Canada are shown in table 4. These irons can be enclosed within an ellipse 875 miles long. Four is an insufficient number of specimens from an ellipse of this size to suggest a shower. Yet if the groupings of hexahedrites in other areas of the world are significant, this may become a promising area for future hexahedrite discoveries.

Southern United States and northern Mexico.—Table 5 lists the specimens recovered in this part of the continent. Six were found in an area extending northeast from Coahuila, Mexico, across Texas to southern Oklahoma (fig. 3). This area can be enclosed by an ellipse with a long axis of about 500 miles. This distance, more than half the long axis of the group of four western hexahedrites

TABLE 3.—*Witnessed meteorite falls between 1800 and July 1962*

SECTION A

Grouped into arbitrary intervals.

	Falls between 1st and 9th	Falls between 10th and 19th	Falls between 20th and end of month
August	23	16	17
September	21	17	17
October	14	18	15
November	8	14	21

SECTION B

Meteorite falls of August 5, October 13, and November 12.

Year	Meteorite	Location	Coordinates		Hour of fall	Type	Percentage of Fe_2SiO_4 in olivine (X-ray)	Gamma index olivine .002±*	Prominent pyroxene present *
			August 5						
1812	Chantonnay	France	46°41′ N.	1°3′ W.	2	Chondrite	23	1.715	Hypersthene
1855	Petersburg	Tennessee	35°18′ N.	86°38′ W.	15.30	Eucrite	...	...	...
1856	Oviedo	Spain	43°24′ N.	5°52′ W.	17.45	Chondrite	...	1.717	Hypersthene
1898	Andover	Maine	44°37′ N.	70°45′ W.	7.30	Chondrite	25	1.720	Hypersthene
1957	Ufana	Tanganyika	4°16′ S.	35°21′ E.	18.20	Mesosid.	...	...	...
			October 13						
1819	Pohlitz	Germany	50°56′ N	12°8′ E.	8	Chondrite	...	1.717	Hypersthene
1838	Cold Bokkeveld	S. Africa	32°50′ S.	19°20′ E.	9	Carbon-ch.	...	...	...
1852	Borkut	Russia	48°9′ N.	24°17′ E.	15	Chondrite	26	1.715	Hypersthene
1914	Appley Bridge	England	53°35′ N.	2°43′ W.	20.45	Chondrite	30	1.732	Hypersthene
1959	Hamlet	Indiana	41°20′ N.	86°35′ W.	21.05	Chondrite	27	1.731	Hypersthene
			November 12						
1843	Verkhne Tschirskaia	Russia	48°25′ N.	43°12′ E.	12	Chondrite	...	1.702	Bronzite
1856	Trenzano	Italy	45°28′ N.	10°1′ E.	16	Chondrite	20	1.707	Bronzite
1902	Kamsagar	India	14°11′ N.	75°48′ E.	13	Chondrite	24	1.721	Hypersthene
1906	Kirbyville	Texas	30°45′ N.	95°57′ W.	15.30	Eucrite	...	...	...
1928	Isthilart	Argentina	31°6′ S.	58°4′ W.	19.30	Chondrite	18	1.707	Bronzite

* Personal communication from Brian H. Mason.

TABLE 4.—*Data on hexahedrites from northern and western areas of United States and Canada arranged by latitude.*

Meteorite	Date found	Latitude	Longitude
Bennett County, S. Dak.	1934	43° 28′ N.	101° 9′ W.
Lombard, Mont.	?	46° N.	111° 24′ W.
Bruno, Canada	1931	52° 16′ N.	105° 21′ W.
Edmonton, Canada	1939	53° 35′ N.	113° 30′ W.

(table 4), exceeds the scatter of stony meteorites from most of the witnessed falls by a factor between 50 and 100. The distance over which the hexahedrites are dispersed is a most difficult fact to account for in accepting the apparent clustering of these irons as evidence of a shower of meteorites.

Only the Chico Mountain, Tex., iron requires further mention here. Acquired by the U. S. National Museum in 1915 from E. M.

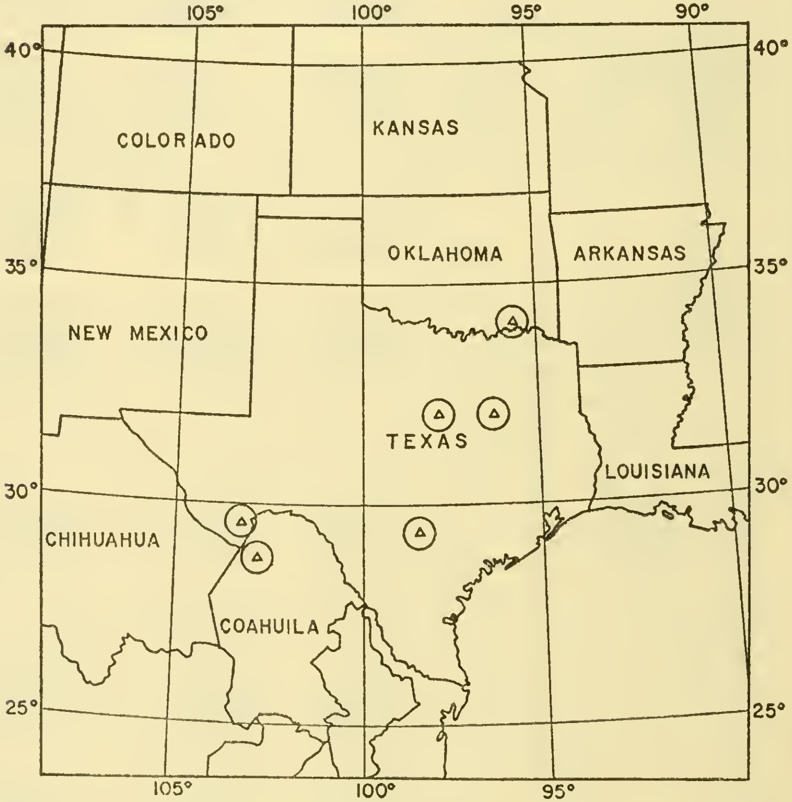


FIG. 3.—Geographic distribution of hexahedrites listed in table 5.

Flynn of Alpine, Tex., it was described by Merrill in 1922 as the Alpine, Brewster County, meteorite. Although it is reported that the original body weighed nearly 2 tons, the piece accessioned in the national collections weighs only 212 grams. Apparently the main mass has vanished.

Merrill's published picture shows that the specimen probably was reheated, but how and where this took place is not known. Actually, the entire surface of the small specimen is granulated, but the texture of the zone near the surface is finer grained than that of the central part. There is no indication of either cleavage or Neumann lines. The chemical analysis Merrill reports is consistent with that of other hexahedrites, and Merrill suggested the possibility that this specimen is related to the Coahuila meteorite.

TABLE 5.—*Data on hexahedrites from Coahuila, Mexico, and Texas-Oklahoma arranged by latitude.*

Meteorite	Date found	Latitude	Longitude
Coahuila, Mexico	1837	28°40′ N.	102°50′ W.
Kendall County, Tex.	1887	29°24′ N.	98°30′ W.
Chico Mountain, Tex.	1915	29° N.	103°15′W.
Richland, Tex.	1951	31°59′ N.	96°14′ W.
Iredell, Tex.	1898	31°58′ N.	97°52′ W.
Soper, Okla.	1938	34°5′ N.	95°37′ W.

Southeastern United States.—The hexahedrites from this area are arranged in table 6 according to the increasing latitudes of their points of discovery. Figure 4 shows the arrangement on a map of all of these finds with the exception of the Cincinnati iron, the omission of which is explained below. The distance from the southernmost one, Tombigbee River, Ala., to the northernmost, Mt. Joy, Pa., is approximately 850 miles. This distance exceeds the length of the strewn fields of stony meteorite falls by a factor of nearly 100.

Foote (1899) mentioned that six pieces of the Tombigbee River meteorite were found in nearly a straight line some 16 km. long, with the heaviest mass to the north. Similarly, the heaviest meteorite in table 6, the Mt. Joy iron, is located in the northeastern end of the 850-mile ellipse. It is easier to assume that the 6 irons along a line 16 km. long are related as a shower than that all 19 meteorites came as a shower. But if the north and south alignment of the Tombigbee River iron is important, all the 19 meteorites perhaps should be regrouped into smaller clusters, more or less in a north–south direction.

Both the Scottsville and Cincinnati irons lie to the north and west of the oval area enclosing the other hexahedrites found in the zone lying in a northeast–southwest direction. However, if the north–south alignment of the six Tombigbee River irons is important, and if the other hexahedrites are grouped into north and south clusters, then the Scottsville and Cincinnati irons fit better into the pattern with the other irons.

TABLE 6.—*Data on the hexahedrites from the southeastern area of the United States arranged by latitude.*

Meteorite	Weight, kilograms	Date found	Latitude	Longitude
Tombigbee River, Ala	43.8	1858	32°13′ N.	88°10′ W.
Auburn, Ala.	3.5	1867	32°37′ N.	85°32′ W.
Locust Grove, Ga	10.0	1857	33°20′ N.	84°8′ W.
Walker County, Ala	75.0	1832	33°50′ N.	87°15′ W.
Cedartown, Ga.	11.3	1898	34°0′ N.	85°16′ W.
Smithonia, Ga.	69.8	1940	34°0′ N.	83°11′ W.
Aragon, Ga. (Cedartown) [1]	(5 gm.)	1898	34°1′ N.	85°3′ W.
Summit, Ala.	1	1890	34°15′ N.	86°25′ W.
Holland's Store, Ga	12.5	1887	34°21′ N.	85°23′ W.
Chesterville, S. C	16.3	1849	34°43′ N.	81°13′ W.
Lick Creek, N. C	7.7	1899	35°5′ N.	84°2′ W.
Murphy, N. C	1.2	1879	35°40′ N.	80°16′ W.
Forsyth County, N. C	22.5	1891	36°1′ N.	80°2′ W.
Mayodan, N. C	15.4	1920	36°23′ N.	79°52′ W.
Scottsville, Ky	10.0	1867	36°46′ N.	86°10′ W.
Indian Valley, Va	14.2	1887	36°55′ N.	80°30′ W.
Keen Mountain, Va	6.6	1950	37°13′ N.	82°0′ W.
Cincinnati, Ohio	(250 gm.)	1870	39°7′ N.	84°30′ W.
Mt. Joy, Pa	385	1887	39°47′ N.	77°13′ W.

[1] Synonym.

Little is known about the Scottsville iron except that it was found in 1878, identified and described by Whitfield in 1887. There is no reason to suspect that it had been transported and abandoned by man.

The Cincinnati iron, which was found near a dwelling house in Cincinnati in 1870, was probably carried there by man from where it fell. The few specimens of this meteorite that are preserved suggest that it was small and easily transportable. Henderson and Perry (1958) found it to be a reheated specimen with a composition in the range of other hexahedrites. Because of its size and the fact that it is unlikely to have fallen in Cincinnati, this specimen is unimportant in this study.

The Keen Mountain, Va., specimen appears to be much younger than the others. Henderson and Perry (1958) assumed that this meteorite was a relatively recent fall because it had a fresh-looking black fusion crust with flight markings. Sections cut through one end showed numerous small open fractures extending into the interior only slightly farther than the thermally heated zone around its surface. Since these fractures contain little brown iron oxide and since this oxide is poorly consolidated, it was estimated by Gordon Davis (personal communication) and Henderson and Perry (1958) that the meteorite may have fallen between 1940 and 1950. Using Ar^{39} measurements, Vilcsek and Wänke (1962) reported the time of fall to be about 900 years ago.

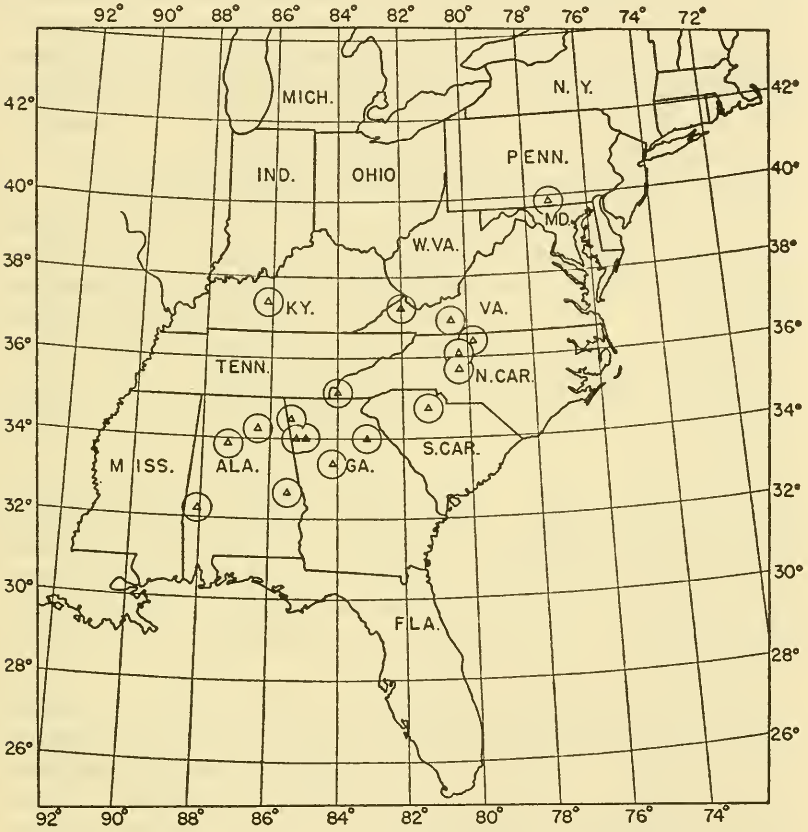


FIG. 4.—Geographic distribution of hexahedrites in table 6. The Cincinnati iron is omitted for reasons given on page 18.

H. Wänke commented as follows about the Keen Mountain iron in private communications: "The terrestrial age of this meteorite according to argon-39 and chlorine-36 measurements is 1100±200 years. I had a little problem with my standards, but this definitely would not change the value of the terrestrial age more than 200 years. The argon-39 content of this meteorite is so low that it must have been 3 half-lives of argon ($T\frac{1}{2}=325$ years) on the ground." A statement based on a measurement should be superior to an opinion about the time needed to alter a fresh flight crust from black to brown. However, 900 years seems a long time for fresh flight crust to survive in a climate as damp as that of Virginia. This iron may be an example of a hexahedrite falling into a cluster of an old hexahedrite fall.

The Walker County, Ala., iron was found in 1832, which makes it the first of this group to be discovered. The data on it came from Farrington's (1915) translation of Cohen's discussion in Meteoritenkunde (1903): "an iron mass of 75 kg. weight was found in 1832 in the northeast corner of Walker County, by a hunter living in Morgan County who preserved it in his house until 1843. . . . It was of an irregular oval form, with a smooth exterior covered with a thick coating of rust. . . ."

The alteration (rust) on the Walker County iron might mean a long terrestrial exposure. However, rust could have formed during the 10 years the specimen was stored in the cabin. Some irons exposed to high humidities corrode faster than ones remaining outdoors where the rain washes off the iron chlorides. Hence, the rust in this instance could represent corrosion products formed within a few years.

The New Baltimore and the Pittsburgh irons should be mentioned here even though they are not listed in table 6. These meteorites and the Mt. Joy iron were found in a straight line across Pennsylvania, and suggested to R. W. Stone (1932) that they were related. A subsequent investigation by Henderson and Perry (1958) indicates that these are unrelated meteorites.

The unique feature of the New Baltimore iron is the large inclusion, about 5 x 6 cm., with an octahedral pattern enclosed by large kamacite grains. The kamacite grains display well-developed, undisturbed Neumann lines, indicating that this kamacite was neither heated nor deformed since these lines formed.

It is difficult to explain the mechanism that produces a meteorite with two different types of Ni–Fe alloys in contact with each other. The possibility of the octahedrite colliding with and penetrating a hexahedrite must be considered. However, if a hexahedrite were struck in space by an oncoming octahedrite, both the target and the impacting object would probably show deformation resulting from their collision. In this meteorite, neither part is deformed. Although collisions between meteorites must have taken place in space, this specimen lacks the most important features one would expect if one iron meteorite penetrated another.

Hexahedrite stragglers in western North America.—Three isolated hexahedrites from the western part of the continent remain to be considered.

1. The Wathena, Doniphan County, Kans., iron. This 556-gram iron (Henderson and Perry, 1949) was found in 1939 near Wathena, Kans., in a locality about 400 miles northeast of the nearest grouping of hexahedrites. Since no other hexahedrites have been found in the intermediate area, the Wathena iron is assumed not to be associated with the foregoing groups.

2. The Pima County, Ariz., iron. This 210-gram mass is reported as having been found before 1947 near Tucson, Ariz. Nothing is known of its history except that it was at the University of Arizona for many years before it was accessioned into the national collections and described by Henderson and Perry (1949). It has exceptionally well developed flight surfaces. Although this strange-looking specimen is small enough to have been easily carried by man, it is thought probable that it fell where it was found, near Tucson.

3. Chico Mountain, Brewster County, Tex., iron. The 212-gram specimen in the National Museum apparently is all that remains of what was reported to be a 2-ton meteorite. So little is known about the history of this iron, and since it was found west of the area in which the meteorites listed in table 5 were found, the Chico Mountain iron is grouped with the stragglers.

SOUTH AMERICA

CHILE

The hexahedrites from Chile are given in table 7, arranged by their increasing latitudes, and plotted on the map in figure 5. Henderson (1941) reported that these irons may represent a shower. On the other hand, the finding of these irons aligned along a railroad could be due to the fact that the exploration in this region followed the course of the railroad. Nitrates were hauled to the railroad for shipment, and the included irons could have been rejected from the ore before shipment. Also, the coordinates of the Chilean hexahedrites may be less accurately recorded than those of the American meteorites.

Thirteen hexahedrites are known from between latitudes 20° and 24° S., while twelve octahedrites were recovered between approximately the same northernmost latitude and 27° S. This is an unusually high proportion of hexahedrites to octahedrites. No hexahedrites are reported south of latitude 24° S., whereas four octahedrites were found there, one of which comes from a point as far south as 33°30′ S. No search has been made for meteorites in the area south of latitude 27°.

TABLE 7.—*Data on hexahedrites from Chile arranged by latitude.*

Name	Weight, kilograms	Latitude	Longitude
La Primitive (Angela)[1]	21.5	19°55′ S.	69°49′ W.
Negrillos	28.5	20°12′ S.	70°10′ W.
Rio Loa	4.0	21°26′ S.	70°5′ W.
Quillagua	78.0	21°36′ S.	69°32′ W.
San Martin	29.0	22°20′ S.	69°45′ W.
Coya Norte	17.0	22°20′ S.	69°40′ W.
Union	22.0	22°30′ S.	69°30′ W.
Tocopilla	75.0	22°40′ S.	69°50′ W.
Sierra Gorda	22.0	22°54′ S.	69°21′ W.
Filomena	20.7	23°0′ S.	69°24′ W.
Mejillones (1875)	(large)	23°7′ S.	70°29′ W.
Mejillones (1905)	14.5	23°7′ S.	70°29′ W.
Puripica	19.0	23°41′ S.	70°15′ W.

[1] Synonym.

Northern Chile is an arid region, while to the south the land is more suitable for agriculture. In northern Chile, owing to the extensive niter mining, more of the land surface has been scraped and sorted than elsewhere. Thus, large, heavy objects, such as iron meteorites, have a good chance of being recovered.

A comparison of statistics on meteorites from two widely separated geographic areas may be criticized because climate, topography, population density, and the uses made of the land have a bearing on the recovery of meteorites. Nevertheless, an area in the United States—Georgia and South Carolina—where a noticeable concentration of hexahedrites occurs, has been compared to northern Chile in table 8.

Georgia and South Carolina together make an area about 1.5 times that of northern Chile, yet more than 3 times as many hexahedrites are reported from Chile as from the larger area in the United States.

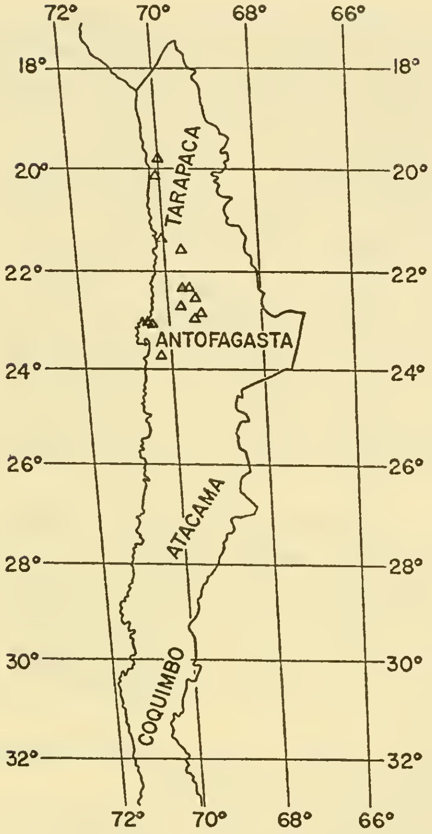


Fig. 5.—Geographic distribution of hexahedrites in table 7.

Ten octahedrites are known from northern Chile, but twelve came from Georgia and South Carolina. The conspicuous difference between the two areas is in the stony meteorites. All six of the stony meteorites from this part of the United States were observed falls, while the one stone from northern Chile was a find. This difference may be due to the fact that the population density of the Chilean area is far lower than in our two states, obviously making it easier for a

Table 8.—*Comparison of areas in which hexahedrites are abundant.*

	Area in square miles	Total meteorites	Hexahedrites	Octahedrites	Ataxites	Stones
Northern Chile....	60,000	26	13	10	2	1
Georgia	59,000	17	3	9	1	4
South Carolina....	31,000	6	1	3	0	2

meteorite to fall unnoticed in Chile. How these two localities would compare if both were as effectively prospected is problematic.

The arid climate of northern Chile favors preservation of meteorites. Stony meteorites from there should be less contaminated than those recovered from more humid areas because, without water, contamination is less likely to penetrate a meteorite. However, exposed meteorites in arid places can suffer from another type of weathering—wind ablation, which, in time, could be an effective way of obliterating a meteorite. Some irons from arid regions have sculptured surfaces that demonstrate how one constituent is ablated faster than another. Wind ablation is relatively rapid compared with chemical weathering in arid areas. The products of mechanical ablation might be confused with meteoritic dust, because undoubtedly some of the metallic iron is removed and accumulates in the wind-blown silt.

Many years ago the author called to C. A. Bauer's attention the possible identity of the northern Chilean hexahedrites and later furnished him with specimens for study. These specimens apparently were later turned over to Signer and Nier (1962), whose measurements are presented in tables 9 and 10, although in a somewhat different order so as to arrange the meteorites in their order of increasing latitude.

Signer and Nier (1962), in discussing the possibility of these Chilean irons being a common fall, said:

> Due to the low concentration of cosmogenic rare gases in these samples, the relative errors in these measurements may be somewhat higher than the 5% found for most other measurements; unfortunately, the samples available were so small that only a single analysis was possible and therefore, no check of reproducibility could be made. With this reservation, it seems possible that the Tocopilla, Coya Norte and Rio Loa belong to the same fall. Negrillos, however, appears to belong to a different fall. It should be mentioned that by nature of the interpretation two meteorites could by coincidence appear to belong to the same fall. The converse does not appear possible.

The overall scatter of the Chilean hexahedrites extends from about 20° to 24° S. latitude, while the three irons that Signer and Nier suspected of being related lie between 21°26′ and 22°40′ S. latitude. Thus, the Rio Loa, Coya Norte, and Tocopilla are confined within about 70 miles of the overall spread of about 240 miles for these Chilean hexahedrites.

TABLE 9.—*Concentrations and nuclide ratios for cosmogenic rare gases of 4 Chilean hexahedrites.* (*From Signer and Nier, 1962.*)

(Neon values are not corrected for slight amounts of atmospheric neon known to be present in some of the runs. Effect is negligible in case of Ne^{21}. Ar^{38} values are corrected for atmospheric argon assuming all the Ar^{40} is of atmospheric origin. Helium values do not require correction for atmospheric helium.)

Meteorite	Weight, milo-grams	He^3 × 10^8	He^4 cc. STP/g.	Ne^{21}	Ar^{38}	$\frac{He^3}{He^4}$	$\frac{Ar^{36}}{Ar^{38}}$	$\frac{Ar^{40}}{Ar^{38}}$	$\frac{Ne^{20}}{Ne^{21}}$	$\frac{Ne^{22}}{Ne^{21}}$	$\frac{He^3}{Ne^{21}}$	$\frac{He^3}{Ar^{38}}$	$\frac{He^4}{Ne^{21}}$	$\frac{He^4}{Ar^{38}}$	$\frac{Ne^{21}}{Ar^{38}}$
Tocopilla	312	68.5	295	0.92	4.70	0.231	0.650	80	2.95	1.24	74.5	14.5	320	63.0	0.195
Coya Norte....	673	30.0	144	0.385	2.20	0.210	0.630	24	1.64	1.05	78.0	13.5	375	65.5	0.175
Rio Loa	708	31.5	140	0.360	2.10	0.226	0.625	46	2.10	1.14	87.5	15.0	390	66.5	0.170
Negrillos	672	9.6	40	0.14	0.69	0.24	0.650	45	2.15	1.16	69	14	285	58	0.20

TABLE 10.—*Conclusions based on the production model and the rare gas concentrations given in table 9.* (*From Signer and Nier, 1962.*)

		Preatmospheric				Production rates			
Meteorite	Recovered mass, weight in kilograms	Mass kg.	Radius cm.	$\frac{r}{R}$	Exposure age my.	He^3 × 10^{10}	He^4 cc. STP/ g. my	Ne^{21}	Ar^{38}
Tocopilla	75	200000	182	0.8-0.9	250 ± 100	27	120	0.37	1.9
Coya Norte	17.9	200000	182	0.6-0.9	250 ± 200	12	58	0.15	0.88
Rio Loa	4	200000	182	0.8 0.9	150 ± 50	21	94	0.24	1.4
Negrillos	28.5	200000	182	0.8-0.9	30 ± 15	32	130	0.47	2.3

ARGENTINA

Only two hexahedrites, the Otumpa and the Tandil, are recorded from Argentina. A field investigation recently was made in the area of the Otumpa meteorite (Campo del Cielo) by the Lamont Geological Observatory under the leadership of Dr. William A. Cassidy. Dr. Daniel J. Milton of the U. S. Geological Survey, associated with Dr. Cassidy in the meteorite studies in Argentina, reports the following: Seven impact craters have been identified distributed along a single line about 18 km. long trending N. 60° E.,S. 60° W. Careful search in one area near the middle of this line indicates that a zone of abundant meteorites (many thousands per square kilometer) have the same ENE-WSW orientation and a width of about 3 kilometers. . . . In addition, a hexahedrite of 7 kg. has been found 65 kilometers N. 60° E. of the northeasternmost crater. The intervening distance has not yet been investigated. Locating this on a map, the middle of the crater line is about 27°35′ S. and 61°40′ W. with the westernmost crater in the Province of Santiago del Estero. The isolated iron comes from approximately 27°23′ S., 61°5′ W.”

The Tandil iron is reported as a witnessed fall, although the details about this fall and its discovery are not satisfactorily documented. If this iron was seen to fall, its geographic relationship with the Otumpa specimens is accidental.

AUSTRALIA

Four of the five Australian hexahedrites listed in table 11 and plotted on the map in figure 6 show a narrow geographic grouping. These irons were found along a north and south line about 35 miles long—the direction in which the Tombigbee River (Alabama) and Chilean irons were aligned. However, in Chile, it would be impossible to align that many meteorites in any direction other than north and south.

TABLE 11.—*Data on Australian hexahedrites.*

Meteorite	Date found	Weight, kilograms	Coordinates	
Bingara 1[1]	1880	(240.7 gms.)	29°53′ S.	150°34′ E.
Bingara 2	1924	6.4	9 miles north of No. 1	
Bingara 3 (Barraba)	unknown	1.34	30°25′ S.	150°37′ E.
Bingara 4 (Warialda)	1919	2.5	29°34′ S.	150°35′ E.
Yarroweyah	1903	9.5	35°59′ S.	145°35′ E.

[1] The spelling of Bingara varies, in some places appearing as Bingera.

Although the Yarroweyah iron was found a long way from the other four Australian hexahedrites, all five can be enclosed within an ellipse approximately 450 miles long. There would be no reason to associate the Yarroweyah iron with the Bingara group were it not for the fact that the hexahedrite grouping in the other parts of the world extends a similar distance. Disregarding the Yarroweyah iron, the distribution of the four Bingara specimens shows that they must be related. However, the ellipse enclosing all the Australian hexahedrites exceeds the area in which fragments are scattered in observed falls of meteorites.

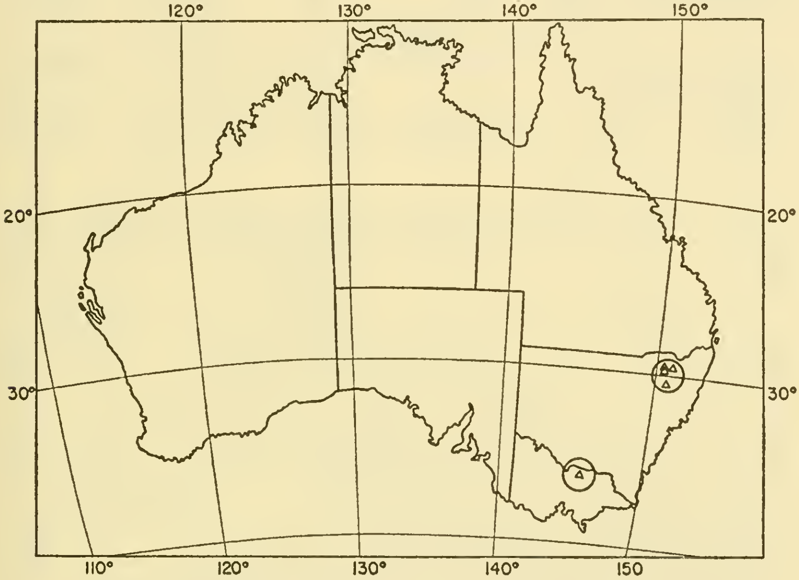


FIG. 6.—Geographic distribution of hexahedrites in table 11.

EUROPE

Since man used iron much earlier in Europe than in the Americas, Australia, or Africa, one might suspect that many of the European meteorites were transplanted or consumed by the early peoples. If this is true, the listing of the specimens in table 12 and the plotting of these on the map in figure 7 may not be reliable.

Two hexahedrites, Opava and Nenntmannsdorf, were found approximately 100 miles apart and close to where the Braunau meteorite fell in 1847. Since these three hexahedrites were found so close together, it seems likely that they fell as a shower.

Generally speaking, all the hexahedrites found in central Europe, Spain, and Russia follow a pattern of alignment which is also characteristic of those found from Mexico to Oklahoma and from Alabama to Pennsylvania and is also evident in those discoveries in Argentina and Australia. This agreement—alignment in a northeast–southwest direction—would not seem to be merely coincidence.

Table 12.—*Data on European hexahedrites.*

Meteorite	Date found	Weight, kilograms	Coordinates	
Opava, Czechoslovakia....	1925	14.3	49°58′ N.	17°54′ E.
Nenntmannsdorf, Saxony.	1872	12.5	50°58′ N.	15°57′ E.
Braunau, Czechoslovakia.	1847 (observed fall)	39.	50°36′ N.	16°18′ E.
Hressk, Russia[1]	1954	11.9	53°14′ N.	27°20.5′ E.
Villanueva del Fresno, Spain	Not given	(Not given)	38°24′ N.	3°26′ W.

[1] Also spelled Gressk.

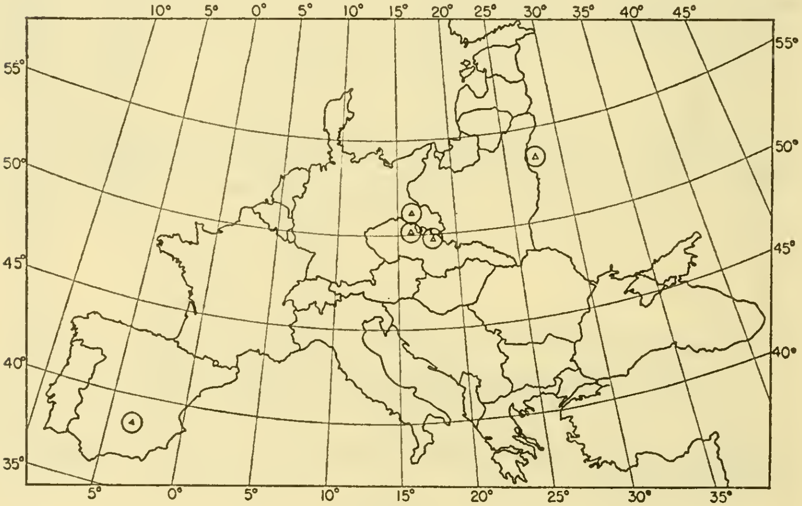


Fig. 7.—Geographic distribution of hexahedrites in table 12.

AFRICA

Although only six African hexahedrites are known (table 13; fig. 8), two pairs occur sufficiently close together to suggest that they fell as separate showers. These are the Bellsbank and Hex River irons in South Africa and the Chinguetti and Siratik in northwest Africa.

Table 13.—*Data on African hexahedrites.*

Meteorite	Date found	Weight, kilograms	Coordinates	
Aswan, Egypt	1955	12	23°59′ N.	32°37′ E.
Chinguetti, French West Africa	1920	?	20°15′ N.	12°41′ W.
Siratik, French West Africa	1716	1.7	14° N.	11° W.
Uwet, Nigeria	1903	54	5°17′ N.	8°15′ E.
Bellsbank, South Africa	1955	38	28°18′ S.	24°15′ E.
Hex River, South Africa	1882	60	33°19′ S.	19°37′ E.

Fig. 8.—Geographic distribution of hexahedrites in table 13.

A YET UNEXPLAINED DISTRIBUTION PATTERN

If a line is drawn on a globe, extending northeasterly from where the Tandil, Argentina iron was found through the places listed in Table 14, it forms an arc which extends almost one quarter the distance of a great circle, and it passes through Braunau, Czechoslovakia, where a hexahedrite fell in 1847.

For what significance it may have, attention is called to two other pairs of hexahedrites, Uwet, Nigeria and Aswan, Egypt, and the Hex River and Bellsbank irons in South Africa, which if connected in this order form two lines which are essentially parallel to the one passing through the places in Table 14 where the 10 hexahedrites were found.

TABLE 14.—*A Yet Unexplained Distribution Pattern.*

Meteorite	Coordinates	
Tandil, Argentina	37°18′ S.	59°10′ W.
Otumpa, Argentina	27°28′ S.	60°35′ W.
Corrego de Arede, Brazil	18°35′ S.	46°30′ W.
Siratik, Mauretania, Africa	14° N.	11° W.
Chinguette, Mauretania, Africa	20°15′ N.	12°41′ W.
Villanueva del Fresne, Spain	38°24′ N.	3°26′ E.
Opava, Czechoslovakia	49°58′ N.	17°54′ E.
Braunau, Czechoslovakia	50°36′ N.	16°18′ E.
Nenntmannsdorf, Saxony	50°58′ N.	15°57′ E.
Hressk, U.S.S.R.	53°14′ N.	27°20.5′ E.

ROLE OF EARLY MAN IN THE DISTRIBUTION OF HEXAHEDRITES

Few iron meteorites other than witnessed falls are known from India and Spain. The reason may be that man found and used them. As stated previously, man used iron in Asia and Europe long before he did in America, Australia, and Africa, yet early North American man is known to have fashioned some things from iron meteorites and to have transported pieces of others from where they fell to his campsites. Previously it was mentioned that the distribution of the Coahuila meteorite is attributed to man. If some meteorites were scattered in this way, man may have effected the distribution of some of the other hexahedrites listed in table 5.

The fact that the hexahedrites ranging from Texas northeastward to Oklahoma are located in an oval provides good reason to believe that man had little to do with them. In this region, there are no natural barriers to prevent him from moving in a north–south or east–west direction any more than in the direction these hexahedrites are scattered. Furthermore, archeological studies in Texas (Shum and Krieger, 1954) show no relationship between the oval area enclosing the places where the hexahedrites were found and the culture pattern of early man in Texas.

Recent archeological work in northern Mexico has demonstrated that the cultural relationships of Chihuahua, Coahuila, eastern Texas, New Mexico, and Arizona are directly connected to influences out of the high culture area of the Valley of Mexico, and that relationships of Mexico and the southeastern part of the United States are along the Gulf Coast and up the Mississippi and its southern tributary, the Red River. From an archeological standpoint, the evidence suggests that man could not have distributed the hexahedrites in Texas over their oval pattern.[3]

American Indians chipped fragments from some large meteorites prior to the time modern man discovered the specimens. The Hopewell Mound Builders apparently transported small pieces of several different types of meteorites considerable distances. At some of the Ohio Mounds, several different types of meteorites have been identified, and at Havana, Ill., meteoritic iron was found fashioned into beads. The Casas Grandes, Mexico, iron, which was excavated from the ruins of a temple, was incased in wrappings similar to those surrounding the bodies found in neighboring graves.

To cite more meteorites which man obviously has transported seems unnecessary, as this study is limited to hexahedrites and only a small proportion of these irons seems to have been disturbed by man (see page 5). Furthermore, since many of the hexahedrites come from limited geographic areas, transportation by man would seem to have been negligible. If man was a factor, why would he concentrate these irons rather than disperse them? To argue that man moved these meteorites outward from a central spot strengthens the point that hexahedrites have a peculiar worldwide distribution.

THE PROBABLE GEOGRAPHIC ABUNDANCE OF HEXAHEDRITES

It can be argued that hexahedrites are equally abundant everywhere and that chance recovery is responsible for the pattern indicating fallout from showers. The best counterargument is the worldwide scatter of hexahedrites, which indicates that they frequently are concentrated into limited areas.

It can also be argued that possibly in certain localities we are dealing with a hexahedrite shower along with one or two single hexahedrite falls. Until the terrestrial ages of meteorites are better understood, it is impossible to assess the validity of such an assumption.

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[3] Personal communications from Dr. Clifford Evans, Jr., curator of the division of archeology, U. S. National Museum.

Six hexahedrites were seen to fall in the last 115 years. Relating this figure to an assumption that perhaps the known meteorites are those which fell in the past 10,000 years, by extrapolation, between 500 and 550 hexahedrites should have accumulated in this period. If this assumption is valid, less than 20 percent of all the hexahedrites have been found.

Although the area of the surface of the earth is slightly less than 200,000,000 square miles, only about 57,510,000 square miles of this is land. No consideration has been given to the hexahedrites which possibly fell into the water nor to the fact that only a small percentage of the land surface is effectively observed for meteorite showers. The above figures were obtained, assuming just 6 hexahedrites fell in the last 115 years, and surely there were more.

If 550 hexahedrites have fallen, and if these were equally scattered over the land surface, there would be one to about every 100,000 square miles of land surface. When the area of the places shown in table 8 is compared with this figure (100,000), or if the areas of the localities where hexahedrites seem to be concentrated are compared to this figure, the conclusion is that these particular meteorites are far from being in random distribution.

INTERFERENCE OF PHOSPHORUS WITH METEORITE STRUCTURES

Iron meteorites that contain considerable amounts of phosphorus often have strange structures. When the schreibersite develops a skeleton structure, such as that shown in the Lake Murray and other similar meteorites, the kamacite grains enclosing the phosphide body become large and equidimensional. Such kamacite grains interfere with the normal development of the structure in the meteorite. Four meteorites with large phosphide inclusions are shown in plates 1-4. Tombigbee River and Bellsbank are hexahedrites, and Santa Luzia, Sao Juliao de Moreira, and Lake Murray are coarse octahedrites.

Apparently no chemical analysis is available for the Lake Murray iron, and erratic nickel values will be obtained if the samples selected for study come from certain parts of the iron. In an area adjacent to the large schreibersite bodies, the nickel will be lower than in the kamacite some distance from these phosphide bodies.

The nickel values in the kamacite around the schreibersite in the Tombigbee River iron are lower than the kamacite more remote from the phosphide bodies (Henderson and Perry, 1958). Similar results were obtained in some unpublished work on other meteorites at the U. S. National Museum.

The Lake Murray, Okla., iron (pl. 1), shows an octahedral pattern with kamacite bands more than 1 cm. wide, but where the large skeletal growths of schreibersite form, the octahedral structure in the matrix is disrupted. The dark square areas are patches applied to protect troilite from being attacked by the etchant. Modern etching techniques have found this precaution unnecessary.

The Bellsbank, South Africa, iron (pl. 2), is a hexahedrite with large schreibersite inclusions. The thin lamellae at the left intersect each other at a variety of angles and are filled with an alteration product. The Neumann lines in the kamacite extend to the breaks, then continue on the other side of the lamellae without a change of direction. Along these lamellae the kamacite is clear, compared with the kamacite more remote from them.

The kamacite surrounding the schreibersite in the Bellsbank iron also is slightly lighter in color than the kamacite remote from the phosphide bodies. If iron is rejected from schreibersite as the temperature falls, of if nickel from the surrounding kamacite enters the phosphide in preference to iron, this may explain the clear kamacite.

The Santa Luzia, Brazil, meteorite (pl. 3), like the Lake Murray, Okla., iron, is a coarse octahedrite with wide kamacite bands, some about 1 cm. wide. However, when schreibersite forms a skeletal habit, the enclosing kamacite becomes equidimensional, and such kamacite bodies disrupt the octahedral pattern. Since the slice illustrated is 0.5 cm. thick, and this schreibersite body is about equally large on both sides of the slice, it probably continued into adjoining slices, thus some conception of its size can be made.

The dark triangular area in the central phosphide body is troilite. In places, the troilite makes a direct contact with the schreibersite; elsewhere, it is in direct contact with the kamacite. Schreibersite more commonly occurs surrounding the troilite.

The Central Missouri iron (pl. 4) was found between 1850 and 1860, but the chemical analysis given by Preston (1900) does not appear to be reliable. After Perry (1944) reexamined this iron, he considered it to be a granular hexahedrite and placed it in the transitional zone between coarse octahedrites and hexahedrites. The Central Missouri iron resembles very closely the Ainsworth, Nebr., meteorite. Both contain large skeletal schreibersites and some alteration products in the fractures separating the coarse kamacite grains. Howell (1908) reports that the 10.64-kg. Ainsworth iron was found beside a creek in Brown County, Nebr., about 6 miles northwest of Ainsworth. His analysis gave 6.49 percent Ni, which, although high for a hexahedrite, may be essentially correct because meteorites with these phosphide inclusions can give a wide range of nickel values depending upon the area selected for study.

PHYSICAL CHARACTERISTICS RELATIVE TO THE FALLS OF HEXAHEDRITES

CLEAVAGE IN HEXAHEDRITES

The cubical cleavage in hexahedrites may have an important bearing on their geographical distribution. Two pieces of the Boguslavka, Siberia, iron were found about 1,700 feet apart, yet they fitted together, Thus, this hexahedrite was split, near the end of its high-velocity flight, comparatively close to the earth while falling nearly vertically.

Any large piece produced by fragmentation of a larger hexahedrite mass will be covered with cleavage surfaces. Also, it will have large open cleavages and numerous small ones extending inward from its surface. While such an irregularly shaped body is in space, the poorly bonded pieces remain attached, but upon entry into our atmosphere, conditions change. When the mass meets appreciable atmospheric resistance, chunks cleave off. Small pieces will decelerate quickly and may fall unnoticed, while the large mass may blaze its way across the sky for hundreds of miles before falling to earth. Hence, many of the cleavages in a hexahedrite approaching the earth will part, causing fragments to separate. Because of this, more pieces may break off from a hexahedrite than from a stony meteorite or from other types of irons. It is said that an iron meteorite is more likely to survive its flight in the atmosphere than a stony meteorite, and conversely, that a stony meteorite is more likely to break in flight than an iron. Because of the cleavages in hexahedrites, there is some doubt about the survival of hexahedrites in flight. Thus, cleavages in this group of irons may account for their geographic distribution.

SIZE DISTRIBUTION OF HEXAHEDRITES

Data on the masses of hexahedrites have been summarized in table 15. Most of the large hexahedrites were never weighed; therefore the weight estimates reported may be inaccurate. Ten of these irons are said to have exceeded 100 kgs., but none of the 10 is as large as the giants in the octahedrite and ataxite groups. Surely, hexahedrites are neither easier nor harder to find than other types of irons. Possibly the limited range in their chemical composition restricted their number; nevertheless, if chemical composition limited their number, it could have no effect on their distribution.

Table 15.—*Hexahedrites arranged according to their weights.*

Weights of more than 1000 kg.:

Chico[1]
Coahuila[2]
Navajo
Otumpa[3]
Sikhote Alin[4]

Weights between 500 and 100 kg.:

Boguslavka
Mt. Joy

Weights between 100 and 50 kg.:

Bennett County
Hex River
Quillagua
Smithonia
Tocopilla
Uwet
Walker County

Weights less than 50 kg.:

Auburn
Aswan
Avče
Barraba
Bellsbank
Bingara
Braunau
Bruno
Cedartown
Central Missouri
(Nedagolla?)
Negrillos
Nenntmannsdorf
Okano
Opava
Pima County
Pirapora
Puripica
Chesterville
Cincinnati
Corrego do Areado
Coya Norte
Edmonton
Filomena
Forsyth County
Holland's Store
Hressk (Gressk)
Indian Valley
Richland
Rio Loa
San Francisco del Mezquital
San Martin
Scottsville
Sierro Gorda
Soper
Summitt
Iredell
Keen Mountain
Kendall County
La Primitiva
Lick Creek
Locust Grove
Lombard
Mayodan
Mejillones (1905) (1875)
Murphy
Tandil
Tombigbee River
Union
Villaneuva del Fresno
Warialda
Wathena
Yarroweyah

[1] Said to weigh about 2 tons.

[2] Several masses larger than 1000 kg. and many smaller pieces in excess of 100 kg.

[3] Many individuals, total weight in excess of 15 tons.

[4] Many tons.

ANGLE OF APPROACH

If a hexahedrite entered our atmosphere at a low angle, the fractured material on its surface would separate, and the fragments that survive the passage through the atmosphere would fall far short of the main mass. The large body would go much farther into our atmosphere before further breaking up or would fall to the ground intact. The widely scattered geographic groups of hexahedrites must be explained by some process that brings one large mass or a cluster of separate similar irons along a trajectory that has a low angle of approach to the earth. Chance recovery of hexahedrites does not explain the distribution of these meteorites.

INCLUSIONS

As far as we know, hexahedrites have the same metallic inclusions as octahedrites with the exception of cohenite, which is relatively abundant in octahedrites but quite rare in hexahedrites. The reason being that iron carbide is more soluble in gamma iron (taenite) than in alpha iron (kamacite), the chief constituent of hexahedrites.

The absence of any appreciable silicate inclusions also may be significant. Although the Spanish meteorite Colomera was classified as a hexahedrite with silicate inclusions, a restudy showed it to have an octahedral pattern and a composition in the octahedrite range. Since the included silicate is olivine, the Colomera iron may be a pallasite, but the 151-gram sample in the U. S. National Museum is too small to be useful in typing a meteorite weighing 134 kg.

RADIATION AGES OF HEXAHEDRITES AND OCTAHEDRITES AND TIME OF DAY OF FALLS

Wänke (1960) noted that by plotting the log N_{Ne} against radius, all meteorites with the same radiation age lie on a straight line. Wänke's plot shows that nearly all the octahedrites lie in a narrow band and thus may have the same radiation age, but that the hexahedrites and ataxites lie definitely lower and thus may have a different history.

Wänke also observed that octahedrites fell between 12 and 24 hours of the day, whereas hexahedrites fell between 2 and 12 hours, or during the morning.

SUMMARY

Seventy hexahedrites are considered in this study. Some of those listed in the Prior–Hey (1952) catalog were omitted because they were incorrectly classified in their original descriptions. When specimens were unavailable for study, it was necessary to rely either upon the author's notes made during visits to other collections, upon published analyses, or upon an interpretation of pictures showing the metallography of the meteorites. When a seemingly reliable analysis reported more than 6 percent nickel, or when a picture showed either plessite or taenite in abundance, the meteorite was no longer considered to be a hexahedrite. If neither a picture nor an analysis of the iron was available, the Prior–Hey classification or the original description was accepted.

Obviously the hexahedrites are not scattered at random over the world. Unfortunately, at this time we do not know how other types of meteorites are distributed. Formerly it was assumed that a shower of iron meteorites would scatter like the stony ones. However, the evidence here presented suggests that hexahedrites have a different fallout pattern from that of stony meteorites, but for reasons not yet known.

Because the four hexahedrites located in Canada and our adjacent northern States are so widely separated that they do not make a convincing case for a meteorite shower, they were not counted. Table 16 gives the number of hexahedrites in each of the areas where evidence exists that a shower of hexahedrites occurred. The hexahedrites from Chile, southeastern United States, Europe, two places in Africa, and Argentina seem to be geographically grouped in a fallout pattern.

Table 16 shows the numbers of hexahedrites which, by grouping, appear to have fallen in showers. If, to these 50 cases, the 6 which were seen to fall are added, we have 56 hexahedrites out of a total of 70. This means that approximately 80 percent of these irons either

TABLE 16.—*The numbers of hexahedrites from the different geographic areas which may be related.*

1 Mexico–Texas, Oklahoma	6
2 Southeastern U. S.	18
3 Chile	12
4 Australia	5
5 Europe	5
6 Africa	4
Total	50
Witnessed falls (excluding the Nedagolla[1])	6
Number accounted for as possible falls	56, or 80 percent
Hexahedrites scattered at random	14, or 20 percent

[1] See page 8.

fit into fallout patterns or were witnessed falls. Such a percentage can hardly be a coincidence.

The fact that hexahedrites are chemically simple and apparently without silicate inclusions raises the possibility that hexahedrites may represent fragments from the core of a larger body. Most theorists agree that the core should be essentially free from silicates, and from a standpoint of quantity, core material should be less abundant than material from the surrounding shells. The hexahedrites meet these two rather basic requirements of core material.

Many of these topics have been presented before societies and symposia since 1950. Critical comments generally can be divided into two types: (1) Meteoritic statistics are too limited to support these groupings; (2) Conditions necessary to accomplish these selected fallout groupings of hexahedrites are difficult to reconcile with basic concepts of astrophysics.

Perhaps some of these criticisms are still valid, but new finds of hexahedrites, as well as investigations of other scientists, have produced more facts to support these proposals than to disprove them. Thus, more investigators seem to agree with the theme here proposed than to disagree with it.

Many assume that meteorites are equally distributed over the earth but because they are discovered by accident, their recovery is limited to fairly settled regions of the surface of the earth. However, these 70 hexahedrites are not uniformly scattered over the area from which meteorites have been recovered. About 70 percent of them are concentrated into 6 geographic areas, and the points of fall or discovery within these areas suggest that they fell as a shower.

The long axes of these strewn fields exceed those of the observed falls of any meteorite, yet are about equal to the paths of several observed fireballs and some of the witnessed displays of falling meteorites. The long axes of the scatter of the individuals in the different geographic areas lie in essentially a northeast–southwest direction.

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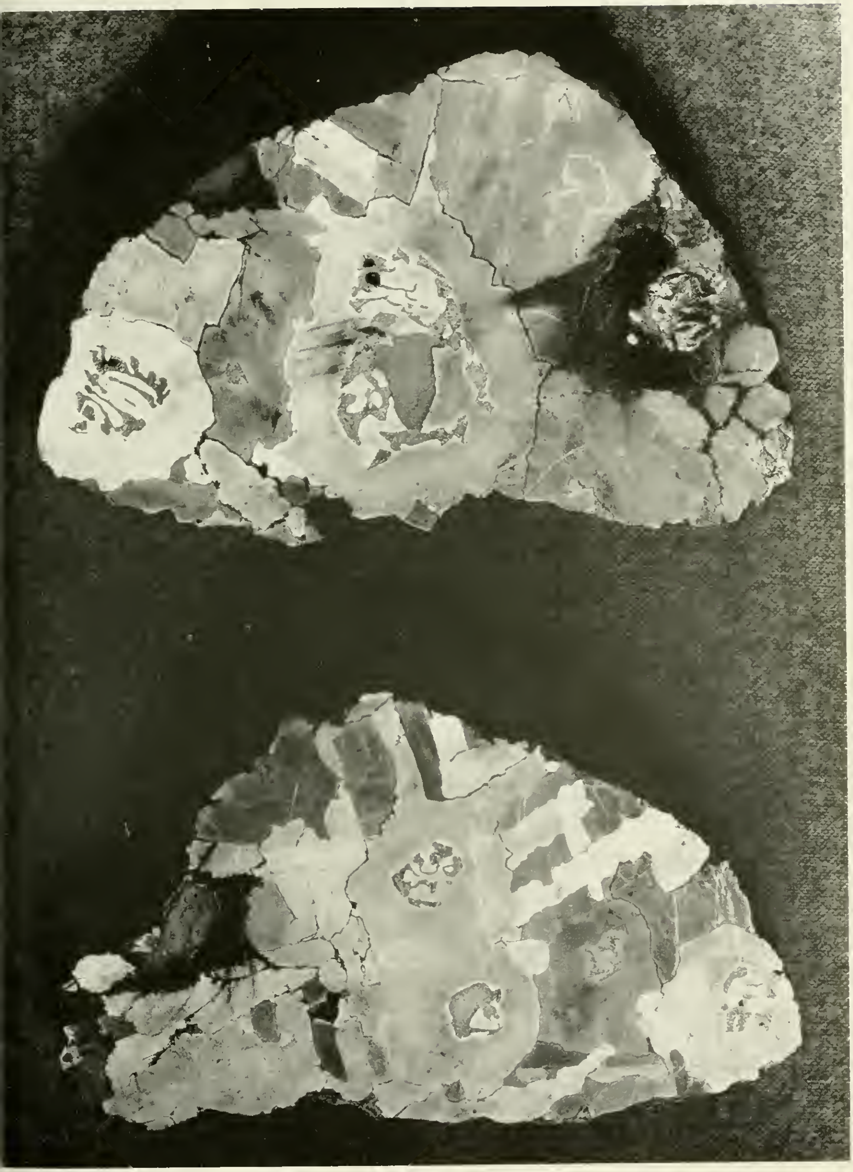
Lake Murray, Oklahoma
Coarse octahedrite with skeletal schreibersite inclusions. (Photograph courtesy of Institute of Meteoritics, University of New Mexico.)

Bellsbank, South Africa
Hexahedrite with large, irregular schreibersite inclusions.



Saint Luzia, Brazil

Skeletal schreibersite inclusions, with large kamacite areas enclosing them, disrupt the orderly octahedral pattern of the kamacite.

Central Missouri
Hexahedrite with large schreibersite inclusions.