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On a Meteoric Iron found in 1884 in the Sub-district of Youndegin, Western Australia, and containing Cliftonite, a cubic form of Graphitic Carbon.

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[Read January 11th, 1887.]

THIS iron was found on January 5th, 1884, by Alfred Eaton, a mounted police constable, when on duty in the sub-district of Youndegin, at a spot distant about 60 chains (three-quarters of a mile) in a north-west direction from the top of Penkarring Rock, and roughly estimated by him as 70 miles east of York, Western Australia; this must be about longitude $117^{\circ}30'$ E. of Greenwich, latitude $31^{\circ}30'$ S. Only one of four observed fragments having been brought in by Mr. Eaton, the late Captain Smith, Commissioner of the Police at Perth, sent him out to Penkarring with a native assistant with instructions to bring in the other three, at the instance of the Rev. Charles G. Nicolay, Curator of the Geological Museum, Fremantle, to whom the late Mr. Edward T. Hardman, F.C.S., the Government Geologist, had expressed his belief in the meteoric origin of the iron. Eaton and his companion started off on horseback at 8 a.m. on February 28th, encamped at a "rock hole" for the night, and leaving at 6 a.m. the next day reached Penkarring at 7.30 a.m. An unsuccessful search was

made for fragments additional to those already observed. Leaving Penkarrig at 7 a.m. on 1st March, they encamped at Morecanning for the night, and arrived at York Police-station at 7 o'clock on the following morning.

To the zeal and thoughtfulness of Mr. Nicolay we are indebted for the preservation of the specimens, and for the particulars of their discovery : by him, at the suggestion of Lady Barker, the largest and the smallest fragments have been generously presented to the British Museum through Mr. R. H. Scott, F.R.S., as Secretary of the Mineralogical Society.

The four fragments were lying loose on the surface, three of them close together, and the fourth about 15 ft. away : they weighed $25\frac{3}{4}$ lbs., 24 lbs., $17\frac{1}{2}$ lbs. and 6 lbs., respectively : in the opinion of Mr. Nicolay they seem to have formed a portion of a spherical mass, although they are individually irregular in shape. Scattered around the iron there were broken pieces, apparently belonging to a shell or outer covering, and of these a weight of 17 lbs. was collected. As the latter fragments consist essentially of magnetic oxide of iron, they are doubtless due to the action of the weather on the meteorite : the samples sent to the Museum have a laminated structure, and one of them is an inch in thickness.

The country around Youndeggin is described as granitic with dykes of quartz, and schistose rocks : there is a superficial covering of sandstone, in which, though widely distributed over the Colony, no fossils have yet been found : there is no appearance of iron ore at Youndeggin, though in many parts of the Colony iron ores are found in abundance. The above circumstances indicate an extra-terrestrial origin for the iron.

The only meteoric iron previously discovered in Australia is that of Cranbourne, near Melbourne, 1,500 miles distant from Youndeggin.

The largest of the two fragments presented to the British Museum weighed $25\frac{3}{4}$ lbs. : it is 12 inches long, 10 inches broad, and has a maximum thickness of 3 inches. In shape it is rudely convex at one side and concave at the other ; its surface presents numerous spherical depressions. It is distinguished from all the meteoric irons in the British Museum collection by two cylindrical holes, completely traversing the iron from back to front : one of them has a diameter varying from 2 to $2\frac{1}{2}$ inches, and a length of $1\frac{1}{2}$ inches ; the other is of nearly the same size : three similar annular openings characterise the iron of Tazewell, Claiborne County, Tennessee, U.S.A., described and figured by the late Professor Lawrence Smith.¹ The large Signet iron, preserved in the National Museum at

¹ *Amer. Journ. Sc.* 1855, Ser. 2, Vol. 19, p. 154.

Washington, is an almost complete ring¹: the meteoric iron of Independence County, described lately by Mr. Hidden,² is likewise remarkable for the presence of a small hole.

The smallest fragment of the Youndegin iron, weighing 6 lbs., also in the British Museum, is likewise concavo-convex, but is without holes: it is 7 inches long, $4\frac{1}{2}$ inches broad, and about 2 inches thick.

The fragment weighing 24 lbs. is similar to the last mentioned; it is $9\frac{3}{4}$ inches long, 6 inches broad, and 4 inches thick: it is to be preserved in the Geological Museum, Fremantle.

The remaining fragment weighing $17\frac{1}{2}$ lbs. has been presented to the Melbourne Museum, Victoria.

The specific gravity was determined from three small pieces of the larger fragment, freed from rust; the numbers obtained were 7.86, 7.85, and 7.72 respectively.

The large specimen was cut on the premises of the Museum by means of hack-saws, and was found to be so hard that three weeks were required for the severance of a fragment of which the cut face is not $2\frac{1}{2}$ inches square: a larger section of another meteoric iron (Nejed) was made in one-third of this time. The surface was next worked down with hard files of increasing fineness, and lastly polished with felt and emery powder.

On this face are seen numerous sections of enclosures, mostly tabular, of a yellowish metallic mineral which is strongly attracted by a magnet: this was found to be schreibersite (phosphide of iron and nickel): some of the enclosures are in parallelism, and parts, isolated on the surface of the iron, are lineally arranged: the edges of the plates are only approximately straight: starting from them, thin cracks containing Schreibersite traverse the surface of the section in irregular directions: one of the plates is an inch long and one-eighth of an inch thick.

No stony matter is visible on the polished surface.

Relative to copper sulphate the iron is almost immediately active.

After exposure to the action of bromine water or dilute nitric acid the section gives no definite figures, but assumes a damascene appearance, very like that of the Tucuman iron, and of some parts of that of Brazos: to the latter iron it is very similar in the proportion and distribution of the Schreibersite: the British Museum sections of the Arva and Sarepta irons are also, in parts, somewhat similar to it in their general characters.

On warming a fragment, weighing 7 grams, in dilute hydrochloric acid,

¹ Ibid. p. 161.

² *School of Mines Quarterly*, Vol. 7, No. 2, Jan. 1886.

the greater part dissolved, and there was left a small residue (56 milligrams) of yellowish metallic scales which are very strongly attracted by a magnet and contain phosphorus: they are doubtless Schreibersite, and identical with the enclosures visible on the polished surface.

None of the cubic crystals, described below, were present in this residue.

No sulphuretted hydrogen was detected in the gas evolved during the solution of the iron; this indicates the absence of troilite from the fragment under examination.

The sulphur precipitated on passing sulphuretted hydrogen into the solution was faintly brown: the colouration was found to be due to traces of copper, the constancy of which as an ingredient of meteoric iron has been insisted upon by Lawrence Smith.

Besides iron, only nickel, cobalt and magnesium, were found in the solution.

As the iron was too hard for its filings to be used as material for quantitative analysis, a large fragment, containing visible Schreibersite, was filed until free from rust: its weight was 8.8200 grams: its specific gravity, at 14°·5 C., relative to water at 4° and allowing for displaced air, was 7.851 (uncorrected 7.86).

The fragment was dissolved in aqua regia in a porcelain dish, and evaporated to dryness, on the water-bath: the residue was treated with strong hydrochloric acid, and again brought to dryness to expel the remaining traces of nitric acid: on warming with water containing some hydrochloric acid, it was found that there was a small insoluble residue, consisting wholly of minute bright opaque greyish-black cubic crystals with metallic lustre. The solution itself was poured into a weighed double filter,¹ and the crystals were washed by decantation, the washings being passed through the double filter: the filter showed no change of weight. The weight of the crystals was found to be 3.1 milligrams.

The filtrate was made up to 1,000 cc., and portions, 125 cc. each, were removed by means of pipettes.

In one portion sulphuric acid was sought for, but not a trace was found, indicating the absence of troilite from this fragment also.

Another portion was evaporated to dryness on the water-bath, and afterwards heated in an air-bath for three quarters of an hour, at a temperature of 140°—145° C.: no silica was obtained. The phosphoric acid in this portion was next concentrated in the manner recommended by

¹ *Original Researches*, by Lawrence Smith, 1884, p. 312.

Lawrence Smith, precipitated as phospho-molybdate,¹ dissolved in ammonia, and weighed as magnesium pyrophosphate.

From a third portion the iron was separated by a double precipitation with sodium acetate, redissolved in hydrochloric acid, and reprecipitated with ammonia.² After ignition it was reduced by heating in a current of hydrogen, and dissolved in dilute hydrochloric acid: in experiments on different portions variable minute quantities of silica were at this point obtained, and were derived probably from the re-agents.

The nickel and cobalt were separated from the magnesium by ammonium sulphide, and weighed together both in the oxidised and metallic condition: after solution of the nickel and cobalt the latter was precipitated by potassium nitrite, and weighed as potassium cobalt sulphate.

In this way the composition of the iron was found to be as follows:—

Iron	...	...	...	...	...	92.67
Nickel	...	...	...	...	...	6.46
Cobalt	...	...	...	...	...	0.55
Copper	...	...	...	...	...	trace
Magnesium	...	...	...	...	...	0.42
Phosphorus	...	...	...	...	...	0.24
Sulphur	...	...	...	...	...	none
Insoluble cubes	...	...	...	...	...	0.04

Total 100.38

If the phosphorus be assumed to be wholly present in combination with iron and nickel, as Schreibersite, with the formula $Fe_3 Ni P$ and percentage composition Iron 55.53, Nickel 29.09, Phosphorus 15.38, the above will correspond to:—

Nickel-iron	...	...	...	...	...	98.82
Schreibersite	...	...	...	...	...	1.56

100.38

As no opaque greyish-black mineral with a metallic lustre, and insoluble in aqua regia, is recognised as occurring in cubic crystals, the satisfactory determination of the nature of the insoluble residue of 3.1 milligrams was expected to be a matter of some difficulty: further, two fragments of the iron, weighing 7 grams and 2 grams respectively, had not yielded a single crystal, and there was thus a possibility of the crystals being so localised as to render impracticable an increase of the quantity of material available for experiment.

¹ *Amer. Jour. Sc.* 1882, Ser. 3, Vol. 23, p. 316.

² *Select Methods in Chemical Analysis*, by Crookes: 2nd edition, p. 517.

³ *Ibid.* p. 272.

The crystals were about a hundred in number, the average thickness of the larger ones being one-fourth of a millimeter (one-hundredth of an inch).

On all the crystals the faces of the cube are predominant: many are sharply defined simple cubes; some have their edges truncated by faces of the dodecahedron, as was proved by measurement on the goniometer; in others the edges are replaced by rounded faces of a tetrakis-hexahedron; or again, one or more of the cube-faces is replaced by a very obtuse, almost flat, square pyramid. One of the cubes shows re-entrant edges, suggesting a lamellar growth. A little group of three parallel crystals was observed.

One of the crystals having been dropped on to a thin layer of red sealing wax melted on a glass plate, was held sufficiently firmly by the cooled wax to allow of its hardness and streak being determined. The hardness is greater than that of rock-salt, and less than that of calcite: it may be expressed as 2.5. The streak on white unglazed porcelain is black and shining.

The crystals are not affected by a magnet.

Of four crystals, two sank to the bottom, and two floated near the surface of a solution of specific gravity 2.12.

The crystals remain unaltered when heated in a glass tube, closed at one end.

They are unattacked by nitro-hydrochloric, sulphuric, or hydrofluoric acids.

They float unaltered in beads of borax, microcosmic salt, or sodium carbonate, held in a blowpipe flame.

On dissolving in water a bead of sodium carbonate and potassium nitrate, in which three of the crystals had been heated, only one crystal was seen, and this was much reduced in size: the solution of the bead gave no evidence of the presence of chromium.

Similar beads, in each of which a crystal had been dissolved, were tested for phosphoric and silicic acids with negative results; nor did the solution of a bead in hydrochloric acid give any precipitate with ammonia, ammonium sulphide, ammonium carbonate, or sodium phosphate.

Heated in a combustion tube in a current of oxygen, hydrogen or chlorine, they are unattacked, even when the glass begins to melt.

Heated in a long narrow porcelain crucible in air or oxygen with the table-blowpipe they appear unaltered, but in a shallow uncovered platinum capsule or small porcelain crucible they slowly disappear, without flame: from the platinum capsule the disappearance was complete, but in the

porcelain crucible there was sometimes left an almost imperceptible black residue : projecting from this, in one instance, minute fibres were seen with the microscope.

Heated with potassium nitrate in a crucible over a Bunsen burner they are unattacked, but disappear very slowly, without deflagration, when heated with the table-blowpipe.

In density, colour and streak, and in its chemical behaviour, the residual mineral thus resembles native graphite, but it is considerably harder, and presents itself in well-defined crystals which belong, like the other crystallised form of carbon, the diamond, to the cubic system : terrestrial graphite, when crystallised, is found only as tabular crystals so indistinctly formed that doubt has long existed as to whether they should be referred to the hexagonal or monosymmetric system.

From other fragments of the iron, weighing altogether about 10 grams, thirty more of the cubic crystals were obtained.

Graphitic carbon, sometimes in large nodules, has been found concreted in several meteoric irons, and has been subjected to careful examination by Lawrence Smith :¹ in structure and powder it is not unlike the compact Borrowdale graphite, and differs completely both from the scaly graphite found native and from that which is presented by certain cast irons ; on the other hand, its conversion into graphitic acid by oxidising reagents is more rapid than that of any terrestrial native graphite experimented upon by him.

In a paper entitled " Graphite, pseudomorphous after Iron Pyrites," Haidinger,² in 1846, described some graphitic crystals which are doubtless identical in their general characters with those furnished by the Youndegin iron : his observation, however, has been forgotten, and is without record in modern meteoric literature. The crystals, of the size, number, and completeness of which Haidinger makes no mention, were obtained by him from a nodule of graphite which had dropped out of the Arva meteoric iron : impressed by the similarity in shape of the nodules of graphite and sulphide of iron present in this meteorite, and by the circumstance that the two minerals are occasionally lying side by side, Partsch conceived the idea that one was pseudomorphous after the other ; and Haidinger and Partsch became convinced of the correctness of this idea by the form of the graphitic crystals, on the cube-edges of which they believed there were faces of the pentagonal dodecahedron π {120}, so common a feature of the crystals of iron pyrites. Of the incorrectness of this explanation

¹ *Amer. Jour. Sc.* 1876, Ser. 3, Vol. 11. p. 388. ² *Pogg. Ann.* 1846, Vol. 67, p. 437.

of the graphitic crystals there can be no doubt: the presence of iron pyrites, crystallised or massive, has even yet not been established for any meteorite; the meteoric sulphide of iron being not the bisulphide but the protosulphide, and having since received from Haidinger himself the specific name of troilite (1863).

Nor is Haidinger's interpretation of the form of the Arva graphitic crystals beyond criticism, for Gustav Rose,¹ to whom the crystals had been kindly sent for inspection, expressed an opinion that the mode of replacement of the cube-edges was suggestive rather of holo-symmetry than of hemi-symmetry—an interpretation which would exclude iron pyrites as a possible antecedent mineral.

The Youndeggin graphitic crystals support the view entertained by Rose: the existence of the dodecahedron-face, of which there is goniometrical proof, is of itself quite sufficient to show that the crystalline form is distinct from that of iron pyrites. The iron pyrites theory being abandoned, and the fact being recognised that no mineral constituent of meteorites has yet been found which crystallises in forms similar to those of the graphitic crystals, there naturally arises a feeling of doubt as to the correctness of the view according to which they are of pseudomorphic origin, and a question as to whether they do not represent a third allotropic condition of crystallised carbon: it is conceivable, in fact, that the explanation by pseudomorphism really resulted from the supposed similarity of the form of the crystals to that of iron pyrites.

Bischof² denies the possibility of explaining the pseudomorphism of terrestrial minerals by any other process than the slow action of water, of which there is no evidence in meteorites; and though it would be unsafe to argue that only in this way could meteoric pseudomorphs be produced, there is sufficient difficulty in accounting for the occurrence of pseudomorphs in the interior of a mass of iron to compel us to demand strong evidence before the pseudomorphism of the graphitic crystals is granted, more especially when we have regard to the fact that no other graphitic pseudomorph has yet been established either in meteoric or in terrestrial minerals.

The Youndeggin crystals were accordingly examined under the microscope with a quarter-inch objective. One of the dodecahedron-faces, an elongated hexagon in shape, showed ridges symmetrical to the truncated edge of the cube, and parallel to the two short edges of the hexagon which meet in

¹ *Beschreibung und Eintheilung der Meteoriten*, 1864, p. 40. *Pogg. Ann.*, 1873, Vol. 148, p. 516.

² *Chemical and Physical Geology*, 1854, Vol. I. p. 33.

one of the trigonal quoins. From the faces of several of the crystals spring acutely conical, almost acicular, projections of the same material, more or less irregular in shape: sometimes there is an approximately spherical growth covering a greater part of a cube-face, and occasionally one of the spherical growths is broken, and is seen to be merely a thin, now empty, shell, of which the bottom is the face of the cube: in shape this is suggestive of a burst bubble. One specimen was apparently a fragment of a hollow cube.

The crystals are easily frangible; one of them, when gently pressed between a glass plate and a sheet of paper, was flattened out and was split parallel to the edges of one of the cube-faces, as if the crystal had been hollow and had collapsed. Examined under the microscope, one of the thin fragments was found to consist of several distinct layers parallel to a cube-face, and on its interior surface was seen a bright triangular face in the zone of a cube-edge: another thin square fragment, doubtless a face of the original cube, has a granulated internal surface, and its edges are bent at right angles to its plane, as if it had formed a portion of a shell. The powder of this crystal was scaly, and gave a scarcely visible streak on the paper. Three other crystals were found to be solid. No cleavage surfaces were visible on the fragments.

The crystals appear to be quite homogeneous in their material.

Although some of these characters point, more or less distinctly, to a pseudomorphic origin of the crystalline form, it cannot be said that they suffice to establish it. The easy frangibility, the absence of evidence of cleavage, the hollowness, and the occasionally crust-like structure, though such as are common in pseudomorphic minerals, are not incompatible with the idiomorphism of these crystals: hollow and skeletal forms, indeed, are frequently a result of a hurried crystallisation, as is so well seen in the artificial crystals of bismuth and of sodium chloride. On the other hand, while the hardness indicates a difference of the material from native graphite, the sharpness, separateness and completeness of the crystals, the brightness of the faces, the delicacy of the acicular projections, and especially of the obtuse, almost flat, square pyramids on some of the faces, are sufficient to prove that the form has never had any other than its present tenant, and that we have here an allotropic condition of crystallised carbon distinct from both diamond and graphite. And we may add that both of the recognised crystallised forms of carbon have long been standing difficulties for the crystallographer: as already pointed out, crystals of graphite are rarely more than mere tables of which there is a controversy as to the crystalline system, and those of the diamond are so different in their geome-

trical characters from the crystals of every other known substance that it cannot be satisfactorily determined whether they are to be referred to a holo-symmetric or to a hemi-symmetric type.

If it had been conceivable that the above characters, and the occurrence in the interior of meteoric iron, are compatible with a change in the material since the first development of the crystalline form, it would have been more easy to imagine that the change has been one of molecular re-arrangement than of substitution, and that the crystals were originally cubes of diamond. In fact, the diamond, when in cubes, has faces not very unlike those of the Youndegin crystals, and shows usually a similar bevelling of its edges by rounded faces of tetrakis-hexahedra. Or, again, it might be argued that during a hurried crystallisation of the carbon, the circumstances, though initially favourable to the formation of diamond, had finally only permitted of the existence of the carbon in a graphitic form.

The nature of the faces, the obtuse pyramid, the spherical growths, the acicular projections, and the parallel groups, are different, however, from anything ever met with in the diamond.

On examination of a large nodule of graphite from the Cocks (or Sevier) county iron, now in the British Museum collection, distinct graphitic crystals, cubo-octohedral in form, were found to be present.

As this kind of crystallised graphitic carbon is unknown among terrestrial minerals, and has so important a bearing on the formation of meteoric graphite, it may conveniently receive a distinctive name, and I therefore suggest the term *Cliftonite*—after Mr. R. B. Clifton, M.A., F.R.S., Professor of Physics at Oxford, who has long interested himself in the physical characters of minerals, and has given great encouragement to their study.
