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Hoba (South-West Africa), the largest known meteorite.

(With Plate I.)

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With chemical analyses by M. H. HEY, B.A., B.Sc.

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[Read June 9, 1931.]

IN 1910 in volume 15 of this Magazine I was able to place on record some details respecting the 'Cullinan' diamond from South Africa, the largest crystal of diamond yet found. I have now been able to collect some information about the largest known meteorite. The facts concerning remarkable objects such as these are apt to become exaggerated and distorted, and it is well to place on record the true and accurate data while they can still be ascertained.

The scanty accounts so far published of the Hoba meteorite give the date of discovery as 'about twenty' or 'about ten years ago'. Its weight has been variously estimated at 40, 50, 60, 70, 87, and 100 tons, and the dimensions mentioned have ranged up to 8 metres.

The locality (fig. 1) where the mass still lies is close to the southern boundary of the Hoba-West farm (no. 322) in the Grootfontein district. It is 12 miles (by road 15 miles) west of the town of Grootfontein (meaning in Dutch, great spring). The mass has consequently, not inappropriately, been referred to as the Grootfontein meteorite. Its position is given approximately by latitude 19° 35′ S., longitude 17° 56′ E. It lies a couple of hundred yards on the east side from the rough side-road leading to Otjihaenene siding on the railway from Grootfontein to Otavi, and only four kilometres from the narrow 2-foot gauge railway-line.

On the German map (1 : 400,000) issued in 1910 by the Survey Department in Berlin, and reproduced by the English Ordnance Survey in 1915, this farm is marked as Paviansfontein, but on the estate map of the South West Africa Company it appears as Hoba-West. The Afrikaans form is Hobà-Wes. The adjoining farm to the east is known as Hoba-Ost (the German form for Hoba-East), and the homesteads of both farms form a group of substantial buildings where the main road crosses the farm boundary. On some maps this is marked simply as Hoba.[1]

The exact date of the discovery of the mass I have not yet been able to ascertain, but it appears to have been late in 1920. Mr. Michael H. Hanssen the then occupier of the farm has since left. Dr. Paul Range, formerly Government Geologist of German South-West Africa, who had made a special study of the meteorites of the country,[2] informs me that the Hoba meteorite was certainly not known previous to the war of 1914–18. The earliest mention of the mass appears to be in a letter dated May 26, 1921, from the late Mr. T. Tönnesen, General Manager in Grootfontein of the South West Africa Company, to the London office, which I am permitted to quote. Accompanying this letter there is a photograph of the meteorite partly exposed in the pit dug round it.

> On the farm Hoba-West, about 20 kilometres to the west of Grootfontein, there is a meteorite, which is about 2·5 by 2·5 metres on the surface and may have a thickness of probably 2 metres (only 1 metre has been exposed). Accordingly the weight would be 87 tons, but it is safer to say 60 tons. The assay shows 81·29 % iron and 17·49 % nickel. The nickel content will probably amount to 10 tons. The stuff is very ductile, precluding blasting. We shall try a saw and eventually an oxy-acetylene flame.

Since all meteorites in South-West Africa are the property of the Government, nothing further was done in the way of mining for nickel.

In September 1921, Mr. M. H. Hanssen wrote from Hoba-West to the Director of Geological Survey of the Union of South Africa in Pretoria, giving the dimensions of the meteorite as over 3 yards by

[1] An incorrect form 'Hobart' is evidently due to the prevalent idea that foreign words must be pronounced as French, in the same way that all foreigners are 'Monsieur'.

[2] P. Range, Meteoriten aus Deutsch-Südwestafrika. Mitt. Deutsch. Schutzgebieten, 1913, vol. 26, pp. 341–343.

3 yards by 39 inches thick, and quoting the results of the assay made by the South West Africa Company.

The first published mention of the meteorite appears to be in Dr. G. T. Prior's 'Catalogue of Meteorites' (British Museum, 1923, p. 73). This was based on a verbal communication from Prof. Charles Palache, who visited the locality when on the Shaler Memorial Expedition from Harvard University to South Africa in

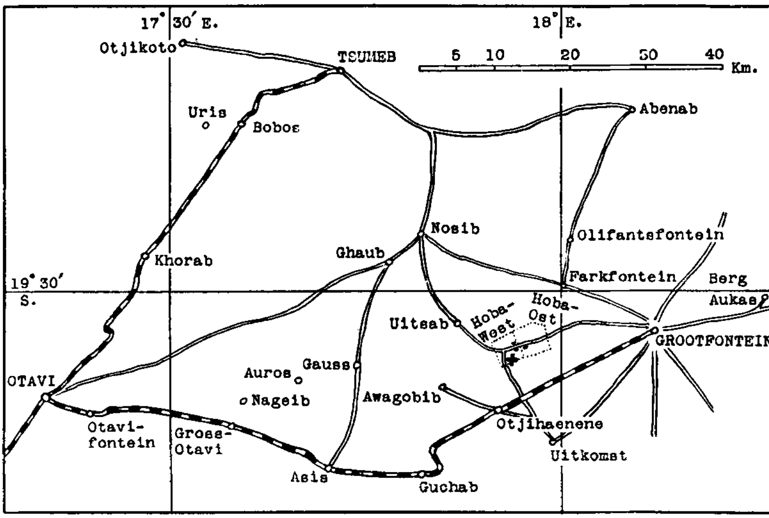


FIG. 1. Sketch-map (1 : 1,000,000) showing the position of the Hoba meteorite, Grootfontein district, South-West Africa.[1]

1922. Some further information in the 'Appendix to the Catalogue of Meteorites' (British Museum, 1927, p. 23) was supplied in 1926 by Dr. A. W. Rogers, the Director of the Geological Survey of the Union of South Africa. This was based on the letter of Mr. Hanssen mentioned above.

The next mention of the meteorite that I have been able to find is an anonymous note headed 'the largest meteors' in 'Science' of March 22, 1929 (New York, vol. 69, p. xii), which was reprinted in the American Mineralogist, 1929, vol. 14, p. 201.

> A seventy-ton meteor [i.e. meteorite] is reported to have been found at Otjihaene [i.e. Otjihaenene], near the head of the Grootfontein railway in the north-eastern part of Southwest Africa, imbedded in soft limestone. Its approximate

[1] The opportunity has been taken to mark on this map the localities of vanadium minerals represented in the British Museum collection.

size is ten by ten by four feet. Though this is said to be the largest meteor actually discovered in the world, it is probably dwarfed by the one which many years ago caused the famous Meteor Crater in Arizona. . . .

In a special number of the 'Zeitschrift für praktische Geologie' issued in June 1929 on the occasion of the XVth Session of the International Geological Congress in South Africa, Prof. H. Schneiderhöhn[1] gave a brief account of the Hoba meteorite. This was based on information supplied by Mr. A. Stahl and is accompanied by a photograph taken by Mr. F. W. Kegel, the General Manager of the mining company at Tsumeb. He states that it was known since about 1920, and gives the dimensions as $3 \times 1\frac{1}{2} \times 1\frac{1}{2}$ metres and the estimated weight as 50 tons. Prof. Schneiderhöhn's work in this district during the years 1914–19 is well known, and in collaboration with Mr. Stahl, who worked on the ground during 1922–26, a geological map has been made. But it was not until 1925 that Mr. Stahl saw the meteorite. Incidentally, Prof. Schneiderhöhn gives a graphic description of a brilliant meteor (fireball) which he himself saw at Tsumeb on September 16, 1917; though this, of course, has no connexion with the Hoba meteorite.

At the British Association meeting in South Africa in August 1929, a paper on 'The new Grootfontein meteorite' was read by Prof. W. J. Luyten,[2] Superintendent of the Boyden station at Bloemfontein of the Harvard University Observatory, who visited the meteorite early in 1929. This paper gives a quite inadequate description of the meteorite, and moreover it contains some inaccuracies. The specific gravity is given as 7·96. Since then the meteorite was visited by myself[3] in September 1929, and by Mr. S. G. Gordon[4] of

[1] H. Schneiderhöhn, Das Otavi-Bergland und seine Erzlagerstätten. Zeits. prakt. Geol., 1929, vol. 37, pp. 85–116. Picture of the meteorite on p. 95, and geological sketch-map showing its position on p. 88. [Min. Abstr., vol. 4, p. 261, footnote.] Another photograph of the meteorite, taken by Prof. Schneiderhöhn in 1929, is reproduced in his Mineralische Bodenschätze im südlichen Afrika. Berlin, 1931, p. 18, fig. 15. [Min. Abstr., vol. 4, p. 484.]

[2] W. J. Luyten, The new Grootfontein meteorite. (Title only.) Rep. Brit. Assoc., 1930, vol. 97 (for 1929, South Africa), p. 315.

— The Grootfontein meteorite. South African Journ. Sci., 1929, vol. 26, pp. 19–20. [Min. Abstr., vol. 4, p. 261.] Three of W. J. Luyten's photographs are reproduced in the Scientific American, 1929, vol. 141, pp. 316–317.

[3] L. J. Spencer, Meteoric irons from South-West Africa. Nat. Hist. Mag. (British Museum), 1930, vol. 2, pp. 240–246. [Min. Abstr., vol. 4, p. 422.]

— Min. Mag., 1930, vol. 22, pp. 272–273 (footnote); 1931, vol. 22, p. 493.

[4] S. G. Gordon, The Grootfontein, Southwest Africa, meteoric iron. Proc. Acad. Nat. Sci. Philadelphia, 1931, vol. 83, pp. 251–255, 3 figs. [Min. Abstr.,

Philadelphia in December 1929. A brief mention of it, as one of the 'sights' of the Grootfontein district, has recently been made by Mr. A. W. Clark[1] of the South West Africa Company. Lastly, a brief account of the meteorite has been given by Dr. Paul Range, who visited it in September, 1929, together with a description by Prof. R. Schreiter of the 'iron-shale' surrounding the mass.[2]

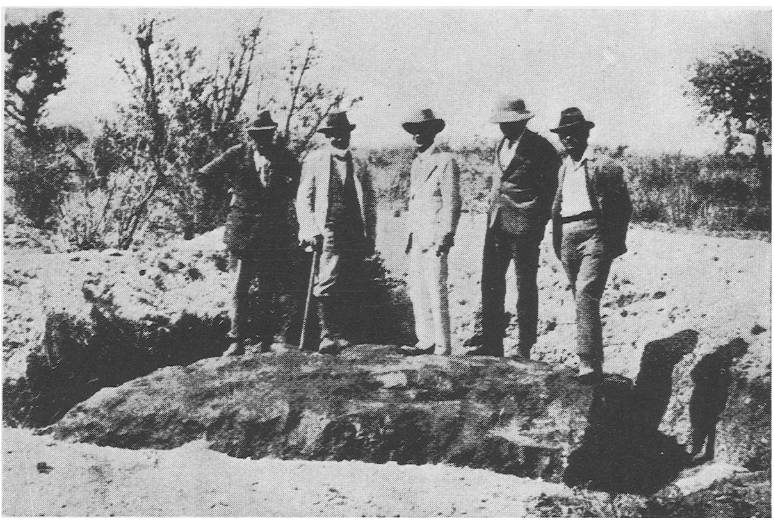


FIG. 2. The Hoba meteoric iron, Grootfontein, South-West Africa. Persons, left to right: Prof. L. C. De Villiers (Pretoria), Dr. L. J. Spencer (London), Mr. W. R. Feldtmann (Grootfontein), Mr. E. Schoenfelder (Grootfontein), Mr. von Schmettau (Tsumeb). Photograph by Prof. W. T. Gordon, September, 1929.

The very successful excursion to South-West Africa organized by the International Geological Congress in 1929 ended on September 5 with a visit from Tsumeb to the Abenab vanadium mine and the large meteorite near Grootfontein.[3] Here the party (a small one, as one motor-car broke down on the way, and the majority of the

vol. 5, p. 11.] A picture of the '100-ton iron meteorite' is also reproduced in the 1930 Year Book of the Acad. Nat. Sci. Philadelphia, 1931, p. 50.

[1] A. W. Clark, The ore-deposits of the Otavi Mountains, South-West Africa. Mining Mag. London, 1931, vol. 44, p. 265.

[2] P. Range and R. Schreiter, Der Hoba-Meteorit in Südwestafrika. Centr. Min., Abt. A, 1931, pp. 390–398, 8 figs. [Min. Abstr., vol. 5, p. 11.]

[3] Compt. Rend. Internat. Geol. Congr. XV Sess. South Africa, 1929, Pretoria, 1930, vol. 1, p. 281.

members had elected to visit the game reserve round the Etosha Pan) was conducted by Mr. W. R. Feldtmann, the General Manager of the South West Africa Company. Unfortunately the visit was rather a hurried one and the time was all too short for any detailed study. Nor was it possible to collect any specimens beyond the 'iron-shale' surrounding the mass. The huge block of metal is

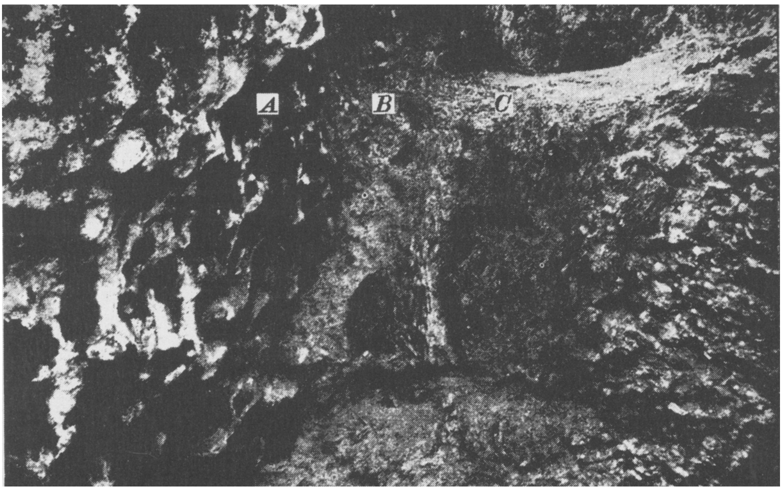


FIG. 3. The Hoba meteoric iron (*A*), Grootfontein, South-West Africa. Side view in the pit, showing the band of 'iron-shale' (*B*) and the surface limestone (*C*). Photograph by Prof. W. T. Gordon, September, 1929.

roughly rectangular in shape with few irregularities and no projecting portions.

When first found only a small portion of the meteorite was showing on the surface. A pit has since been dug partly round the mass; and at one end, where the pit is about six feet in depth, a small portion of the under surface has been exposed. The top surface is approximately flat (fig. 2) and level with the surrounding ground. A dozen people can walk round on the level surface. No attempt has been made to move the mass, and it is not known whether the under surface is flat or not. The mass is embedded in a white, soft and porous, surface limestone (Kalahari Kalk) from which it is separated by a layer one foot in thickness of laminated 'iron-shale' (figs. 3 and 4). This 'iron-shale' is dark-brown to black in colour with a dark-brown streak, and it is magnetic. It consists largely of limonite with some magnetite and perhaps also trevorite ($NiFe_2O_4$). It shows green nickel stains and is seamed with white calcium carbonate from the surface limestone. The lamination of the shale follows the contour of the meteorite, being vertical at the sides (fig. 3) and horizontal at the base (fig. 4). There is a sharp separation between the shale and the metal, though the metal shows

FIG. 4. The Hoba meteoric iron (*A*), Grootfontein, South-West Africa. View of base at bottom of pit, showing the band of 'iron-shale' (*B*) and the surface limestone (*C*). Photograph by Prof. W. T. Gordon, September, 1929.

a little rusting and scaling on the surface. The rock underlying the surface limestone at this spot is granite, close to the junction with the dolomite of the Otavi formation. The ground is level and there is no crater around the meteorite.

The dimensions of the block taken with a steel tape are 295 × 284 cm. (about 10 × 9 feet) on the large flat surface, with a thickness at one end of 122–111 cm. and at the other end of 75–55 cm. With a specific gravity of 7·96 this corresponds to a weight of 60 metric tons[1] for the block. The block shows a complex of broad and shallow concave surfaces. There are no large and prominent pits and no angular corners. It is just a huge block from which it is difficult to detach any portion. I have previously suggested[2] that

[1] Metric ton of 1000 kilograms = 2205 lb. avoirdupois.
[2] L. J. Spencer, Min. Mag., 1930, vol. 22, p. 272.

this characteristic surface of iron meteorites is the result of slow atmospheric weathering, rather than the result of rapid burning during the brief flight through the earth's atmosphere. The foot of 'iron-shale' seen in situ represents the amount of weathering that the mass has undergone since it has lain in the ground. This perhaps indicates the original size of the mass: adding 30 cm. all round, an original weight of 88 tons would be indicated (curiously the same as Mr. Tönnesen's first estimate).

Since my visit, several further visits have been made by Mr. Feldtmann, and he has very kindly supplied me with some further information, including the exact position of the meteorite, as indicated on the sketch-map (fig. 1).[1] With a magnetic compass he found that the mass is magnetized with polarity. The (geographically) north end of the block attracts the south end of the needle and vice versa, and along the side there is a median neutral zone. For the purpose of determining the magnetic axis of the meteorite a six-foot length of drill-steel was magnetized, and Mr. A. W. Clark found that the axis is about 14° east of the earth's present magnetic axis. No doubt the meteorite became magnetized in the earth's field when it fell with a violent concussion; but whether it would be possible to deduce from this figure the date of the fall is very doubtful.

Mr. Feldtmann has also been able to secure a piece of the meteorite, which was generously presented in 1930 to the British Museum by the South West Africa Company. After obtaining official permission from the Administrator of South-West Africa and from the Department of Mines, the piece was sawn off under his personal supervision. This was done by two natives working for two days and with a considerable consumption of hack-saw blades. The specimen (B.M. 1930,976) obtained is a wedge-shaped piece weighing 2489 grams ($5\frac{1}{2}$ lb.) with a triangular cut surface measuring 22×9 cm. (about 15 square inches). It shows two earlier cuts that had been made surreptitiously by unauthorized persons, and also the wilful damage done with an oxy-acetylene blowpipe. The meteorite has unfortunately been disfigured all along one top edge by some stupid person with an oxy-acetylene blowpipe. After smoothing and polishing the smallest of the three cut surfaces, and cutting off a piece from the thin end for more convenient microscopical examination, the

[1] Information has also been kindly supplied by Mr. L. G. Ray, the Chief Inspector of Mines for South-West Africa.

specimen now weighs 2444 grams. Mr. Feldtmann also sent 83 grams of the sawdust, which is still available for any further investigation.

The metal is comparatively soft and quite malleable, and is more easily worked than some other meteoric irons. It takes a brilliant steel-grey polish. The larger polished surface (7×6 cm.) shows a few (five) rounded or elongated bronze-coloured areas of troilite, the largest $3 \times \frac{1}{2}$ mm., and the others much smaller. Also numerous minute tin-white specks of schreibersite (or cohenite ?). Both the troilite and the schreibersite (?) are softer than the nickel-iron groundmass, and they are worn down to a lower level. From each speck of schreibersite (?) there is a minute pit with the shape of an acute isosceles triangle, the speck being at the narrow base-line. These pits are parallel over the whole surface and they all point in the same direction. From their sides, first one and then the other, they reflect light simultaneously over the whole surface. This effect was, however, produced only after the surface had been much worn by repeated polishing.

Etching the polished surface with very dilute nitric acid for a few minutes reveals no distinctive structure. Even with longer etching in stronger acid there are no indications of Widmanstätten figures or Neumann lines. The surface is merely dulled. At a certain angle, however, a reflected sheen is shown uniformly over the whole surface, except on a few scattered areas of small size. At another angle the latter show a reflected sheen all together, and the main area is then dull (fig. 5). This effect is mentioned and figured in S. G. Gordon's paper (loc. cit., 1931, p. 253). The main area evidently represents a single crystal individual, and the smaller portions are no doubt in twinned position with respect to the main portion. The boundaries between the two areas are sharply defined, sometimes with straight edges and sometimes dovetailed into each other, suggesting lamellar twinning.

The minute tin-white specks of schreibersite (?) show up more prominently on the etched surface. They are of irregular distribution and have the form of slender needles or curved hairs. In cross-section they show as minute circular areas, scattered singly over the surface or aggregated into small clusters. With rather deeper etching the needles and hairs show a groove along the axis, and the circular areas show a sunken centre.

The larger polished surface on the main specimen is adjacent to the edge that has been fused with an oxy-acetylene blowpipe. The very thin fused layer was not attacked by the etching reagent, and it forms a narrow (0·1 mm.) bright border on the etched surface. Beyond this, the heating appears to have had no effect on the iron.

A second polished surface (3 × 1 cm., fig. 5), on the small piece cut from the thin end of the specimen and 18 cm. away from the fused

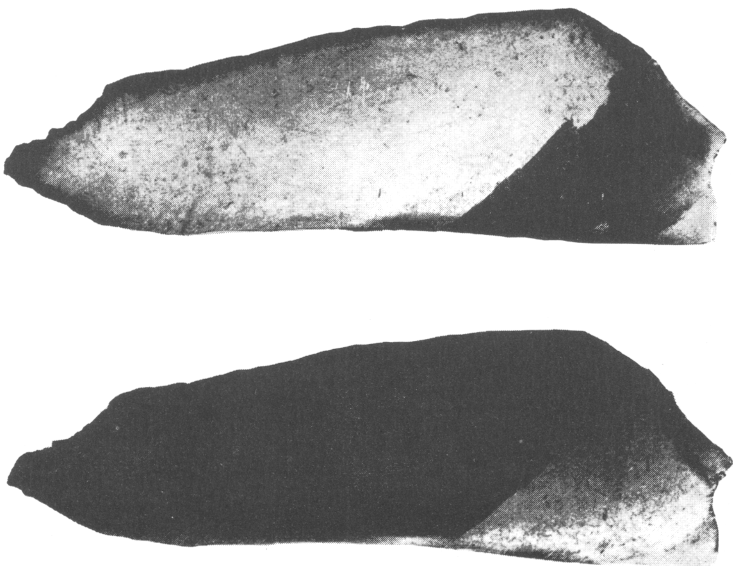


FIG. 5. Photographs taken at different angles of the smaller polished and etched surface (3 × 1 cm.) of the Hoba meteoric iron, showing the oriented sheen. Photographs by H. G. Herring. × 3.

area, has been kindly examined by Dr. J. M. Robertson at the Royal School of Mines, London, with the permission of Prof. Sir Harold Carpenter, F.R.S. The section was repolished and very lightly etched with a 1 % solution of nitric acid in alcohol. His photomicrographs (plate I) taken with an oil-immersion objective show under a magnification of 820 diameters a minute duplex structure somewhat similar to that of plessite. Fig. 7, taken at the junction of the two portions that show oriented sheens at different angles, shows this structure with two directions. Figs. 10 and 11 of one of the schreibersite (?) specks show a border of pale yellow material with a white inner portion. With further etching, as noted above, it seems to be this central portion that is more deeply attacked.

The Hoba meteorite is to be classed as a nickel-rich ataxite.[1] Previously known meteoric irons of this class are tabulated below in the order of their nickel percentages.[2] None of these nickel-irons was observed to fall, and the supposed meteoric origin of the last two with exceptionally high content of nickel has been questioned. In view of its present situation, any origin other than meteoric for the Hoba mass is inconceivable.

Nickel-rich Ataxites.

Name and country.	Date of find.	Ni %.	Fe : Ni.
Babb's Mill, Tennessee (Blake's Iron) ...	1842	11·09	8·0
Illinois Gulch, Montana	1899	12·67	6·9
Deep Springs, North Carolina	1846	13·44	6·4
South Byron, New York	1915	13·47	6·5
Cape of Good Hope, South Africa ...	1793	15·67	5·9
Kokomo, Indiana	1862	15·76	5·3
Iquique, Chile	1871	15·86	5·3
Ternera, Chile	1891	16·22	5·1
Tlacotepec, Mexico	1903	16·23	5·1
Hoba, South-West Africa	1920	16·24	5·1
Linville, North Carolina	1882	16·32	5·1
Smithland, Kentucky	1839	16·42	5·0
Botetourt County, Virginia	1850	17·0	5·0
Shingle Springs, California	1869	17·17	4·8
Babb's Mill, Tennessee (Troost's Iron) ...	1842	17·30	4·7
Weaver, Arizona	1898	17·92	4·5
Klondike, Yukon	1901	18·20	4·4
Morradal, Norway	1892	18·77	4·2
San Cristobal, Chile	1882	25·60	2·9
Lime Creek, Alabama	1834	29·99	2·2
Santa Catharina, Brazil	1875	33·97	1·9
Lafayette, Colorado	1908	59·4	—
Oktibbeha Co., Mississippi	1854	62·01	0·3

Chemical composition.—As with other meteoric irons it would appear that the composition is somewhat variable from place to place, but this may be due to the difficulty in obtaining an average sample and also to inaccuracies of analysis. The earliest analysis

[1] The term ataxite (from ἀταξία, disorder) for compact structureless meteoric irons was introduced by A. Brezina in 1896, Die Meteoritensammlung des k. k. naturhist. Hofmuseums, Ann. naturhist. Hofmus. Wien, 1896, vol. 10, p. 295. The same term had been earlier applied by F. Loewinson-Lessing in 1888 (Tschermak's Min. Petr. Mitt., 1888, vol. 9, p. 529) to a brecciated volcanic rock with an irregular arrangement of the fragments.

[2] Compiled from G. T. Prior, Catalogue of Meteorites (British Museum), 1923, and Supplement, 1927; and O. C. Farrington, Analyses of iron meteorites compiled and classified, Field Columbian Museum, Chicago, 1907, publication 120, Geol. Ser., vol. 3, no. 5, pp. 100-105.

made in 1921 in the laboratory of the South West Africa Company at Grootfontein gave Fe 81·29, Ni 17·49 %. Later analyses by Mr. Somerville in the same laboratory gave Fe 81·60, Ni 15·8 %, and Fe 80·47, Ni 17·10 % ; and a determination of iron alone Fe 82·8 %. The nickel percentage (17·42) given by W. J. Luyten (1929) is a miscopy of the first Grootfontein analysis. The results of Mr. M. H. Hey's complete analysis made in the Mineral Department of the British Museum are given below (I), together with details of the method employed.

Analyses of the Hoba Meteoric Iron.

	Fe.	Ni.	Co.	Cu.	S.	P.	C.	Total.	Sp. gr.	Fe/Ni.
I.	83·44	16·24	0·76	0·03	trace	trace	0·02	100·49	7·96	5·1
II.	82·40	16·76	0·74	—	0·02	trace	—	99·92	7·971	4·9

I. Analysis by M. H. Hey. Carbon as insoluble residue after distillation of iron in chlorine. Sulphur and phosphorus present, but less than 0·01 %.

II. Analysis by S. G. Gordon, loc. cit., 1931, p. 254.

Through the kindness of Prof. Sir Harold Carpenter a separate carbon determination was made in the Metallurgical Laboratory of the Royal School of Mines, London, on 5 grams of the filings of the Hoba meteorite; this gave C 0·026 %.

Method of Analysis (by M. H. Hey).—A few notes on the method of analysis may not be out of place, as the analysis of meteoric irons presents certain difficulties not sufficiently emphasized by the text-books. The ammonia precipitation invariably carries down some nickel with the iron, and is quite unsatisfactory.[1] The method usually employed is to separate the iron from the nickel and cobalt by the basic acetate precipitation and then precipitate the nickel with dimethylglyoxime and the cobalt with α-nitroso-β-naphthol. This procedure is satisfactory, but tedious; not only must three, or at least two, basic acetate precipitations be made to obtain the iron free from nickel, but it is almost essential to test all the precipitates to make sure the separation has been effective, and this involves bringing the ferric oxide into solution by a pyrosulphate fusion.

The first method tried was to precipitate the nickel first with dimethylglyoxime in ammoniacal tartaric acid solution.[2] This gives a rapid and accurate determination of the nickel, but the subsequent estimation of cobalt and iron is troublesome. Hydrogen sulphide does not precipitate the iron completely unless the excess of dimethylglyoxime is destroyed by evaporation with sulphuric and nitric acids. It was sought to avoid this difficulty by making the determinations of iron, nickel, and cobalt on three separate portions. The iron may be accurately determined by dissolving the filings in dilute sulphuric acid in a current of carbon dioxide; a quantity of pure potassium permanganate rather insufficient to oxidize the whole of the iron is weighed out, dissolved and added, and the

[1] Cf. G. T. Prior, Min. Mag., 1914, vol. 17, p. 132.

[2] Method of O. Brunck, Zeits. angew. Chem., 1907, vol. 21, p. 1849; 1914, vol. 27, p. 317.

titration completed with standard permanganate solution. We have thus reliable methods for the iron and nickel, but a rapid and reliable method for the cobalt could not be found. The old cobaltinitrite method was found to give too low results (0·11 and 0·13 % Co in the Mbosi and Hoba meteorites, subsequently found to contain 0·62 and 0·76 % respectively). It is, however, useful to supplement an analysis by the method outlined below, or by the basic acetate method, with a determination of either the iron or the nickel by the above methods. Such a check is particularly useful when the basic acetate method is used, avoiding the necessity of a pyrosulphate fusion to test the purity of the iron precipitate, and was used by Dr. Prior (loc. cit.).

While these first attempts to find a satisfactory substitute for the basic acetate precipitation failed, it was found possible to base a rapid and reliable method on the process of F. A. Gooch [1] for the separation of iron from the complex alumina precipitate of rock analysis (consisting of ferric oxide, alumina, titania, zirconia, rare-earths, phosphoric acid, &c.). Gooch obtained an accurate separation by heating the oxides in a current of hydrogen chloride containing some chlorine at 200 to 300° C., pure ferric chloride subliming while the other oxides remained behind unchanged.

Now neither nickel, copper, nor cobalt chloride is volatile at 300° C.[2] If, therefore, we heat the filings to 200 to 300° C. in a current of chlorine gas, the iron should sublime as ferric chloride, while cobalt, copper, and nickel chlorides remain behind in the boat. This proves to be the case. Using ½ to 1 gram of coarse filings,[3] and heating in a current of chlorine, first for an hour at 200° to 250° C., then for three hours at 250° to 300° C. there remains in the boat a chamois-yellow powder of $NiCl_2$, while a fine black sublimate of $FeCl_3$ forms where the tube leaves the oven.[4] A couple of trap flasks, one empty, and one filled with water, trap any ferric chloride carried forward by the stream of gas, and also collect the phosphorus and sulphur. The chlorine is best generated from manganese dioxide, salt, and strong sulphuric acid; it then needs no further drying, while its hydrogen chloride content does no harm.

The distillation completed, the residue of nickel and cobalt chlorides in the boat is dissolved in water and a little acid. It will usually be found that some of the coarser filings have become coated with nickel chloride and are not completely attacked; they dissolve in the acid. The solution is filtered through a tared Gooch crucible, and any small residue of carbon, &c., weighed.[5] In the

[1] F. A. Gooch, Methods in chemical analysis, New York, 1912, p. 504. F. A. Gooch and F. S. Havens, Amer. Journ. Sci., 1899, ser. 4, vol. 7, p. 370. W. F. Hillebrand, Bull. U.S. Geol. Surv., 1919, no. 700, p. 133.

[2] Cobalt chloride is stated to be volatile in a current of chlorine (Roscoe and Schorlemmer, Treatise on chemistry, 4th edition, London, 1907, vol. 2, p. 1255). No temperature is given, but presumably it must have been at least 400° C. I have failed to find any volatilization at 300° C. in special experiments with pure $CoCl_2$.

[3] The amount used should be regulated to the class of meteorite. With nickel-rich ataxites and finest octahedrites ½ gram will suffice, while for coarsest octahedrites, hexahedrites, and nickel-poor ataxites, 1 gram will be necessary.

[4] The boat should be placed about 10–12 cm. from the point where the tube leaves the oven. The tube around the boat and for at least 5 cm. beyond it should be quite free from sublimate when the reaction is complete.

[5] Sublimation of the iron in a current of chlorine is sometimes used in iron

filtrate a small amount of iron is usually present, from the unattacked metal above mentioned; it is precipitated with ammonia, dissolved and reprecipitated, and the precipitate reserved to add to the main iron precipitate. Being only one or two per cent. of the total, this small iron precipitate does not carry down any weighable amount of nickel with it.

In the filtrate from the small iron precipitate, nickel is precipitated with dimethylglyoxime. The filtrate from the nickel dimethylglyoxime is acidified and cobalt precipitated with α-nitroso-β-naphthol. Finally, a small amount of cadmium chloride (0·02–0·05 gram) is added to the filtrate from the cobalt, and hydrogen sulphide passed in. The cadmium sulphide serves as a 'collector', making it possible to filter off the minute precipitate of copper sulphide; after solution in dilute nitric acid, the copper is determined colorimetrically with ammonia, the solution being evaporated if necessary to a small bulk.

The ferric chloride sublimate in the tube is dissolved and washed out into the second trap flask, into which the first (empty) one is also washed out. The solution is made up to a suitable volume in a measuring flask, well mixed, and half taken for the determination of iron; as no other metal is present, a single ammonia precipitation and quite a short washing suffices.[1] In the other half of the solution, sulphur, now present as sulphuric acid, is determined as barium sulphate, while phosphorus is precipitated and weighed as ammonium phosphomolybdate.

The method outlined above has particular advantages where the amount of material available is small, for it is possible, by taking advantage of the colorimetric methods for copper, cobalt, and phosphorus, to determine these constituents, as well as the iron and nickel, on a single portion of as little as 0·2–0·3 gram with reasonable accuracy. The one disadvantage of the method, the need for setting up a chlorine generator, tube-oven, and absorption flasks, is small, and would be negligible in a series of analyses.

In order to test this method, a trial analysis was made of the Mbosi meteorite, which had already been analysed by Mr. F. Oates (Min. Mag., 1931, vol. 22, p. 490); the results obtained (loc. cit., p. 492) were in excellent agreement with those of Mr. Oates.

The Hoba meteorite was analysed by the above method, using 0·5017 gram of filings, with the results given on p. 12. A separate determination of iron by the semi-volumetric method above described gave 83·70 %; a determination of nickel by the dimethylglyoxime method gave 16·35 %; and one of iron and cobalt together after destruction of the organic matter in the filtrates from the nickel gave 84·13 %.

The specific gravity determined by hydrostatic weighing on a piece of 26 grams gave the value 7·96. A determination made on the

and steel analysis (see, e.g., A. A. Blair, Chemical analysis of iron, 6th edition, Philadelphia, 1906, p. 73), but a dull red-heat appears always to be employed.

[1] If only ½ gram of filings were taken and the amount of sulphur is likely to be small, the whole solution may be used for the sulphur determination, and then halved for the iron and phosphorus determinations. In this case the ferric hydroxide should be dissolved and reprecipitated.

filings by the pyknometer method in carbon tetrachloride gave 7·87.

The magnetic 'iron-shale' surrounding the mass of iron has also been analysed with the following results:

	I.	Mol. ratios.		II.	Mol. ratios.	
Fe_2O_3 ...	58·14	0·3641		65·48	0·4101	
FeO ...	13·25	0·1844		5·60	0·0779	
NiO ...	16·13	0·2160	0·4056	8·88	0·1189	0·2047
CoO ...	0·39	0·0052		0·59	0·0079	
CaO ...	nil	—		—	—	
H_2O ...	11·83	0·6566		8·47	0·4701	
Total ...	99·74			89·02		
Sp. gr. ...	—			4·021		

I. Analysis of 'iron-shale' by M. H. Hey.
II. Partial analysis by S. G. Gordon (loc. cit., 1931, p. 254).

Mr. Hey reports that during solution of the material in acid there was a slight effervescence, which may be due to the presence of metallic iron, or perhaps of iron or nickel carbonate. The excess of monoxides over Fe_2O_3 shown in his analysis suggests metallic iron, but there would be no surplus of Fe_2O_3 for combination with the water. The material is clearly a mixture. Calculating all the nickel (and cobalt) as $NiO.Fe_2O_3$, Mr. Hey's analysis would correspond with 51·84 % and Mr. Gordon's with 22·72 % of trevorite;[1] but in neither case are the results consistent with a mixture of limonite, haematite, magnetite, and trevorite.[2]

In the 'iron-shale' which I was able to supply to Prof. V. M. Goldschmidt,[3] he found germanium to the extent of 0·01–0·1 %.

The Largest Meteorites.—Like fish stories, those about big meteorites are also apt to dwindle somewhat when examined critically. The recorded weights of most large meteoric irons are merely estimates, and, owing to the irregular shape of the masses, these estimates have varied between wide limits. Further, it is usually not stated whether the 'tons' are the metric ton (2205 lb.), the English long ton (2240 lb.), or the American short ton (2000 lb.); but the error

[1] Trevorite of A. F. Crosse (1921) was shown by T. L. Walker (1923) to be a distinct mineral $NiFe_2O_4$ of the spinel group. [Min. Abstr., vol. 2, p. 249.]

[2] See E. V. Shannon, The oxidation of meteoric irons. . . . Proc. U.S. Nat. Mus., 1927, vol. 72, art. 21. [Min. Abstr., vol. 3, p. 534.]

[3] V. M. Goldschmidt, Die Naturwissenschaften, 1930, vol. 18, p. 1007; Verhandl. Gesell. Deutsch. Naturfor. Ärzte, 1931, vol. 91 (for 1930, Königsberg i. Pr.), p. 1007. [Min. Abstr., vol. 5, p. 7.]

here is inappreciable in comparison with that of the estimate of the weight.

The largest single block preserved in any museum is the fine mass of 'Ahnighito', or 'The Tent', in the American Museum of Natural History in New York City. This was transported in 1897 from Cape York, north Greenland, by Admiral R. E. Peary,[1] who himself estimated the weight at 90 to 100 tons. It is now put at '36½ tons'.[2] Although not stated, this weight would appear to be in short tons, for O. C. Farrington [3] gives the equivalent as 33,113 kilograms; that is, rather over 33 metric tons, or 32½ English (long) tons. Two other masses of the Cape York meteoric iron transported by Peary to the American Museum of Natural History are 'The Woman' of about 3000 lb., and 'The Dog' of about 1100 lb. More recently, in 1925, another mass, the 'Savik', has been transported from Cape York to Copenhagen; and in this case the weight was determined by actual weighing to be 3401·7 kg. (= 3·4 metric tons).[4]

Another large mass, also in the American Museum of Natural History, of which the weight has been actually determined, is that of Willamette, Oregon. This was weighed on the railway scales at Portland, Oregon, giving 31,107 lb. This weight is usually stated as 15·6 or 15½ tons (i.e. short tons); it is equivalent to 14·2 metric tons, or 13·9 long tons.

An enormous mass of meteoric iron, said to measure about 100 metres in length and about 40 metres in height, has been stated to have been found in 1921, together with other smaller masses, about 45 km. SW. of Chinguetti in the Adrar desert, Mauretania, French West Africa. It is compared with an overhanging cliff partly buried in a sand dune. A piece weighing 4½ kg. was described by Prof. A. Lacroix [5] in 1924, but there has been no further mention or confirmation of the larger mass. It sounds rather like a traveller's story, or perhaps metres may be a miscopy for centimetres.

[1] R. E. Peary, Northward over the 'Great Ice' . . . and n account of the discovery and bringing home of the 'Saviksue' or great Cape-York meteorites. London, 1898, vol. 2.

[2] E. O. Hovey, Amer. Mus. Nat. Hist. New York, Guide Leaflet, 1907, no. 26, p. 23; F. A. Lucas, ibid., 1926, no. 64, p. 14. [Min. Abstr., vol. 3, p. 395.]

[3] O. C. Farrington, Meteorites. Chicago, 1915. In a chapter (pp. 54–59) on the size of meteorites, where the 'ton' unit has not in all cases the same value.

[4] O. B. Bøggild, Meddel. om Grønland, 1927, vol. 74, p. 15. [Min. Abstr., vol. 3, p. 535.]

[5] A. Lacroix, Compt. Rend. Acad. Sci. Paris, 1924, vol. 179, p. 309. [Min. Abstr., vol. 3, p. 393.]

Some other large meteoric masses have been inferred, but never actually found. The 'Meteor Crater' near Cañon Diablo in Arizona, with a diameter of 4000 feet and a depth of 570 feet was probably formed by the impact of a gigantic meteorite.[1] Many masses of iron with a total weight of over six metric tons, the largest piece 460 kg., have been found around the crater, but borings within the crater have not revealed any larger mass. The Siberian meteor of June 30, 1908, was supposed to have fallen as a meteorite and variously estimated to weigh from 130 to half a million tons, but nothing has ever been found.[2]

The following list of the largest known and authenticated masses of meteoric iron is a revision of that given by Prof. O. C. Farrington in his book 'Meteorites' (1915, p. 58).

The Largest Meteorites.

Name and country.	Date of find.	Metric tons.	Present location.
Hoba, South-West Africa	1920	60	In situ
Cape York, Greenland ('Ahnighito') ...	1895	33·1	New York City
Bacubirito, Mexico	1863	24½	In situ
Willamette, Oregon	1902	14·2	New York City
Chupaderos, Mexico (I)	1852	14·1	Mexico City
Mbosi, Tanganyika Territory	1930	12	In situ
Morito (=San Gregorio), Mexico	1600	10·1	Mexico City
Chupaderos, Mexico (II)	1852	6·77	Mexico City
Bendegó, Brazil	1784	5·36	Rio de Janeiro
Cranbourne, Victoria	1854	3·50	British Museum
Cape York, Greenland ('Savik')	1913	3·40	Copenhagen

The above are all irons. The largest single meteoric stone is one of 338 kg. (745 lb.), which fell quite recently, on February 17, 1930, at Paragould, Arkansas.[3] The next largest stone is that which fell on June 9, 1866, at Knyahinya, Czechoslovakia, and weighs 293 kg.; this is in the Natural History Museum at Wien. Other large stones, Long Island, Kansas (564 kg.), and Bjurböle, Finland (330 kg.), were broken into fragments by their fall, either in the atmosphere or when striking the ground. The largest single stone in the British Museum

[1] Min. Abstr., vol. 4, pp. 427–428; vol. 5, p. 16.

[2] Min. Abstr., vol. 2, p. 357; vol. 3, pp. 92, 256; vol. 4, pp. 261, 428; vol. 5, p. 17.

[3] Annual Report Field Museum of Natural History, Chicago, for 1930, 1931, vol. 8, p. 374, and plate 29. The weight of this stone has also been given as 820 lb. Apparently 745 lb. is the weight of the portion now in the Chicago Museum. [Min. Abstr., vol. 5, p. 12.]

collection is that of Parnallee, India, which fell on February 28, 1857, and weighs 60·55 kg. (133½ lb.).

EXPLANATION OF PLATE I.

Photomicrographs of the polished and etched section (fig. 5 in text) of the Hoba meteoric iron, Grootfontein, South-West Africa.

(Photomicrographs by Dr. J. M. Robertson.)

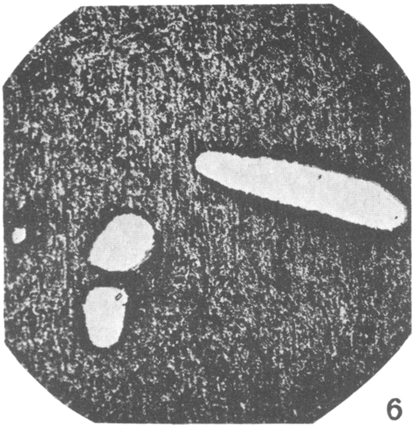
FIG. 6. Minute plessite-like structure with blebs of schreibersite (?). ×100.

FIG. 7. Two areas of plessite-like structure with different orientations. ×100.

FIGS. 8 and 9. Plessite-like structure. ×820.

FIG. 10. Schreibersite (?) in groundmass of plessite. ×820.

FIG. 11. Schreibersite (?) area. The bordering portions outside the dark lines are pale yellow and the inner portions are white. ×820.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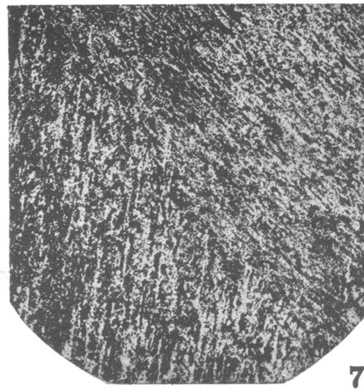
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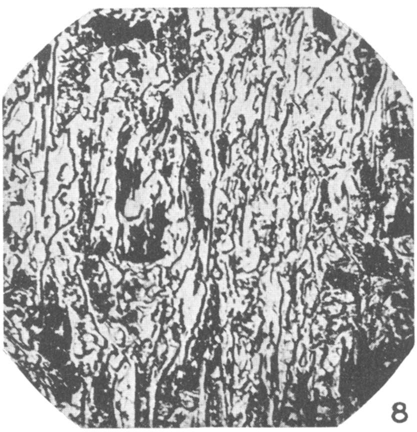
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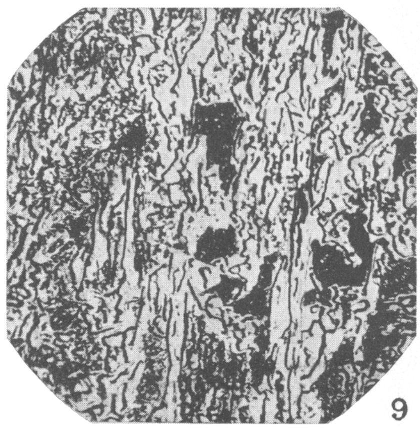
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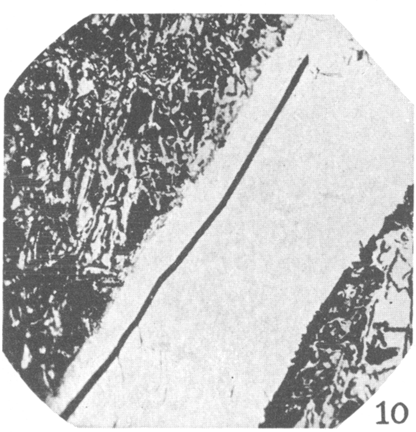
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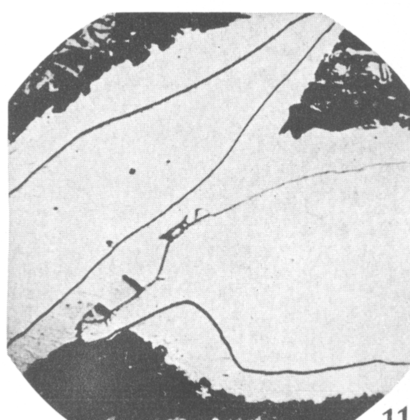
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L. J. SPENCER: THE HOBA METEORIC IRON.