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On the Meteoric Stones which fell near Zomba, British Central Africa, on January 25th, 1899: with notes on the chemical analysis of such bodies. [With a map of the District, Plate I].

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[Read, in sections, on June 20th, 1899, April 3rd, 1900, and June 19th, 1900, respectively.]

Part I.—The Circumstances of the Fall of the Stones.

ON January 25th, 1899, at 7.54 a.m., a loud noise as of an explosion was heard at the settlement of Zomba, British Central Africa, and for many miles around; almost simultaneously therewith, several small stones were seen to reach the earth in the neighbourhood of Zomba and were collected by the observers of their fall.

Mr. Alfred Sharpe, C.B., His Majesty's Commissioner and Consul-General for the Protectorate of British Central Africa, Mr. J. F. Cunningham, Secretary to the Administration, and Mr. J. McClounie, the Acting Collector of Revenues, on hearing the detonation, surmised that it had an origin in the entry of a meteorite into the earth's atmosphere, and with praiseworthy zeal and energy at once proceeded to collect, by aid of the telegraph and by personal interviews with the witnesses, all the reliable evidence that could be obtained relative to so extraordinary a

phenomenon. A Report, embodying this information and the notes made by Mr. Cunningham and Mr. McClounie, was sent by Mr. Sharpe to the British Museum; four of the stones, generously presented by Mr. Sharpe, Mr. Cunningham and Mr. McClounie, were forwarded at the same time for scientific examination and for subsequent preservation in the Meteorite Collection of the Museum.

The details given in the Report may be classified as follows:—

LUMINOUS METEOR AND TRAIL.

[*Zomba.*] “There being much cloud at the time, nothing was visible to indicate that a meteorite had entered the earth’s atmosphere.”

[*Blantyre.*] “A native named Bwanali, who was sitting in the open near the Government buildings, saw, a little before 8 a.m., a star of exceptional brilliancy pass across the sky in the direction of Lake Shirwa (roughly, west to east).” “A native capitao in the employment of Mr. James Lindsay makes a similar statement, and adds— it left a trail or tail behind it.”

[*Chivomo.*] “Mr. H. C. McDonald telegraphed that several natives saw the star and smoke. They stated that it appeared to pass over Cholo.”

[*Fort Johnston.*] “Mr. O. C. Ockenden, the Acting British Vice-Consul, telegraphed that the meteorite had been seen from Fort Johnston.”

[*Chengali’s village.*] “Sergeant-Major Bandawe, of the British Central Africa Rifles, who was on his way to Zomba, saw the meteor when he was at Chengali’s village to the west of Lake Pamalombe. It left a trail, and exploded in the direction of Chikala.”

Owing to the cloudy state of the sky the luminous meteor was thus seen from only a small number of places, and presumably for only small portions of its path. It must have been far above the clouds, for it was seen from places 180 miles apart. The meteor appears to have been travelling in an approximately easterly direction, and was seen to explode when near a line drawn from Lake Pamalombe to Chikala.

DETONATION.

(a). *Places at which it was heard.*

[*Top of Mt. Zomba.*] Mr. Sharpe says:—“I heard one very loud report.”

[*Zomba.*] Mr. Cunningham says:—“There was heard a crash like thunder.”

[*Blantyre.*] “The native Bwanali heard an explosion like a crash of thunder. A native captao in the employment of Mr. James Lindsay makes a similar statement.”

[*Chikwawa.*] “Mr. J. O. Bowhill, the Judicial Officer at Chikwawa, heard the explosion as he was standing near his house. It seemed to him to come from the direction of Blantyre.”

[*Katunga.*] “Mr. C. B. Vertue, the Agent of the African Lakes Company, made inquiries, and states that the explosion was heard by Muri (a native servant), ‘James’ and Mgano (capitaos), Njeresa and Mpeni (natives in charge of cattle).

“A native from Katunga’s village came in to Chikwawa and told the Collector of Revenues that the explosion had been heard in that village.”

[*Chiromo.*] “Mr. H. C. McDonald telegraphed that several natives heard the explosion.”

[*Fort Johnston.*] “Mr. O. C. Ockenden telegraphed that the explosion had been heard at Fort Johnston.”

As far as could be ascertained, neither the luminous meteor nor the detonation had been remarked by any one at Kota-Kota, Nkata or Karonga, places which are north of Fort Johnston and lie on the western shore of Lake Nyasa; they are in telegraphic connection with Zomba.

(b). *Character of the Detonation.*

The character of the detonation as heard by an observer would vary to some extent according to his situation.

[*Zomba.*] Mr. J. F. Cunningham says :—“I heard a crash like thunder, the reverberations lasting for a few minutes afterwards. When I heard it, I suspected what it was, but thought it might possibly be a dynamite explosion on the road to the new Residency, where I knew the Road-Engineer, Mr. William Fletcher, and a party of men were at work. I sent an inquiry to Mr. Fletcher, and he sent back word that he also had heard the explosion, but that it had not occurred on the Road.”

Mr. J. McClounie says :—“The loud report had the precision of a cannon. I was indoors at the time, but instantly rushed out to see what had happened. My attention was drawn towards the east by the continuous rolling noise. The natives also were looking in an easterly direction.”

[*Top of Mount Zomba.*] This mountain rises to a height of 6,000 feet above the sea, and is on the western side of the settlement, which is

itself 2,900 feet above the sea. Mr. Sharpe says:—"I heard one very loud report; then for some two minutes a long rumbling or buzzing noise, gradually getting fainter and fainter; I should not call it reverberations."

[*Kuntamba's village.*] "The chief Kuntamba, at his village about three miles from the Residency, to the west of the road to Domasi, heard a noise like thunder."

[*Blantyre.*] "The native Bwanali heard an explosion like a crash of thunder."

The detonation was thus a single one; at Blantyre and about 50 miles away in the villages north-east of Zomba it was as loud as thunder: it was heard also at Chiromo, about 90 miles south of the settlement of Zomba, and also beyond Fort Johnston, which is at a distance of 70 miles to the north of Zomba; to the observers at Zomba itself the sound seemed to come from the east.

FALL OF STONES.

About an hour after the detonation had been heard, news reached the Residency that several stones had fallen in native villages on the eastern slopes of Mount Zomba. As many as ten were ascertained to have been found, and these have been preserved: only those stones were discovered which fell near to people or houses, and possibly they form only a small proportion of those which actually reached the earth.

The following is the history of the individual stones:—

Stone No. 1. Weight 2 oz. (57 grams). Fell at Kuntamba's village, about three miles from the Residency, to the west of the road going to Domasi. The chief Kuntamba gave the following account to Mr. Cunningham:—"This morning I was standing near my house when I heard something fall on the rock there" (pointing to a fairly level slab of granite, measuring 20 feet by 12 feet, near his house). "Immediately after, I heard a noise like thunder. I went to the rock and saw where a stone had fallen, and I picked up some small bits."

Mr. Cunningham adds:—"There was a large crowd of the village people present when the chief told me this, and two of them, Matendu and Laici, personally vouched for its accuracy. The fragment has only a small portion of outer crust. It is the largest of the pieces found at this spot."

Stone No. 2. Weight 4½ ozs. (128 grams). Fell at Kumpamba's village, 3 miles from the Residency along the Domasi road. The fall was witnessed by the chief and others. It is the smallest of the completely encrusted stones.

- Stone No. 3. Weight 1 lb. 3 ozs. (589 grams). It was seen by a native to fall on the outskirts of the last-mentioned village. It is incomplete, a large piece having been broken off through impact against a stone when it fell. Presented to the British Museum by Mr. McClounie.
- Stone No. 4. Weight 3 lbs. 5 ozs. (1502 grams). Fell on the border of a new garden on the verge of the forest about 400 yards to the south of the Likangala River, near Chiropa's village. A native was hoeing in the garden when the stone fell. The place was stony, and a corner of the meteoric stone was chipped off by the fall.
- Stone No. 5. Weight 12½ ozs. (354 grams). Fell at Kampunga's village on Buchanan's Estate. "It was about noon when we (Mr. Ravenor and Mr. Cox) got to Kampunga's village (to inquire about the stone reported by Mr. Cunningham to have fallen there). We found the village people squatting round the stone in a circle, discussing the 'miracle' as they called it. No one had touched or approached the stone, and when we arrived it was still lying where it had fallen. The story of its advent was given as follows:—'A woman was pounding corn under a tree, within about ten yards of her hut, when the stone fell. The whole village heard the detonation immediately afterwards, and gathered to where the woman was standing to view the stone. They were afraid of it, thinking it enchanted, and they sat at a distance round it, each giving a version of its probable origin and meaning.' It fell on hard ground, but, as there were no rocks about, I (Mr. Ravenor) was able to dig it up complete. It is covered with crust."
- Stone No. 6. Weight 5 lbs. 12½ ozs. (2622 grams). Fell to the south of the Likangala River, to the west of Stone No. 4. It is the largest stone found, is completely encrusted, and has the usual pittings.
- Stone No. 7. Weight 1 lb. 18 ozs. (822 grams). Fell at Chope's village, near Songani. It is probably only part of the fallen stone, for one large surface is not encrusted. Presented by Mr. Cunningham to the British Museum.
- Stone No. 8. Weight 1 lb. 6½ ozs. (688 grams). Fell at Chirunga's village, two miles from the Residency, near the Domasi road. The side shown by a photograph of the stone is completely covered with crust.
- Stones Nos. 9 and 10. Weights 14½ ozs. (411 grams) and 1 lb. 1 oz. (482 grams), respectively. Both of them fell at Kanyama's village,

and have been presented by Mr. Sharpe to the British Museum; they are almost completely encrusted stones. "Several people heard them crashing through the trees, and after a search found first one stone and, later on, the other."

Mr. McClounie says that one small stone in its fall cut a twig from the branch of a tree; this was two miles from Zomba, off the Liwonde road; several of the other pieces were picked up at or near this place.

As the meteorite travelled in a more or less easterly direction and reached the ground only a short distance from Zomba (Plate I), and the detonation seemed to the observers at Zomba itself to come from the East, it follows that the detonation is really a consequence of the break-up of the meteorite, and not, as has been sometimes suggested, due to the rush of air into the vacuum left behind the meteorite during its flight.

AREA OF DISTRIBUTION OF THE STONES.

Mr. McClounie says:—"As far as I know at present the area over which stones have fallen is about 9 miles long and 3 miles wide. Whether any fell outside this area may never be known." [The positions of the stones as indicated in the map, Plate I, must be only approximate].

The dimensions thus assigned by Mr. McClounie are exactly identical with those of the area over which the stones were distributed in the case of the meteoritic fall at Knyahinya, Hungary, on 9th June, 1866. The area of distribution of the stones, in the case of a meteoritic shower, has rarely been found to measure more than ten miles by three.

The two heaviest stones, Nos. 6 and 4, weighing respectively 5 lbs. 12½ ozs. and 3 lbs. 5 ozs., were found at the southern end of this area. The next largest, No. 7, still weighing 1 lb. 13 ozs., and probably not more than half of the stone which fell, was at the northern end of the area, and not far from the smallest completely encrusted stone, No. 2, weighing 4½ ozs.; the complete stone, No. 7, may have really been the largest which fell. Stones Nos. 9 and 10, weighing respectively 14½ ozs. and 1 lb. 1 oz., were also found north of the smallest stone.

The area of distribution on the earth's surface of the stones of a large meteoritic shower is usually, not always, elongated in the direction of flight of the luminous meteor, and the stones are generally distributed within this area approximately according to size, the larger ones being near the end towards which the meteor's flight was directed. A distribution precisely according to size would be a necessary result of the resistance of the air on the individuals of an at first closely packed swarm of similar meteoric stones moving through the earth's atmosphere in a

direction inclined to the vertical, if each stone remain unbroken during its flight. But an admixture of sizes may result in various ways. For instance, a stone may be broken up into scattered unequal fragments at a point in its passage through the atmosphere such that the subsequent path of the fragments is not long enough for the differentiating effect of the resistance of the air to render of no moment their initial scattering in various directions.

Having regard to such considerations, it will be seen that the number of stones found at Zomba is too small and the sizes are too intermingled to admit of any sound inference as to the direction of the meteor's path from a mere study of the distribution of the fallen material, but the distribution, especially if No. 7 was really the largest stone, is not inconsistent with the direction suggested by the observations already referred to. It seems likely that the stones resulted from the breaking up of a single mass within the earth's atmosphere: there was only one detonation, and presumably only one important epoch of fracture; as the stones are completely encrusted, the scattering of the fragments must have taken place at a point where their velocity was high enough to cause superficial heating to a high temperature. As there is no mention, in the Report, of deep penetration of the ground, it is probable that the velocity was comparatively small at the time of impact on the earth's surface.

MATERIAL OF THE STONES.

It may be added that the material of the stones was observed to be unlike that of any of the rocks of the district, and that the specific gravity of two of the stones was determined by Mr. T. J. Binnie, Acting Chief Surveyor, to be 3.5, which is much higher than that of any of the Zomba rocks; further, Mr. McClounie noticed the numerous metallic particles glittering on the fractured surface, and proved that the material has a directive action on a compass-needle.

Part II.—The Characters of the Stones.

THE CRUST.

The crust is brownish-black to black in colour; it is mostly smooth, but in parts is scoriaceous or wrinkled; it shows occasional protuberances. The crust is dull, but a spot, 7 mm. in diameter, on Stone No. 7 is lustrous: in the case of Stone No. 3 a patch of crust, 3 mm. by 4 mm., is transparent and of a light green colour. On Stone No. 7 there is a linear ridge which can be traced round one of the edges of the stone for a

distance of 70 mm. ; a fracture of the crust shows that the ridge is the prolongation of a black vein in the stone. The thickness of the crust averages 0.5 mm. and reaches a maximum of 1 mm.

Each of the stones Nos. 9 and 10 has one side different in aspect from the others ; instead of being comparatively uniform in curvature, this side is covered with pit-like depressions.

THE FRACTURED SURFACES.

The fractured surface of Stone No. 7 shows part of a broken troilite-nodule, 5 mm. wide, of irregular form ; an unbroken chondrule, 2 mm. in diameter, projects above the general surface ; in one part is a material of vitreous lustre, curved, nearly linear and 2 mm. long.

A freshly-made fracture of Stone No. 8 varies in parts from white to whitish-grey in colour : one portion shows a dark grey oval patch, 12 mm. by 7 mm. ; another was found to break through a beautifully regular bluish or bluish-grey chondrule, $2\frac{1}{2}$ mm. in diameter.

SPECIFIC GRAVITY.

The specific gravity was determined for a fragment, weighing 18.8522 grams, of Stone No. 8 : the fragment was free from crust and exactly similar in aspect to a fragment of the same stone used for chemical analysis. The loss of weight in distilled water at 20.2° C. was 3.8978 ; the air was extracted from the pores by the air-pump. Duly corrected, the weight of one cubic centimeter at 20.2° C. is 3.545 grams.

MICROSCOPIC EXAMINATION.

Thin sections prepared for the microscope, when examined with the unassisted eye by reflected light, show small, very irregularly shaped, lustrous, metallic constituents (nickel-iron), and also still smaller dull opaque black particles (completely enclosed nickel-iron, troilite or chromite), dispersed through a greyish-white stony material : one of the five sections shows part of a black vein. By ordinary transmitted light the stony material is seen, with the aid of the microscope, to consist almost wholly of a nearly colourless crystalline groundmass, constituted of crystals which are chiefly small and rarely show any boundary due to the section of a natural face. Between crossed Nicols the groundmass (olivine, enstatite and plagioclastic felspar) is seen as a bright small-grained mosaic (grey, yellow, red, blue and green) interspersed with small and large crystals (the latter chiefly olivine) ; here and there, small quantities of a mineral nearly or quite free from cracks and polarising in grey tints (probably plagioclastic felspar) fill up intervening irregular

spaces and mould the other crystallised material: the general aspect being very like that of sections of the meteorites of Linn County, Grossliebenthal, Girgenti and Alfianello. Enclosed in the groundmass, and intimately connected therewith, are some chondrules, few in number and almost all of them white. One of them is perfectly round and has a well marked shell, the whole of the kernel and the shell extinguishing the light simultaneously (monosomatically) and being constituted apparently of short blocks, characters which are very common in olivine-chondrules: further, as is not unusual, particles of nickel-iron are closely grouped round the greater part of the outer boundary of the shell. A second chondrule is very similar, but no shell is evident and the block-structure is less marked. A third chondrule, almost monosomatic, shows a triple shell. Other chondrules are polysomatic, being composed of several crystals having different optic orientations. In each of two slides is a section of a chondrule which, looked at with the unassisted eye, is black by reflected light; with the microscope and crossed Nicols, it is seen to consist of a transparent substance polarising in grey tints (probably plagioclastic feldspar) and enclosing opaque particles which are densely packed in the centre and are almost absent near the circumference of the chondrule: a similar black chondrule is shown by a section of the Grossliebenthal meteorite. Some patches of material seen in the sections are micro-crystalline aggregates and are possibly enstatite.

Chemical Examination.

As there is necessarily more or less speculation in the interpretation of the results observed during the chemical examination of a mechanical mixture of compounds having one or more chemical elements in common, the observations and calculations are conveniently kept quite distinct from each other and recorded in separate sections. Both are given in detail, so that future investigators of meteoric stones may know the kind of difficulty which presents itself in such an inquiry, and may form an estimate of the weight to be assigned to the numerical results arrived at.

Section I. Observations.

WEIGHTS OBTAINED IN THE COURSE OF THE CHEMICAL ANALYSIS.

Magnetic Separation.

1. A freshly broken, easily frangible, crustless fragment of Stone No. 3, weighing 14.6 grams, was crushed in a steel mortar, and afterwards pulverised, in small portions at a time, in an agate mortar; it was impossible, owing to the presence of malleable grains of nickel-iron alloy,

to reduce the material in this way to a fine powder of uniform composition. The alloy was next magnetically extracted by means of a seven-toothed iron comb, such as is used by grainers, but which had been magnetised: the powder being worked through in small quantities at a time. The residual powder was again pulverised in the agate mortar and the magnetic separation repeated. At the end of a series of operations the material had been divided into two parts; the one, attracted, weighing 2.0144 grams; the other, unattracted, weighing 12.4208 grams; the total quantity of material available for analysis being thus 14.4352 grams. The attracted material consisted of particles of different sizes; some of them were about a millimeter in diameter; much of the remainder consisted of smaller but still coarse grains, and another portion consisted of particles which were extremely minute and thus readily oxidisable on exposure to air or moisture: the unattracted material was an impalpable powder of a bluish-grey colour and apparently quite free from iron-rust.

ATTRACTED MATERIAL: TOTAL WEIGHT 2.0144 GRAMS.

Treatment with solution of mercuric ammonium chloride.

2. 0.7421 gram of the attracted material was transferred to a small flask and treated with cold mercuric solution in an atmosphere of hydrogen as described in a previous paper,¹ the flask and contents being frequently shaken during the daytime; after the action had proceeded for some time, the liquid was quickly filtered, and the insoluble matter was washed with cold water which contained a little mercuric solution and had been boiled to expel dissolved air. For each of the first two extractions 200 cc. of the mercuric solution were used; for each of the next five, 100 cc.: the first extraction was allowed to proceed for 3 hours; each of the next four, for 24 hours; the sixth, for 96 hours; and the seventh, for 24 hours.

Each of the extracts was acidified, heated to boiling, and precipitated by sulphuretted hydrogen, and the several filtrates were evaporated to dryness. The residue from the third extract showed by its colour that an appreciable amount of alloy had been extracted by the mercuric solution, and there was still an evident tinge of colour even in the residue from the seventh extract; the coloration was much smaller in the case of the fourth and fifth extracts than in that of the third, while those of the sixth and seventh, though evident, were only just appreciable; the last

¹ Mineralogical Magazine, 1894, vol. 10, p. 293.

two were of about equal intensity although the sixth extraction had occupied four days and the seventh only one. There was by this time much admixed mercury and mercurous chloride, protecting the material to some extent from the action of the solvent; possibly, also, some of the particles of the alloy were so large as to require a very prolonged action to produce solution; possibly some had been superficially oxidised and were partially sheltered by the oxide from contact with the liquid: undissolved particles of alloy are very liable to be superficially oxidised when exposed to the air during the filtration. The extraction, although incomplete, was accordingly not further proceeded with at this stage.

The various precipitates produced by the sulphuretted hydrogen were ignited and the mercury driven off; there remained a small brownish residue, which was soluble in warm hydrochloric acid, and gave a rich yellow solution; it was again precipitated by sulphuretted hydrogen, and the filtrate, which may contain a little iron carried down by the mercuric sulphide, was added to the main extracts. The brown precipitate weighed after ignition 0.0001 gram, and was found to be due to the presence of copper. The extracts having been collected together, the iron was oxidised, and at the same time the ammonium chloride decomposed, by evaporation with strong nitric acid; the residue was then treated with strong hydrochloric acid and again evaporated to dryness. From the dilute solution the iron was separated from the nickel by a fourfold precipitation with sodium acetate; probably two precipitations would have sufficed, for it was afterwards found that the nickel separated by the third and fourth precipitations was scarcely large enough to be appreciable. After a final precipitation with ammonia and ignition, the precipitate weighed 0.4933 gram. Of this, 0.4054 gram was ignited in a current of hydrogen and treated with hydrochloric acid; the insoluble SiO_2 weighed 0.0028, and was probably due to the action of the voluminous boiling liquid on the glass during the four precipitations of the iron. The dissolved iron was precipitated by ammonium sulphide, and the filtrate, which showed no trace of nickel (thus indicating the completeness of the separation from that metal), was evaporated to dryness; the ammoniacal salt was expelled by gentle ignition: from the residue then obtained, a small quantity of phosphorus (presumably due to oxidation of schreibersite, phosphide of iron and nickel) was eventually separated by molybdic solution and afterwards by magnesia mixture: the $\text{Mg}_2\text{P}_2\text{O}_7$ weighed only 0.0005.

The nickel and cobalt were twice precipitated by caustic potash and bromine water; as oxides they weighed 0.0606, as metal 0.0487. The

cobalt was separated from the nickel by the nitrite method and converted into potassium cobalt sulphate ($8K_2SO_4 \cdot 2CoSO_4$); this weighed 0.0166.

3. The residue from the action of the mercuric solution was in two parts: one part, still adherent to the filter, weighed after ignition (and therefore partial oxidation) 0.0019 gram; the other part, which had been washed from the filter, contained some bright metallic spangles (probably schreibersite, phosphide of iron and nickel) mingled with much mercurous chloride, mercury and coarse grains of silicate; further, much of the material was found to be still magnetic; after being heated in a current of hydrogen to a temperature just below visible red heat until no further volatilisation took place, it weighed 0.3866 gram. The residual powder, instead of consisting of light coloured silicates, as had been expected, was almost wholly of a dull black colour, but further contained the lustrous metallic spangles already referred to; and the whole was attracted by the compass-needle, showing that the coarse grains of silicate, obviously present, themselves contained magnetic matter. It was inferred that the powder consisted largely of magnetic oxide of iron; the residue was therefore heated to low redness in a current of hydrogen, again submitted to the action of the mercuric solution, transferred back to the boat and again heated in hydrogen; as the residue was not much diminished and was still of a dull black colour, the operations were repeated, the temperature being raised to full red heat, but with a similar result. After a further extraction with mercuric solution, the residue was again heated in hydrogen to a full red heat and weighed (0.2759 gram). The part adherent to the filter weighed, after ignition, 0.0091 gram. The combined extracts yielded, after a double precipitation with sodium acetate, Fe_2O_3 0.0489 and $Ni(Co)$ 0.0185.

4. As the total residue had only been reduced by the last operations from 0.3866 gram to 0.2850 gram and was not appreciably changed in aspect, it was decided to treat the residue with hydrochloric acid and to analyse it in the same way as the unattracted material.

0.2757 gram was treated on the waterbath with dilute HCl (s. g. 1.06); there was immediate effervescence, which lasted for ten minutes. From this it is inferred that particles of alloy had been protected from the mercuric solution by a coating of oxide or by enclosure in grains of olivinic silicate, probably in both ways. The silica set free by the acid was separated by means of sodic solution and weighed (0.0447 gram). The residue washed from the filter weighed 0.1280 and was white; the part adherent to the filter weighed, after ignition, 0.0129 gram.

From the acid solution the following weights were obtained :—

$\text{Fe}_2\text{O}_3, \text{SiO}_2$ 0·0450 (yielding SiO_2 0·0013, presumably due to the action on the vessels).

$\text{Ni}(\text{Co})\text{O}$ 0·0088 ; yielding $\text{Ni}(\text{Co})$ 0·0072.

CaO 0·0086, probably almost entirely due to the action on the glass and porcelain during the precipitation of the iron and the separation of the nickel.

$\text{Mg}_3\text{P}_2\text{O}_7$, 0·1187.

UNATTRACTED MATERIAL : TOTAL WEIGHT 12·4208 GRAMS.

Extractions with Water, Alcohol and Ether.

5. 1·0017 grams of the unattracted material were transferred to a platinum dish and covered with 100 cc. of distilled water ; after being boiled the solution was allowed to cool and then filtered without prolonged standing ; the filtrate was opalescent. It was evaporated to dryness, 100 cc. of water were again added, and the liquid was boiled. It was afterwards filtered, the filter being on this occasion left unwashed ; the filtrate was now limpid and yet contained all the soluble matter ; the powder adherent to the dish and filter was doubtless finely divided silicate which had been in a state of suspension and had caused the opalescence. The soluble residue yielded by the evaporation of the filtrate weighed 0·0026 gram, or 0·26 per cent.

Its solution was inactive to litmus and turmeric, and gave a rich yellow colour to the Bunsen flame. On spontaneous evaporation it began to deposit a precipitate as soon as it became concentrated, the liquid becoming quite milky in appearance when its volume had decreased to a cubic centimeter ; after the evaporation was complete, the residue, examined with the microscope, was seen to consist mostly of small crystals optically isotropic, but of no distinct form ; there were a few isolated groups of radiating birefringent plates, and also some isolated acicular crystals having straight extinction. The solution gave no precipitate with ammonia and ammonium chloride, even on boiling, but was found to contain calcium and a minute amount of magnesium. It contained sulphate in considerable quantity, but only an extremely minute trace of chloride ; no phosphate could be detected. This is virtually the same result as was obtained in the examination of the Makariwa stone¹ ; in that case it was inferred that the salts found in the extracting water were due to a partial oxidation of the protosulphide of iron (troilite) to

¹ Ibid. p. 297.

sulphate, and to the subsequent action of the dissolved sulphate on the silicates, but it was uncertain whether the oxidation had taken place during the aqueous extraction itself or while the stone was lying buried in the ground. As the Zomba stone was quite fresh, it may be concluded that the oxidation of the troilite takes place during the boiling, and that the soluble salts may be accounted for without being regarded as original constituents of the meteoric stone.

The residue left after treatment with the distilled water was digested with 50 cc. of absolute alcohol for three days, and afterwards with 50 cc. of ether for 30 minutes; in neither case was anything weighable extracted.

Determination of chromite: absence of diamond.

6. The same residue was treated finally with hydrofluoric and sulphuric acids. The insoluble material was transferred to a watch-glass and microscopically examined; as it was entirely opaque and of metallic lustre, no diamond could be present; after ignition it weighed 0.0035 gram and gave the reactions of chromium. The above number corresponds to 0.35 per cent. of chromite in the unattracted material; but it is only a minimum, for part of the chromite, being very finely divided, would probably yield to the attack of the acid and be carried into solution.

Determination of sulphur and phosphorus: absence of titanium.

7. 0.9920 gram, treated in the way described in a previous paper¹, yielded BaSO_4 0.1481 and $\text{Mg}_2\text{P}_2\text{O}_7$ 0.0024. During these operations, it was ascertained that titanium was absent.

Determination of the alkalis.

8. 0.4815 gram, analysed by the Lawrence Smith method, gave:—Sodium and potassium chlorides 0.0135; tested with a small spectroscope only the sodium line was visible: K_2PtCl_6 (free from filter) 0.0040; adherent to filter and ignited, 0.0036.

A blank experiment simultaneously made with the same reagents gave:—Sodium and potassium chlorides, 0.0021; K_2PtCl_6 (free from filter) 0.0056; adherent to filter and ignited, 0.0012.

Treatment with mercuric solution.

9. 4.9856 grams were treated with mercuric solution in an atmosphere of hydrogen, as already described; the extraction proceeded for 24 hours and was performed three times. The first extract was appreciable; the second and third showed only slight tinges of colour.

¹ Ibid. p. 298.

The combined extracts yielded :—

CuS (ignited in air) 0·0003.

After oxidation of the iron and decomposition of the ammonium chloride, the residue was green, showing its comparative richness in nickel: the solution gave

$\text{Fe}_2\text{O}_3, \text{SiO}_2$ 0·0025, yielding SiO_2 0·0004.

NiO 0·0007.

CaO 0·0040, probably almost entirely due to the action on the glass and porcelain during the precipitation of the iron and the removal of the nickel.

$\text{Mg}_2\text{P}_2\text{O}_7$ 0·0037.

Treatment with hydrochloric acid and sodic solution: First Portion.

10. 2·5065 grams of that part of the unattracted material which had not been subjected to the action of the mercuric solution were extracted three times with dilute hydrochloric acid, according to the method described in a previous paper.¹ In this case the extracts were decanted from the undecomposed material (admixed with free silica), and the decanted liquid and the undecomposed material separately evaporated to complete dryness; the continued action of the acid on the main material during the evaporation was thus prevented, though a certain amount of action on the finely divided silicate suspended in the liquid cannot be avoided. The free silica was next extracted with strong solution of sodium carbonate (to which a piece of caustic soda had been added); in the last stages of the washing of the undecomposed material a little of the finely divided silicate passes through the pores of the filter; the amount of this was afterwards determined. The sodic extract was examined, not only for silica, but for bases.

The following numbers were obtained :—

a. Undecomposed material: part washed from filter, 0·9186; part adherent to filter and ignited, 0·1328.

b. The acid solution yielded :—

$\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0·4689; of this 0·4150, after the iron had been expelled by the Deville-Cooke method, gave $\text{Al}_2\text{O}_3, \text{SiO}_2$ 0·0055, and from this 0·0019 of SiO_2 was obtained.

MnS 0·0068.

NiO 0·0001.

The rest of the acid solution, containing the calcium and magnesium, was lost.

¹ Ibid. p. 302.

c. The sodic solution yielded :—

SiO_2 , with trace of undecomposed material, 0·4909. After treatment with HF and H_2SO_4 and subsequent ignition, 0·0089. The residue thus obtained was partly reddish and partly white ; the former was oxide of iron, the latter was found to contain magnesium ; the residue was thus due to the trace of undecomposed material which had passed through the pores of the filter.

$\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0·0048, yielding SiO_2 0·0081 and the Fe_2O_3 , as judged from the colour, being small.

CaO 0·0020, partly due to action on the vessels.

Treatment with hydrochloric acid and sodic solution : Second Portion.

11. 2·7888 grams of the unattracted material, which had been subjected to the action of the mercuric solution (§ 9) and still contained mercury and mercurous chloride, treated in the above way with hydrochloric acid, gave the following :—

a. Undecomposed material : part washed from filter, 1·0981 ; part adherent to filter and ignited, 0·0516.

b. The acid solution yielded :—

$\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0·5018 ; of this 0·4169 gave $\text{Al}_2\text{O}_3, \text{SiO}_2$ 0·0044, which yielded SiO_2 0·0028.

MnS 0·0074.

NiS (after ignition in air) 0·0012.

(CaO , due to action on the vessels, 0·0022.)

CaO 0·0105 (in all the analyses the calcium was twice precipitated).

SiO_2 0·0061 was obtained after the decomposition of the ammonium chloride by nitric acid, and is a measure of the amount of action on the vessels.

$\text{Mg}_2\text{P}_2\text{O}_7$ 1·8884.

c. The sodic solution yielded :—

SiO_2 , with trace of undecomposed material, 0·5301.

After treatment with HF and H_2SO_4 and subsequent ignition, 0·0017.

$\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0·0065 ; of this 0·0046 gave $\text{Al}_2\text{O}_3, \text{SiO}_2$ 0·0082, which itself yielded SiO_2 0·0007.

CaO 0·0018 (probably due, in part at least, to the action on the glass and porcelain).

d. Another portion, weighing 2·0588 grams, lost 0·0512 of volatile material when heated, in a current of hydrogen, in a platinum boat

contained in a platinum tube supported in an oven at 298° C. ; at this low temperature the troilite remains unaffected.

Treatment with hydrochloric acid and sodic solution: Third Portion.

12. 2·0817 grams of the unattracted material, which had been subjected to the action of the mercuric solution (§ 9), but from which the volatile material had been removed by heating at a low temperature in a current of hydrogen, gave the following numbers :—

a. Undecomposed material: part washed from filter, 0·8107; part adherent to filter and ignited, 0·0241.

b. The acid solution yielded :—

$\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0·8775; of this 0·8852 gave $\text{Al}_2\text{O}_3, \text{SiO}_2$ 0·0018, and the latter when analysed yielded Al_2O_3 0·0001, SiO_2 0·0016.

CuS (ignited in air) 0·0008.

MnS 0·0056.

Ni(Co) 0·0010.

CaO 0·0107.

SiO_2 0·0067 was obtained after the decomposition of the ammonium chloride by nitric acid, and is a measure of the amount of action on the vessels.

$\text{Mg}_2\text{P}_2\text{O}_7$ 1·0958 (and this includes the calcium and aluminium due to the action of the nitric acid on the porcelain dish).

The sodic solution yielded :—

SiO_2 , with trace of undecomposed material, 0·4208. After treatment with HF and H_2SO_4 and subsequent ignition, 0·0026.

$\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0·0069; of this 0·0047 gave $\text{Al}_2\text{O}_3, \text{SiO}_2$ 0·0022, and the latter when analysed gave Al_2O_3 0·0024, SiO_2 0·0001.

(CaO , due to action on porcelain dish, 0·0012).

Examination of the blank sodic solution.

13. The amount of the alumina extracted by the sodic solution being appreciable though small, and the amount of sodic solution used being large, it was desirable to make similar experiments on the sodic solution itself. Taking the same amount of sodic solution (20 grams of crystallised sodium carbonate and $2\frac{1}{2}$ grams of caustic soda) as was used in the last analysis, the following numbers were obtained :—

SiO_2 0·0049.

$\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0·0009 (the alumina and silica being probably inappreciable).

CaO 0·0005.

CaO 0·0019, due to action on the porcelain dish.

$\text{Mg}_2\text{P}_2\text{O}_7$ nil.

Undecomposed Material: Specific gravity.

14. The material left undecomposed by the acid and sodic solutions was white in colour, but there was admixed with it a little black material of higher specific gravity than that of the silicate; the black material was found to be chromite. The specific gravity of the admixture was determined from 1.2831 grams of the material by means of a 9 cc. pycnometer. The usual corrections for the temperature of the water and for the displaced air being made, it was found that the weight of the material which occupies a cubic centimeter at 17° C. is 3.171 grams.

Undecomposed Material: Chemical analysis.

15. 0.8981 gram of the undecomposed material was fused with mixed potassium and sodium carbonates. There was a perceptible action on the platinum crucible involving the eventual separation of a little platinum from the magnesium pyrophosphate, but otherwise not interfering with the analysis. The chromite was partially decomposed, and the chromium which passed into solution manifested itself by the green colour of the oxides after the iron had been removed from the ignited precipitate by the Deville-Cooke method; the oxides of iron, aluminium and chromium had been twice precipitated together in dilute solution by the sodium acetate method and finally with ammonia; they were thus free from magnesium.

The following numbers were obtained:—

SiO₂ + chromite 0.5056.

Chromite, after treatment with HF and H₂SO₄, 0.0027.

Fe₂O₃, Cr₂O₃, Al₂O₃, SiO₂ 0.1545; of this 0.1201 yielded Cr₂O₃, Al₂O₃, SiO₂ 0.0898, which itself on being analysed gave Cr₂O₃ 0.0054, Al₂O₃ 0.0314, SiO₂ 0.0006, the loss being probably Al₂O₃.

MnS 0.0042.

CaO 0.0369 (a double precipitation with ammonium oxalate).

Mg₂P₂O₇ 0.5984.

16. *Alkalies.* 0.4994 gram of the undecomposed material, analysed by the Lawrence Smith method, gave:—Sodium and potassium chlorides 0.0183; K₂PtCl₆ (free from filter) 0.0079; adherent to filter and ignited 0.0025. During the operation the chromite was, partially at least, converted into chromate, and Cr₂O₃ 0.0018 was separated from the alkaline solution before the mixed chlorides could be weighed.

Undecomposed material: Action of hydrochloric acid and sodic solution.

17. It is well known that the residue from the treatment with hydrochloric acid and sodic solution is far from insensible to the action of

those reagents; it became desirable to ascertain the amount of this action under similar circumstances to those of the analyses of the unattracted material itself.

1.0388 grams of the undecomposed material were therefore treated in the same way as the unattracted material. The following numbers were obtained:—

a. Residual material: part washed from filter, 0.8807; part adherent to filter and ignited, 0.0363.

b. The acid solution yielded:—

$\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0.0150; of this 0.0080 gave Al_2O_3 0.0005 and SiO_2 *nil*.

SiO_2 0.0022 was obtained from the solution, and is a measure of the action on the vessels.

CaO 0.0076.

After decomposition of the ammonium chloride by nitric acid, SiO_2 0.0033 and $\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3$ 0.0008 were separated from the solution, and were due to the action of the nitric acid on the porcelain dish.

$\text{Mg}_3\text{P}_2\text{O}_7$ 0.0649.

c. The sodic solution yielded:—

SiO_2 , with trace of undecomposed material, 0.0763.

After treatment with HF and H_2SO_4 and subsequent ignition, 0.0014.

$\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0.0071; of this 0.0060 gave $\text{Al}_2\text{O}_3, \text{SiO}_2$ 0.0052, and the latter when analysed gave Al_2O_3 0.0048 and SiO_2 *nil*.

CaO 0.0028.

[Further CaO 0.0016, due to action of nitric acid on the porcelain dish.]

$\text{Mg}_3\text{P}_2\text{O}_7$ *nil*.

Undecomposed material: Effect of ignition.

18. As the undecomposed material contains a considerable proportion of ferrous oxide, it was probable that ignition would appreciably increase its weight. It is necessary to determine the amount of this action, for that part of the silicate which is adherent to the filter cannot be weighed until after ignition.

0.0332 gram of the undecomposed material, after ignition with the gas blowpipe, became 0.0331; there was thus no appreciable change of weight, the increase of weight by oxidation being neutralised by loss due to volatilisation.

Undecomposed material : Effect of hydrofluoric and sulphuric acids followed by ignition.

19. Similarly, it is necessary to determine the effect of hydrofluoric and sulphuric acids, followed by ignition, in order to determine for each case the amount of the finely divided silicate which has passed through the pores of the filter and is admixed with the silica. It was found that 0.0696 gram of the undecomposed material gave after this treatment a residue which weighed 0.0572.

Action of nitric acid on the porcelain.

20. For the precipitation of the small amount of calcium, it is necessary to add to the solution enough ammonium oxalate to convert not merely the calcium itself, but also the magnesium, into oxalate, otherwise part of the calcium may remain in solution. The large amount of ammoniacal salt thus introduced has to be removed before the precipitation of the magnesium: if this is effected by evaporation and ignition, there is great danger of loss through spurting; if it is effected by evaporation with strong nitric acid, there is an appreciable action on the porcelain dish and the magnesium precipitate is not quite pure. The amount of action depends on the duration of the evaporation with nitric acid and on the amount of the latter; it will thus vary in different experiments. To gain some idea of the amount of the action, the silica and calcium thus brought into solution were on several occasions determined and have been recorded above:—

SiO₂ 0.0061 (§ 11), 0.0067 (§ 12).

CaO 0.0036 (§ 4), 0.0040 (§ 9), 0.0020 (§ 10), 0.0013 (§ 11),
0.0022 (§ 11), 0.0012 (§ 12).

The mean of the numbers for the CaO is 0.0024; the weight of the corresponding Ca₃P₂O₇ would be 0.0054: this amount may therefore be properly subtracted from the determined weight of the Mg₃P₂O₇ when the amount of nitric acid used has been about the average.

Section II. Calculations.

Interpretation of the analytical results.

Atomic Weights.

21. The atomic weights used in the following calculations are those

recommended by Professor F. W. Clarke, in the Seventh Annual Report of the Committee on Atomic Weights¹, namely:—

Al	26·9	Fe	55·6	O	15·88
Ba	136·4	H	1	P	30·75
Ca	39·8	K	38·82	Pt	193·4
Cl	35·18	Mg	24·1	S	31·83
Co	58·55	Mn	54·6	Si	28·2
Cr	51·7	Na	22·88		
Cu	63·1	Ni	58·25		

It is convenient to make the calculations in the following order.

Undecomposed Material.

22. *Alkalies.* K_2PtCl_6 0·0079 (§ 16) corresponds to KCl 0·0024 ; 0·0025, adherent to the filter and ignited, if taken as Pt·2KCl, corresponds to KCl 0·0019 ; making altogether KCl 0·0035. From the blank experiment (§ 8), K_2PtCl_6 0·0056 and Pt·2KCl 0·0012 correspond respectively to KCl 0·0017 and KCl 0·0005 ; making in all 0·0022 ; as the direct weight of the chlorides was only 0·0021, the whole 0·0021 must have been potassium chloride. The potassium chloride due to the silicate is thus 0·0014. The mixed chlorides due to the silicate weigh 0·0188 (§ 16)—0·0021 (§ 8) or 0·0162 ; hence the NaCl due to the silicate is 0·0148.

These amounts of NaCl and KCl correspond respectively to Na_2O 0·0079 and K_2O 0·0009 for 0·4994 of undecomposed material, and to Na_2O 1·58, K_2O 0·18 per cent. ; no stress can be laid on the number for K_2O .

As the undecomposed material had been boiled three times, each time for five minutes, in a strong sodic solution, it is not inconceivable that soda might have been introduced into its composition. But the residue had been subjected to a very long continued washing to secure the complete removal of soluble matter ; further, there is already a certain amount of sodium in the mixed silicates before the digestion with sodic solution (§ 5, § 8), and a consideration of the weights of the soda in the mixed silicates and the undecomposed material suggests that the sodium is an original constituent of the latter.

23. 0·1201 (§ 15) of mixed oxides consists of Cr_2O_3 0·0054, Al_2O_3 0·0833, Fe_2O_3 0·0808 and SiO_2 0·0006 ; hence 0·1545 of mixed oxides

¹ Journ. Amer. Chem. Soc. 1900, vol. 22, p. 70.

consists of Cr_2O_3 0·0070, Al_2O_3 0·0428, Fe_2O_3 0·1039 (and SiO_2 0·0008, due to the action on the glass).

Cr_2O_3 0·0070 must have been originally present as chromite ($\text{FeO}\cdot\text{Cr}_2\text{O}_3$) and requires FeO 0·0033; chromite 0·0103 has thus been decomposed further, undecomposed chromite 0·0027 was admixed with the main silica. The total chromite was therefore 0·0130.

Fe_2O_3 0·1039 corresponds to FeO 0·0935; of this 0·0033 is due to chromite, leaving 0·0902 for the silicate.

MnS 0·0042 corresponds to MnO 0·0034.

Deducting 0·0054 (§ 20) from the weight obtained for the $\text{Mg}_2\text{P}_2\text{O}_7$ 0·5384, the pure $\text{Mg}_2\text{P}_2\text{O}_7$ is 0·5330, corresponding to MgO 0·1930.

For 0·8981 of undecomposed material (§ 15), Na_2O is 0·0141 and K_2O 0·0016 (§ 22).

Hence we have the following numbers :—

		Zomba.		Linn County.
		Percentages for silicate.	Oxygen.	Percentages for silicate.
Chromite	0·0130	—	—	—
SiO_2	0·5029	56·83	30·10	55·08
FeO	0·0902	10·19	2·26	} 13·58
MnO	0·0034	0·39	0·09	
MgO	0·1930	21·81	8·68	} 12·22
CaO	0·0369	4·17	1·19	
Al_2O_3	0·0428	4·84	2·27	4·86
K_2O	0·0016	0·18	0·03	} 0·44
Na_2O	0·0141	1·59	0·41	
Total	0·8979	100·00		100·00
Weight taken	0·8981			

The percentage composition of the silicate approaches very closely to the corresponding silicate in the Linn County meteorite as analysed by Rammelsberg.¹

24. The undecomposed material being insoluble in water, the alkalis must be present as constituents of an insoluble compound, presumably feldspar; the presence of the latter is further suggested by the fact that the dyad constituents are insufficient to form an aluminous pyroxene with the alumina and silica.

¹ Monatsb. Ak. Wiss. Berlin, 1870, p. 458.

The CaO cannot be wholly present as a constituent of lime-felspar ($\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$); for in such case the oxygen of the Al_2O_3 must have been 3·57 instead of 2·27, without the alumina required for the soda-felspar being taken into account.

Hence it is reasonable to assume:—

1. That all the alumina is due to felspar (an admixture of albite and anorthite).
2. That all the alkali is due to felspar (albite).
3. That the excess of lime above that required to form felspar is a constituent of the remaining silicate (enstatite).

With these assumptions the following numbers may be obtained:—

The oxygen of $(\text{Na},\text{K})_2\text{O}$ being 0·44, that of the Al_2O_3 and SiO_2 forming albite ($\text{Na}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 6\text{SiO}_2$) will be respectively 1·32 and 5·28. The total oxygen of the Al_2O_3 being 2·27, there is left 0·95 for the oxygen of the Al_2O_3 forming anorthite ($\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$); the oxygen of the corresponding CaO and SiO_2 will thus be respectively 0·32 and 1·28.

We therefore have the following distribution of the oxygen:—

	Total Oxygen.	Oxygen of—		
		Enstatite.	Albite.	Anorthite.
SiO_2 ...	30·10	23·54	5·28	1·28
FeO ...	2·26	2·26	—	—
MnO ...	0·09	0·09	—	—
MgO ...	8·68	8·68	—	—
CaO ...	1·19	0·87	—	0·32
Al_2O_3 ...	2·27	—	1·32	0·95
K_2O } Na_2O }	0·44	—	0·44	—

The total oxygen of the bases of the enstatite, namely 11·9, is slightly more than half that of the silica (23·54). On the other hand, the original constituents of the meteorite have been digested first with hydrochloric acid and then with sodic solution; the latter, while removing the free silica, would be expected to act to some extent on the silicates which resisted the acid, and to carry away the resultant silica, alumina and lime, leaving the corresponding oxides of iron and magnesia from the decomposed enstatite as part of the final residue.

25. The above distribution of oxygen corresponds to the following composition for the silicates themselves:—

		Enstatite.	Felspar.		Total.
			Albite.	Anorthite.	
SiO ₂	...	44.44	9.97	2.42	56.83
FeO	...	10.19	—	—	10.19
MnO	...	0.89	—	—	0.89
MgO	..	21.81	—	—	21.81
CaO	...	3.04	—	1.13	4.17
Al ₂ O ₃	...	—	2.78	2.06	4.84
K ₂ O	...	—	0.18	—	0.18
Na ₂ O	...	—	1.59	—	1.59
		-----	14.52	5.61	-----
		79.87	20.13		100.00

26. The composition of the above felspar is

				Percentages.	Calculated for Oligoclase (Ab ₃ An ₁).
SiO ₂	...	...	12.89	61.55	62.1
CaO	...	...	1.13	5.61	5.3
Al ₂ O ₃	...	...	4.84	24.04	23.9
K ₂ O	...	...	0.18	0.90	} 8.8
Na ₂ O	...	...	1.59	7.90	
			20.13	100.00	100.0

27. The percentage composition of the above enstatite is

		Zomba Enstatite.	Lodran Enstatite.
SiO ₂	...	55.64	55.85
FeO	...	12.76	12.13
MnO	...	0.49	—
MgO	...	27.81	32.85
CaO	...	3.80	0.58
		—	Al ₂ O ₃ 0.60
		100.00	101.51

The numbers thus obtained for the Zomba enstatite are very similar to those obtained by Professor Tschermak for the Lodran enstatite: in the latter case the enstatite grains were so coarse that they could be picked out and a sufficient amount be separated for a special analysis.¹

¹ Sitzungsber. Ak. Wien, 1870, Band 61, Abtheil. 2, p. 465.

28. The mineral composition of the undecomposed material is

Enstatite	...	79·87	78·71
Oligoclase	...	20·18	19·84
Chromite	...	1·47	1·45
		101·47	100·00

Specific gravity of the Zomba enstatite.

29. Since the proportions by weight of the three constituents of the undecomposed material and the specific gravities of two of them (felspar and chromite) are known, it is now possible from the specific gravity of the mixture (§ 14) to calculate the specific gravity of the third constituent (enstatite). The specific gravity of oligoclase Ab_3An_1 is 2·66 : that of chromite varies from 4·32 to 4·57 (Dana), the mean of which is 4·44 : that of the mixture was found to be 3·171 (§ 14). The total volume of a mixture being the sum of the volumes of the constituents, it follows that, if x be the specific gravity of the enstatite,

$$\frac{78\cdot71}{x} + \frac{19\cdot84}{2\cdot66} + \frac{1\cdot45}{4\cdot44} = \frac{100}{3\cdot171}$$

Whence x is 3·314.

The specific gravity of the Lodran enstatite was directly determined by Professor Tschermak to be 3·313.

Undecomposed material: Amount of action of hydrochloric acid and sodic solution.

30. The trace of undecomposed material, which, after treatment with hydrofluoric and sulphuric acids, weighed 0·0014 (§ 17), must before that treatment have weighed 0·0017 (§ 19); hence SiO_2 is 0·0746 : and the total amount of undecomposed silicate is 0·0017 + 0·8807 + 0·0868 or 0·9187; for ignition does not appreciably alter the weight of the undecomposed material (§ 18). After deduction of SiO_2 0·0049 due to the sodic solution itself (§ 18), we have, for the SiO_2 due to the silicate, 0·0697.

For the hydrochloric acid extract :—

Fe_2O_3, Al_2O_3, SiO_2 0·0150 consisted of Fe_2O_3 0·0140 (corresponding to FeO 0·0127), Al_2O_3 0·0009, SiO_2 *nil*.

Deducting 0·0054 from $Mg_3P_2O_7$ 0·0649 as being really $Ca_2P_2O_7$ due to the action of the nitric acid on the porcelain (§ 20), we have $Mg_3P_2O_7$ 0·0595, corresponding to MgO 0·0215. Collecting the results :—

			Acid Extract.	Sodic Extract.	Total Extract.
SiO ₂	...	...	—	0·0697	0·0697
FeO	...	...	0·0127	—	0·0127
MnO	...	...	—	—	—
MgO	...	...	0·0215	—	0·0215
CaO	...	...	0·0076	0·0023	0·0099
Al ₂ O ₃	..	...	0·0009	0·0062	0·0071
K ₂ O	}	...	undet.	undet.	undet.
Na ₂ O					
Total extract					0·1209
Undecomposed residue					0·9187
Weight found					1·0396
Weight taken					1·0388

Hence it follows that when the undecomposed material is subjected to the action of hydrochloric acid and sodic solution in the same way and for the same length of time as in the analysis of the mixed powder itself, no less than 11·64 per cent. pass into the acid or sodic solution. As there is little alumina in the acid extract, either the felspar is only very slightly attacked by the acid, or the alumina is set free in such a form as to be only with difficulty soluble in the acid, though removable by the sodic solution¹; more probably the greater part of the decomposition of the felspar is due to the sodic solution itself.

If we allow soda in sufficient proportion to form oligoclase with the alumina (§ 24) the percentage composition of the total extract is

SiO ₂	...	...	56·44
FeO	...	...	10·29
MnO	...	...	—
MgO	...	...	17·41
CaO	...	...	8·02
Al ₂ O ₃	...	...	5·75
K ₂ O	}	..	2·09
Na ₂ O			
			100·00

The total extract has thus nearly the same composition as the original mixture (§ 23). The chief part of the solvent action on the enstatite is

¹ Jour. Chem. Soc. vol. 41, 1882, Transactions, p. 159.

due to the acid; the silica set free by this action is removed by the sodic solution, which at the same time acts to some extent on the felspar, taking all the constituents into solution, and probably to some extent on the enstatite, removing the silica and lime but leaving its oxide of iron and magnesia in the final residue. The corresponding oxide of iron and magnesia left in the undecomposed residue by the action of the previous sodic solution will have passed into the acid extract.

Unattracted material: Treatment with mercuric solution.

31. Fe_2O_3 0·0021 (§ 9) corresponds to Fe 0·0015. Hence the total amount of alloy extracted by the mercuric solution from 4·9856 grams of the unattracted material was at most 0·0022, containing 31·82 per cent. of nickel; as already stated, the high percentage of the nickel was already manifested by the colour of the extract. This again points to the easy oxidation of the iron of the finer particles of nickel-iron during the exposure to the air in the course of the magnetic separation and afterwards; the nickel being less easily oxidised and less readily attracted by the magnet, the percentage of the nickel in the metallic portion still left with the unattracted material will be higher than in the original nickel-iron.

Unattracted material: Alkalies.

32. K_2PtCl_6 0·0040 (§ 8) corresponds to KCl 0·0012; 0·0036, adherent to the filter and ignited, if taken as $\text{Pt}\cdot 2\text{KCl}$, corresponds to KCl 0·0016; making altogether KCl 0·0028.

From the blank experiment (§ 22) the KCl due to the reagents is 0·0021; hence only KCl 0·0007 can be assigned to the silicate.

The mixed chlorides due to the silicate weigh 0·0135 (§ 8)—0·0021 (§ 22), or 0·0114; the NaCl is thus 0·0107.

These amounts of NaCl and KCl correspond respectively to Na_2O 0·0057 and K_2O 0·0004 for 0·4815 of material, and to Na_2O 1·18 and K_2O 0·08 per cent.

As the total amount of matter extracted from the unattracted material by boiling water amounted to only 0·26 per cent. and part of it consisted of calcium and magnesium, it is inferred that the alkalies were present in the unattracted material as constituents of an insoluble compound, presumably felspar.

Unattracted material: First Portion.

33. The trace of undecomposed material which, after treatment with hydrofluoric and sulphuric acids weighed 0·0089 (§ 10), must before that treatment have weighed 0·0047 (§ 19); and the total amount of undecom-

posed material is $0\cdot0047 + 0\cdot9186 + 0\cdot1828$ or $1\cdot0561$, for ignition does not appreciably alter the weight of the undecomposed material (§ 18).

The true SiO_2 is $0\cdot4909 - 0\cdot0047$ or $0\cdot4862$: but of this $0\cdot0049$ are due to the sodic solution itself (§ 18): the SiO_2 really due to the silicate is thus $0\cdot4813$. Of the $\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ $0\cdot0048$, the Fe_2O_3 was small and probably only that from the sodic solution itself $0\cdot0009$ (§ 18), the SiO_2 was $0\cdot0031$ (making the total SiO_2 $0\cdot4844$) and (by deficit) Al_2O_3 is $0\cdot0008$.

The $\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ $0\cdot4689$ from the acid extract consists of Fe_2O_3 $0\cdot4578$ (corresponding to FeO $0\cdot4120$), Al_2O_3 $0\cdot0040$ (and SiO_2 $0\cdot0021$ due to action on the vessels).

Further $2\cdot5065$ of unattracted material contain an amount of sulphur (§ 7) corresponding to FeS (troilite) $0\cdot1412$, which is itself equivalent to FeO $0\cdot1155$; as this iron is in the acid extract, only FeO $0\cdot2965$ (*i.e.* $0\cdot4120 - 0\cdot1155$) is due to the silicate.

MnS $0\cdot0068$ corresponds to MnO $0\cdot0055$.

[NiO $0\cdot0001$ may be neglected in the calculations.]

Hence we have:—

				Percentages.	
Undecomposed material	...	...	1·0561	42·13
Troilite	...	...	0·1412	5·63
SiO_2	...	...	0·4844	19·33
FeO}	...	...	0·2965	11·83
MnO}	...	...	0·0055	0·22
MgO}	...	...	undet.	undet.
CaO}	...	...	undet.	undet.
Acid extract	0·0040	} Al_2O_3	...	0·0048	0·19
Sodic extract	0·0008				
K_2O}	...	...	undet.	undet.
Na_2O}	...	...	undet.	undet.
Total			1·9885	79·33	
Weight taken			2·5065	100·00	

Unattracted Material: Second Portion.

84. The amount of volatile material corresponding to $2\cdot7338$ of the material taken for analysis would be $0\cdot0680$ (§ 11), and the weight of the pure material was thus $2\cdot6653$.

The trace of undecomposed material which after treatment with hydrofluoric and sulphuric acids weighed $0\cdot0017$ (§ 11) must before that treatment have weighed $0\cdot0021$ (§ 19): and the total amount of undecomposed material is $0\cdot0021 + 1\cdot0981 + 0\cdot0516$, or $1\cdot1518$, for the weight of the undecomposed material is not appreciably altered by the ignition (§ 18).

The true SiO_2 is thus $0\cdot5296 - 0\cdot0021$ or $0\cdot5275$; but of this $0\cdot0049$ is due to the sodic solution itself (§ 18); the SiO_2 really due to the silicate being therefore $0\cdot5226$.

The $\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0·0065 consists of Fe_2O_3 0·0020, Al_2O_3 0·0035 and SiO_2 0·0010 (making the total SiO_2 0·5236): deducting Fe_2O_3 0·0009 as due to the sodic solution itself, Fe_2O_3 0·0011 has passed into the sodic solution from the silicate (possibly through finely divided silicate passing through the pores of the filter).

The $\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0·5013 of the acid extract consists of Fe_2O_3 0·4960, Al_2O_3 0·0019 and SiO_2 0·0034 (due to action on the vessels).

(NiS ignited 0·0012 may be omitted in the calculations.)

MnS 0·0074 corresponds to MnO 0·0060.

The $\text{Mg}_3\text{P}_2\text{O}_7$ (pure) is 1·3834 (§ 11) — 0·0054 (§ 20) or 1·3780, corresponding to MgO 0·4989.

The total Fe_2O_3 is 0·4960 + 0·0011 or 0·4971, corresponding to FeO 0·4474: further, 2·6653 of the unattracted material contain an amount of sulphur (§ 7) corresponding to FeS (troilite) 0·1502, which itself is equivalent to FeO 0·1259: as this iron is in the acid extract, only 0·3215 (*i.e.* 0·4474 — 0·1259) of FeO is due to the silicate.

The total CaO obtained is 0·0013 + 0·0105 or 0·0118; from this must be deducted 0·0005 as due to the sodic solution (§ 13).

Also 2·6653 of the unattracted material contain (§ 22) K_2O 0·0022, Na_2O 0·0315; and the 1·1518 of undecomposed material contain (§ 22) K_2O 0·0021, Na_2O 0·0182: hence there must have passed into the acid and alkaline solutions K_2O 0·0001 (or *nil*) and Na_2O 0·0133.

Collecting the results we have:—

			Percentages.	
Undecomposed material	...	...	1·1518	43·21
Troilite	...	...	0·1502	5·64
SiO_2	...	...	0·5236	19·65
FeO	...	...	0·3215	12·06
MnO	...	...	0·0060	0·23
MgO	...	...	0·4989	18·72
CaO	...	...	0·0118	0·42
Acid extract 0·0019)				
Sodic extract 0·0035)	Al_2O_3	...	0·0054	0·20
K_2O}	...	...	<i>nil</i>	<i>nil</i>
Na_2O}	...	...	0·0133	0·50
Total			2·6820	100·63
Weight taken			2·6653	100·00

Unattracted Material: Third Portion.

35. The trace of undecomposed material which, after treatment with hydrofluoric and sulphuric acids weighed 0·0026 (§ 12), must before that treatment have weighed 0·0032 (§ 19); and the total amount of undecomposed material is 0·0032 + 0·8107 + 0·0241, or 0·8380, for the undecomposed material is not appreciably altered in weight by ignition (§ 18).

The true SiO_2 is thus $0.4208 - 0.0082$ or 0.4176 , but of this 0.0049 is due to the sodic solution itself (§ 13); hence the SiO_2 really due to the silicate is 0.4127 .

The $\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0.0069 consists of Fe_2O_3 0.0037 , Al_2O_3 0.0031 (SiO_2 0.0001 , making the total SiO_2 0.4128).

Deducting Fe_2O_3 0.0009 as due to the sodic solution itself, Fe_2O_3 0.0028 has passed into the sodic solution from the silicate (possibly through finely divided silicate passing through the pores of the filter).

The $\text{Fe}_2\text{O}_3, \text{Al}_2\text{O}_3, \text{SiO}_2$ 0.3775 consists of Fe_2O_3 0.3755 , Al_2O_3 0.0002 (SiO_2 0.0018 , due to the action on the vessels).

CuS (ignited) 0.0003 and $\text{Ni}(\text{Co})$ 0.0010 may be neglected during the calculation.

MnS 0.0056 corresponds to MnO 0.0046 .

The $\text{Mg}_2\text{P}_2\text{O}_7$ (pure) is 1.0958 (§ 12) $- 0.0054$ (§ 20) or 1.0904 , corresponding to MgO 0.3948 .

The total Fe_2O_3 is $0.3755 + 0.0028$ or 0.3783 , corresponding to FeO 0.3405 ; further, 2.0817 of the unattracted material contain an amount of sulphur (§ 7) corresponding to FeS (troilite) 0.1145 which itself corresponds to FeO 0.0936 ; as this iron is in the acid solution, only $0.3405 - 0.0936$, or 0.2469 , of FeO is due to the silicate.

The total CaO obtained is $0.0023 + 0.0107$ or 0.0130 ; from this must be deducted 0.0005 as due to the sodic solution (§ 13).

Also 2.0817 of the unattracted material contain (§ 32) K_2O 0.0017 , Na_2O 0.0241 ; and the 0.8380 of undecomposed material contains (§ 22) K_2O 0.0015 , Na_2O 0.0133 : hence K_2O 0.0002 (or *nil*) and Na_2O 0.0108 must have passed into the acid and sodic extracts.

Collecting these results we have:—

				Percentages.	
Undecomposed material	...	...	0.8380	41.25
Troilite	...	...	0.1145	5.64
SiO_2	...	...	0.4128	20.32
FeO}	...	...	0.2469	12.15
MnO}	...	...	0.0046	0.23
MgO}	...	...	0.3948	19.43
Acid extract	0.0107	} CaO	...	0.0125	0.61
Sodic extract	0.0018				
Acid extract	0.0002	} Al_2O_3	...	0.0033	0.16
Sodic extract	0.0031				
K_2O}	...	...	<i>nil</i>	<i>nil</i>
Na_2O}	...	...	0.0108	0.53
Total			2.0882	100.32	
Weight taken			2.0817	100.00	

36. Bringing the results together for convenience of comparison, we have :—

	I.	II.	III.	Mean.	Oxygen.
Undecomposed material } ...	42·13	43·21	41·25	42·20	—
[Troilite ...	5·63	5·64	5·64	5·64]	—
SiO ₂ ...	19·33	19·65	20·32	19·77	10·47
FeO ...	11·83	12·06	12·15	12·01	2·67
MnO... ..	0·22	0·23	0·23	0·23	0·05
MgO... ..	undet.	18·72	19·43	19·07	7·59
CaO	undet.	0·42	0·61	0·51	0·15
Al ₂ O ₃ ...	0·19	0·20	0·16	0·18	0·08
[Na ₂ O... ..	undet.	0·50	0·53	0·51]	0·13
Total	79·33	100·63	100·32	100·12	
Weight taken	100·00	100·00	100·00	100·00	

In the analysis of the first portion, the three successive extractions with acid were allowed to proceed for 1½ hours, 2 hours and 2 hours, respectively ; in the case of the second portion the times were 2 hours, 1½ hours, and 2 hours, respectively ; in that of the third portion, each extraction lasted two hours. As it has been shown (§ 30) that no less than 11·64 per cent. of the undecomposed material are decomposed during such extractions, it follows that the variation from 41·25 per cent. to 43·21 per cent. in the amount of residue in the three analyses is sufficiently accounted for by variations of circumstances during the extractions ; for instance, of the times for which each extraction is allowed to proceed, the temperature of the extracting acid, the frequency of renewal of the evaporated water, and so on. The actual extract corresponds very closely to olivine, and neglecting the soda and alumina has the following composition :—

	Per cent.	Oxygen.	Muddoor.	Linn County.
SiO ₂	19·77	38·25	20·26	38·32
FeO	12·01	23·23	5·16	23·29
MnO	0·23	0·45	0·10	—
MgO	19·07	36·89	14·68	36·90
CaO	0·51	1·18	0·34	1·07
			Al ₂ O ₃	0·42
	51·59	100·00		100·00

This composition is virtually identical with that calculated by Crook¹ for the olivine of the Muddoor meteorite and also is very nearly that of the "decomposed portion" of the Linn County stone as analysed by Rammelsberg².

Some of the silica, however, must have been originally in combination with the soda and alumina which have been neglected, and further a small quantity of the remaining constituents is due to the action of the hydrochloric acid and sodic solution on the enstatitic silicate.

37. An estimate of the quantities due to the action on the refractory silicates can be obtained by assuming that they are in the same proportion to the undecomposed residue as in the analysis mentioned in § 30. But the estimate will be only approximate, for in the analysis of the mixture the strength of the acid and its decomposing effect are diminished owing to the action of the olivine: further the gelatinous silica from the olivine will partially protect the other silicates from the acid; and the presence of the compounds due to the decomposition of the olivine may have a disturbing effect on the action of the acid.

These considerations being disregarded, it follows from § 30 that when the residue weighs 88.36 the following amounts due to the refractory silicates have passed into solution:—SiO₂ 6.57, FeO 1.20, MgO 2.03, CaO 0.93, Al₂O₃ 0.67, R₂O 0.24; hence for the residue 42.20 the corresponding amounts are SiO₂ 3.14, FeO 0.57, MgO 0.97, CaO 0.44, Al₂O₃ 0.32, R₂O 0.11, making in all 5.55. Deducting these amounts from the quantities found in the solution (§ 36), we have for the less refractory silicate itself:—

SiO₂ 16.63, FeO 11.44, MnO 0.23, MgO 18.10, CaO 0.07, Al₂O₃ 0.14,
Na₂O 0.40.

Omitting the CaO, Na₂O, Al₂O₃ as being possibly extraneous, we have the following composition:—

		Per cent.	Oxygen.	Muddoor (observed).
SiO ₂	16.63	35.84	18.98	SiO ₂ 35.46
FeO	11.44	24.65	5.48	FeO 24.36
MnO	0.23	0.50	0.11	} 21.11
MgO	18.10	39.01	15.52		MgO 38.61
				CaO 1.13
				Al ₂ O ₃ 0.44
	<hr/>	<hr/>		<hr/>
	46.40	100.00		100.00

¹ Die Chemische Natur der Meteoriten, von C. Rammelsberg, 1879, p. 54.

² Monatsb. Ak. Wiss. Berlin, 1870, p. 459.

The nearness of the oxygen-ratio to that of olivine is thus lessened by the deduction of the quantities resulting from the action on the refractory silicates; but the composition is almost identical with that observed by Crook for the decomposable silicate of the Muddoor meteorite.

According to this interpretation, the total amount of enstatite, felspar and chromite in the unattracted material would be 47.75 per cent., 42.20 per cent. remaining undecomposed and 5.55 per cent. passing into the acid and sodic solution.

Unattracted Material: Chromite.

38. Since the unattracted material yields 42.20 per cent. of undecomposed residue (§ 36) and the latter itself contains (§ 28) 1.45 per cent. of chromite, the unattracted material must contain 0.61 per cent. of chromite. By direct extraction with hydrofluoric and sulphuric acids only 0.35 per cent. was isolated, but probably some is decomposed and passes into solution (§ 6). Similarly, the chromium obtained during the determination of the alkalis corresponds to only a small fraction of the total chromite.¹

39. The enstatite and oligoclase of the unattracted material will thus (§§ 37, 38) amount to (47.75 - 0.61 or) 47.14 per cent., and this will consist (§ 28) of 37.65 of enstatite and 9.49 of oligoclase; the troilite is 5.64 per cent. (§ 36): hence the olivine amounts to 46.61 per cent. The mineral composition of the unattracted material (neglecting minute quantities of nickel-iron and schreibersite) will therefore be

				Total weight.
Olivine	...	46.61		5.7894
Enstatite	...	37.65		4.6764
Oligoclase	...	9.49		1.1787
Troilite	...	5.64		0.7005
Chromite	...	0.61		0.0758
		100.00		12.4208 grams.

Attracted Material: First Set of Extracts.

40. The $\text{Fe}_2\text{O}_3, \text{P}_2\text{O}_5, \text{SiO}_2$ 0.4933 (§ 2) consists of Fe_2O_3 0.4895 (corresponding to Fe 0.3427), P_2O_5 0.0003 (corresponding to P 0.0001), (SiO_2 0.0028 due to the action on the vessels).

The phosphorus being present as Fe_2NiP (schreibersite) requires Fe 0.0004, Ni 0.0002.

The Ni(Co) due to nickel-iron (§ 2) is thus 0.0487 - 0.0002 or 0.0485.

¹ Mineralogical Magazine, 1894, vol. 10, p. 307.

Hence we have :—

Extracted :—Nickel-iron	$\left\{ \begin{array}{l} \text{Fe} \quad 0\cdot0342 \\ \text{Ni(Co)} \quad 0\cdot0485 \end{array} \right\}$	0·8908
Schreibersite	... ..	0·0007
Residue (§ 3)	... ..	0·8385
	Total	0·7900
	Weight taken	0·7421

No great stress can be laid on the loss of weight (0·0121), owing to the character of the necessary operations.

The percentage composition of the nickel-iron (0·8908) which has passed into solution is Fe 87·59, Ni(Co) 12·41.

Further, $3\text{K}_2\text{SO}_4 \cdot 2\text{CoSO}_4$ 0·0166 corresponds to Co 0·0024 : hence the percentage composition of the Ni(Co) is Ni 95·07, Co 4·93, and that of the nickel-iron is Fe 87·59, Ni 11·80, Co 0·61, Cu *trace*.

Attracted Material: Second Set of Extracts.

41. Fe_2O_3 0·0489 (§ 3) corresponds to Fe 0·0307 ; and the Ni(Co) is 0·0135.

Hence we have :—

Extracted :—Nickel-iron	$\left\{ \begin{array}{l} \text{Fe} \quad 0\cdot0307 \\ \text{Ni(Co)} \quad 0\cdot0135 \end{array} \right\}$	0·0442
Residue (§ 4)	... ..	0·2850
	Total	0·3292
	Weight taken	0·3366

As before, no stress can be laid on the loss of weight (0·0074) ; the percentage composition of the nickel-iron (0·0442) extracted in the second series of operations is Fe 69·46, Ni(Co) 30·54.

Attracted Material: Residue.

42. The $\text{Fe}_2\text{O}_3, \text{SiO}_2$ 0·0450 (§ 4) consists of Fe_2O_3 0·0447 (corresponding to Fe 0·0306) and SiO_2 0·0013 (due to the action on the vessels).

$\text{Mg}_2\text{P}_2\text{O}_7$ 0·1137 corresponds to MgO 0·0412 (having regard to the smallness of this amount, the action of the nitric acid on the vessels must likewise have been small, and no deduction is made) ; the MgO being due to the silicates, other constituents in corresponding proportion must likewise be due thereto ; hence the quantities will be (§ 35) :—

SiO_2 0·0420, MgO 0·0412, FeO 0·0245, MnO 0·0005, CaO 0·0011, making altogether 0·1093 of silicate decomposed by the hydrochloric acid ; this leaves SiO_2 0·0027 (namely 0·0447—0·0420) unallotted ; the above quantities are only approximate, for the enstatitic and felspathic

silicates are acted on by the acid and sodic solutions, and their proportions to the olivine are probably different from those which obtain in the unattracted material. Further, FeO 0·0245 of the silicate corresponds to Fe 0·0191 which is included in the above total Fe 0·0806; the Fe due to the alloy itself is thus 0·0115.

Hence we have :—

Final residue (enstatite, &c.)	...	0·1409	(§ 4)
Silicate decomposed (olivine, &c.)	...	0·1093	
Fe	... ..	0·0115	
Ni(Co)	... ..	0·0072	
Unallotted SiO ₂	... ..	0·0027	
		0·2716	Total
		0·2757	Weight taken

The loss in this case (0·0041) is, partly at least, oxygen: the amount of oxygen necessary to convert the whole of the iron into Fe₃O₄ would be 0·0044. That there is a certain amount of unoxidised metal present is shown by the effervescence of the material with the acid (§ 4): that there is oxide present is indicated by the extreme slowness of action of the mercuric solution on the material (§ 3). As there is only a small proportion of black opaque matter visible in the thin sections when examined with the microscope, and this is probably chromite, the oxidation had probably taken place during the analysis itself, as already suggested (§ 2). The iron and nickel in this residue corresponding to original metal will thus be Fe 0·0115, Ni(Co) 0·0072, corresponding to 0·0187 of alloy having the percentage composition Fe 61·50, Ni(Co) 38·50.

48. Hence we have the following results :—

		Nickel-iron.	Fe.	Ni(Co).	Percentage of Ni(Co).
First Extracts	...	0·9908	0·3423	0·0485	12·41
Second Extracts	...	0·0442	0·0307	0·0135	30·54
Residue	... ..	0·0187	0·0115	0·0072	38·50

Hence, of the total nickel-iron contained in the attracted material, 86·13 per cent. are removed in the first set of extractions, 9·75 in the second, and the remaining 4·12 is left partly as oxide and partly as metal, the latter protected from the mercuric solution by enclosing oxide or silicate. The variation of the percentage of nickel (cobalt) from 12·41 to 38·50, as the extraction proceeds, does not necessarily imply the existence of different alloys of nickel-iron in the material; it is probably a

mere result of the easier oxidation of the iron than the nickel during exposure of the alloy to the atmosphere in the course of the operations.

Attracted Material: Mineral Composition.

44. Calculation, from these numbers, of the composition of the various residues leads to the following composition for the attracted material:—

			Grams.
Nickel-iron	...	...	1·2422
Olivine	...	...	0·8373
Enstatite	...	...	0·8474
Oligoclase	...	...	0·0875
			2·0144;

for the proportion of the decomposed to the undecomposed silicate is known from § 42, and the proportion of the enstatite to the oligoclase may be taken to be the same as for the previous similar material (§ 28).

Mineral Composition of the Fragment.

45. From §§ 39, 44, the mineral composition of the complete fragment was:—

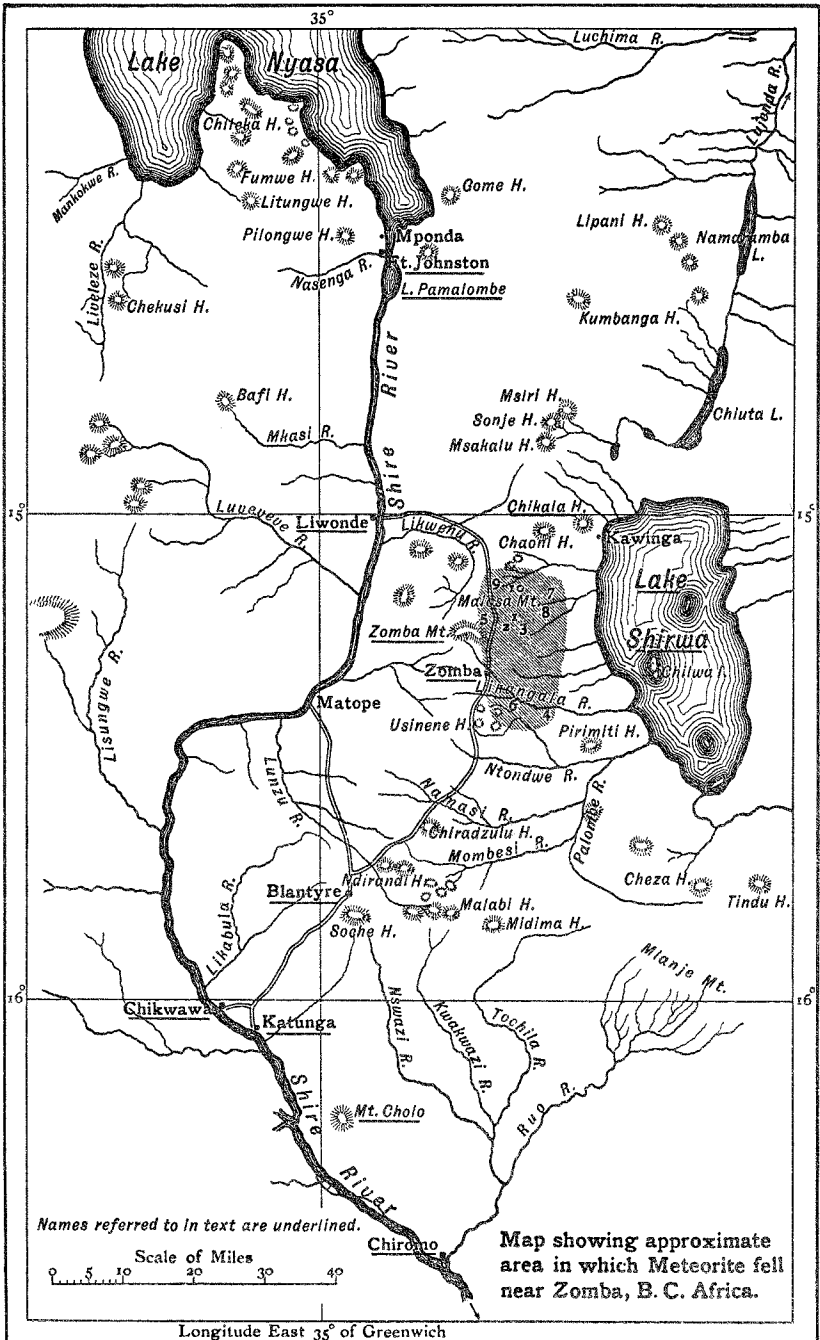
	Grams.	Zomba. Percentages.	Linn County. ¹ Percentages.
Nickel-iron	... 1·2422	8·61	10·54
Olivine	... 6·1267	42·44	41·85
Enstatite	... 5·0288	34·80	41·24
Oligoclase	... 1·2662	8·77	
Troilite	... 0·7005	4·85	6·37
Chromite	... 0·0758	0·53	—
14·4852		100·00	100·00

Mineralogical Relationship to other Meteoric Stones.

The Zomba meteorite thus consists of a stony material composed of olivine and enstatite in nearly equal quantity admixed with a certain amount of oligoclase; embedded in this stony material are nickel-iron and troilite in considerable quantity and small amounts of chromite and schreibersite. In the aspect of the thin sections as seen under the microscope, in the proportions of the mineral constituents (§ 45), in the percentage chemical composition of the silicate decomposed by hydrochloric acid (§ 36) and in that of the silicate obtained as a residue after the action of the acid and the sodic solution (§ 23), the Zomba meteorite

¹ Monatsb. Ak. Wiss. Berlin, 1870, p. 458.

closely resembles the stone which fell in Linn County, Iowa, U.S.A., on 25th February, 1847; different parts of one meteoric stone would generally show greater differences. The composition here assigned to the Zomba enstatite, after analysis of what is interpreted to be a mixture of enstatite and oligoclase, is very near to that found by Professor Tschermak for the coarse grains of enstatite which he was able to isolate from the Lodran stone for chemical determination (§ 27), and the specific gravity as calculated for the Zomba enstatite from the specific gravity of the mixture is virtually identical with the specific gravity directly determined by Professor Tschermak for the isolated Lodran mineral (§ 29). Further, it is found that the "undecomposed residue," when itself subjected to the treatment used in the analysis of the unattracted material, loses nearly 12 per cent. of its weight; the enstatite is chiefly acted upon by the acid, the oligoclase by the sodic solution (§ 30).



L. FLETCHER: ZOMBA METEORITE.

Walker & Cockerell sc.