COMMUNICATIONS FROM THE OXFORD MINERALOGICAL LABORATORY. No. XVII.

On the structure and composition of the Chandakapur meteoric stone.

(*With Plates IX and X.*)

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[Read November 17, 1908.]

Introduction. (H. L. B.)

AMONG the chief treasures of the University Museum is a large piece of the meteoric stone which fell at or near Chandakapur in the valley of Berar, India, on June 6, 1838. The specimen has been for many years in the collection, but there seems to be no record of its acquisition or previous history. The weight was formerly 3329·5 grams,[1] but the stone was cut in two in 1899 and a portion exchanged with the late Mr. J. R. Gregory for a number of representative specimens of meteorites. A series of five thin sections were prepared at the same time, and about five grams of fragments remained, which have been used for the analysis described below. About 100 grams were lost in the cutting and preparation of sections, and 1385 grams were sent to Mr. Gregory. The weight of the piece now remaining at Oxford is 1839 grams.

With a specimen of the meteorite sent to H. J. Brooke by G. B. Sowerby in 1843, and now in the Cambridge Mineralogical Museum, is a letter from Sowerby enclosing a copy of one from Lady Elizabeth Harvey which quotes the following account of the fall, sent to her with two of the stones, therein called Nos. 1 and 2, by Colonel H. Smith, apparently about 1840.[2]

'At twelve o'clock at noon on the 6th of June, 1838, three meteorolites were discharged from the heavens with a loud explosion, the sky being cloudless and the atmosphere serene and calm at the time. They fell

[1] Owing to a clerical error this appears in Wülfing's Catalogue ('Die Meteoriten in Sammlungen,' 1896) as 6329 grams.

[2] Copies of this account, with slight differences in the weight of No. 3 (7 lb. 7 oz. according to the Edinburgh copy) and in the spelling of names, have been found with the specimens at Oxford and Edinburgh (see below, p. 351).

simultaneously at the undermentioned villages[1] in the valley of Berar, situated Lat. 21° 45′, Long. 77° 20′ E.

[Grams.]

'At Chandakapoor, Pergunna Akoat, No. 1, weighing 11 lb. 3 oz.' [5074]

'At Burguon, Pergunna Burnaira Jemgge,
No. 2, weight 1 lb. 3½ oz.' [552][2]

'At Denulgaon Pergunna Puning Makagaon,
No. 3, weight 7 lb. 7½ oz.' [3342]

[8968][2]

'The third stone I saw but could not procure. It smelt strongly of sulphur. The villages were about a mile distant from each other, and the stones fell in a straight line.

'H. Smith, Brigadier
'Commanding at Ellidpoor'. [i.e. Ellichpoor]

If it may be assumed that this is a complete list of the stones known from this fall—and there appears to be no evidence to the contrary—it is possible to trace with some degree of certainty the subsequent history of the principal fragments.

The Royal Scottish Museum at Edinburgh contains a specimen labelled 'Chandakapoor' and weighing 2935 grams, and the label states that 'the original mass weighed 11 lb. 3 oz.' This specimen can therefore hardly be other than a portion of the stone No. 1, mentioned by Colonel Smith. It shows a surface covered with crust, a fractured surface, and a (probably more recent) wheel-cut surface.

In the same collection is also another stone, of 698 grams, labelled 'Burgaon 6th June, 1838, 1 lb. 8½ oz.', and accompanied by a copy of the letter from Colonel Smith quoted above. This, although the letter (as copied) speaks of 1 lb. 3½ oz., must clearly be No. 2. It is unbroken and entirely covered with crust, except at one or two points, where it has been chipped.[3]

It is unfortunately not now possible to ascertain how or when either

[1] The names of the villages are variously spelled in the other copies, as Akout, Akoat; Burgaon, Bargeon; Burnaira, Barnaire Jacqgu (?); Deursulgaon, Drunlgar. 'Ellidpoor' should doubtless be Ellichpoor (as in the Edinburgh copy).

[2] If, as seems probable, No. 2 is identical with the smaller of the two specimens at Edinburgh, its weight should be 698 grams, making the total weight of the fall about 9114 grams.

[3] The weight given in Professor Wülfing's table (loc. cit.) for the Edinburgh specimens appears to be traceable to some error in the weighing of the larger stone or in the conversion of its weight into grams.

of these specimens came into the Edinburgh Collection, but there is evidence that they were both there, together with another fragment of the same mass as No. 1, weighing $4\frac{1}{4}$ oz. (or about 120 grams), which cannot now be traced, in 1861; for they are mentioned in a list of meteorites made in that year by the Assistant Conservator of the Museum, Mr. J. B. Davies. The weight of the large piece of No. 1 is there given as 6 lb. $7\frac{3}{4}$ oz., or about 2941 grams.

The greater part of No. 1 having been traced to Edinburgh, the Oxford stone must be identical with No. 3, as would seem probable also from a comparison of the weights. All the fragments existing in other collections (amounting in 1893 to 1765 grams, according to Wülfing) must, consequently, have been portions of No. 1.

Since a piece of the stone (weighing 32·4 grams and now preserved at Cambridge) appears from the letter mentioned above to have been sent to Brooke by Sowerby in 1843, and since two fragments now in the British Museum, weighing 521 and 239 grams, were bought from Sowerby in 1843 and 1844 respectively, it follows that No. 1 must have been broken or cut soon after its arrival in England, and that at least a portion of it passed into Sowerby's possession from Lady Harvey, probably in 1843. Buchner[1] indeed states that Sowerby possessed a stone weighing 4200 grams, and this, if correct, would indicate that the large Edinburgh specimen must also have been obtained from him.

I have ascertained that fragments of the meteorite exist at the present time in the following collections:—

	Grams.
Budapest (42, 6, 0·8)	48·8
Calcutta (33·8, 19·8, 15·6, 0·7[2])	69·9
Cambridge (32·3, 1·9)	34·2
Edinburgh (Chandakapur 2935, Burgaon 698) ...	3633
London (B. M.) (521, 239, and three fragments) ...	764
„ (M. P. G.) (163·8, 3·5)	167·3
New Haven (41)	41
Oxford (1839)	1839
Tübingen (197, 8·9[3])	205·9
Vienna (1318, 98, 7)	1423
Ward-Coonley Collection (68, 23)	91
	8317·1

[1] O. Buchner, 'Die Meteoriten in Sammlungen,' Leipzig, 1863, p. 60.

[2] The small fragment has since been presented to the Oxford Museum, (1909).

[3] This fragment is said by Professor Wülfing to belong to the group Cia and not to be really Chandakapur. See, however, p. 354.

Of these, the larger of the two specimens in the Museum of Practical Geology in London and of those at Tübingen, are stated on the labels to be from a mass weighing 11 lb. 3 oz. The former was at one time in the collection of W. Nevill, and is mentioned in the catalogue of that collection, printed in 1877.

The portion of the Oxford stone cut off in 1899 passed into the hands of Mr. Julius Böhm, and a piece weighing 1318 grams is now in the Hof Museum at Vienna.

Since the Oxford specimen seems to have represented the whole of the mass which fell at Denulgaon (No. 3), the presence on it of a large fractured surface, showing no traces of fusion, points to its having originally formed part of a larger mass which split during its fall when at no great height from the ground. The Edinburgh portion of No. 1 also shows fractured surfaces but it is not possible to say if it is a part of the same mass.

Physical Characters of the Stone. (H. L. B.)

Form, Crust, and Macroscopic Characters.

Before being divided, the Oxford specimen had the form of a flattish block, of roughly rhombic outline, about $13 \times 12 \times 6$ cm. (see Plate IX, fig. 1).[1] Except on the large face at the back, which was a clean fracture, the whole stone was bounded by a natural external surface showing characteristic shallow pits and covered with a thin, dull, brownish crust. This latter is slightly rough, but shows no distinct lines of flow which might indicate the direction of flight of the stone.

The specimen was cut along a horizontal plane through AA, and the upper portion remains at Oxford.

On a recent fracture (probably dating from 1899), the stone appears compact, and of a grey colour with a few rusty specks and minute spangles of nickel-iron, and here and there a glittering crystal of olivine. On an older broken surface it is brownish-grey, with more numerous spots and general rusting. On the cut surface (1899) the colour and rusting are similar to those of the older fracture, and numerous chondrules (up to 6 mm. diameter, but usually much less) are visible. They are roundish, ovoid, or somewhat irregular, and mostly of a lighter colour (grey) than their surroundings. On the fractured surface the chondrules do not project or leave hollow casts, as in the group of

[1] A cast of the specimen is kept in the Museum.

'Kügelchenchondrite' of Tschermak, but break with the matrix, and are not very conspicuous on the rough surface.

The larger of the Edinburgh specimens shows three fairly flat, crusted surfaces, meeting in an obtuse corner, the longest edge being about 11 cm. in length. The back of the specimen is irregular, broken and somewhat splintered, except at one corner, where a piece (probably wedge-shaped) has been cut off, leaving a smooth surface of pear-shaped outline, about 14×9 cm. The fractured surface is greyish, with rusty spots, but without visible chondrules. On the smooth cut surface the iron grains are bright and the matrix of a darker mottled grey. The crust is thin, brownish and dull, slightly reticulated in some places, in others slightly rippled with streaming-marks.

The smaller specimen is of a somewhat flattened pear-shape, and is covered with a blackish crust. Its dimensions are about $11 \times 9 \times 5$ cm.

Of the two specimens in the British Museum, the smaller shows a flat polished surface, and is brownish-grey, with a streak of bluish-grey colour running through it. Numerous small chondrules are visible on the polished surface (especially on the bluer part), with grains of iron, one of which is embedded in a larger grain of brassy troilite. The larger specimen also shows some bluish patches and streaks in a grey mass. Its surface is partly covered by a slightly rough, brownish crust. Both the stones show traces of thin black veins on their fractured surfaces.

The Chandakapur stone is classed by Brezina[1] in the group of 'Breccia-like Intermediate Chondrites' (Cib) of Tschermak's classification.

The differently coloured patches in the specimens in the British Museum may perhaps point to the existence of a 'breccia-like' structure in the parent mass, so that these fragments might probably be classed as Cib, or from the presence of veins as Cia; but there is no indication of such a structure in the Oxford or Edinburgh specimens, and the Oxford stone at least (and probably the other also) should rather be classed with the 'Intermediate Chondrites' (Ci).

Assuming that the specimens in the British Museum are correctly named, there appears to be considerable variation in the structure of different stones from this fall, and even in different fragments of the same stone (No. 1).

The specific gravity was given by Greg[2] as 3·53: it has not been re-determined.

[1] A. Brezina, 'Die Meteoritensammlung des k.k. Hofmuseums am 1. Mai 1895.' (Ann. des k.k. Naturhist. Hofmuseums, 1896, vol. x, p. 248.)

[2] R. P. Greg, Phil. Mag., 1854, ser. 4, vol. viii, p. 460.

Microscopic Characters.

An examination of the sections under the microscope shows that by far the most important constituents are olivine and minerals of the pyroxene group. There are also present specks of nickel-iron, some other opaque materials (including rust and possibly some glass), and a few minute grains, probably representing felspar. Well-formed chondrules are numerous and show a remarkable variety of form and structure. They are mostly round or ovoid, usually with a diameter of 0·8 to 1·2 mm., while some few are irregular and probably fragmentary. Some are sharply bounded by an opaque border of iron, more or less rusted, while others shade off into the surrounding matrix. They mostly contain olivine or pyroxene in various forms, or a mixture of both, often with some included glass. The matrix is granular, of varying coarseness, and consists of irregular fragments of the same materials as the chondrules, usually of smaller size, though large fragments also occur. In some places it is hard to say whether a certain area represents chondrule or matrix. Except where the section is stained with iron, there is a prevailing absence of colour, all the transparent minerals being colourless, while only the matrix of some of the porphyritic chondrules and a few semi-opaque radial-fibrous chondrules are grey or brownish.

The Constituent Minerals.

The olivine occurs in grains and well-formed crystals, as well as forming monosomatic chondrules, and shows uniform extinction and the usual bright interference-colours.

Of the minerals identified as pyroxene there appear to be several varieties present. They are all colourless and show high relief, but they differ in their birefringent properties. The following may be distinguished:—

(α) Oblong crystals and grains, somewhat fibrous, with a longitudinal cleavage and traces of transverse cracks, showing uniform straight extinction and low interference-colours (grey or sometimes yellow), and compensated by a quartz-wedge[1] inserted transversely. These are typical rhombic pyroxene.

(β) Similar crystals and grains, showing imperfect, patchy extinction (approximately straight) and compensation as above.

(γ) Similar crystals and grains, showing a more or less regular lamellated structure and resembling a plagioclase-felspar, but for the

[1] i. e. one cut with its length parallel to the principal axis of the crystal.

high relief. One crystal, which appears to be cut nearly at right angles to the plane of the lamellae, gives on two adjacent lamellae extinction-angles of $31\frac{1}{2}°$ and $34\frac{1}{2}°$ on either side of the junction.

From their general similarity in appearance and the existence of intermediate forms, it may be inferred that these all represent varieties of the same mineral. The apparently uniform crystals (*a*) would then be really compound, but with a finer twin-lamellation than the others. This material probably constitutes the bulk of the silicate unattacked by hydrochloric acid, and according to the analysis (p. 372) will have the composition of a bronzite [1] poor in iron.

In this connexion we may recall the observation, by Fouqué and Michel Lévy, of the occurrence of a monoclinic magnesium-pyroxene with twin-lamellation resembling that of a plagioclase, in the meteorites of Rittersgrün and Sarbanovac,[2] and in the products of the experiments of Ebelmen [3] and Meunier [4] on the artificial reproduction of meteorites.

If the above explanation is correct, the material affords a confirmation of the view held by Groth as to the pseudosymmetric character of the 'rhombic pyroxenes'.

There are also a few fibrous fragments and grains showing higher interference-colours and a large extinction-angle, which may probably represent a monoclinic pyroxene of the ordinary type (e. g. C in fig. 5).

Here and there in the ground-mass, lying among and sometimes enclosing grains of bronzite, may be seen small, colourless particles with weak birefringence and no visible relief. They show traces of a biaxial interference-figure, and are probably felspar, though there is no indication of twinning or of cleavage.

The Chondrules.

Some of the principal types of chondrules are shown in Plates IX and X, figs. 2–11.

The commonest are polysomatic olivine chondrules with either granular or porphyritic structure, the latter often showing very well-formed crystals embedded in a compact, brownish glass. The crystals are usually rhombic or six-sided in outline, and then lie irregularly in the chondrule (figs. 2 and 3), but they are not uncommonly elongated and

[1] i. e. if this term be used for rhombic pyroxenes with 5 to 15 per cent. of FeO (cf. E. Cohen, 'Meteoritenkunde,' 1894, Part i, p. 282).

[2] F. Fouqué and A. Michel Lévy, Bull. Soc. Min. de France, 1881, vol. iv, p. 280; see also E. Cohen, loc. cit., p. 300.

[3] Ebelmen, Ann. Chim. Phys., 1851, ser. 3, vol. xxxiii, p. 58.

[4] S. Meunier, Compt. Rend. Acad. Sci. Paris, 1880, vol. xc, p. 349.

tend to lie in parallel positions (fig. 4), thus showing a transition to the monosomatic chondrules enclosing parallel layers of glass (somewhat similar to those which have been described by Tschermak[1]) which occasionally occur here (fig. 5, cf. also fig. 6).

Almost equally common are chondrules consisting of large prismatic crystals of pyroxene of types α, β, γ, either alone (as A, in fig. 7), or with some crystals or grains of olivine (as B, in fig. 7).

Round chondrules, with eccentric-fibrous structure, are not uncommon (figs. 9 and 10). The fibres show straight extinction and transverse compensation, with low colours, and are probably bronzite. The fibres may radiate from one or from several centres. One such chondrule shows a circular outline with a smooth concavity on one side (fig. 10). The regular arrangement of the fibres, which radiate from a point slightly outside the limits of the chondrule, is in no way disturbed by the latter. The chondrule was probably formed in contact with another somewhat larger one, of which, however, no trace remains. A small indentation of the same kind may be seen in B, fig. 9.

Certain bronzite chondrules, usually of roughly oval or irregular form, show a peculiar grating-like structure (A, in fig. 9), due to the inclusion of layers of glass in a large crystal in definite directions. The chondrule shown in the figure appears at first to be monosomatic, but compensation with the quartz-wedge shows that it consists of two crystals with parallel extinction, but with their principal vibration-directions crossed, each portion being compensated on insertion of the wedge at right angles to the layers of glass. The latter appear to be parallel to a (100), while the section is roughly parallel to c (001).

Several examples of monosomatic olivine chondrules are present, of the remarkable type, with a circular nucleus containing regularly arranged glass inclusions, observed by Tschermak[2] in the meteorites of Tieschitz, Mezö-Madaras, and Alfianello. The most striking of these is shown in fig. 6. The border is optically continuous with the nucleus, the whole showing practically uniform extinction, and cleavage-cracks may be traced from the border into the nucleus. The latter consists of a more or less regular intergrowth of olivine with granular, brownish, isotropic glass, resembling graphic granite; while the border is free from glass but contains numerous irregular grains of nickel-iron and other opaque materials (rust?). The chondrule shows no definite outline, but spreads

[1] G. Tschermak, 'Die mikroskopische Beschaffenheit der Meteoriten,' (Stuttgart, 1883–1885), Plate viii, fig. 4; x, 2; xi, 2.

[2] G. Tschermak, loc. cit.

out irregularly into the surrounding matrix in a way which strongly suggests that it has grown *in situ*, possibly before the solidification of the matrix.

Another bordered chondrule, with more regular platy inclusions in its nucleus, is shown in fig. 5. Here, however, a portion of the border is granular and the outline is sharply defined by a thin shell of rust (?).

A few chondrules, such as C in fig. 9, consist of lamellae showing alternately colours of high and low order, which appear to represent an intergrowth of two pyroxenes.

An angular fragment of compact fibrous material (probably bronzite), is grey and semi-opaque with fine dusty inclusions, but has a pale yellowish border, free from inclusions, completely surrounding it (A, fig. 11).

One granular olivine chondrule, seen at the edge of fig. 11, is surrounded by a triple border consisting of three concentric layers of black, opaque inclusions lying in a finely granular material.

Chemical Analysis. (H. E. C.)

I. *Experimental Work.*

Principles of the Method Employed.

§ 1. For the determination of the proportions and composition of the nickel-iron and various constituent minerals present in the meteorite, the methods adopted by Mr. L. Fletcher[1] in the analysis of the Zomba and Makariwa meteoric stones have been applied in the present work. Briefly these are—

(i) A preliminary separation of the magnetic material from the dry powder by means of a magnet, and the extraction of the metallic constituents from the two portions so obtained, by the prolonged action of a solution containing mercuric chloride, in an atmosphere freed from oxygen (§§ 3–5).

(ii) The reduction of rust, magnetite, sulphides, and phosphides to the metallic state by ignition in hydrogen, and extraction of the resulting metals with mercuric solution (§ 15).

(iii) The separation of the silicates into two portions, by treatment with hydrochloric acid under conditions favourable to the attack of olivine but not of pyroxene or felspar (§ 18).

[1] L. Fletcher, Mineralogical Magazine, 1901, vol. xiii, p. 1; 1894, vol. x, p. 287.

(iv) The analysis of the resulting fractions (§§ 6–14, 16–17, 19–20) and the estimation of alkalis and of sulphur and phosphorus (§§ 22, 24) by the usual analytical methods.

The Material.

§ 2. The material used for the analysis consisted of seven small fragments, weighing together rather less than 5 grams, which were obtained during the slicing of the Oxford specimen in 1899. Four showed fused crust on some part of their surface, and all were superficially rusted. The largest fragment weighed, after removal of crust, 1·3375 grams. This and two other portions were scraped clean, and weighed 2·0210 grams before crushing.

Magnetic Separation.

§ 3. The fragments were first crushed in a covered agate mortar, and the stony portion finely powdered, after removal of the nickel-iron and other magnetic minerals with a magnetized knife-blade, care being taken to avoid loss of powder and splinters during the operations. The portion attracted by the magnet weighed 0·2843 gram, the portion unattracted 1·7341 grams[1], making 2·0184 grams in all (sample A) The amount lost during powdering and magnetic separation was, therefore, 0·0026 gram.

The 'attracted' portion, representing for the most part nickel-iron, schreibersite, and perhaps troilite,[2] was by no means free from silicates, while it was anticipated that the material left after the magnetic separation would still contain finely divided magnetic minerals entangled among the non-magnetic particles. In order to determine the amount of nickel-iron present, and also to effect as complete a separation as possible of the metallic from the non-metallic constituents of the stone, it was therefore necessary to treat both the attracted and the unattracted portions with mercuric solution.

[1] Referred to as 'the attracted portion' and 'the unattracted portion', respectively.

[2] Some authors have stated that two varieties of iron sulphide occur in meteorites, of which one is magnetic and regarded as identical with terrestrial pyrrhotite (Fe_nS_{n+1}), while the other is non-magnetic, or only feebly magnetic, and has been assumed to consist of monosulphide (FeS). In the present paper, the name troilite is used for iron sulphide in general, without regard to its magnetic or non-magnetic character.

Dissolution of Free Metals by means of a Mercuric Solution.

The Mercuric Solution.

§ 4. Iron, nickel, cobalt, and copper all dissolve readily in solutions of mercuric chloride, metallic mercury being precipitated, and, in the case of iron, mercurous chloride also, owing to the partial oxidation of ferrous to ferric chloride at the expense of the mercuric salt. If the operation be carried out in air a scum of yellow basic iron chloride rapidly forms, and in order to keep all the iron in solution it is convenient to allow the action to proceed in an atmosphere of hydrogen.

Mercuric chloride, however, except in dilute solution, has an appreciable action upon troilite. Indeed the latter may be completely dissolved by prolonged heating on the water-bath with an aqueous solution of mercuric chloride. The same reagent also attacks olivinic silicates to some extent, the action being doubtless in both cases attributable to acid formed by hydrolysis of the salt. The acidity may be reduced by the introduction of chlorine ions, as, for example, by the addition of a neutral soluble chloride, such as ammonium chloride. Thus cold solutions of the double salt $HgCl_2 \cdot 2NH_4Cl \cdot 2H_2O$ react neutral and do not attack silicates, troilite, or schreibersite. Friedheim,[1] Fletcher,[2] Tassin,[3] and others, have used this salt with success, 12 grams being dissolved in one litre; and this concentration has been adopted for the present work. In practice, 7·8 grams of mercuric chloride were dissolved with 3·1 grams of ammonium chloride in air-free water, and the solution made up to one litre.

The Extraction.

§ 5. The 'attracted' and 'unattracted' portions were transferred to separate Jena glass flasks and known volumes of the reagent added. The air in the flasks was then displaced by a current of hydrogen, and the gas passed at a convenient rate through the solutions, which were frequently shaken. After a time the precipitates were allowed to settle, the solutions decanted off through filters, and fresh mercuric solution added as before. The filter-papers were rapidly washed with a stream of diluted mercuric solution, and each filtrate at once acidified with hydrochloric acid. As it was proposed to investigate the process of solution of the nickel-iron alloys, the several extracts were analysed separately.

[1] C. Friedheim, Sitzungsber. Akad. Wiss. Berlin, 1888, p. 345.

[2] L. Fletcher, loc. cit. (vol. x, pp. 288, 293).

[3] W. Tassin and G. P. Merrill, Proc. United States National Museum, 1907, vol. xxxii, p. 241.

The results showed that both 'unattracted' and 'attracted' portions were at first materially attacked. The former, however, gave a negligibly small yield of iron after five extractions, occupying one week in all and requiring 450 c.c. of the reagent; while the 'attracted' material required eight extractions, extending over about seven weeks, 550 c.c. of the mercuric solution being used.

Analysis of the Extracts.

Method of Precipitation.

§ 6. The acidified extracts were separately treated with hydrogen sulphide, and the resulting black precipitates examined for non-volatile material by gentle ignition. In all cases a minute residue remained, but it was soon apparent that the mass of this bore no relation either to the volume of the reagent used or to the length of time allowed for an extraction.

§ 7. The filtrates were severally reduced in bulk by evaporation on the water-bath, and oxidized by addition of a little nitric acid. For the separation of iron from nickel and traces of cobalt, the method of repeated precipitation with ammonia in presence of ammonium chloride has been used, as recommended by von Baumhauer.[1]

The oxidized filtrates were heated to boiling and about 0·5 gram of solid ammonium chloride added; then ammonia until the liquid was distinctly alkaline. The mixture was boiled for ten minutes and allowed to stand overnight. The supernatant liquid was then decanted off, the precipitate washed with hot water, dissolved in hydrochloric acid, and after addition of a little ammonium chloride re-precipitated with ammonia. The process was repeated for the third time, as before, the mixture being boiled for a considerable time, with addition of ammonium chloride, before filtering. The precipitate on the paper was then washed until free from chloride. This procedure is believed to afford a satisfactory separation of iron from nickel,[2] and was followed in every precipitation of ferric hydroxide.

§ 8. The filtrates were evaporated down and cooled, and after addition of ammonia were saturated with hydrogen sulphide. The liquids were

[1] E. H. von Baumhauer, Arch. Néerland. Sci., 1871, vol. vi, p. 46.

[2] A test-experiment was made with approximately equal weights of ferrous-ammonium and nickel-ammonium sulphates; after a threefold precipitation of the iron with ammonia as above, the solution showed no trace of iron on being tested with potassium thiocyanate, while the precipitate contained no determinable amount of nickel hydroxide.

then allowed to stand[1] in the cold until the sulphides settled in filterable form; the precipitates were filtered off, and the filtrates neutralized with acetic acid and treated with hydrogen sulphide in order to remove traces of nickel dissolved by the ammonium sulphide. In general, two precipitations are necessary and sufficient, as may be shown by the failure of the Pozzi-Escot molybdate test for nickel[2] at that stage in a test-experiment with nickel-ammonium sulphate.

The precipitates were dissolved and the nickel and cobalt reprecipitated with potassium hypobromite and weighed as (NiO + CoO). The sulphide-precipitate was found to be free from manganese and zinc.

§ 9. In order to determine whether the mercuric solution had attacked the silicate to a measurable extent, the solutions, when freed from nickel and cobalt, were tested in the usual manner for calcium and magnesium. The lime obtained from all the extracts amounted only to 0·0010 gram, the magnesia to 0·0008 gram. An independent analysis of the solution obtained by boiling the 'unattracted' portion with water in a platinum dish, further proved the very small solubility of the calcium and magnesium minerals in water.[3]

Estimation of Iron, etc., in the Extracts.

§ 10. The sesquioxide-precipitates from all the extracts weighed 0·1512 gram, the nickel and cobalt oxides 0·0288 gram. The former were brought into soluble form by fusion with potassium bisulphate, and the iron determined, after reduction to the ferrous state, by titration with acid permanganate in the usual manner. The results indicated 0·1053 gram of metallic iron, corresponding to 0·1504 Fe_2O_3. It follows that the extracts with mercuric solution were free from chromium and aluminium.

Thus the composition of the metallic portion of the stone, expressed in percentages of the total material, is:—

Fe	... ...	5·25 per cent.
(Ni,Co)	... ...	0·55 „
Cu	... ...	trace.

[1] The precipitation of nickel sulphide by means of colourless ammonium sulphide is a time-reaction, which is apparently accelerated by light. Possibly the rate of precipitation may depend upon the rate of formation of ammonium polysulphides.

[2] M. E. Pozzi-Escot, Compt. Rend. Acad. Sci. Paris, 1907, vol. cxlv, p. 435.

[3] 0·1667 gram of the powder was treated with 50 c.c. distilled water and evaporated to dryness on the water-bath. After repeating the process four times,

Results of the analysis of the successive extracts.

§ 11. The several non-volatile residues, left after removal of the mercury (§ 6), weighed altogether 0·0087 gram, of which 0·0038 gram came from the extracts of the 'attracted', and 0·0049 gram from those of the 'unattracted' portion.

The residues gave with hydrochloric acid a yellow solution consisting of ferric chloride with some slight traces of copper chloride. In estimating the iron obtained in solution at each extraction, that carried down in this way with the mercuric sulphide has therefore been included.

§ 12. The following tables show the amounts of iron and nickel removed by successive extractions. In the last column is given the ratio Ni : (Fe + Ni).

No. of extraction.	Period.	Mercuric solution used c.c.	Fe grams.	Ni grams.	Ni : (Fe + Ni) per cent.
		'Attracted' Portion.			
1.	3·5 hours	100	0·0563	0·0072	11·3
2.	16 ,,	50	0·0259	0·0041	13·6
3.	15 ,,	100	0·0082	0·0020	20·0
6.	7 days	50	0·0030	0·0013	30·2
7.	20 ,,	100	0·0015	0·0008	34·8
		'Unattracted' Portion.			
1.	3·5 hours	150	0·0049	0·0026	34·6
2.	16 ,,	100	0·0013	0·0007	35·0
3.	30 ,,	50	0·0012	0·0008	40·0
4.	96 ,,	100	0·0022	0·0017	43·6

In the 4th, 5th, and 8th extracts of the 'attracted,' and the 5th of the 'unattracted' portion, the amount of NiO never exceeded 0·0005 gram.

§ 13. The fact observed by Mr. Fletcher in the case of Zomba and Makariwa, that the proportion of nickel to iron increases as the extraction proceeds, is borne out by these results with Chandakapur; and it is further interesting to note that the proportion of Ni : (Fe + Ni) in the last extract of the attracted portion is 34·8 per cent., or almost as

the solution gave, on analysis in Jena glass vessels, 0·0008 gram CaO and 0·0017 gram $Mg_2P_2O_7$.

Mr. Fletcher found the soluble material of the Zomba stone to consist principally of calcium sulphate. It is interesting therefore to note that Chandakapur contains practically no soluble calcium salt, and that the aqueous extract contains no sulphate. The dissolved material consists for the most part of sodium carbonate.

high as that in the alloy common to Zomba and Youndegin,[1] which contains about 38·5 per cent. of nickel. The 'unattracted' material furnishes a still higher percentage of nickel, the first extract representing an alloy as rich in this metal as the last of the 'attracted' extracts. The alloy represented by the fourth extract of the 'unattracted' portion of Chandakapur would contain 43·6 per cent. of nickel, the highest value yet observed in a meteoric stone.[2]

§ 14. These results are perhaps not so surprising when the following points are considered:—

(i) The alloys of iron and nickel become more brittle and less malleable as the proportion of nickel increases. An alloy rich in nickel is thus more likely to be reduced to a fine state of division during crushing than one richer in iron, and it is the smaller magnetic particles which escape separation during treatment with the magnet.

(ii) The alloys rich in nickel are less magnetic than those richer in iron. This is a further reason for the appearance of the nickel-rich metal in the 'unattracted' portion.

(iii) The rate of solution of nickel-iron alloys in solvents of both metals is greater for alloys poor in nickel than for those rich in nickel.

Some experiments have shown that when iron and nickel form a galvanic couple in mercuric-ammonium chloride, only the iron passes into solution, the nickel receiving a protective layer of mercury and mercurous chloride. If compounds of iron and nickel, and mixed crystals of these elements, also dissolve the more readily in mercuric solution the higher their content of iron, the proportion of nickel in the metallic material still unattacked, and hence in the material passing into solution, should be found to increase as the extractions proceed.

(iv) Supposing oxidation to occur during extraction and filtration, the iron will be affected by it more than the nickel. The material thus left in the metallic state will be richer in nickel than before, and this will be shown by an ever increasing proportion of nickel, as compared with iron, in the extracts. The fact that Chandakapur is a rusted stone renders it difficult to decide to what extent the iron may have become oxidized during the analytical operations. This, however, could readily be determined in the case of a meteorite free from rust when mercuric extraction was commenced.[3]

[1] L. Fletcher, Mineralogical Magazine, 1908, vol. xv, p. 147.

[2] The anomalous taenite, isolated by acid from the Beaconsfield iron, alone shows a higher proportion, viz. 48·6 per cent. (see O. Sjöström, Sitzungsber. Akad. Wiss. Berlin, 1897, p. 1041).

[3] Cf. L. Fletcher, Mineralogical Magazine, 1908, vol. xv, p. 147.

Treatment of the Residues unattacked by Mercuric Solution.

Reduction of rust, magnetite, schreibersite, and troilite, and extraction of the reduced metals.

§ 15. The metallic material having now been extracted as completely as possible from both the 'attracted' and the 'unattracted' portions, the residues containing the non-metallic constituents were filtered off and washed, the runnings being added to the last extracts. The dried residues were mixed and worked over with the magnet, in order to separate the non-metallic magnetic minerals (magnetite, schreibersite, and perhaps troilite [1]) from the non-magnetic rust and silicates. Each part was then transferred to a porcelain boat and heated to bright redness in a stream of hydrogen. Mercury and mercurous chloride were thus removed, and all constituents except the silicates and chromite reduced to the metallic state. After forty-eight hours no further evolution of hydrogen sulphide (from the decomposition of troilite) could be observed, and the products were allowed to cool in hydrogen. The reduction-product (N) of the non-magnetic material was of a greyish-black colour, that (M) of the magnetic material quite black. Both N and M were treated with mercuric solution in a stream of hydrogen. While both gave up considerable amounts of iron to the solvent (M yielding 0·0966 gram, and N 0·0170 gram, of Fe_2O_3), only M contained any weighable quantity of nickel (0·0086 gram (Ni,Co)O), traces only being found in N. It may be inferred therefore, that if the material has undergone oxidation during the extractions of § 5, the iron only has been measurably affected.

The mercuric extracts of M and N further yielded the following amounts of silica and bases [2]—

SiO_2	...	...	...	...	0·0022 gram.
CaO	...	...	...	...	0·0053 „
MgO	...	...	...	...	0·0017 „

Analysis of the silicate-residues remaining after extraction.

§ 16. The residues left after removal of free iron and nickel from M and N were of a light grey colour, becoming brown on ignition, and then weighed, together, 1·7752 grams. After fusion with sodium and

[1] See foot-note to § 3.

[2] Due to some action on the silicates during reduction. Cf. L. Fletcher, Mineralogical Magazine, 1901, vol. xiii, p. 17.

potassium carbonates in the usual way,[1] a few dark, gritty particles (chromite ?) remained on extraction of the melt, and as these did not yield to a further fusion for thirty minutes with sodium carbonate, they were removed with the silica and weighed after volatilization of the latter with hydrofluoric acid.

§ 17. The following results were obtained from the analysis of the material submitted to fusion :—

	Grams.	
SiO_2...	0·7674	including the silica from the mercuric extracts.
Fe_2O_3	0·4442	
Al_2O_3	0·0841	
Cr_2O_3	0·0022	
NiO (including CoO)	0·0015	
CaO	0·0495	including the lime and magnesia from the mercuric extracts.
MgO	0·4313	
Unattacked chromite	0·0068	
CuO	traces.	

The percentage results are collected in the table on p. 371.

Determination of the composition of the Silicates present.

Separation of the Silicates by treatment with hydrochloric acid.

§ 18. In order to determine, if possible, the actual silicates present in the meteorite, and to find their approximate composition, the method of separation by hydrochloric acid, under conditions favourable to the attack of olivine without appreciable gelatinization of pyroxenes and felspars, was employed.[2]

For this purpose a mixture of 1·06 specific gravity (made by diluting three parts of concentrated hydrochloric acid of sp. gr. 1·16, with five parts of water) was used, as recommended by Mr. Fletcher. As no more of

[1] Only a portion of the material should have been used for this purpose, but by an oversight the whole was mixed with the carbonates. Fresh samples of the stone consequently had to be used for the estimations described in §§ 18-20, 22, 24. The comparison given in § 21 shows, however, that the main sample resembles the smaller one of § 18 closely in composition, so that a comparison of the results obtained from the various portions is probably justifiable.

[2] L. Fletcher, Mineralogical Magazine, 1894, vol. x, p. 288.

the portion of material originally extracted with mercuric solution was available, another fragment of the stone (B), which weighed, after grinding, 0·5326 gram, was treated with about 100 c.c. of the acid in a platinum basin on the water-bath. At the end of half an hour the yellow extract was decanted off through a filter and a fresh extraction carried out for a further 30 minutes. A third extraction of a similar kind was continued for one hour: the third extract was practically colourless. The residue, consisting of unattacked silicates and gelatinous silica, with a little chromite, was well washed by decantation (the washings being also passed through the filter) and then heated on the water-bath with a strong solution of sodium carbonate until there was no gelatinous silica visible, when the alkaline solution was poured off through the same filter (now holding a little silica from the washings). The residue was again treated with hot sodium carbonate solution and finally washed with boiling water.

In order to determine the mass of the undissolved silicate on the filter-paper, it was dried, transferred to a platinum crucible and weighed (= 0·1488 gram). It was then ignited at a bright red-heat and reweighed (= 0·1469 gram). The paper (ash = 0·0002 gram) with its traces of adhering silicate was now burnt into the crucible, ignited, and the whole again weighed (= 0·1866 gram). The residue on the paper was thus determined as $\frac{0\cdot1488}{0\cdot1469} \times 0\cdot0395$, or 0·0401 gram. Thus the material unattacked by hydrochloric acid will weigh altogether 0·1889 gram; that attacked by acid 0·3437 gram.

Analysis of the separated Silicates.

§ 19. The 'bases' of the attacked silicates were obtained in solution as chlorides in the acid extracts. These further contained chlorides of iron and nickel from the free metal, sulphides, phosphides, and oxides present in the stone. After removing the silica from this solution in the ordinary manner, the sesquioxides were separated by a threefold precipitation with ammonia (§ 7), the nickel by means of ammonium sulphide, the calcium by double precipitation with ammonium oxalate, and the magnesium with ammonium phosphate.

The alkaline extract was acidified with hydrochloric acid, and the main portion of the silica of the attacked silicate obtained from this by evaporation in the usual manner.

The following were the results obtained:—

Silicate attacked by Acid.

SiO_2	0·1027 gram.
MgO	0·0765 „
FeO[1]	0·0931 „
CaO	0·0046 „
Al_2O_3	0·0112 „
Cr_2O_3	nil
K_2O, Na_2O	not determined.

The percentage composition is given in the table on p. 372.

§ 20. The unattacked silicate was dried and fused with sodium carbonate, and the melt analysed according to the ordinary methods of rock analysis.[2] The following results were obtained:—

Silicate unattacked by Acid (with Chromite).

SiO_2	0·1018 gram.
MgO	0·0379 „
FeO	0·0150 „
CaO	0·0146 „
Al_2O_3	0·0132 „
Cr_2O_3	0·0003 „
Chromite	0·0032 „
CuO	trace
K_2O, Na_2O	not determined

The percentage composition is given in the table on p. 372.

Comparison of results obtained from different portions of material.

§ 21. When a comparison is made between the results obtained from the portion of the stone (A) used for the bulk analysis (2·0184 grams, see § 3) and from that (B) divided into two parts according to the behaviour with hydrochloric acid (0·5326 gram, see § 18), the following percentage values are obtained for silica and for the four principal bases combined with it:—

[1] In order to obtain the amount of FeO present in the silicate, an amount of Fe_2O_3 corresponding to the amounts of nickel-iron, phosphide, sulphide, and oxide, present in the stone (see § 22) has been subtracted from the total Fe_2O_3 precipitated, and the remainder considered as representing FeO.

[2] W. F. Hillebrand, 'The Analysis of Silicate and Carbonate Rocks.' United States Geol. Survey Bull. No. 305, 1907, pp. 1–200.

	A (2·0184 grams.)	B (0·5326 gram.)
SiO_2 ...	38·02	38·39
MgO ...	21·31	21·48
CaO ...	2·42	3·60
FeO ...	19·81	20·29 [1]
Al_2O_3 ...	4·17	4·58

It thus appears probable that fragments of the Chandakapur stone show a fairly constant average composition in samples of half a gram. The collecting together of results obtained from several different samples could not be justified except on these grounds.

Estimation of Sulphur and Phosphorus.

§ 22. During the reduction in hydrogen described in § 15 a considerable amount of hydrogen sulphide was formed. This gas was also evolved when the stone was treated with dilute acid. A fresh portion (C) of the stone, which weighed, after grinding, 0·5774 gram, was treated with aqua regia, and from the solution of sulphates and phosphates so produced, the sulphur was removed as barium sulphate and the phosphorus as magnesium-ammonium phosphate, according to the methods described by Mr. Fletcher.[2]

The weights obtained were—

BaSO 0·0752 gram, corresponding to 1·79 per cent. Sulphur.

$Mg_2P_2O_7$ 0·0033 gram, corresponding to 0·16 per cent. Phosphorus.

From these values it follows that 3·13 per cent. of iron is combined with sulphur as troilite (FeS), and 0·60 per cent. with phosphorus and nickel as schreibersite (Fe_2NiP). When this iron is weighed as Fe_2O_3, as was done in treating the reduced material of § 15 and in the analysis of the portion of the stone attacked by hydrochloric acid (§ 19), the sulphide accounts for 0·0902 gram and the phosphide for 0·0171 gram of Fe_2O_3 in 2·0184 grams of the stone.

Estimation of Rust and Magnetite.

§ 23. The reduced product (M) of the non-metallic magnetic minerals, was found to yield only 0·0966 gram Fe_2O_3 (§ 15), though from the values given in the last section it appears that the troilite and schreibersite together should yield 0·1073 gram Fe_2O_3, and this quantity would be

[1] See foot-note to § 19.

[2] L. Fletcher, Mineralogical Magazine, 1894, vol. x, p. 298.

further increased if, besides troilite and schreibersite, magnetite was also present in the material attracted by the magnet (§ 15). It is therefore possible that the unattracted material still retained a portion of the feebly magnetic or non-magnetic[1] troilite, whose reduction would then account for part of the Fe_2O_3 obtained from N.

If this view be accepted, we obtain, by subtracting 0·1073 gram from the total ferric oxide (= 0·0966 + 0·0170 gram) yielded by M and N, 0·0063 gram, as a measure, in terms of Fe_2O_3, of the rust and magnetite in 2·0184 grams of the stone. In the absence of further data as to the composition and amount of the rust, we shall probably not be much in error if we take it and the magnetite together, calculating them as Fe_3O_4.[2] They then constitute 0·30 per cent. of the meteorite.

Estimation of the Alkalis.

§ 24. A test (see § 9, foot-note) made to determine to what extent the stone is soluble in water, showed that an alkaline substance containing sodium could be obtained by evaporating an aqueous extract to dryness.

(i) An experiment was made with a portion (D) of the stone reduced to fine powder and weighing 0·5367 gram. This was treated with water for three hours in a platinum dish on the water-bath, the water being replenished as required. After filtration of the solution and evaporation to dryness, a white residue remained which effervesced slightly with hydrochloric acid. The chloride so formed weighed 0·0043 gram, and represented 0·0005 gram K_2O, with 0·0019 gram Na_2O.

(ii) The insoluble residue was treated with hydrochloric acid in the manner described in § 18, except that the unattacked silicate was filtered off without treatment with sodium carbonate. The acid extract was evaporated to dryness, the residue gently ignited, and dissolved in water. The bases other than soda and potash were then removed by the method adopted after a Lawrence Smith fusion. The mixed chlorides eventually obtained weighed 0·0081 gram and yielded 0·0015 gram K_2PtCl_6.

(iii) The residue unattacked by acid was left mixed with gelatinous silica on the filter-paper. It was dried, and after transferring to a platinum crucible with the ash of the filter-paper was heated with pure calcium carbonate and ammonium chloride according to the method of Lawrence Smith.

After complete removal of calcium, 0·0039 gram of mixed alkali chlorides was obtained. Chloroplatinic acid precipitated 0·0043 gram K_2PtCl_6.

[1] See foot-note to § 3.

[2] Cf. L. Fletcher, Mineralogical Magazine, 1894, vol. x, p. 313.

From these values it follows that the alkalis of—

(i) are equivalent to 0·0005 gram K_2O and 0·0019 gram Na_2O.

(ii) are equivalent to 0·0003 gram K_2O and 0·0039 gram Na_2O.

(iii) are equivalent to 0·0008 gram K_2O and 0·0015 gram Na_2O.

The meteorite thus contains[1] 0·29 per cent. K_2O and 1·26 per cent. Na_2O, the greater part being contained in the material dissolved by dilute hydrochloric acid, of which 0·23 per cent. is K_2O and 1·67 per cent. Na_2O. A portion comparatively richer in potash is contained in the silicates unattacked by acid, of which K_2O forms 0·42 per cent. and Na_2O 0·78 per cent.

II. General Results of the Analysis.

Chemical Composition.

§ 25. From the values obtained above, the following results may be collected, expressing the composition of (1) the meteorite in bulk, (2) the metallic portion, (3) the silicates attacked by acid, (4) the silicates unattacked by acid :—

1. *Composition of the meteorite in bulk.*

In metallic state.	Iron	5·25
	Nickel (and cobalt)	0·55
	Copper	trace
Combined.	Iron (as troilite and schreibersite) ...	3·73
	Nickel and cobalt (as schreibersite) ...	0·81
„	Phosphorus	0·16
„	Sulphur	1·79
	Rust and magnetite	0·30
	Chromite	0·51
	SiO_2	38·02
	MgO	21·31
	FeO	19·81
	CaO	2·42
	NiO	0·07
	Al_2O_3	4·17
	Na_2O	1·26
	K_2O	0·29
		99·95

[1] Uncorrected by blank determination.

2. *Metallic Portion.*

Iron	90·5
Nickel and cobalt [1] ...	9·5
Copper	trace
	100·0

3. *Silicates attacked by Acid.*

Of the material attacked by hydrochloric acid, 85·74 per cent. is composed of silicates, the rest being the oxides, sulphides and phosphides, and the free metals. The following values for the composition of the silicate portion are calculated from the experimental numbers given in § 19 :—

		Oxygen, per cent.		
SiO_2 ...	34·85 ...	18·46		
MgO ...	25·96 ...	11·28		
FeO ...	31·59 ...	7·03	18·7	
CaO ...	1·57 ...	0·44		
Al_2O_3 ...	3·80 ...	1·79		21·08
K_2O ...	0·27 ...	0·04		
Na_2O ...	1·96 ...	0·50		
	100·00			

4. *Silicates unattacked by Acid.*

Of the material not attacked by hydrochloric acid, 97·81 per cent. consists of silicates, the remainder being chromite. After deducting the latter, the following values are calculated from the experimental numbers given in § 20 :—

		Oxygen, per cent.		
SiO_2 ...	55·10 ...	29·19		
MgO ...	20·52 ...	8·27		
FeO ...	8·12 ...	1·80		
CaO ...	7·91 ...	2·26	15·94	
Al_2O_3 ...	7·13 ...	3·34		
K_2O ...	0·43 ...	0·07		
Na_2O ...	0·79 ...	0·20		
	100·00			

[1] Cobalt was found to be present in very small amount. Manganese and zinc were shown to be absent.

The 'oxygen ratio' for the silicates attacked by acid approximates to 1 : 1, that for the unattacked silicates to 1 : 2. The principal silicates belong therefore for the most part to the types $R_2''SiO_4$ and $R''SiO_3$, corresponding with the olivine and pyroxene groups respectively. This result is in harmony with the observations on thin sections described above.

Mineralogical Composition.

§ 26. From the foregoing results the following statement of the mineralogical composition of the meteorite may be deduced:—

Metallic alloys	5·80
Troilite	4·92
Schreibersite	1·06
Chromite	0·51
Magnetite and rust...	0·30
Silicates:[1]	
Olivine	53·47
Pyroxenes and felspars	33·89
	99·95

III. Relationship in Composition to other Chondritic Meteorites.

§ 27. The Chandakapur stone falls into the large class of stony meteorites with a small percentage of metal, to which the chondrites of Chantonnay, Krähenberg, Waconda, Mauerkirchen, Montrejeau, Nerft, Pultusk, Stavropol, Girgenti, Makariwa, Knyahinya, &c., belong.

To some of these it bears a noticeable quantitative as well as qualitative resemblance in the minerals present, particularly to Makariwa, Krähenberg, Waconda, and Nerft.

In detail, however, Chandakapur has several interesting peculiarities of composition. For example, the constitution of its nickeliferous iron is not in harmony with the empirical rule of W. Flight, which states that the alloys are richer in nickel the more sparingly they occur. If the series—Krähenberg, Girgenti, Pultusk, Hainholz—which are in ascending order of metallic content, be taken for comparison, the nickel-iron of Chandakapur should contain about 14 per cent. of nickel instead of 9·5 per cent.

[1] Including some 'glass', which, as shown by Ulrich, mainly passes into the 'attacked' portion.

Of more importance, however, are certain features of the composition of the silicates.

The most noteworthy points in the composition of the olivinic and pyroxenic silicates given above, are the comparatively large amounts of alumina in both, and the very marked difference between them in the proportion of iron to magnesium which they contain.

The ratio Fe : Mg in the unattacked part of Chandakapur is 1 : 4·6, and if the nomenclature adopted by Cohen[1] be used, the rhombic pyroxene will thus be a bronzite approaching enstatite. With this small ratio is associated a high alumina-value (7·13 per cent.), which seems to be a fairly regular feature in stones of this class. Thus in L'Aigle, Fe : Mg = 1 : 2·6 in the unattacked portion, and this latter contains 5·19 per cent. alumina. In the Chantonnay series (Knyahinya, Seres, Blansko) where Fe : Mg = about 1 : 3·5, there is about 6 per cent. of alumina. Further examples of this relation are found in the stones of Novo-Urei, Kernouve, Ställdalen, and Stavropol, where Fe : Mg varies between 1 : 4 and 1 : 5·3, and the alumina value is always high.

The largest proportions of alumina are found in the eucritic stones (e. g. Stannern, Jonzac, Juvinas, Sherghotty) where it is associated with lime, either in an augitic or anorthitic molecule. High alumina-values are, however, well known outside the class of the eucrites. Thus Brush found 8·05 per cent. alumina associated with only 0·67 per cent. alkali in the Waconda stone ; the alumina in this instance was present as anorthite. Results of a similar nature were obtained by Apjohn in the analysis of the Limerick meteorite.[2] The high proportion of lime and alumina associated together in the unattacked silicates of Chandakapur would seem to indicate the presence of a plagioclase-felspar or monoclinic pyroxene. The presence of the alkalis would also suggest that a portion of the alumina is contained in a felspar molecule ; but in view of the comparatively trifling amounts of augite and felspar recognizable in the sections, it seems probable that the alumina and lime may be present in one of the varieties of bronzite. It is also possible that a part of the alumina may occur in the glass-inclusions observable in the sections.

The silicate gelatinized by acid contains only a small amount of lime, and the iron and magnesium are present in the atomic proportion 1 : 2 An olivine of this form[3] (containing a little lime) was observed by von Baumhauer in the L'Aigle stone. It is the hyalosiderite of terrestrial

[1] E. Cohen, 'Meteoritenkunde,' 1894, Part i, p. 282.

[2] J. Apjohn, Journ. Chem. Soc., 1874, ser. 2, vol. xii, p. 103.

[3] $Fe_2SiO_4 . 2Mg_2SiO_4$.

olivines, and was said by Rammelsberg[1] to occur in eleven meteorites known to him, including Mauerkirchen, Montrejeau, Lancé, Parnallee, and Chassigny.

With the exception of the high values for alumina, which are not easily explicable, the general results obtained in the analysis harmonize fairly with the mineralogical composition observed in the microscopic sections.

Our thanks are due to Dr. S. J. Shand and to Mr. L. J. Spencer, for facilities to examine the specimens in the Royal Scottish Museum at Edinburgh, and in the British Museum, respectively; to the curators of numerous museums and other gentlemen, for information concerning the specimens in their collections; to Prof. E. A. Wülfing; and to Mr. A. Robinson, of the University Museum, for his skilful execution of the photographs reproduced in the plates.

Explanation of Plates.

Plate IX.

Fig. 1. Front view of the Chandakapur meteoric stone No. 8 (before cutting), showing crust and pittings. At the back is a fractured surface, roughly parallel to the front. The portion above the line *AA* is still preserved in the Oxford University Museum. (× $\frac{2}{5}$.)

Fig. 2. Section (× 14) showing an oval porphyritic olivine chondrule (*A*) with well-formed crystals and grains of olivine embedded in a granular, brownish matrix, and an outer shell of iron; *B* and *C*, chondrules containing olivine with bronzite; *D*, a small chondrule of bronzite with one large crystal and some smaller grains; *E*, a small chondrule showing a mosaic of fibrous bronzite.

Fig. 3. Section (× 14) showing a chondrule (*A*) with large porphyritic olivine crystals in compact greyish matrix; a granular olivine chondrule (*B*); *C*, a monosomatic olivine chondrule (section perpendicular to an optic axis) with concentric nucleus traversed by a network of glass (?); the semi-circular marking represents a rusty stain and shows the outline of the nucleus. *D* is a small oval chondrule, with shell of iron and compact radial-fibrous structure, of bronzite possibly with some monoclinic pyroxene.

Fig. 4. Section (× 14) showing a chondrule (*A*) with porphyritic olivine crystals elongated along the *c*-axis (tabular parallel to *b*(010)?), in a compact greyish matrix; *B* and *C*, chondrules of granular olivine with iron shell; *D*, a porphyritic olivine chondrule with angular outline; *E*, a small chondrule resembling *D* in fig. 3.

Fig. 5. Section (× 14). *A*, a nearly monosomatic olivine chondrule with nucleus consisting of parallel crystals, elongated along the *c*-axis and probably

[1] C. F. Rammelsberg, Abhand. Akad. Wiss. Berlin, 1870, p. 138; 1879, p. 24.

tabular parallel to *b* (010), separated by layers of black glass, and a border partly in parallel position and partly granular, surrounded by a thin black line; a granular olivine chondrule (*B*); an irregular chondrule (fragment?) (*C*), formed of radiating prisms of monoclinic pyroxene. The sinuous white line represents a crack in the section.

PLATE X.

Fig. 6. Section (× 14) showing a monosomatic chondrule (*A*) with nucleus containing regularly arranged glass inclusions and border enclosing opaque specks (see p. 357); *B*, a chondrule containing prisms of bronzite and grainsf olivine; *C*, a fragment of fibrous bronzite.

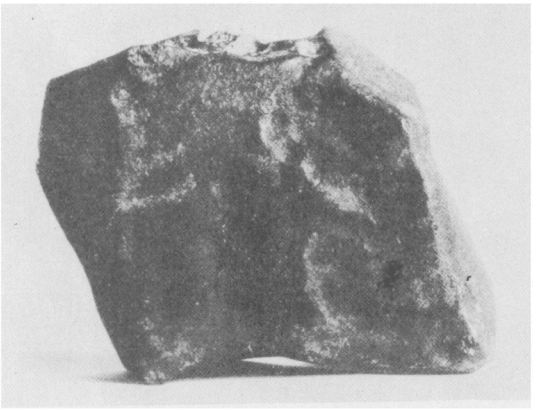
Fig. 7. Section (× 14) showing two large porphyritic chondrules, consisting (*A*) of bronzite prisms with a few grains of olivine, (*B*) of prisms of bronzite and olivine lying side by side.

Fig. 8. Section (× 14) showing (*A*) a large bronzite chondrule composed of several crystals cut in longitudinal and oblique directions; *B*, a sharply defined chondrule containing grains of olivine in a matrix of dark brown glass(?); *C*, a chondrule containing a large olivine crystal surrounded by small grains of bronzite.

Fig. 9. Section (× 14) showing (*A*) a broken, oval chondrule composed of two bronzite individuals with grating-structure due to enclosed layers of glass parallel to *a* (100) (section nearly parallel to *c* (001) for both crystals); *B*, a round chondrule of radial-fibrous bronzite with indented edge; *C*, portion of a chondrule formed of an intergrowth of two pyroxenes. (With crossed nicols.)

Fig. 10. Section (× 14) showing (*A*) a chondrule of fibrous bronzite with concave indentation; with small chondrules of granular olivine (*B*), bronzite prisms (*C*), and a large crystal of olivine bordered by segmental crystals of bronzite (*D*). (With crossed nicols.)

Fig. 11. Section (× 14) showing (*A*) a fragment of grey fibrous bronzite with light yellowish border; *B*, a chondrule of large radiating crystals of α- and γ-bronzite enclosing small grains of olivine; *C*, a chondrule of granular olivine with triple border of black inclusions; *D*, small chondrule composed of grains of olivine and β-bronzite.



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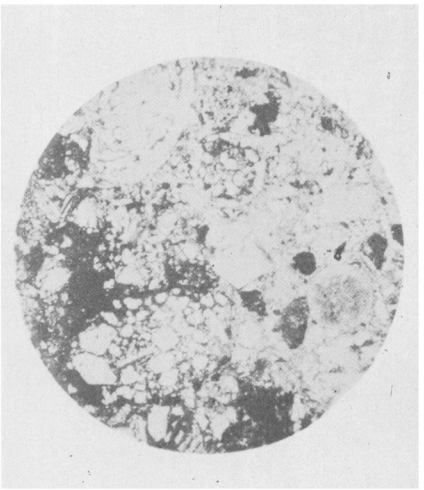

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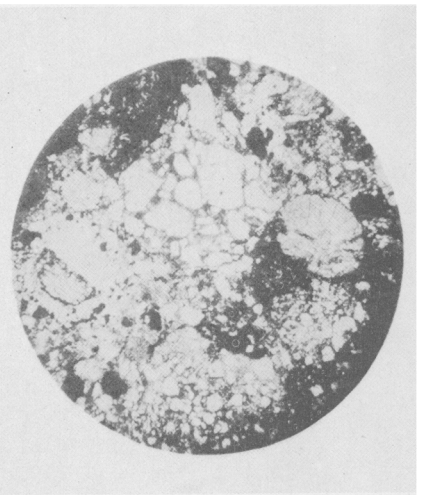

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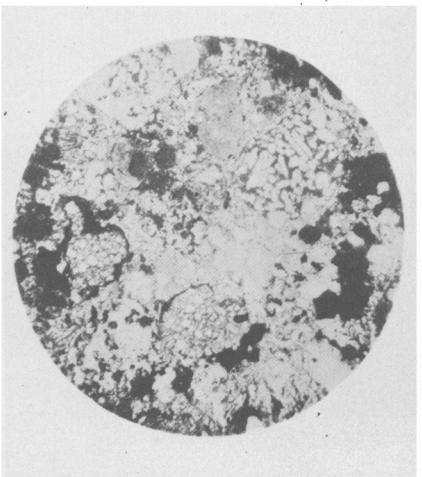

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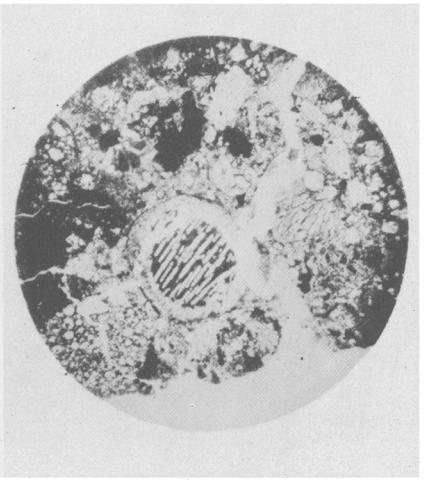

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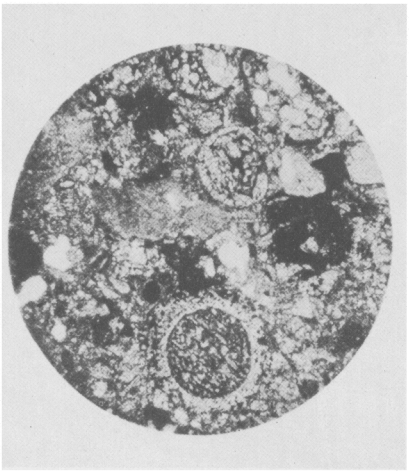
H. L. BOWMAN AND H. E. CLARKE: THE CHANDAKAPUR METEORIC STONE.



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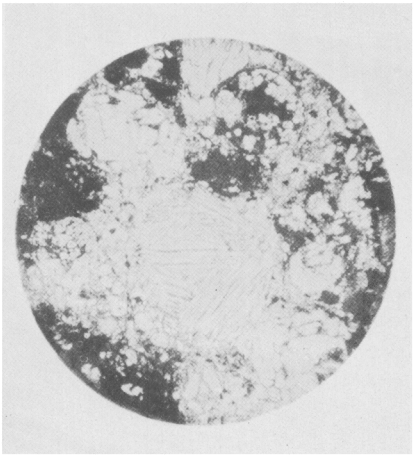

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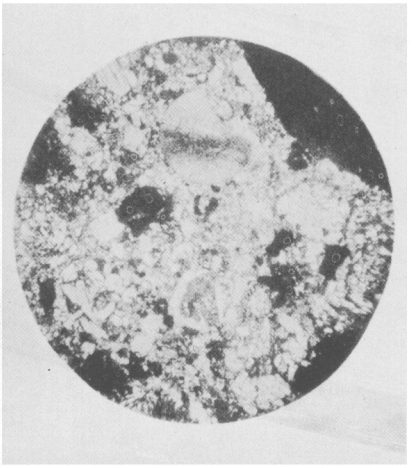

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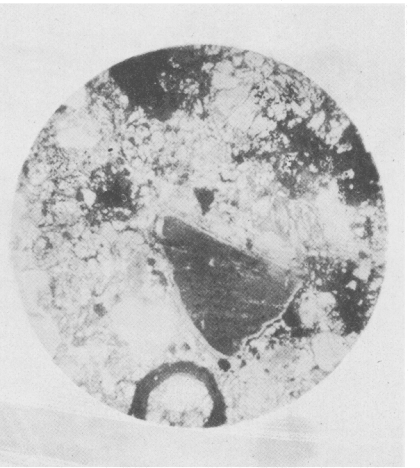

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