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The Meteoric Stones of Launton, Warbreccan, Cronstad, Daniel's Kuil, Khairpur, and Soko-Banja.[1]

(*With Plates I–IV.*)

By G. T. Prior, M.A., D.Sc., F.R.S.

Keeper of the Mineral Department of the British Museum.

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THE investigation of the Launton, Warbreccan, and Cronstad meteorites was undertaken with the object of placing on record descriptions of these stones. Launton and Warbreccan were found to conform very well with the type of Baroti and Wittekrantz, containing from 7–9 per cent. of nickel-iron, described in a previous paper.[2] Cronstad, however, which contained as much as 18 per cent. of nickel-iron, showed so much variation from that type as to suggest a passage towards the rare Hvittis class of chrondritic stone containing even larger amounts of nickel-iron. The scope of the paper was therefore

[1] Communicated by permission of the Trustees of the British Museum.
[2] G. T. Prior, Mineralogical Magazine, 1913, vol. xvii, p. 22.

widened by investigations of the Daniel's Kuil and Khairpur meteorites, which in thin sections were found to resemble strikingly the Hvittis stone. Finally, a new analysis of the Soko-Banja meteorite was made in order to test whether the interrelation between the amount and chemical composition of the nickel-iron and the chemical composition of the ferromagnesium minerals, which had been found to subsist between Baroti and stones containing much larger amounts of nickel-iron, also extended in the opposite direction to stones containing smaller amounts.

LAUNTON.

According to the description published soon after its fall by Mr. William Stowe, a surgeon of Buckingham,[1] the Launton meteoric stone fell 'on Monday, the 15th day of February, 1830, at half-past seven in the evening, in the garden of John Bucknell, a labourer in the employment of Mr. Cross, farmer, at Launton, near Bicester, Oxon. Its descent was accompanied with a most brilliant light, which was visible for many miles around, and attended with a *triple* explosion, which was described to me, by a person who heard it at the distance of four miles, as resembling the rapid discharge of three ordinary guns. It penetrated some newly dug mould nearly a foot deep; and, though seen to strike the earth, was not sought for till the following morning when, of course, it had become cold. A man named Thomas Marriot was passing near the garden at the moment, and states that it came rapidly towards him from the north-east, not perpendicularly but *obliquely*, appearing about the size of a cricket-ball.'

The stone, which weighed 2 lb. 5 oz., soon after its fall passed into the possession of the Rev. Dr. John Lee of Hartwell House, near Aylesbury, who declined to part with any of it to other collectors. In 1853, however, he presented a cast of the stone to the British Museum. A note on the fall of the stone was sent by Professor W. H. Miller of Cambridge in 1841 to Poggendorff's Annalen der Physik und Chemie (vol. liv, p. 291), in which he states that he had obtained the particulars from a catalogue in Dr. Lee's house in London. A brief description of the stone is given in 'Aedes Hartwellianae, or Notices of the Manor and Mansion of Hartwell' (1851, p. 141), by Captain W. H. Smyth. It is also mentioned in the same author's 'Cycle of Celestial Objects' (1844, vol. i, p. 163).

The subsequent history of the stone illustrates very strikingly the perils which may beset rare or type specimens preserved in private

[1] W. Stone, Mag. Nat. Hist., 1831, vol. iv, p. 139.

collections, for after Dr. Lee's death the meteorite appears to have been practically lost sight of, until in 1889 inquiry was made about it by the late Sir Arthur H. Church, and later by Sir Lazarus Fletcher, then Keeper of the Mineral Department of the British Museum. On hearing from Mr. Mark Merriman, the son of Dr. Lee's solicitor, that Colonel E. D. Lee still preserved the contents of Dr. Lee's Museum at Hartwell House, Sir Lazarus Fletcher applied to Colonel Lee for information relative to the meteorite, but received the reply that the Launton stone was not in the Hartwell Museum. Nothing daunted, however, in March 1895 he paid a visit to Hartwell House, and was able to point out to Colonel Lee that a meteorite in the Museum labelled Esnandes was none other than the missing Launton stone, as it exactly resembled the model in the British Museum. The identity of the stone was confirmed by the fact that the label in the box containing it bore a number (250) which in the manuscript catalogue of Dr. Lee's collection referred to the Launton meteorite. As a result of this visit, the meteorite, later in the same year, was acquired for the British Museum Collection.

Physical Characters.

The stone (Reg. No. 77528), which is complete except for broken corners, and is covered with the usual dull black crust, measures roughly $4\frac{1}{2}\times 3\times 2\frac{1}{2}$ inches. Its present weight, after cutting off a small portion for analysis, &c., is 998 grams. The original weight was 1023 grams. Its specific gravity is 3·35, as determined by hydrostatic weighing of the whole stone. In shape the stone is a rough four-sided prism (Plate I, fig. 1), with one terminal face square and smooth and rather smaller than the other, which is irregular and broken. Of the prism faces three are fairly smooth, but the fourth and larger surface is very irregular, showing 'thumb-marks', sharp ridges, and indentations. Beneath the crust the material has the characters of a white to grey (intermediate) chondrite, but brown patches show that the nickeliferous iron has undergone some oxidation: it is traversed by a few thin, black veins.

Under the microscope, a thin section shows no unusual features. Grains of nickel-iron and troilite are seen in a matrix of bronzite and olivine. Chondrules consisting chiefly of radiating bronzite are few and are mostly of irregular shape merging into the matrix. A little interstitial matter between the olivine and bronzite grains is for the most part isotropic and is rendered almost opaque by included black grains. The section is crossed by several thin veins of dark, opaque material enclosing here and there lenticular patches of olivine and bronzite. Stainings of oxide of iron occur throughout the slide especially along these veins. The above characters show that the stone belongs to the intermediate veined chondrite group, Cia.

Chemical Composition.

The analyses were made by the method described in previous papers.[1] They were conducted with due care, but the determination of minor constituents, such as Pt, Cu, Au, &c.,[2] was not attempted. To effect the division of the material into attracted and unattracted portions a magnetic comb, not so strongly magnetic as to attract the troilite, was used. For the separation of iron and nickel in the attracted material two precipitations with sodium acetate were found to be sufficient, the determination of the nickel being checked by a precipitation with dimethylglyoxime in another portion of the solution. In the determination of the alkalis care was taken to convert into chloride any sulphate resulting from the oxidation of the troilite.

For the analysis a fragment of the meteorite weighing nearly 9 grams was separated by the magnetic comb into an attracted portion weighing 1·0114 grams and an unattracted portion weighing 7·6063 grams. The results of the analyses of the two portions are given below, together with the bulk-analysis obtained by combining these results.

	Attracted.	Unattracted.	Bulk-analysis.
Fe	61·33	—	7·20
Ni	10·24	—	1·20
Co	0·68	—	0·08
Fe	0·58	4·15	3·80
S	0·33	2·38	2·18
SiO_2	4·51	43·55	39·70
TiO_2	—	0·20	0·18
Al_2O_3	—	2·67	2·40
Cr_2O_3	—	0·35	0·31
Fe_2O_3	—	1·66	1·49
FeO	2·52	13·39	12·35
MnO	—	0·32	0·29

[1] G. T. Prior, Mineralogical Magazine, 1913–14, vol. xvii, pp. 24, 132.

[2] On the occurrence of such elements in meteorites see G. P. Merrill, Mem. Nat. Acad. Sciences, Washington, 1916, vol. xiv, p. 1.

		Attracted.		Unattracted.		Bulk-analysis.
NiO	...	—	...	0·13	...	0·12
CaO	...	0·79	...	2·21	...	2·09
MgO	...	4·65	...	27·05	...	24·89
K_2O	...	—	...	0·10	...	0·09
Na_2O	...	—	...	1·12	...	1·01
P_2O_5	...	—	...	0·17	...	0·15
H_2O	...	—	...	0·47	...	0·42
Insoluble	...	14·32	...	—	...	—
		99·95		99·92		99·95

In order to determine the composition of the olivine, a portion of the unattracted material weighing about one gram was digested with dilute hydrochloric acid (sp. gr. 1·06), and the soluble portion analysed. To avoid any decomposition of the bronzite and felspar, only a single digestion was made, so that some olivine still remained undecomposed in the insoluble portion. The result of the analysis was as follows:—

SiO_2	...	17·05
FeO	...	9·25
CaO	...	0·35
MgO	...	17·34
FeS, &c.[1]	...	8·94
Insoluble	...	46·65
		99·58

The composition of the olivine deduced from this analysis is approximately expressed by the formula 8·3 $Mg_2SiO_4 . Fe_2SiO_4$.

The mineral composition of the meteorite deduced from the bulk analysis and the known composition of the olivine is:—

$NaAlSi_3O_8$	...	8·54				
$KAlSi_3O_8$	...	0·56	...	10·82	...	Felspar.
$CaAl_2Si_2O_8$	...	1·72				
$FeO.TiO_2$	...	...	...	0·33		
$FeO.Cr_2O_3$	...	...	...	0·45	...	Chromite.
Fe_2O_3	...	...	...	1·49		
NiO	...	...	...	0·12		
$3Ca_3P_2O_8 . CaO$	...	...	...	0·36	...	Apatite.

[1] From analysis of unattracted portion.

$CaSiO_3$	...	3·17				
$FeSiO_3$	...	6·31	...	29·50	...	Bronzite.
$MgSiO_3$	...	20·02				
Fe_2SiO_4	...	12·61	...	41·91	...	Olivine.
Mg_2SiO_4	...	29·30				
Fe	...	3·80	...	5·98	...	Troilite.
S	...	2·18				
Fe	...	7·20				
Ni	...	1·20	...	8·48	...	Nickel-iron.
Co	...	0·08				
H_2O			...	0·42	...	Water.
				99·86		

Specific gravity, 3·35.

The analyses show that the Launton meteoric stone contains about $8\frac{1}{2}$ per cent. of nickel-iron, in which the ratio of Fe to Ni is about 6, and olivine and bronzite having chemical compositions represented approximately by the formulae $3{\cdot}3\,Mg_2SiO_4 . Fe_2SiO_4$ and $3CaSiO_3 . 5\,FeSiO_3 . 22MgSiO_3$ respectively. In chemical composition, therefore, the stone belongs to the same type as Baroti and Wittekrantz described in a previous paper.[1]

Warbreccan.

The three stones (Reg. No. 1905, 377–379) of this fall were purchased for the British Museum Collection in 1905 from Mr. B. Warwick, of London, who had obtained them from Mr. T. C. Wollaston of Adelaide. The finder of the stones, Mr. R. Pope, from whom Mr. Wollaston had received them, first heard of them from the natives of central Queensland in 1904. It is probable that they had been seen to fall, for in his letter to Mr. Wollaston giving an account of the find, Mr. Pope speaks of the fear in which the stones were held by the blacks. He says: 'They are deadly afraid of them and cover them up in the bush with Kangaroo grass, twisted gidya bark, and mud, and throw dry boughs over the top. Their idea is if the sun sees them more stones will be shaken down to kill the poor black fellow. They will not go near them, when once covered, nor show the way to any one.' It was with great difficulty, therefore, that, by the aid of an old

[1] G. T. Prior, Mineralogical Magazine, 1913, vol. xvii, p. 22.

stockman who was well acquainted with the district, he was at length enabled to trace the stones. The spot at which they were found was about 40 miles west of Windorah, central Queensland, in the Warbreccan run, 'a rough lonely country', as described by Mr. Pope, 'away from all civilization, in which you can ride all day and see no one'.

Physical Characters.

The shape and size of the three stones are shown in Plates I and II. Two of them are remarkable for their size, which is surpassed by only one other specimen of an aerolite in the British Museum Collection, that of Parnallee. They measure roughly $12 \times 11\frac{1}{2} \times 9$ inches and $14 \times 11 \times 7$ inches respectively. The weights of the three stones are 31,610 grams (about 69 lb.), 29,100 grams (about 64 lb.), and 443 grams (about 1 lb.) respectively. The largest stone seen on the left in Plate I, fig. 2, and in two positions in Plate II, figs. 1 and 2, is pitted with 'thumb-marks' on all its surfaces except on two which are fairly flat and smooth (see Plate II, fig. 2). The dull black crust is thin, and shows few signs of flow of material except near the sharp point seen in Plate II, fig. 1, at the top. Fractured surfaces show small grains of nickel-iron and larger and less uniformly distributed nodules of troilite in a white matrix crossed by a few thin, dark veins, and in parts stained brown by oxidation. The specific gravity of a fragment weighing about 12 grams of this stone is 3·48, as determined by hydrostatic weighing. The other large stone shown on the right in Plate I, fig. 2, and in two positions in Plate II, figs. 3 and 4, is flatter than the first. It has one large, fairly flat and smooth surface (on the left in fig. 4), but the other faces are irregular and pitted with 'thumb-marks', though not so thickly as on the largest stone. The crust of the stone has weathered to a brownish-red colour. The small stone, seen in the centre in Plate I, fig 2, is of very irregular shape with one end sharply pointed. Both crust and fractured surfaces have weathered to a red colour as in the second stone.

Under the microscope, a thin section from the largest stone shows small grains of nickel-iron and troilite in the usual aggregate of olivine and bronzite. Very few chondrules with good circular outline are present. In one section there are only two, one of fibrous bronzite and one of olivine in concentric rings. In another section the only chondrule had an interior consisting of detached grains of olivine in colourless isotropic material clouded with black inclusions, and an exterior consisting of a broad ring of olivine in optical continuity with the internal grains. The interstitial material between the olivines and bronzites in parts is isotropic, and in parts feebly doubly refractive with refractive index less than Canada balsam. The stone belongs to the white-veined chondrite group Cwa.

Chemical Composition.

For the analyses a fragment cut from the largest stone (1905, 377) and weighing nearly 17 grams was taken. This was crushed and separated by the magnetic comb into an attracted portion weighing 1·5553 grams, and an unattracted portion weighing 14·8902 grams. The results of the analyses are as follows:—

	Attracted.	Unattracted.	Bulk-analysis.
{Fe	63·79	—	6·03
{Ni	11·23	—	1·06
{Co	0·85	—	0·08
{Fe	0·68	4·39	4·09
{S	0·39	2·51	2·31
SiO_2	3·91	43·13	39·86
TiO_2	—	0·23	0·21
Al_2O_3	—	1·87	1·71
Cr_2O_3	—	0·45	0·41
Fe_2O_3	—	2·35	2·15
FeO	2·23	13·78	12·84
MnO	—	0·43	0·39
NiO	—	0·13	0·12
CaO	trace	2·19	2·01
MgO	4·19	26·57	24·75
K_2O	—	0·08	0·06
Na_2O	—	1·01	0·92
P_2O_5	—	0·28	0·26
H_2O	—	0·87	0·80
Insoluble	11·54	—	—
O and loss	1·19	—	—
	100·00	100·27	100·06

In order to determine the composition of the olivine, an analysis was made of a portion of the unattracted material digested with dilute hydrochloric acid with the following result:—

SiO_2	...	16·60
FeO	...	9·62
MgO	...	18·09
FeS, &c.[1]	...	10·53
Insoluble	...	44·68
		99·52

The composition of the olivine deduced from this analysis is approximately 3·37 $Mg_2SiO_4 . Fe_2SiO_4$.

The mineral composition of the meteorite calculated from the bulk-analysis and the composition of the olivine is:—

$NaAlSi_3O_8$	...	7·81			
$KAlSi_3O_8$	...	0.33	8·50	...	Felspar.
$CaAl_2Si_2O_8$	...	0·36			
$FeO.Cr_2O_3$	...	...	0·60	...	Chromite.
$FeO.TiO_2$	...	...	0·39		
Fe_2O_3	...	...	2·15		
NiO	...	...	0·12		
$3Ca_3P_2O_8.CaO$	...	...	0·59	...	Apatite.
$CaSiO_3$	...	3·33			
$FeSiO_3$	...	8·02	33·54	...	Bronzite.
$MgSiO_3$	...	22·19			
Fe_2SiO_4	...	12·02			
Mg_2SiO_4	...	27·78	39·80	...	Olivine.
Fe	...	6·03			
Ni	...	1·06	7·17	...	Nickel-iron.
Co	...	0·08			
Fe	...	4·09			
S	...	2·31	6·40	...	Troilite.
H_2O	...		0·80	...	Water.
			100·06		

Specific gravity, 3·48.

[1] From analysis of unattracted portion.

The Warbreccan meteorite contains about 7 per cent. of nickel-iron in which the ratio of Fe to Ni is about 6, and olivine and bronzite of which the chemical compositions are represented approximately by the formulae $3{\cdot}4\,Mg_2SiO_4 . Fe_2SiO_4$ and $2CaSiO_3 . 4FeSiO_3 . 15MgSiO_3$ respectively. In chemical composition, therefore, the stone belongs to the same type as Launton and Baroti.

Cronstad (Kroonstad).

The British Museum Collection contains two specimens of this fall. One (52149), now weighing 285 grams, was presented in 1878 by Mr. John Sanderson, and the other (55428) weighing 882 grams was acquired in 1884 by exchange with the Bloemfontein Museum through the Curator, Dr. H. Exton. The following extract from the minutes of the Bloemfontein Museum giving the date of fall of the meteorite is taken from a letter sent by Dr. Exton in 1886 to Mr. T. Davies, then assistant in the Mineral Department of the British Museum :—

'Dec. 8th, 1877.—Presented by His Honour President Brand, portion of a meteoric stone which fell at Cronstadt, O. F. S., on the 19th November, 1877, at about 4 p. m.'

In the same letter Dr. Exton refers to the loud report and flash of light attending the fall of the meteorite, as described in the newspaper report at the time, and states that the facts were well authenticated, having been witnessed by many observers in the large tract of country (18 miles) over which fragments of the meteorite on its rupture were scattered. According to W. Flight,[1] the shower took place in a wooded district, so that few stones could be collected. A short account of the two stones, weighing respectively 1382 and 663 grams, in the Bloemfontein Museum, has been given by Professor W. A. Douglas Rudge.[2]

Of the British Museum specimens, the larger one (Plate III, fig. 2) is a nearly complete stone, being covered with the usual dull black crust except on one fairly flat surface of fracture. The crust is thin and is slightly pitted, but shows little sign of flow of material. The surfaces are fairly smooth, and only show a few 'thumb-marks' on two of them. The other specimen (Plate III, fig. 1) has been cut from a very irregular flat stone, and has a similar pitted crust. One large surface is fairly smooth except for two 'thumb-marks', but the others are very rough and irregular, and one shows a series of fairly deep

[1] W. Flight, 'A Chapter in the History of Meteorites,' 1887, p. 205.
[2] W. A. D. Rudge, Trans. Roy. Soc. S. Africa, 1912, vol. ii, p. 211.

grooves. The specific gravity of this stone is 3·61, as determined by hydrostatic weighing.

A thin section under the microscope shows a few fairly sharply defined chondrules, some of fibrous and radiating bronzite and others of olivine grains, in a granular matrix of olivine and bronzite, with troilite, and much nickel-iron in grains and long, vein-like patches. One chondrule had a curiously indented, circular outline. The stone belongs to the grey chondrite group Cg.

Chemical Composition.

For the analysis a fragment from the smaller specimen (52149), weighing nearly 11 grams, was separated by the magnetic comb, into an attracted portion weighing 2·7414 grams, and an unattracted portion weighing 7·7118 grams. The results of the analyses are as follows :—

	Attracted.	Unattracted.	Bulk-analysis.
Fe	63·72	—	16·71
Ni	5·91	—	1·55
Co	0·88	—	0·28
Fe	0·75	3·94	3·29
S	0·43	2·25	1·88
SiO_2	3·92	46·16	37·24
TiO_2	—	0·38	0·30
Al_2O_3	—	3·08	2·41
Cr_2O_3	—	0·47	0·37
FeO	1·93	11·04	9·17
MnO	—	0·05 [1]	0·04
NiO	—	0·13	0·10
CaO	—	1·85	1·45
MgO	4·30	28·66	23·61
K_2O	—	0·09	0·07
Na_2O	—	0·86	0·67
P_2O_5	—	0·32	0·25
H_2O	—	0·44	0·34
Insoluble	17·79	—	—
	99·63	99·72	99·68

[1] Probably too low, as the separation from iron was by means of ammonia. This applies also to the following analyses, but not to those of Launton and Warbreccan.

An analysis of the portion of the unattracted soluble in dilute hydrochloric acid (sp. gr. 1·06) gave the following result:—

SiO_2	...	14·85
FeO	...	7·49
MgO	...	16·36
FeS, &c.	...	6·63
Insoluble	...	54·78
		100·11

The composition of the olivine deduced from the analysis is approximately 4 $Mg_2SiO_4 . Fe_2SiO_4$.

The mineral composition of the meteorite calculated from this result and that of the bulk-analysis is as follows:—

$NaAlSi_3O_8$	...	5·64				
$KAlSi_3O_8$	...	0·39	...	9·43	...	Felspar.
$CaAl_2Si_2O_8$	...	3·40				
$FeO.TiO_2$	...	...	...	0·56		
NiO	...	...	...	0·10		
$FeO.Cr_2O_3$	...	...	...	0·54	...	Chromite.
$3Ca_3P_2O_8.CaO$	...	...	...	0·56	...	Apatite.
$CaSiO_3$	...	0·94				
$FeSiO_3$	...	5·80	...	35·03	...	Bronzite.
$MgSiO_3$	...	28·29				
Fe_2SiO_4	...	7·97	...	29·44	...	Olivine.
Mg_2SiO_4	...	21·47				
Fe	...	3·29	...	5·17	...	Troilite.
S	...	1·88				
Fe	...	16·71				
Ni	...	1·55	..	18·49	...	Nickel-iron.
Co	...	0·23				
H_2O	...		...	0·34	...	Water.
				99·66		

Specific gravity, 3·61.

The analyses show that Cronstad exhibits some variation from the type to which Baroti, Wittekrantz, Launton, and Warbreccan belong. It contains over 18 per cent. of nickel-iron instead of less than 10, and this iron is much poorer in nickel, the ratio of iron to nickel being about 11 instead of 6 as in Baroti. Moreover, this higher percentage of a nickel-poor iron is associated with a diminished amount of oxide of iron in the ferromagnesium minerals, for the ratios of MgO to FeO in the olivine and bronzite of Cronstad are 4 and 6 respectively, whereas in Baroti they are 3 and 4.

Reference to the list of forty-one analyses of chondritic stones given in a previous paper (loc. cit., pp. 36-37) will show that in most of the stones, which like Cronstad contain higher percentages of nickel-iron than 10 (e.g. Beaver Creek, Cape Girardeau, Utah, and Winnebago County), the nickel-iron is also poor in nickel and there is a similar tendency to a diminution of iron in the ferromagnesium minerals. Now there is a chondritic stone, viz. Hvittis, in which this tendency reaches a limit, for in this stone which contains even higher amounts of a nickel-poor iron than Cronstad, the magnesium silicate is a pure enstatite practically free from iron. The examination of thin sections in the British Museum Collection showed that there were two other stones, viz. Daniel's Kuil and Khairpur, which strikingly resembled the Hvittis stone, and contained like it the mineral oldhamite in fair amount. It was decided, therefore, to make investigations of these two meteorites.

Daniel's Kuil.

The Daniel's Kuil meteorite was first described by J. R. Gregory,[1] who, when in South Africa, had obtained the only stone of the fall from Captain Nicholas Waterboer. It had been given to the latter by the native Griqua, who had witnessed its fall near his hut. According to information supplied to Mr. Gregory by the Rev. James Good, the missionary to whom the native, after bringing it to Griqua Town, showed the stone, it fell on March 20, 1868, at Daniel's Kuil, two days' journey N.N.E. of Griqua Town, Griqualand West, South Africa, and was warm when picked up. The weight of the stone was only 2 lb. 5 oz., and it was in two halves when it came into the possession of Mr. Gregory. The meteorite was brought to London and soon afterwards was partially analysed by Sir Arthur H. Church.[2]

The specimens (42388, 42502, 42503) in the British Museum Collection are fragments of the stone and were all obtained from Mr. Gregory. They now weigh 222, 121, and 88 grams respectively, and fit together

[1] J. R. Gregory, Geol. Mag., 1868, vol. v, p. 531.

[2] A. H. Church, Journ. Chem. Soc., 1869, vol. vii, p. 22.

so as to give a fair idea (Plate III, fig. 4) of the complete stone of which they constitute nearly a half. As seen in the model (Plate III, fig. 3) the complete stone was elongated with rounded surfaces coated with the usual dull black crust. In the specimens the crust shows traces, but not well-marked, of lines of flow of molten material. Fractured surfaces have the peculiar dark grey, hard and rough character shared with Cléguérec, Moti-ka-nagla, and other crystalline stones rich in nickel-iron. The specific gravity, as determined on about 1 gram of material with the pyknometer, is 3·66.

Under the microscope, the section shows much nickel-iron in grains and irregular patches and troilite in smaller grains, in a crystalline matrix which consists, as shown by the following analyses, of a nearly pure enstatite. The stone is in fact precisely similar to Hvittis, and like that meteorite contains a notable amount of oldhamite which in section is seen in patches of reddish-yellow grains, often surrounded by a black reflective ring of what appears to be graphitic material. Chondrules are rare, and consist only of irregular radiating pyroxene. The above characters, coupled with the results of the analyses, show that the meteorite belongs to the rare Hvittis type to which, as shown by Lacroix,[1] Pillistfer also belongs.

Chemical Composition.

The material used for analysis consisted of a fragment of specimen (42502) weighing about 14 grams, which was separated by the magnetic comb into an attracted portion weighing 4·2188 grams and an unattracted portion weighing 9·5458 grams. The results of the analyses of these portions were as follows:—

	Attracted.	Unattracted.	Bulk-analysis.
Fe	77·33	—	23·70
Ni	5·83	—	1·78
Co	0·39	—	0·12
Fe	—	7·03	5·15
S	trace	4·02	2·94
Ca	—	0·65	0.48
S	—	0·52	0·38
SiO_2	3·32[2]	51·12	38·47
TiO_2	—	0·16	0·12

[1] A. Lacroix, Bull. Soc. franç. Min., 1905, vol. xxviii, p. 70.

[2] The percentage of silica is unaccountably high as compared with that of the

	Attracted.	Unattracted.	Bulk-analysis.
Al_2O_3 ...	— ...	2·43 ...	1·78
Cr_2O_3 ...	— ...	0·32 ...	0·23
Cr_2S_3 ...	— ...	0·40 ...	0·29
FeO ...	— ...	0·59 ...	0·28
NiO ...	— ...	0·15 ...	0·11
MnO ...	— ...	0·03 ...	0·02
CaO ...	0·17 ...	1·34 ...	1·08
MgO ...	0·21 ...	29·45 ...	21·63
K_2O ...	— ...	0·21 ...	0·15
Na_2O ...	— ...	0·88 ...	0·64
P_2O_5 ...	— ...	trace ...	trace
H_2O ...	— ...	0·47 ...	0·34
Graphite,[1] &c.	— ...	0·38 ..	0·32
Insoluble	12·65 ...	— ...	—
	99·90	100·15	99·91

The percentage of oldhamite was estimated from the calcium obtained in solution after digesting a portion of the unattracted in water slightly acidified with acetic acid. A portion of the unattracted digested with dilute hydrochloric acid (sp. gr. 1·06) to which some nitric acid was added gave an insoluble residue of enstatite, &c., amounting to 84·58 per cent. The solution contained, besides troilite, daubreelite, and oldhamite, only 0·58 per cent. of SiO_2 and 0·26 per cent. MgO, so that the bulk of the silicates were contained in the insoluble. An analysis of the insoluble after ignition gave the following result:—

SiO_2 ...	59·76
Al_2O_3[2] ...	2·78
FeO ...	0·18
CaO ...	1·31
MgO ...	34·28
Na_2O ...	1·04
K_2O ...	0·25
	99·60

MgO. In the analysis of St. Marks, a stone probably also belonging to the Hvittis type, Cohen noted a similar excess of silica in the soluble portion (Ann. S. African Museum, 1906, vol. v, p. 14), and free silica was also detected in thin sections of the meteorite under the microscope.

[1] Loss on ignition of insoluble. [2] Containing a little Cr_2O_3.

The small amount of iron obtained in the analysis belongs probably to chromite and not to the enstatite. Much of the chromium appears to have passed into the soluble portion of the unattracted and is therefore in all probability in the form of daubreelite, $FeS.Cr_2S_3$, instead of chromite. In this respect the meteorite is similar to Hvittis in which Borgström determined the presence of daubreelite.[1]

The mineral composition deduced from the analyses is as follows :—

$NaAlSi_3O_8$	5·48			
$KAlSi_3O_8$	2·01	8·47	Felspar.	
$CaAl_2Si_2O_8$	0·98			
$FeO.TiO_2$	...	0·36		
$FeO.Cr_2O_3$	...	0·34	Chromite.	
$FeS.Cr_2S_3$	...	0·40	Daubreelite.	
$MgSiO_3$	54·01	55·76	Enstatite.	
$CaSiO_3$	1·75			
Ca	0·48	0·86	Oldhamite.	
S	0·38			
Fe	5·07	7·96	Troilite.	
S	2·89			
Fe	23·55			
Ni	1·78	25·45	Nickel-iron.	
Co	0·12			
H_2O		0·34	Water.	
C		0·32	Graphite.	
		100·26		

Specific gravity, 3·66.

The result of the investigation of Daniel's Kuil has been to show the precise similarity of this meteorite with the rare type of stone of which Hvittis and Pillistfer, and somewhat doubtfully St. Marks, have been hitherto the only representatives. In this type it would seem that the tendency for the predominence of magnesia over ferrous oxide in the ferromagnesium minerals exhibited by Cronstad and other chrondritic stones rich in nickel-poor nickel-iron reaches its limit, for the only silicate, besides felspar, which the members of the Hvittis class contain, consists of a pure enstatite free from iron.

[1] L. H. Borgström, 'Die Meteoriten von Hvittis und Marjalahti.' Bull. Comm. Géol. Finlande, 1903, vol. iii, No. 14, p. 24.

KHAIRPUR.

An account of the fall of the stones of the Khairpur meteorite was given soon after the event by H. B. Medlicott.[1] The fall took place on September 23, 1873, partly in the state of Bhawalpur and partly in the Multan district, on either side of the Sutlej, the greatest number of stones falling near the village of Khairpur, 72° 12′ E. long., 29° 56′ N. lat., 36 miles east-north-east of Bhawalpur. Of the numerous stones which fell only six appear to have been preserved in the Indian Museums. According to a list given by Medlicott (l. c., p. 34) they are as follows :—

		lb.	oz.	grains.
A. Lahore Museum	... ...	10	12	126
B. Indian Museum	... ...	9	11	219
C. " "	... ...	7	14	236
D. Geological Museum	... ...	1	2	412
E. " "	... ...		8	79
F. " "	... ...		6	70

The first five stones fell at Khairpur and were found 'imbedded in the earth at a depth of about 1½ feet at various places, about a mile and a half from Khairpur to the eastward, and about a mile apart'. The sixth was received from Colonel Ralph Young, Commissioner of Multan, as having fallen near Mylsi. According to Medlicott it is probably one of the seven stones recorded by Captain Lang, Deputy Commissioner for the Multan district, as found on the Multan side, 'four at different spots near Gogewala well, close to E. S. E. of Mahomed Moorut; two at Khurampur on the right bank of the Sutlej, and one at Araoli, two miles N.W. of Khurampur'. The range of the Khairpur meteoric stones is estimated by Medlicott to have had a length of sixteen miles, and a breadth of about three miles. The remarkable phenomena attending the fall were described by the Rev. G. Yeates of the Church Missionary Society, Multan, who observed them from a spot 12 miles south of Multan. At 5.10 a.m., 45 minutes before sunrise, a cluster of luminous meteors, having the appearance of a rocket just bursting, was seen to move steadily from a spot close to the star Algenib, about 15° above the horizon in the west, to a point nearly due east, through nearly 180°, crossing the meridian close under Orion at an altitude of about 50°. The larger fragments of the cluster, taking the lead, glowed with an

[1] H. B. Medlicott, Journ. Asiatic Soc. Bengal, 1874, vol. xliii, p. 33.

intense white light, and were surrounded and followed by a great number of smaller ones, the whole leaving behind a broad brilliant fiery-red train, which continued very bright for some time and was distinctly traceable for more than three-quarters of an hour afterwards, before finally breaking up into silvery-grey clouds which were dispersed by the wind. About four minutes after the first appearance of the meteorite, there was a loud report followed by a long reverberation. A very similar account of the phenomena was given by a correspondent of the 'Pioneer' newspaper of September 30, 1873, who describes the meteorite as appearing first as a brilliant star moving slantingly upwards and towards him, and then bursting almost immediately like a rocket, but without scattering to any extent. All the fragments or stars, numbering twenty, were distinctly visible and moved in parallel courses, each leaving a tail of red light behind it, which blended together to form a huge band of light from one end of the heavens to the other.

The three specimens (51366, 51189, 48369) of the Khairpur meteorite in the British Museum Collection now weigh respectively 3010, 201, and 65 grams. The largest and smallest stones were obtained by exchange from the Calcutta Museum in 1877 and 1875 respectively, and, judging from their original weights of 7 lb. 14 oz. and 1397 grains (3 oz. 84 gr.), are probably the stones C and E of Medlicott's list. The third stone was presented by A. Brandreth through W. G. Spottiswoode in 1877. All three stones are coated with a dull black crust which is so thin that in many places it has been worn away. The largest specimen is a portion of a still larger stone. In the figure (Plate IV, fig. 1) it is resting on a broad cut surface. It is of irregular shape, but shows one nearly flat surface (on the left of figure) only partially covered with crust (see Medlicott, l. c. p. 34). The other surfaces (as seen on the right of figure) are traversed by bands darker than the rest of the crust. The specific gravity of specimen 48369 is 3·49 as determined by hydrostatic weighing, and that of 51189, 3·48.[1]

Under the microscope, thin sections present characters indistinguishable from that of Daniel's Kuil, and show much nickel-iron and troilite in a crystalline matrix of enstatite, occasionally exhibiting radiating structure. Oldhamite is present in fair amount: in one section a piece of this mineral, orange-red in colour and exhibiting well-marked cubic

[1] The specific gravity is low as compared with Daniel's Kuil, but the Khairpur stones had undergone more oxidation. The method of determination by hydrostatic weighing also gives lower results than that by the pyknometer.

cleavage, measured about 4 mm. in length. As in Daniel's Kuil, graphitic material is present in rings generally surrounding grains of oldhamite, and in one case crossing a chondrule of radiating enstatite. The meteorite is almost precisely similar to Daniel's Kuil and, as shown by the following analyses, belongs like it to the rare Hvittis group.

Chemical Composition.

For the analyses, a fragment weighing about 8 grams of the smallest specimen (48869) was used. By means of a magnetic comb it was divided into an attracted portion weighing 1·8419 grams, and an unattracted portion weighing 6.0431 grams. The results of the analyses are :—

	Attracted.	Unattracted.	Bulk-analysis.
{ Fe	72·05	—	16·83
{ Ni	5·54	—	1·29
{ Co	0·73	—	0·17
{ Fe	0·96	5·27	4·47
{ S	0·55	3·01	2·56
{ Ca	—	0·24	0·19
{ S	—	0·19	0·15
SiO_2	1·59	52·37	42·64
TiO_2	—	nil	nil
Al_2O_3	—	2·18	1·76
$FeO.Cr_2O_3$	—	0·49	0·39
$FeS.Cr_2S_3$	—	0·36	0·29
Fe_2O_3	—	3·57	2·88
NiO	—	trace	—
CaO	0·98	1·58	1·46
MgO	trace	28·61	23·09
K_2O	—	0·13	0·10
Na_2O	—	0·99	0·80
P_2O_5	—	trace	trace
H_2O	—	0·25	0·20
Graphite	—	0·51	0·41
Insoluble	17·44	—	—
	99·84	99·70	99·68

Again in the analysis of the attracted as in that of Daniel's Kuil occurs a certain amount of apparently free silica. The CaO in the attracted portion is also difficult to account for; in amount it is about sufficient to form oldhamite with the sulphur, but the idea that this mineral was enclosed in the iron is too uncertain to warrant departure from the usual plan of attributing the sulphur to troilite.

The analysis of the unattracted is the combined result of analyses of the soluble and insoluble constituents of the unattracted, together with separate determinations of the chromium, sulphur, and water, as follows:—

Soluble.			Insoluble.		
SiO_2	...	0·48	SiO_2	...	60·65
Fe_2O_3 [1]	...	3·02	TiO_2	...	nil
CaO	...	0·56	Al_2O_3	...	2·55
MgO	...	0·15	Cr_2O_3	...	0·38
NiO	...	trace	FeO	...	0·77
{Ca	...	0·24	CaO	...	1·13
{S	...	0·19	MgO	...	33·42
Cr_2S_3 [2]	...	0·25	K_2O	...	0·15
{Fe	...	5·34	Na_2O	...	1·16
{S	...	3·05			100·21
C [3]	...	0·51			
H_2O	...	[0·25]			
Insoluble	...	85·57			
		99·61			

The oldhamite was determined from the calcium obtained by digesting the unattracted material in water slightly acidified with acetic acid. The small amount probably does not represent the average in the stone, for in some sections the mineral appears to be fairly plentiful (see p. 18).

The mineral composition deduced from the analyses is as follows:—

$NaAlSi_3O_8$	...	6·85 }				
$KAlSi_3O_8$	...	0·56 }	...	8·25	...	Felspar.
$CaAl_2Si_2O_8$	...	0·84 }				
$FeO.Cr_2O_3$	...	...	...	0·39	...	Chromite.
$FeS.Cr_2S_3$	...	...	...	0·29	...	Daubreelite.

[1] Rrepresents excess of Fe over that required to form FeS: it is considered to be the result of oxidation of the sample analysed, and is reckoned as Fe_2O_3.

[2] Calculated from difference between total Cr and that in the insoluble.

[3] Loss on ignition of insoluble.

$MgSiO_3$	...	57·64	...	60·31	... Enstatite.
$CaSiO_3$	...	2·67			
Ca	...	0·19	...	0·34	... Oldhamite.
S	...	0·15			
Fe	...	4·47	...	7·03	... Troilite.
S	...	2·56			
Fe	...	16·83			
Ni	...	1·29	...	18·29	... Nickel-iron.
Co	...	0·17			
Fe_2O_3	...	...	...	2·88	
SiO_2	...	...	...	1·51	
H_2O	...	...	...	0·20	... Water.
C	...	...	...	0·41	... Graphite.
				99·90	

Specific gravity, 3·49.

The result of the analyses is to show that Khairpur contains oldhamite and consists mainly of a nearly pure enstatite free from iron and a nickel-iron poor in nickel (Fe : Ni=13). It is precisely similar in composition to Daniel's Kuil and like it belongs to the rare Hvittis type of chondritic stone.

The results of the analyses of Cronstad, Daniel's Kuil, and Khairpur indicate generally that in chondritic stones containing large amounts of nickel-iron (over 10 per cent.), that iron is poor in nickel and corresponds to the hexahedrites and nickel-poor octahedrites of the siderites, whereas in stones like Baroti containing from 7–9 per cent. of nickel-iron, that iron is much richer in nickel and corresponds to the nickel-rich ataxites. Moreover, in the stones containing more than 10 per cent. of nickel-iron the magnesium silicates contain a smaller proportion of ferrous oxide, and in the Hvittis type are practically free from iron.

In order to test whether this interrelation between the amount and composition of the nickel-iron and the composition of the ferromagnesium silicates extended in the opposite direction to chondritic stones containing a less amount of nickel-iron than Baroti, it was decided to make a new analysis of the Soko-Banja stone, for the analyses of this and some other stones (Krähenberg, Ngawi, Buschhof, and Makariwa) lent considerable support to the view that in such stones the small amount of iron was richer in nickel[1] and the ferromagnesium minerals richer in iron. This stone was chosen since there was plenty of material in the British Museum Collection, and the old analysis by S. M. Losanitch showed some discrepancies, for although the stone is stated to contain about 4 per cent. of nickel-iron, the bulk-analysis, as calculated by Wadsworth from the analyses of the soluble and insoluble material, shows practically none.

Soko-Banja.

Descriptions of the phenomena attending the fall of the Soko-Banja meteorite have been given by E. Doll,[2] and by S. M. Losanitch.[3] According to these accounts the meteorite fell about 2 p.m. on October 13, 1877, in the neighbourhood of Soko-Banja, in the district of Alexinatz, Serbia. High up in a clear sky a luminous ball was first observed, from which after a short time proceeded a large white cloud, and twenty-five seconds later three detonations were heard. The stones were seen to fall by peasants working in the fields, and were picked up the same day. Ten stones were found, of which the largest weighed 38 kg. and two others 16 kg. each. The total weight was about 80 kg. The individual stones were scattered over an area of about 12 km. from N. to S. and about 2 km. from E. to W. The path of the meteorite formed with the magnetic meridian an angle of 220° 50′ from N.E. to S.W. and was very steep. The explosion took place at a height of about 7,000 metres.

Physical Characters.

The specimen (51857) in the British Museum from which material was taken for analysis weighs 1,970 grams and is a portion of a much larger stone. As seen in Plate IV, fig. 2, the dull black crust shows some well-defined 'thumb-marks' and patches of the red soil in which the stone fell. The fractured surface is pale grey and shows numerous chondrules perfectly spherical and easily detachable. The structure is somewhat clastic, for besides the chondrules there are many small irregularly-shaped fragments which can also be easily detached from the rather friable matrix; some of these fragments measure as much as 2 cm.

[1] W. Flight (Proc. Roy. Soc., 1881–2, p. 34) more than thirty years ago came to the conclusion that the less the amount of nickel-iron in meteoric stones the richer it was in nickel, but hitherto the idea appears to have met with no general acceptance.

[2] E. Doll, Verh. k.-k. Geol. Reichsanstalt, Wien, 1877, p. 283.

[3] S. M. Losanitch, Ber. Deutsch. Chem. Gesell., 1878, vol. xi, p. 96.

across. Troilite is seen in nodules up to 1 cm. in diameter scattered sparingly through the mass, but the nickel-iron only occurs in small grains scarcely to be distinguished with the naked eye.

Under the microscope, numerous and well-defined chondrules are seen in a crystalline matrix: most are of densely fibrous bronzite, but some show small olivines in good crystals sharply defined in a dark grey, glassy base. Troilite is plentiful in minute grains and also attached to nickel-iron which occurs in rounded grains sparsely distributed. The fragmental material is clearer and more definitely crystalline than the main mass, and contains fewer chondrules. The specific gravity of the stone has been given by Losanitch as 3·502.

Chemical Composition.

A fragment weighing about 15 grams was separated by the magnetic comb into an attracted portion weighing 0·9210 grams and an unattracted portion weighing 13·7830 grams. The results of the analyses are as follows:—

	Attracted.	Unattracted.	Bulk-analysis.
Fe	47·46	0·21	3·17
Ni	15·83	0·07	1·06
Co	1·37	...	0·09
Fe	—	3·33	3·17
S	trace	1·90	1·81
SiO_2	3·93	43·29	41·45
TiO_2	—	0·10	0·10
Al_2O_3	—	1·97	2·12
Cr_2O_3	—	0·38	0·36
FeO	3·60	18·40	17·73
MnO	—	0·05	0·05
CaO	nil	2·02	1·92
MgO	4·90	26·61	25·63
K_2O	—	0·07	0·07
Na_2O	—	0·89	0·85
P_2O_5	—	0·26	0·24
H_2O	—	0·18	0·17
Insoluble	22·73	—	—
	99·82	99·73	99·99

Analysis of a portion of the unattracted soluble in dilute hydrochloric acid gave the following result:—

SiO_2	...	20·29
FeO	...	14·44
CaO	...	0·35
MgO	...	19·26
FeS, &c.[1]	...	5·51
Insoluble	...	40·17
		100·02

The composition of the olivine given by this analysis is approximately $2\frac{1}{2}Mg_2SiO_4 . Fe_2SiO_4$.

The mineral composition calculated from the preceding analyses is as as follows:—

$NaAlSi_3O_8$	...	7·21					
$KAlSi_3O_8$	...	0·65	...	9·09	...	Felspar.
$CaAl_2Si_2O_8$	...	1·23				
$FeO.TiO_2$	...	...	...	0·18		
$FeO.Cr_2O_3$	...	...	...	0·45	...	Chromite.
$3Ca_3P_2O_8.CaO$	...	...	...	0·56	...	Apatite.
$CaSiO_3$	...	2·82				
$FeSiO_3$	...	8·64	...	30·60	...	Bronzite.
$MgSiO_3$	...	19·14				
Fe_2SiO_4	...	18·20	...	49·61	...	Olivine.
Mg_2SiO_4	...	31·41				
Fe	...	3·17	...	4·98	...	Troilite.
S	...	1·81				
Fe	...	3·17				
Ni	...	1·06	...	4·32	...	Nickel-iron.
Co	..	0·09				
H_2O	...	...	...	0·17	...	Water.
				99·96		

The above results confirm the general accuracy of Losanitch's analysis and show that Soko-Banja contains only about 4 per cent. of nickel-iron very rich in nickel (Fe : Ni = 3), and olivine and bronzite much richer in iron than in Baroti, the ratio of MgO to FeO in the olivine being about $2\frac{1}{2}$, and in the bronzite 3.

[1] From analysis of unattracted portion.

Conclusion.

As a general result of the analyses of the stones described in this paper, the conclusion is drawn that *in chondritic meteoric stones the less the amount of metallic iron the richer it is in nickel, and the richer in iron are the ferromagnesium minerals.*

The significance of this result with respect to the genetic relationship of meteorites, and the idea that a magma such as gave rise to meteorites of the Hvittis type is the source from which the other types of meteoric stones have been derived by progressive oxidation of the nickel-iron, are considered in the following paper.

Explanation of Plates I–IV.

Plate I, fig. 1.—Meteoric stone which fell at Launton, Bicester, Oxfordshire, on February 15, 1830. Weight 998 grams. Reg. No. B.M. 77528. (× $\frac{2}{3}$.)

—— fig. 2.—Meteoric stones collected in 1904 in the Warbreccan run, 40 miles west of Windorah, central Queensland. B.M. 1905, 377–379. (× $\frac{1}{7}$.)

Plate II, figs. 1 and 2.—Two views of the largest of the Warbreccan meteoric stones. Weight 31,610 grams (about 69 lb.). B.M. 1905, 377. (× $\frac{1}{8}$.)

—— figs. 3 and 4.—Two views of the Warbreccan meteoric stone, weighing 29,100 grams (about 64 lb.). B.M. 1905, 378. (× $\frac{1}{8}$.)

Plate III, fig. 1.—Fragment, weighing 285 grams, of one of the meteoric stones which fell at Cronstad, Orange Free State, South Africa, on November 19, 1877. B.M. 52149. (× $\frac{1}{2}$.)

—— fig. 2.—Another of the Cronstad meteoric stones, weight 882 grams. B.M. 55428. (× $\frac{1}{2}$.)

—— fig. 3.—Plaster cast of the meteoric stone which fell at Daniel's Kuil, Griqualand West, South Africa, on March 20, 1868. B.M. 65884. (× $\frac{1}{2}$.)

—— fig. 4.—Three fragments (total weight 431 grams) fitted together, and reconstructing one-half of the Daniel's Kuil meteoric stone. B.M. 42388, 42502, 42503. (× $\frac{1}{2}$.)

Plate IV, fig. 1.—Fragment, weighing 3,010 grams, of one of the meteoric stones which fell at Khairpur, near Bhawalpur, Punjab, India, on September 23, 1873. B.M. 51366. (× $\frac{2}{3}$.)

—— fig. 2.—Fragment, weighing 1,970 grams, of one of the meteoric stones which fell at Soko-Banja, Alexinatz, Serbia, on October 13, 1877. B.M. 51857. (× $\frac{2}{3}$.)

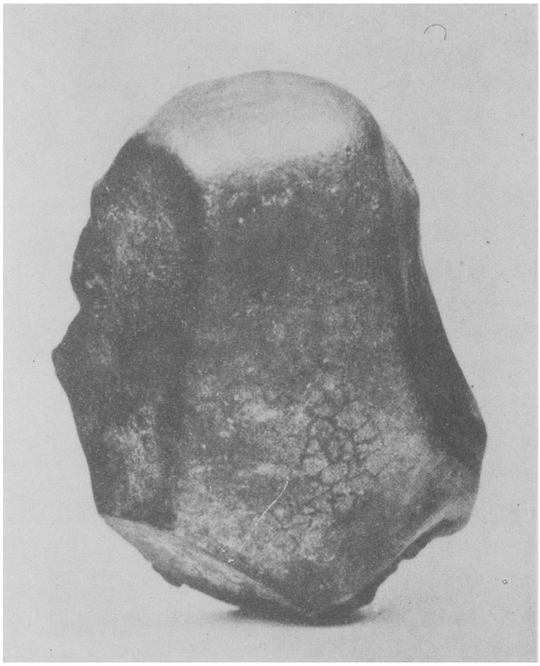

FIG. 1.

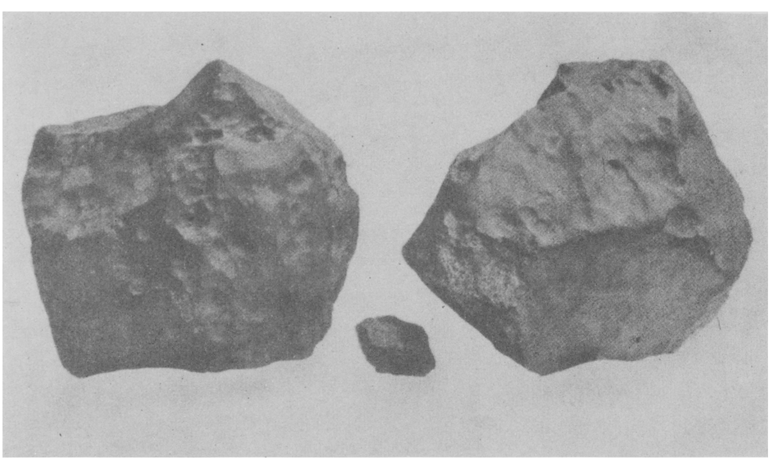

FIG. 2.

G. T. PRIOR: METEORIC STONES OF LAUNTON AND WARBRECCAN.

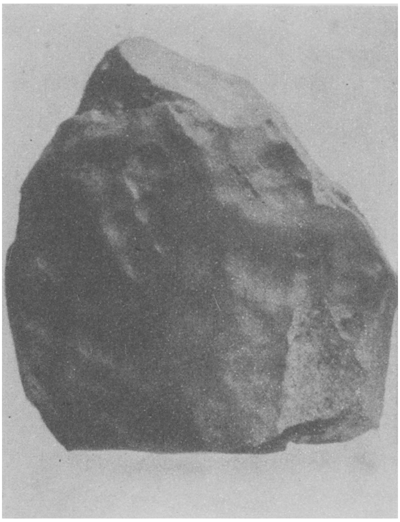

FIG. 1.

FIG. 2.

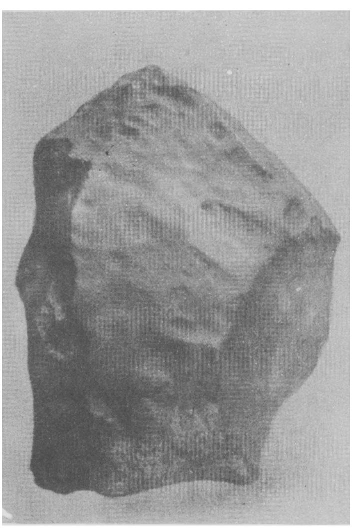

FIG. 3.

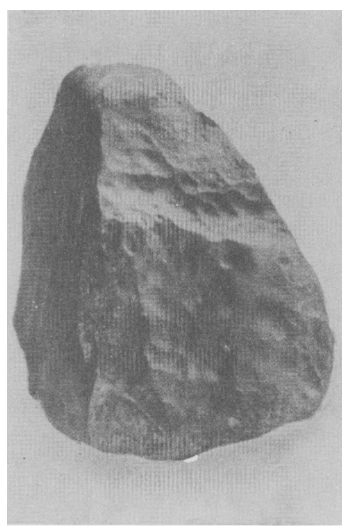

FIG. 4.

G. T. PRIOR: METEORIC STONES OF WARBRECCAN, QUEENSLAND.

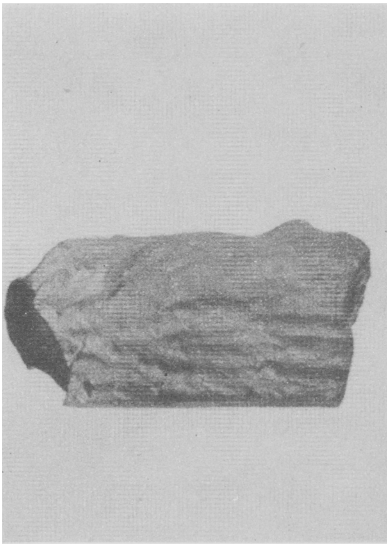

FIG. 1.

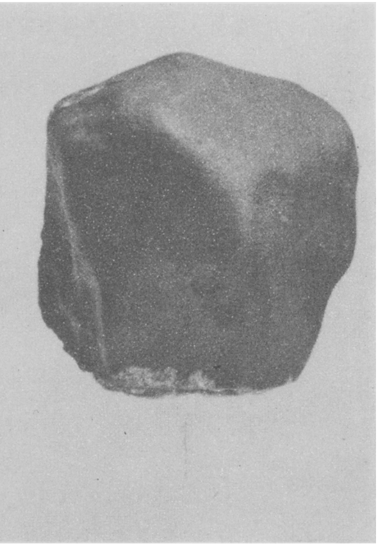

FIG. 2.

FIG. 3.

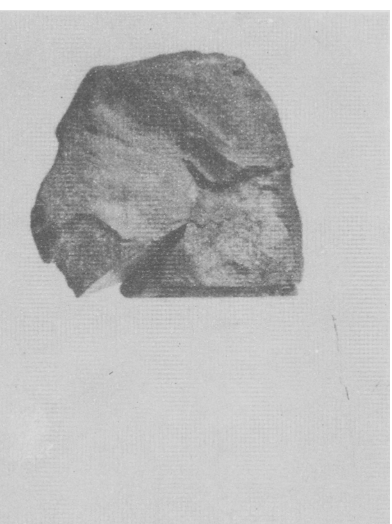

FIG. 4.

G. T. PRIOR: METEORIC STONES OF CRONSTAD AND DANIEL'S KUIL.

FIG. 1.

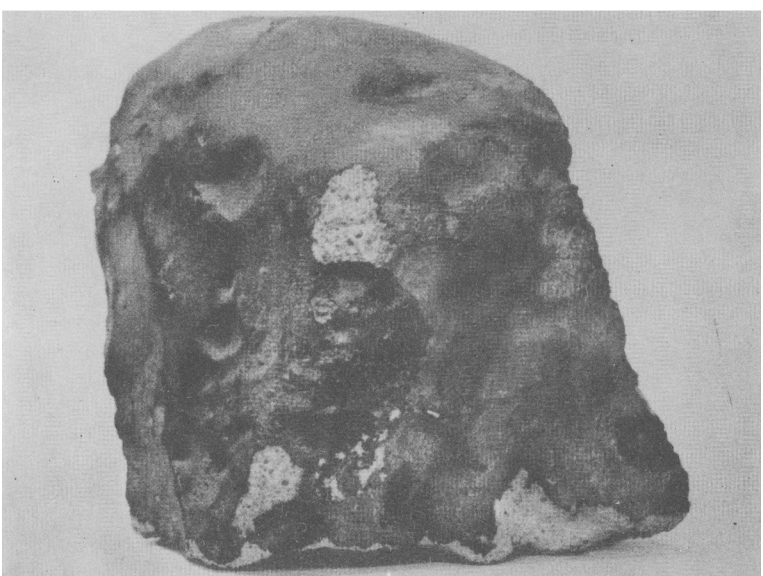

FIG. 2.

G. T. PRIOR: METEORIC STONES OF KHAIRPUR AND SOKO-BANJA.