

*Papers and notes on the
genesis and matrix of the diamond*

Henry Carvill Lewis, Thomas George Bonney

To
The University of Michigan

In accordance with
the wishes of the late
Prof. Henry Carvill Lewis, M.A., F.G.S.
Mrs Carvill Lewis
has the honour to present
The University of Michigan
with a copy of
Prof. Carvill Lewis' monograph on
The Genesis of the Diamond,
and respectfully asks that an
acknowledgement of the due receipt of
the same may be sent to her.

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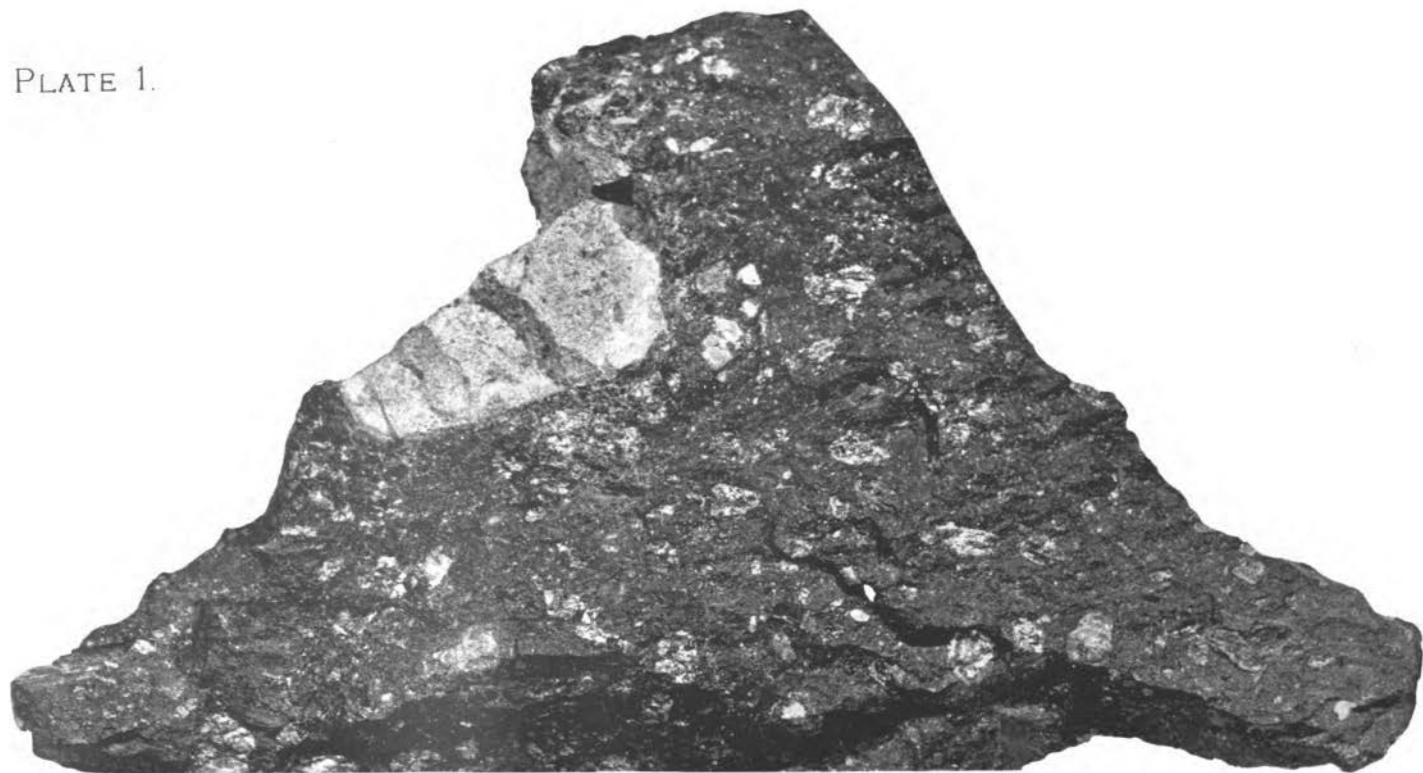
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THE DIAMOND

PLATE 1.



FRAGMENT OF THE DIAMOND-BEARING ROCK FROM KIMBERLEY.

PAPERS AND NOTES
ON THE
GENESIS AND MATRIX
OF
63764
THE DIAMOND

BY THE LATE

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EDITED FROM HIS UNPUBLISHED MSS.

BY

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NOTE

Mrs. CARVILL LEWIS gladly avails herself of this opportunity to express her indebtedness and gratitude to Professor T. G. BONNEY for his kindness in arranging and editing the papers and notes contained in this book, in accordance with the wishes of the late Professor Henry Carvill Lewis, whose desire it was that his researches on the origin and matrix of the diamond should be given to the scientific world.

Ms. A. 1112 5-19-38

P R E F A C E

A FEW words of explanation are necessary in order to indicate my connection with this book and what has or has not been attempted in preparing it for publication. Shortly after the death of Professor Carvill Lewis in July 1888, in accordance with directions given during his last illness, the manuscripts of his two papers on the diamond-bearing rocks of Kimberley, communicated to the British Association at the meetings in 1886 and 1887 respectively, together with the specimens on which he had worked and a number of miscellaneous notes, were given by Mrs. Lewis to Professor G. H. Williams of the Johns-Hopkins University, who had kindly promised to carry out his late friend's desires by preparing the incomplete material for publication, as soon as his other duties and engagements permitted. But the pressure of these was so great that an opportunity had not been found when he too was taken away from this world by the same disease (typhoid fever) which had proved fatal to Professor Lewis. As I have been for many years a student of the structure and history of olivine rocks and serpentines, I had felt great interest in the papers to which I had listened at Birmingham and Manchester, and thought it would be most unfortunate if the numerous careful and minute observations which they

contained were much longer delayed in publication, or, perhaps, were even lost to science. Accordingly I informed Mrs. Lewis that if she would entrust the manuscripts to me I would do my best to arrange them for publication, stating at the same time that I could not attempt more than to act as an editor to the materials which had been left by her late husband. From some of the documents it was obviously his intention, had his life been spared, to have carried on his researches and to have made additions to the original papers so as to bring the subject down to the date of publication. But this task, as I told Mrs. Lewis, I could not undertake. Parts of the subject lay rather outside my usual lines of work, so that very much time would have had to be spent in hunting through the geological, and more especially mineralogical, literature of the last eight or nine years on the chance of finding something throwing light on the questions treated by Professor Lewis. As the hours which I can devote to prosecuting my own investigations are none too numerous already, I was unable to undertake what would have been of little profit and hardly any interest. To me no work is so irksome as that of searching through periodicals on the chance of lighting upon some contribution—possibly in itself of little value—to the literature of a subject.

Thus the two papers, forming the first and second sections of this book, are printed very nearly as they were left by Professor Lewis. The references have been tested and corrected, and a few changes have been made here and there in phrase or in the order of sentences. These changes, however, are merely editorial, such as the author himself would have most probably made in finally revising his manuscript for the press. Accordingly the statements printed and the results given represent his views, at

any rate in 1887, and, so far as I know, at the time of his death. Of the third section nothing had been written; the materials consisted only of some very brief 'jottings' and a small set of rock specimens. The latter, however, appeared to me to have such an important bearing on the subject of the first two sections that I have drawn up a statement of the facts concerning them from such literature as I have found, and have written some brief descriptions of the structures, macroscopic and microscopic, of the specimens themselves.

In addition to the above-named materials, Professor Lewis left numerous notes on the occurrence of diamonds in other countries, and on various matters bearing more or less indirectly on the subject of the two papers. Two pocket-books also were placed in my hands, containing memoranda of a journey through some districts in the United States where diamonds had been, or were said to have been, discovered. From these I compiled two other sections, weaving the materials of the latter, after considerable condensation, into a continuous narrative. The manuscript was set up in type, but Professor Rosenbusch, to whom the whole of the proofs were submitted, was of opinion that they would not augment the value of the earlier part of the book, because the notes on localities were obviously incomplete, and the journeys were more negative than positive in their results. Moreover, many of the facts recorded had already, owing to the lapse of time, become incorporated into literature readily accessible to students. I had myself felt a like misgiving, but, for a reason which will appear below, felt bound to alter or to cancel as little as possible. But when fortified by such an authority on this special topic as Professor Rosenbusch, in whose laboratory at Heidelberg much of the work

embodied in the first and second section had been done, I had no hesitation (with the concurrence of Mrs. Lewis) in following his advice. So this portion has been cancelled, and as the book now stands it comprises all the manuscript that Professor Lewis had left in a fairly complete state, with a little supplementary work which has a very direct bearing on the subject of his two papers, and for which he had collected specimens.

Several months elapsed, owing to various circumstances, before Mrs. Lewis could place the late Professor's manuscripts and the other materials in my hands. In the interval Sir J. B. Stone, M.P., when I was a guest at Erdington Grange, his pleasant home near Sutton Coldfield, showed me a collection of specimens which he had obtained during a recent visit to the Kimberley mines. Among these were two lumps of the diamond-bearing rock, each as large as three or four ordinary cabinet specimens, and in a much better state of preservation than any which I had previously seen. One of these he kindly gave to me, asking me to examine its structure, and allowing me to make use of the other materials in his possession. Some microscopic sections were prepared from this specimen, and, in addition to others already in my collection, the gift of Professor Boyd Dawkins, I had the advantage of studying one or two small but well-preserved pieces of the rock, which had been presented to Miss C. A. Raisin by C. J. Alford, Esq., as well as others kindly lent to me by the late Professor A. H. Green.¹ The results of these studies were published in the *Geological Magazine* for 1895 (pp. 492-502) in a paper jointly written by Sir J. B. Stone, Miss C. A. Raisin,

¹ He died after a short illness, the result, I fear, of overwork, in August 1896. A good geologist and a most unselfish man, *multis ille bonis flebilis occidit!*

and myself. Our conclusions in one respect differed a little from those expressed by my lamented friend Professor Lewis—viz. as to the origin of the diamond-bearing rock to which he has given the name Kimberlite. Its precise nature is undoubtedly very difficult to determine. It differs from any rock, whether peridotite or serpentine, known to me, and my experience, especially in regard to the latter, is a rather large one. Its structure is hardly such as I should expect to result from the hydration of a glass, the chemical composition of which nearly corresponded with that of olivine, and it seems to me improbable that the material would have remained in a glassy condition throughout pipes or necks of such great size, which also have now been excavated to a considerable depth. Olivine is not a very fusible mineral, and vitreous peridotites are even more rare and limited in extent than tachylites; indeed, I am doubtful whether I have ever really met with one. Some, indeed, of the fragments in these diamond-bearing breccias (for, whatever may be the explanation, they undoubtedly exhibit a brecciated structure) may—probably do—represent either a glassy or at any rate a very compact form of peridotite (now converted into serpentine); but I regard them, together with the olivine, augite, mica, garnets, and other large minerals (not excluding the diamonds) as true 'fragments,' like the pieces of shale which are sometimes found associated with them, produced by the explosive destruction of more coarsely crystalline rocks of earlier consolidation, and not the result of a fluxional movement in a magma which had previously reached a stage of partial separation and incomplete consolidation, and had in addition incorporated fragments of overlying rocks in its upward progress. The subject, however, is one of great difficulty, and it may be that Professor

Lewis' explanation is the more correct one. I refer to my own conclusions only because they were formed quite independently; for at that time abstracts merely of Professor Lewis' papers had been published, and from these I had formed the impression that the name 'kimberlite' designated the serpentinous fragments which were embedded in the breccia, and not the rock itself. But whatever be the ultimate result of that part of the inquiry, this would not necessarily affect my friend's views as to the genesis of the diamond—viz. by the action of an extremely basic rock upon carbonaceous material—or diminish the value of his elaborate researches into the structure and mineral composition of its matrix.

There remains only the pleasant duty of returning, on behalf of Mrs. Lewis and for myself, most hearty thanks to two friends: to J. J. H. Teall, Esq., F.R.S., who has most kindly taken the admirable micro-photographs of the slices of the Kimberley and the Kentucky rock, in order to illustrate this work; and to Professor Rosenbusch, who has been so good as to read and criticise the proofs. Only those who, like the editor, have learned from experience of his books the rich stores of his mineralogical and petrographical knowledge can fully appreciate the value of his generous assistance in putting on record some of the work produced by one who studied in his laboratory at Heidelberg.

T. G. BONNEY.

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FRAGMENT OF THE DIAMOND-BEARING ROCK FROM KIMBERLEY
(NATURAL SIZE) *Frontispiece*

This specimen was obtained at the diamond workings by Sir J. B. Stone, M.P., F.G.S., in 1894, and given by him to the editor. It came from the De Beers mine, and from the deepest level then worked—viz. rather more than 1,000 feet. It is a characteristic but slightly coarse variety of the rock, in very good preservation, exhibiting very well its peculiar brecciated structure. The largest fragment is a rather decomposed compact serpentinous rock; the smaller grains are mostly mineral—partially serpentinised olivines and pyroxenes, with a few flakes of mica, which, however, cannot be distinguished in the plate.

PLATE II

MICROSCOPIC STRUCTURE OF PART OF A SLICE CUT FROM THE
SPECIMEN OF KIMBERLEY ROCK REPRESENTED IN PLATE I.
($\times 22$ DIAMETERS) (*Upper Figure*) . *To face p. 72*

Nearly in the centre of the figure is a rather rounded grain of mica, showing the usual cleavage, and bordered by alteration products (p. 25). The large grain, part of which is shown on the S.W. side, is most probably enstatite, serpentinised externally, the difference of tint in the border corresponding with a slight difference in the character of the replacing mineral. The smaller grain near the mica (to the S.E.) probably is also enstatite, but completely changed; others are serpentinised olivine, but larger grains of this mineral, only changed at the border, occur in other parts of the slice. The grain partly included in the figure and to the W.N.W. of the mica is very compact in structure, seemingly composed of minute serpentinous materials, and possibly may be a rock fragment (? of a glassy peridotite). The separate mineral grains, as will be seen, decrease in size till they become indistinguishable from the granular matrix of serpentine, calcite or dolomite, iron oxide, perovskite, &c.

PLATE II

MICROSCOPIC STRUCTURE OF PART OF A SLICE CUT FROM A SPECIMEN OF KIMBERLITE FROM ELLIOTT COUNTY, KENTUCKY ($\times 28$ DIAMETERS); *see* PAGE 66 . . . (Lower Figures) . To face p. 72

To the S.S.E. of the centre and rather nearer to the edge is a grain of biotite, showing cleavage planes, and slightly bordered as above. The large grain, partly included to the S.S.W., is olivine, almost wholly converted to serpentine. The remaining grains are the same mineral in various stages of change, but the rather large one just N. of the centre possibly may be enstatite. The matrix consists, as before, of a mixture of granules of serpentine, iron oxide, perovskite, &c.

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SECTION I

ON A DIAMOND-BEARING PERIDOTITE AND ON THE HISTORY OF THE DIAMOND

By H. CARVILL LEWIS, M.A., F.G.S.

(Read at the Meeting of the British Association at Birmingham, 1886¹)

THE discovery of diamonds at Kimberley, South Africa, has proved to be a matter not only of commercial but also of much geological interest. Here the diamonds occur under conditions which are unlike those of any other known locality, and are worthy of special attention.

The first diamond was found in South Africa in 1867, when a large specimen was picked out of a lot of rolled pebbles gathered in the Orange River. This led to the river diggings in the Orange and Vaal rivers, which continue to the present time, but are now only worked at three or four points.

In 1870, when perhaps 10,000 persons had gathered along the banks of the Vaal River, the news came of the discovery of diamonds at a point some 15 miles away from the river where the town of Kimberley now stands. These were the so-called 'dry diggings,' which at first were thought to be alluvial deposits, but have proved to be volcanic pipes of a highly interesting character. In 1871 four mines were discovered in close proximity to Kimberley, all of which have since become famous. They are known as Du Toits Pan, De Beers, Kimberley, and Bulfontein mines, all

¹ This date must be understood as limiting the phrases applying to time throughout the paper.

of which could be enclosed by a circle $3\frac{1}{2}$ miles in diameter. The mines lie at the northern end of a great plateau, known as the Upper Karoo Plateau, which extends from the Bokkeveldt mountains at the Cape of Good Hope to the border of the Transvaal Republic, varying in elevation from 2,700 to 6,000 feet above sea level.¹ The four principal mines at Kimberley, at an elevation of about 3,900 feet, are close to one another. The two principal mines in the Orange Free State (Koffe-fontein and Jagers-fontein) lie S.E. of Kimberley, the former 30 miles, the latter 60 miles distant.

In 1872, 30,000 persons had assembled about the four mines, and other mines were soon discovered in the neighbouring territory. At the present time, 15 distinct diamond mines (dry diggings) are known in Griqua Land, Urot and the adjoining Orange Free State; none of the others, however, as yet equal in richness the four great mines first discovered. These four all have the same geological structure, each being a separate pipe; and all are remarkably rich in diamonds. It has been estimated that since the opening of these mines more than *six tons of diamonds*² have been extracted from them, being probably greater than the total combined previous production of all the other mines in the world. It was soon discovered that these pipes went down vertically to an unknown depth, penetrating the surrounding strata.

The diamond-bearing material first excavated was a soft yellowish friable substance, readily crumbling when exposed. At the depth of about 100 feet it became darker and harder, and finally acquired a slate blue or dark green colour, resembling some varieties of serpentine. This is the well-known 'blue earth' of the diamond mines, which proved to be richer in diamonds than the wholly decom-

¹ *Cape of Good Hope Official Handbook*, 1886, p. 169.

² T. Reunert, *Cape of Good Hope Official Handbook*, 1886, p. 212. Moule, 'Mémoire sur la géologie générale et sur les mines de diamants de l'Afrique du Sud,' *Ann. des Mines*, vii. 1885, p. 193.

posed and weathered portion first penetrated, and called 'yellow ground.' This 'blue earth' or 'blue ground' is taken out of the mine and exposed to the sun, and it is then capable of being readily crushed and washed for the extraction of its included diamonds. The 'blue ground' is greasy to the touch like serpentine, and is full of enclosed fragments of slate and other substances. It has been found to become harder and more stony the deeper it is penetrated, and to continue vertically downwards to an unknown depth. The deepest sinkings in Kimberley mine are now 600 feet below the surface, still in the same compact material.¹ At this depth the true nature of the diamond-bearing substance is more clearly apparent than

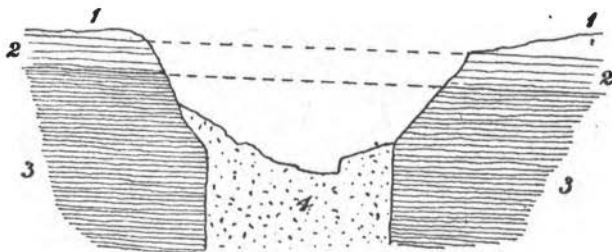


FIG. 1.—Du Toit's Pan Mine, 1885. (Sketch by Professor Lewis from the Colonial Exhibition, 1886). 1, debris; 2, yellow shale; 3, black shale; 4, diamond-bearing rock

it was when the workings were carried on in the more decomposed material. Quite recently, both in the Kimberley and De Beers mines the remarkable rock has been reached which forms the subject of the present paper.

The first scientific publication regarding the matrix of the Kimberley diamonds appears to be that of Prof. E. Cohen, in 1872,² and, in England, of Mr. E. J. Dunn, in 1873.³ Before that date, however, Mr. G. W. Stow⁴ and Dr. John Shaw⁵ had described the general geology of the region, and

¹ They have been carried to a very much greater depth since 1886.—T. G. B.

² *Neues Jahrb.* 1872, p. 857.

³ *Quart. Journ. Geol. Soc.* xxx. 1874, p. 54.

⁴ *Ibid.* xxviii. 1872, p. 3 (cf. *Geol. Mag.* 1871, p. 49).

⁵ *Ibid.* p. 21.

Prof. T. Rupert Jones and Mr. Thos. Davies had identified a number of the minerals occurring associated with the diamond. Mr. Dunn has described the occurrence so well that I cannot do better than quote some extracts from his paper.¹

‘The conditions under which diamonds occur in South Africa are quite different from those of every other known locality, and are so unusual as to deserve the earnest attention of all geologists.

‘At the junction, and back for a distance of from one to several feet, the edges of the shale are bent sharply *upwards*. The contents of these “pipes” in the shale are the same in all cases, and show distinctly that they are of igneous origin. The base is more or less decomposed gabbro (?) or euphotide (?), through which are scattered particles, fragments, and huge masses of shale, nodules of dolerite, occasional fragments of chloritic schist, micaceous schist and gneiss. The principal *foreign* ingredient is the shale, which in many places, particularly at Colesberg Kopje, is thoroughly comminuted, forming a *breccia* with euphotide (?) as a base. Where large masses of shale occur, the lines of the bedding, as might be expected, are not horizontal, but lie in all directions.

‘For a depth of from 30 to 40 feet, cracks, joints, and irregular cavities filled with red sand from the surface penetrate; with the sand, and showing that it has come from the surface, are fragments of ostrich egg-shell, small rounded grains of chalcedony, agate, &c., identical with the same substances mixed with the surface soil.

‘At 130 feet, the greatest depth so far attained, the rock becomes compact, tough, and shows the original texture, though the ingredients are altered, notably the pyroxene or augite into bronzite.²

‘The entangled blocks of shale and sandstone are frequently altered, the latter sometimes into quartz rock.

¹ *Quart. Journ. Geol. Soc.*, xxx. 1874, p. 54.

² Probably diallage is here meant; the name bronzite, which formerly was used somewhat vaguely, being now restricted to a rhombic pyroxene.—T. G. B.

'A very well-known fact on the diamond-fields, and one rather in favour of the euphotide (?) being the *mother rock*, is that each of the pipes furnishes diamonds easily distinguishable from those found in the others. Bulfontein produces small white stones, occasionally specked and flawed, but very rarely coloured; while Du Toits Pan, within half a mile, seldom yields other than coloured stones. So well marked are the characteristics of the diamonds from the various diggings, that diamond buyers can generally tell by the appearance of a stone the locality from which it has come.'

Mr. Dunn's paper was followed in the same year by a description of the microscopic character of the diamond-bearing rock by Professor N. S. Maskelyne and Dr. W. Flight.¹

The specimens examined and analysed by them were unfortunately all decomposed more or less, none coming from a depth greater than 180 feet. They identify a bronzite (two varieties, one bright green, one buff coloured), a variety of smaragdite, garnet, ilmenite, a diallage (much altered) and a mica-like mineral. Opaline silica, occasionally hyalite, sometimes resembling hornstone, is disseminated through the rock; the mica-like mineral is described, analysed, and named *vaalite*, it being regarded as an outlying member of the *vermiculite* family; the smaragdite, in brilliant greyish green fragments, green bronzite and a much altered bronzite, resembling that in the meteorite of Breitenbach, are also analysed, as is the rock of Bulfontein. This gives (water being undetermined) :—

CaCO ₃	.	.	.	.	.	59·625
MgCO ₃	.	.	.	.	.	4·972
FeCO ₃	.	.	.	.	.	3·016
SiO ₂	.	.	.	.	.	20·700
Al ₂ O ₃	.	.	.	.	.	0·553
FeO	.	.	.	.	.	4·296
MgO	.	.	.	.	.	5·799
CaO	.	.	.	.	.	0·524
						99·485

¹ *Quart. Journ. Geol. Soc.* xxx. 1874, p. 406.

Additional particulars, of which a brief summary is subjoined, are supplied in more recent papers by Mr. Dunn,¹ which are founded upon facts brought to light by fresh excavations.

The bedding of the black shales surrounding the mines is turned upwards at the edges of the pipe. These shales are very combustible and carbonaceous; in one part of Kimberley Mine, where accidentally fired, they have smouldered on for eighteen months. The shales extend at least forty miles away, underlying the whole district. Diamonds are most abundant where the pipe is surrounded by shales. The author suggests that the carbon for the diamonds was supplied by these shales. If so, the atmosphere would be the original source of the diamond, for the plants absorbed carbonic acid from the air, and their remains made the shales carbonaceous.

These shales belong to the Karoo beds. In Camdebro anthracite occurs in these beds; perhaps the result of distillation, due to a large dyke which underlies the anthracite.

The dyke-like masses² at De Beers differ from the main mass only in being finer grained and less readily decomposed. They are two to three feet thick, and cut through the pipe and the shales and dolerite in all directions. Mr. Dunn also shows that the pipes must be more recent than the dolerite sheets, for the rudely tabular dolerite is tilted up at 40° at the wall of the pipe. Included masses of dolerite also occur in the pipes, which at Bulfontein have been rounded by attrition into boulder-like masses.

Among recent papers on the diamond regions must be

¹ *Quart. Journ. Geol. Soc.* xxxiii. 1877, p. 879. *Ibid.* xxxvii. 1881, p. 609.

² *Note by Professor Lewis.* The so-called *dykes* at De Beers are merely harder and finer grained parts of the mass which are not decomposed. Down to 100 feet below the surface, shells, charcoal, &c., have entered into the blue ground.

mentioned those of Prof. E. Cohen, of Mr. Hudleston, and of Mr. Dunn. Mr. Hudleston¹ holds that the matrix of the diamond was a sort of volcanic breccia, which was made hydrous at a considerable depth and ejected in a wet state accompanied by steam, like the product of a mud volcano. The earlier theories as to the origin of the diamond have, in the light of new facts, quite given way to the theory that the diamonds belong to and are part of the matrix in which they lie, and that this matrix is in some way of volcanic origin, either in the form of mud or ashes or lava.

As the geology of the region has been described by many observers, it may suffice to say that the diamond-bearing pipes penetrate strata of Triassic age which are known as the Karoo beds. Griesbach² and Stow³ in 1871 showed that this Karoo formation was penetrated by great interstratified sheets of so-called dolerite, melaphyre and amygdaloidal melaphyre, and that below the series of stratified rocks fundamental clay slates and gneisses or granite occurred, which latter came to the surface in Natal and the adjoining regions. The intrusion of the dolerite sheets in the Karoo beds is held to have occurred in a subsequent part of the Triassic period known as that of the Stormberg beds.⁴ As Professor Rupert Jones⁵ and others have shown, the Kimberley shales belong to the lower Karoo formation. The diamond-bearing pipes penetrating and enclosing fragments of all these formations are thus clearly of upper Triassic or post-Triassic age.

I now come to the description of the rocks which, through the courtesy of Mr. T. Hedley, in charge of the

¹ *Proc. Geol. Assoc.* viii. 1883-4, p. 65.

² C. L. Griesbach, 'On the Geology of Natal,' *Quart. Journ. Geol. Soc.* xxvii. 1871, p. 53.

³ G. W. Stow, 'On some points in South African Geology,' *Quart. Journ. Geol. Soc.* xxvii. 1871, p. 497.

⁴ *Cape of Good Hope Official Handbook*, 1886, p. 83.

⁵ *Mining Journ.* 1886, p. 771.

diamond exhibit at the Colonial Exhibition, I have been able to examine. They come from De Beers Mine, and having been found at a greater depth and in a much less decomposed condition than the specimens primarily examined, it has become possible now, for the first time, to determine the exact nature of the matrix of the diamond.

The rock occurs in two types, one not bearing diamonds, the other diamantiferous, and the distinction between them is suggestive. Both occur in the same mine, and are dark, compact, heavy rocks, closely resembling one another, and differing mainly in the fact that one is free from en-

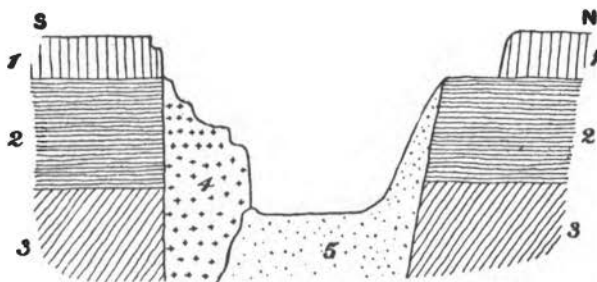


FIG. 2.—De Beers Mine, 1885. (Sketch by Professor Lewis from the Colonial Exhibition, 1886.) 1, basalt; 2, shale; 3, hard ground; 4, floating reef (true eruptive rock, with more bronzite, no enclosures, no diamonds); 5, diamond-bearing rock

closures of foreign substance, while the other is full of fragments of shale and other impurities. It is the latter which is diamantiferous.

A section of either of these shows that we have to do with a volcanic rock, composed mainly of olivine, and containing no felspar, *i.e.*, a peridotite. I will describe first that which is free from inclusions, known as "Hard Wack Floating Reef (the word 'reef' meaning anything which is worthless). It occurs deep down in the mine, and is a massive black rock. Microscopic examination shows abundant grains of olivine in a remarkably fresh condition; many of them are rounded, but others show crystalline faces. That olivine is rounded is a common feature, both in volcanic rocks and in meteorites. The cleavages accord-

ing to $\infty P \infty$ and $\infty P \infty$ are unusually well marked, that according to $\infty P \infty$ being often in straight lines almost as good as in felspar. Olivine is known to occur in rocks in three different habits, according as the rock is granular, porphyritic, or a crystalline schist, as Rosenbusch¹ has well described. The rock in question contains olivine, with the form belonging to porphyritic rocks. The distinct crystalline shape has been altered by subsequent corrosion. Olivine is the main ingredient of the rock, all other minerals being accessory.

Of these the principal are enstatite and biotite. The enstatite is clear, not pleochroic, and is readily determined by its parallel extinction; the biotite is in crystals, which are usually rounded by corrosion, as is indicated by the black rim which often surrounds them. Similar rims are well known around the biotite of many andesites, trachytes, and related rocks. The black rim is shown to be made of a mixture of magnetite and augite, and is thickest when the ground mass is holocrystalline, and thinnest when most glassy. The very thin rims here argue a glassy base. The biotite, as in peridotites and nepheline-basalt, is usually twinned after the law of Tschermak.

Serpentines with garnet occur as dykes in the Vaal River. Dr. J. Shaw speaks of serpentines,² and Professor T. R. Jones of garnets, in Vaal River gravels.³ Dr. Shaw⁴ also states that dykes cross the Vaal River and make rapids. Garnets abound in these gravels, also tourmalines, talc, and mica.

¹ *Mikrosk. Physiogr.* 2^e Aufl. Bd. i. 1885, p. 410.

² *Quart. Journ. Geol. Soc.* xxviii. 1872, p. 22.

³ *Ibid.* p. 18.

⁴ *Ibid.* p. 21.



SECTION II

THE MATRIX OF THE DIAMOND

By H. CARVILL LEWIS, M.A., F.G.S.

(Read at the Meeting of the British Association at Manchester, 1887)

At the last Meeting of this Association ¹ I had the honour of giving a short description of the remarkable rock which forms the matrix of the diamond in South Africa. Since then, as I have received fresh material, it has been possible to study it carefully, both microscopically and chemically, and to compare the geological features of Kimberley with those of other diamond localities in various parts of the world.

Without repeating what was then said, I will merely remind you that the diamond-bearing rock was shown to be an eruptive neck of post-Triassic age, penetrating and enclosing fragments of Karoo shales, and that this rock is a porphyritic peridotite of peculiar structure, closely analogous to a similar rock in Elliott Co., Kentucky.²

The rock, which was obtained from a depth of about 500 feet, is much less decomposed than the material usually obtained in the diamond mines, and both its composition and structure can be readily studied under the microscope.

It is a dark-green heavy rock, resembling a dense serpentine, in which one sees with the naked eye glistening plates of brown biotite, small deep-red garnets, and large dark-green crystals or grains of olivine and bronzite.

¹ At Birmingham, 1886. *Brit. Assoc. Report*, 1886, p. 667.

² For a description of this rock, see Section III.

The last two minerals being of identical colour with the rest of the rock are not so conspicuous as the first two. Scattered through the whole rock are a large number of angular fragments of altered black shale. These are often so abundant as to give the rock a brecciated appearance. The rock takes a good polish, and, on such polished surfaces, the olivine is clearly seen to be the predominating mineral, and to occur in porphyritic crystals, lying in a ground-mass of serpentine. Traces of fluidal structure are also seen in polished specimens. The rock resembles, externally, certain dark picrites, like those of Tringenstein or Schriesheim, yet even its general appearance is different from that of any other known rock.¹

The rock from Kentucky has the same characters, though containing less numerous foreign fragments.

We now proceed to the more exact description of this rock. We will consider (1) the minerals of which it is composed, (2) its chemical composition, (3) its structure, (4) its geological characters and significance.

(1) CONSTITUENT MINERALS

The following minerals occur in the Kimberley rock, many of them being detected only under the microscope.

Olivine, forming the larger portion of the rock, often quite fresh.

Enstatite, *chrome-diopside*, *smaragdite* and *bastite*, often in fine green plates or crystals.

Biotite, a very prominent ingredient.

Garnet, common in bright red grains.

Perovskite, abundant in microscopic crystals.

Magnetite, *chromite*, *ilmenite*, *picotite*, common under the microscope.

Apatite, *epidote*, *orthite*, *tremolite*, *tourmaline*, *rutile*, *sphene*, *leucoxene* (scarce and minute).

¹ So far as my knowledge goes, this remark, though written almost ten years ago, still holds good. A general idea of the aspect of the rock may be obtained from Plate I.—T. G. B.

Serpentine, calcite, zeolites, chalcedony, and talc, as decomposition products. Also an undetermined mineral, probably *cyanite*, and finally *diamond* (scarce).

Olivine.—Olivine forms the most abundant constituent in the rock, occurring in porphyritic crystals or rounded grains, which may attain considerable size. These crystals are sometimes over a centimetre in diameter, though usually of smaller dimensions, and are sprinkled plentifully in a serpentinous base. The dark-green colour is so nearly that of the whole rock that the olivine is not so conspicuous as the mica, although, as seen in thin sections, it is much more abundant. Many of the crystals are comparatively fresh, with the hardness and lustre of unaltered olivine. Others are partly changed into serpentine, while others, again, are entirely replaced by serpentine.

Except an occasional grain of a spinellid or, more rarely, enstatite, the fresh olivine is pure and free from solid enclosures. Occasionally bubble-like inclusions of gas or glass occur, in the form of minute elongated rounded cavities. These are often aggregated together in plant-like growths, such as are not uncommon in the olivine of a porphyritic eruptive rock. They also occur in strings traversing the crystal. With a high power these inclusions are seen to be of a brown colour resembling glass (negative crystals?). The interesting changes which Prof. Judd¹ has shown to occur in the olivine of deep-seated rocks, whereby secondary enclosures are produced, through the process which he has called 'schillerisation,' are entirely absent here.

An unusual feature in the olivine of the Kimberley rock is its perfect cleavage. This cleavage is so perfect that in ordinary light the mineral would be at once designated as bronzite or diallage. In polarised light the high double refraction distinguishes it from enstatite, and the parallel extinction from diallage or diopside. This cleavage is

¹ *Quart. Journ. Geol. Soc.* xli. 1885, p. 352.

parallel to the brachypinacoid ($\infty P\bar{\infty}$), an optic axial bisectrix appearing in sections with the most marked cleavage.

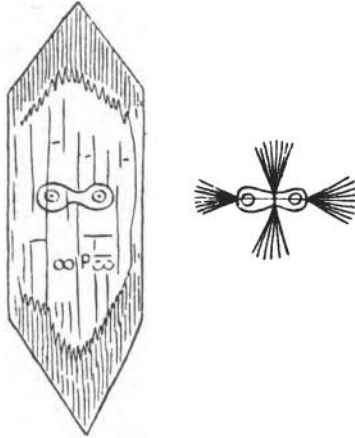


FIG. 3.—Olivine crystal seen parallel to $\infty P\bar{\infty}$ and showing excellent cleavage along $\infty P\bar{\infty}$, and poorer cleavage along OP . The fibrous basaltic mineral into which it is altered has fibres parallel to the principal cleavage. A bisectrix occurs at right angles to the section, and the plane of the optic axis is parallel to the base

There are also secondary cleavages, and the usual irregular cracks so common in olivine.¹

Olivine has not been detected in the ground mass of this rock. It is usually in the form of crystals, more or less rounded and corroded, and even when completely changed to serpentine, the original crystalline form can generally be recognised.

Corrosion cavities (the 'einbuchtungen' of the Germans) are sometimes seen in the olivines.

The following are some of these :



FIG. 4.—Corrosion cavities



FIG. 5.—Corrosion cavities

¹ Zirkel, *Mikrosk. Beschaff. der Min.* 1873, p. 214.

The olivine alters by decomposition either into serpentine, or into tremolite, or into a bastitic fibrous mineral. The alteration into serpentine proceeds in the usual manner, beginning at the outer edge and in cracks in the crystal, and gradually penetrating deeper, as new cracks are formed, until the change is complete. A homogeneous nearly isotropic serpentine is the final result. Fibrous serpentine or chrysotile also forms around the olivine grains, and in this case the chrysotile fibres stand more or less at right angles to the original faces of the crystal. The chrysotile is much more highly doubly refracting than the compact serpentine, which latter, when most dense, is often nearly isotropic. Another serpentinous mineral is faintly pleochroic in pale shades of green, and is, perhaps, more nearly related to bastite.

Tremolite (fig. 6) in the form of asbestos occurs as a secondary mineral pseudomorphic after olivine. It frequently happens that while serpentinisation begins at the outside of a crystal, fibrous tremolite begins growing within, finally forming a mass of asbestiform fibres surrounded by a zone of green serpentine. These asbestos fibres often grow partly parallel to the vertical axis, and partly parallel to the domes of the olivine. They are distinguished from other minerals by their high colour in polarised light, and by vertical fibres separated by partings or cleavages like those which divide sillimanite, and by an obliquity of extinction at about 15° . They are perfectly colourless and non-pleochroic. A fibre may be compact in the centre or at one end, and at the other end may be fringed out into fine hair-like asbestos.

In the second figure (7) two olivine crystals have grown side by side, their axes parallel. A thin green rim of serpentine surrounds each crystal. A round grain of olivine remains in each, and crystals of tremolite surround it. Between the tremolite and the serpentine is a pseudomorphic mass of talcose substances, in which lie rutile needles parallel to the faces of the crystal.

Another kind of alteration, rare in the Kimberley rock, but very common in the Kentucky variety, is into a peculiar finely fibrous substance of dark blue colour. The olivine is never wholly changed into this material, which appears only at the two extremities of a crystal or along cracks. The fibres always stand parallel to the cleavage planes of the olivine, and seem to be due to a finer splitting up of these cleavage planes until they become fibrous. This fibrous substance is faintly pleo-

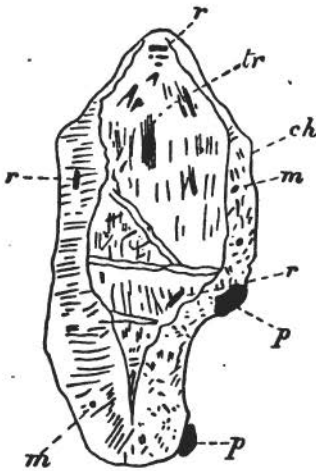


FIG. 6.—Diagrammatic. *r*, rutile needles; *tr*, tremolite; *ch*, chrysotile; *m*, magnetite or chromite; *p*, perovskite

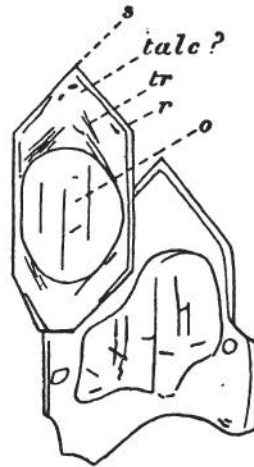


FIG. 7.—Diagrammatic. *s*, serpentine; *tr*, tremolite; *o*, olivine; *r*, rutile

chroic like bastite, and seems to be a new variety of that mineral. (It is seen only in the Kentucky rock.) Dr. Rosenbusch suggested to me that it resembled the 'aerinite' of Lasaulx,¹ also a product of alteration. It will be more fully treated under the description of bastite. The unusually perfect cleavage in the olivine is particularly well developed near the edges, where the fibrous substance is formed. This alteration is at the edges of otherwise

¹ *Neues Jahrb.* 1876, p. 352; *Bull. Soc. Min. de France*, i. 1878, p. 125.

perfectly fresh olivine, and appears to be an incipient stage of serpentinisation.

The alteration into serpentine is shown in figures 8 and 9; and into the chloritic mineral in figure 10.

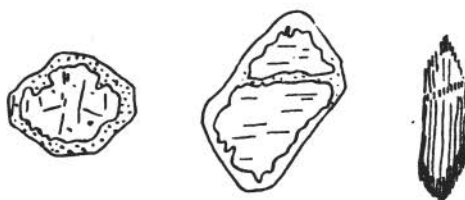


FIG. 8

FIG. 9

FIG. 10

Alterations of olivine

The most interesting result of the serpentinisation of the olivine is the production of secondary rutile. Rutile never appears in the fresh olivine, but as serpentinisation begins rutile needles form along the border of the decomposing olivine, their longer axes being parallel to the outlines of the original crystal. When serpentinisation has proceeded so far that only an inner kernel of olivine remains, rutile needles may be formed all around this inner kernel, lying in the serpentine pseudomorph, not irregularly as if ordinary enclosures, but in fixed crystallographical directions parallel to the olivine outlines. Figures 11 to 15 exhibit this secondary rutile.

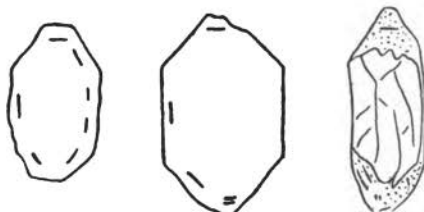


FIG. 11

FIG. 12

FIG. 13

Rutile in olivine

The rutile needles have originated within from small particles of titaniferous iron enclosed in the olivine, or from

titanic acid in its composition. Sometimes a grain of titanitic iron can be seen imbedded in the rutile needles, as in fig. 16. The rutile crystals are rarely geniculated.



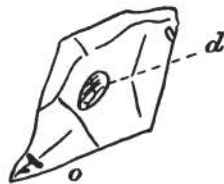
FIG. 14.—Rutile



FIG. 15.—/d. FIG. 16.—(with titanitic iron)

The production of secondary rutile through the decomposition of olivine does not appear to have been previously noticed, although in decomposing phlogopite or biotite¹ it is a not uncommon occurrence, and its association with titanitic iron² is well known. One of the most interesting and unusual features of the olivine in this rock is that it is younger than or contemporaneous with the chrome diopside and bronzite. Bronzite occurs enclosed within it, but olivine has not been observed enclosed within the bronzite. When thus enclosed in the olivine the bronzite is of more or less rounded form.

In fig. 17, a rounded grain of clear diopside with good cleavages or partings is enclosed in fresh olivine (Kentucky peridotite).

FIG. 17.—Kentucky peridotite. *d*, diopside; *o*, olivineFIG. 18.—*e*, enstatite, with specks of biotite

¹ Cohen, *Neues Jahrb.* 1882, ii. p. 194.

² Cathrein, *Zeits. für Kryst.* vi. 1882, p. 244; Lasaulx, *Zeits. für Kryst.* viii. 1884, p. 54.

In fig. 18, the enclosed mineral is enstatite, distinguished from the diopside by much lower double refraction and by parallel extinction. The enstatite here encloses secondary biotite scales, and the biotite in turn contains small hexagons of hematite.

As is well known, olivine is almost always older than the more acid pyroxene in any given rock. Unless we suppose that a subsequent fusion has produced it, or that there is a secondary olivine, there would appear to be an exception here to the useful and generally applicable rule that the constituents of a magma crystallise out in the order of diminishing basicity.¹ According to Hussak,² augite and hornblende occur enclosed in olivine in the picrite-porphyrone of Steierdorf, Banat, and the enclosure of enstatite in olivine is often seen in meteorites. It is probable that these are cases of contemporaneous crystallisation.

A highly refracting rhombic mineral, resembling olivine, also occurs in some remarkable zones which surround the bronzite in the Kimberley rock, and which have the appearance of contact-fusion zones. These zones, in which the olivine makes a pegmatitic or 'eozoonal' structure, as in the chondri of meteorites, will be discussed more fully under the description of enstatite. They may be the rudimentary stage of the compact olivine enclosing enstatite, and point to the contemporaneous and rapid crystallisation of olivine and enstatite—a common occurrence in meteorites.

The significance of olivine as a characteristically igneous mineral, and as one readily produced by dry fusion, is well known.³ It is a mineral of special interest, as regards the part it plays in connecting deep-seated terrestrial rocks with those of celestial origin.⁴ As the predominating constituent of the present rock, it places this clearly among the

Rosenbusch, *Neues Jahrb.* 1882, ii. p. 7.

² *Verhandl. der geol. Reichsanstalt*, 1881, p. 260.

³ Bourgeois, *Reproduction Artificielle des Minéraux*, Paris, 1884, p. 108.

⁴ Daubrée, *Études Synthétiques de Géologie Expérimentale*, Paris, 1879, p. 538; Wadsworth, *Lithological Studies*, 1884, p. 84.

peridotites, while the idiomorphic character of the crystals, and the evidence of the action of a corrosive magma upon them, class the peridotite among the volcanic rather than the plutonic series.

Pyroxenic Minerals.—Three clear green minerals, almost identical macroscopically, occur in the peridotite of Kimberley, and are found loose in the decomposed 'blue ground.' These are smaragdite, bronzite, and chrome diopside or diallage. These minerals are so hard and clear and free from inclusions that they have been cut as gems. They all have a light grass green colour, and are unattacked by acid, and all sink in a Thoulet's solution, having a specific gravity of 8. They can be distinguished from each other by specific gravity, by blowpipe tests, and especially by optical means. All are coloured by chrome oxide, as is shown by blowpipe tests.

Smaragdite.—This has the hornblende cleavage, and an extinction of about 15° . It has a fine green colour, and in thin sections it is pleochroic in shades of green. The mineral has been analysed by Maskelyne and Flight, who found the composition of loose fragments in the blue ground of Du Toits Pan to be as follows :

SiO ₂	52·97
Al ₂ O ₃ (with Cr ₂ O ₃)	1·94
FeO	4·52
CaO	20·47
MgO	17·49
Na ₂ O	1·77
H ₂ O	0·58
	<hr/>
	99·74

Bronzite and Bastite.—Of the three related green minerals in the peridotite, bronzite is the most abundant.¹ It

¹ In the specimens from Kimberley, examined by Miss Raisin and myself (*Geol. Mag.* 1895, p. 496), the green mineral in most, if not in all, cases was not an enstatite, but an augite.—T. G. B.

occurs in crystals or crystalline plates with the characteristic fine striation of enstatite, parallel to the vertical axis. It has a weaker double refraction than the other two minerals, its colours in polarised light being of the first order. It gives parallel extinction, and the cleavage plates show no hyperbolas. The plane of the optical axes is parallel to the cleavage. The colour is a paler green than that of the other two minerals. Before the blowpipe it is infusible, or nearly so. The specific gravity, as determined in Klein's cadmium solution, was 8.199. Maskelyne and Flight¹ have analysed loose fragments from the 'blue ground' of Du Toits Pan, as follows:—

SiO ₂	55.91
Al ₂ O ₃	2.64
Cr ₂ O ₃	0.54
FeO	4.99
NiO	trace
MgO	34.91
CaO	0.45
	99.44

They draw attention to the resemblance of this bronzite to that in the meteorite of Breitenbach. If, with Tschermak,² we draw the line between bronzite and enstatite at a content of 5 per cent. of iron protoxide, it will be seen that our mineral is just on that line; and thus, as having an intermediate composition, may be called with equal propriety either bronzite or enstatite.

The bronzite sometimes alters into biotite, which may occur in it in scales or plates which appear to be secondary. It also alters into bastite, which often entirely replaces the bronzite, and may be quite an abundant constituent. Bastite is distinguished from bronzite by a faint yellowish colour,

¹ *Quart. Journ. Geol. Soc.* xxx. 1874, p. 411.

² *Lehrb. der Mineralogie*, Wien, 1885, p. 443.

weak pleochroism, and by the appearance of a bisectrix in cleavage flakes. The plane of the optic axis is parallel to the fibres, and there is parallel extinction. It has a somewhat more fibrous character than bronzite, and with the latter forms the most abundant constituent of the rock after olivine.

The blue fibrous substance which forms an alteration rim around olivine has already been mentioned. This peculiar mineral, common in the Kentucky rock, has a dark indigo colour, and is faintly pleochroic, being dark indigo blue when the nicols are parallel to the fibres, and light greenish blue when at right angles ($c > b$ or a). The plane of the optic axes is parallel to the fibres and the c axis and $c = a$. The blue colour disappears on heating the slide in acid, and the mineral is gelatinised. All these are the characters of bastite. In some cases it is almost isotropic, while in other cases some of the fibres have a double refraction nearly as high as enstatite, the tints rising nearly to yellow of the first order. In colour it somewhat resembles glaucophane.

Bastite is well known as an alteration product of bronzite, but has not previously been observed as a result of the change of olivine. From this circumstance, and from its deep blue colour, it may be justly considered as a new variety of bastite.¹

Chrome-diopside.—The chrome-diopside has a fine emerald green colour, richer than that of the other two minerals. The specific gravity is higher than that of bronzite, being 3.267 (determined in cadmium solution). Its ready fusibility before the blowpipe, and its much higher colours in polarised light, also distinguish it from the bronzite. Cleavage fragments show a very faint pleochroism, not nearly as distinct as that of smaragdite, and an extinc-

¹ I have occasionally observed a blue tinge, almost like a stain, and generally similar to this, in examining dark-coloured serpentines. I doubt whether its value is so great as to constitute a variety.—T. G. B.

tion angle of 39° : In converging polarised light an axis appears on cleavage fragments which are parallel to $\infty P\acute{o}$.

Three cleavages or partings, each well developed, also occur in chrome-diopside, so that it readily cleaves into almost cubical rhombs. It has an excellent cleavage parallel with $\infty P\acute{o}$, another, less perfect, parallel with $\infty P\tilde{o}$, and another parallel with OP. This last is the salite parting, and not a true cleavage. It is probably, as Tschermak,¹ Vom Rath,² and others have shown, due to the interposition of thin twinning lamellæ parallel to the base, and the mineral might be called a salite. Von Koksharow³ speaks of the 'zusammensetzungsfächen' in chrome-diopside from the Urals as often confounded with true cleavage faces. The ordinary augitic prismatic cleavage is not apparent microscopically on these basal parting sections, but the pinacoidal cleavages are seen as fine lines crossing each other at right angles and parallel to the sides of the section.

A cleavage fragment gave the angles $\infty P\acute{o} \wedge OP = 106^\circ$, and $\infty P\tilde{o} \wedge OP = 90^\circ$.

The face of the best cleavage, parallel to $\infty P\tilde{o}$ has a pearly lustre, and is nearly or quite free from striæ. The orthopinacoidal cleavage plates are striated vertically, and show in convergent light a single axis identical with that seen in cleavage plates of diallage.

The low extinction angle, 39° , is typical of a pure lime-magnesia diopside, free from iron, for both iron and magnesia, as Tschermak,⁴ Wiik,⁵ Herwig⁶ and Doelter⁷ have shown, tend to increase the extinction angle. The so-called omphacite, occurring in eclogites, peridotites, olivine bombs, and serpentines, seems to be but another name for

¹ *Min. Mitth.* 1871, p. 22.

² *Zeits. für Kryst.* v. 1881, p. 495.

³ *Materialien zur Mineralogie Russlands*, iv. 1862, p. 259.

⁴ *Min. Mitth.* 1871, p. 22.

⁵ *Finska Vetensk. Soc. Förhandl.* xxiv. 1882, p. 33; xxv. 1883, p. 109.

⁶ *Programme des Gymn. Saarbrücken*, Nr. 416, 1884.

⁷ *Neues Jahrb.* 1885, ii. p. 43.

chrome-diopside, the composition and optical characters being identical.¹

Chrome-diopside gives birth to granular calcite, which always accompanies it when decomposed. When there is any doubt in the section as to whether a mineral is bronzite or chrome-diopside, the presence of calcite on its edges and in its cracks is often a sufficient criterion for diopside. The composition is probably that of the pure diopside molecule, CaO , MgO , 2SiO_2 .

Chrome-diopside is well known to occur with enstatite in dunite, in herzolitite and in other peridotites and serpentines, and in the 'olivine bombs' which are enclosed in basalt. Descloiseaux has described a chrome-diopside in the platiniferous (and diamantiferous?) peridotite of Nischne-Tagilsk, Urals.

Fluid or glass inclusions, resembling those in the olivine, were noticed in cleavage fragments of the chrome-diopside, which were otherwise pure.

The fact has already been pointed out that bronzite and chrome-diopside occur sometimes enclosed in olivine, and sometimes surrounded by what seems to be a fusion zone. This fusion zone or growth zone has a peculiar worm-like radiating structure, which may be compared with that of the kelyphite rim² around garnets in serpentine, or the radial zones around olivine in certain norites³ and gabbros, or the so-called granophyric⁴ or pegmatitic⁵ structure in some quartz-porphyrines, or the structure in the chondri of meteorites.⁶ The principal mineral in these zones is a colourless substance, in short worm-like forms, with a high index of refraction, high

¹ Schrauf, *Zeits. für Kryst.* vi. 1882, p. 329.

² *Ibid.* p. 358.

³ Törnebohm, *Neues Jahrb.* 1877, p. 388; Becke, *Min. und Petr. Mitth.* iv. 1882, p. 450; Adams, *American Naturalist*, 1885, p. 1087.

⁴ Rosenbusch, *Mikrosk. Physiogr.* ii. 1887, p. 388.

⁵ Michel Lévy, *Bull. Soc. Géol. France*, iii. 1875, p. 199; *Ann. des Mines*, viii. 1875, p. 337.

⁶ Wadsworth, *Lithological Studies*, 1884, p. 89.

double refraction, positive character, parallel extinction, and with traces of vertical and basal cleavage. The axis of greatest elasticity is at right angles to the best cleavage ($b =$). The high colours in polarised light are identical with those of olivine, and serpentine sometimes replaces it. All these characters point to olivine as the mineral forming the greater part of the zone. These olivine prisms are all rounded, and radiate irregularly from the central bronzite. They are imbedded in a nearly amorphous glass-like brown serpentinous substance, and are accompanied by small quantities of calcite, and of a mineral with a high-index of refraction, but very low double refraction, which occurs in rectangular prisms, has traces of a cleavage in partings parallel to the base, and is negative. This microlith, however, was noticed only in a few cases. Olivine, it seems, is the main constituent of these zones. The grains are generally so minute and crowded together that they form a grey highly refracting fibrous border or fringe around the enstatite, like leucoxene around titanite iron. Farther away from the enstatite the grains become larger and more worm-like, so that they can be separately studied. The structure of these zones resembles that figured by Becke,¹ as occurring around garnets in a garnet-olivine rock from Karlstätten, Lower Austria, and called by him 'centric' structure. He has figured a similar structure in the omphacites of certain eclogites,² and speaks of it as 'darmzottenähnlich.'³

It has often been called a pegmatitic or micro-pegmatitic structure, since, in many instances, a number of the grains have the same orientation, extinguishing simultaneously, the two substances being contemporaneously crystallised. This is also the case, to a limited extent, in the zones under consideration. Perhaps the term centro-pegmatitic would more nearly express it. From its

¹ *Min. und Petr. Mitth.* iv. 1882. p. 326. (See Plate II. figs. 2 and 3.)

² *Loc. cit.* p. 319. (Plate III. fig. 15.)

³ *Ibid.* p. 322.

resemblance to organic alga-like forms it might also be called 'eozoonal.' More nearly allied, however, than any of these is a peculiar structure, often found in meteorites, for it is a phase of the so-called chondritic structure. As will subsequently appear, our rock has some close resemblances, both in composition and structure, to certain meteorites; the structure of the zone that we are now attempting to describe has frequently been observed in meteorites, and has given rise to various conjectures.

In the Kentucky rock I have noticed the same pegmatitic olivine zones around the enstatite. The olivine grains in these zones are imbedded in a brown, nearly isotropic, substance, which suggests a serpentinised glass or base.

Mica.—The mica is, next to the olivine, the most abundant mineral, and in hand specimens it is the most conspicuous mineral. When the rock has been exposed to the weather it appears sprinkled with glittering mica crystals which, when weathered, form silvery spangles on the black rock. The 'blue ground' and the soil about the diamond diggings, both at Kimberley and on the Vaal river, contain many fragments of mica, which is thus regarded as the principal indication of diamonds. In the rock which we are describing it is of a dark red-brown colour, like biotite or phlogopite, and is apparently quite fresh and undecomposed. Plates half a centimetre in diameter are very common, and sometimes pieces occur two centimetres in diameter. It is brittle when fresh. Before the blowpipe this mica melts quietly to a dark glass—sometimes slightly exfoliating.

Under the microscope the mica is seen to be nearly pure and unaltered. It occurs usually in thick isolated plates or crystals, lying like the olivine porphyritically in the ground mass. These are frequently polysynthetically twinned, according to the law so ably expounded by Tschermak. It is indicated by the different absorption in the alternate layers. The extinction angle between the two

alternate striæ is about 10° , showing an extinction for single lamellæ of 5° .

The mica seldom occurs in well bounded crystals, being more usually found in irregular plates. Sometimes the crystals are corroded, as if from a re-solution of the magma. Sometimes also a narrow rim of 'opacite' surrounds the mica, this being particularly observable in such crystals as have been greatly corroded and rounded. This black rim (the 'opacit rand') is never thick, and is only sometimes present. Sometimes the edges of the mica crystals are curved, this being the result of motion in the rock. In certain cases the mica is found to contain very small short thick rods of a highly refracting dark red substance, probably rutile. These rutile needles lie parallel to the base, and are probably a result of the partial decomposition of the mica. They indicate that the mica contained a small percentage of titanium. The production of rutile as a secondary mineral has been frequently observed in magnesia-mica.¹

Another mode in which the mica occurs is around the garnets in the rock. Sometimes a large red pyrope will be entirely surrounded by a narrow zone of brown mica.

A third method of occurrence of the mica is in the form of small scales in enstatite, here apparently due to the alteration or corrosion of that mineral. This was noticed in only a few instances, and especially in those in which the enstatite was enclosed in olivine. In one instance, small scales of magnesia-mica alone were enclosed in olivine, as though the original enstatite had been entirely replaced by the mica.

A fourth association in which we find magnesia-mica is as a product of the apparent fusion or metamorphism of

¹ Rosenbusch, *Mikrosk. Physiogr.* i. 1885, p. 483; Dathe, *Zeits. Deutsch. Geol. Gesell.* xxxiv. 1882, p. 35; Cross, *Min. und Petr. Mitth.* iii. 1881, p. 372; Zirkel, *Ber. der Sächs. Gesell. der Wiss.* 1875, p. 202; Kalkowsky, *Die Gneiss-Formation des Eulengebirges*, 1878, p. 28; Williams, *Newes Jahrb. Beil.* Bd. ii. 1883, p. 617.

enclosed fragments of shale or other rocks. These enclosures are sometimes entirely altered into a nearly opaque dirty grey aggregate, largely composed of a pleochroic mica, apparently an impure scaly biotite. These mica scales are highly pleochroic, and are, perhaps, another mica than that which composes the large porphyritic crystals, for the latter seem to be primary constituents of the rock. By decomposition or serpentinisation the mica is altered into an irregular mass of sericite, or talc-scales, in which round or oval masses of an apparently isotropic gum-like substance occur.

The optical characters of the mica are unusual. Unlike ordinary biotite, it has a weak pleochroism. As a prismatic section is revolved over the polariser the light brown colour, while varying in intensity, does not become dark. Similar weakly pleochroic magnesia-micas have been observed in other ultra-basic rocks. Zirkel¹ noticed such a mica in the leucitite of the Leucite hills, Wyoming territory; and Judd² has described an altered magnesian mica with feeble pleochroism in the 'Scyelite' of Caithness.³ The mica in the Kimberley rock has the usual index of refraction and high double refraction; it has a very small optic axial angle, and is a mica of the second order. The 'strike figure' has one ray parallel to the symmetry plane, and to the plane of the optic axes. Optically, therefore, it is a meroxene or phlogopite.

Maskelyne and Flight⁴ have analysed this mica in a decomposed state. In the soft 'blue ground' of Du Toits Pan this mica in decomposing has absorbed much water and become a vermiculite, exfoliating when heated. To this substance Maskelyne and Flight have given the

¹ 'Microscop. Petrogr.' *U.S. Geol. Expl.* 40th Par. vi. 1876, p. 261.

² *Quart. Journ. Geol. Soc.* xli. 1885, p. 405.

³ [I have observed a rather similar mica in a picrite from Sark, which presents a considerable resemblance to scyelite. *Geol. Mag.* vi. 1889, p. 110.—T. G. B.]

⁴ *Quart. Journ. Geol. Soc.* xxx. 1874, p. 409.

name of 'Vaalite.' In this state it is a soft yellow or bluish-green micaceous mineral, containing nearly 10 per cent. of water.

The following is the composition of the 'Vaalite':—

SiO ₂	.	.	.	.	.	40.83
Al ₂ O ₃	.	.	.	.	.	9.80
Fe ₂ O ₃	.	.	.	.	.	6.84
Cr ₂ O ₃	.	.	.	.	.	trace
MgO	.	.	.	.	.	31.84
Na ₂ O	.	.	.	.	.	0.67
H ₂ O	.	.	.	.	.	9.72
						<u>99.20</u>

Garnet.—Deep-red rounded grains of clear pyrope are abundant in the 'blue ground,' and these, with black grains of titanite iron, remain with the diamonds in the final washings. Pyropes are also seen imbedded in the dark green peridotite rock. They have been utilised as gems. The pyropes which were observed in thin sections were isotropic, nearly pure and always rounded. In one case a pyrope was surrounded by a zone of magnesia-mica. Cracks penetrate the pyropes irregularly, as is usual.

Another variety of garnet occurs, which greatly resembles the diamond. These garnets are very small, colourless, or with a faint tinge of green, and have such a high index of refraction that it is difficult to see their shape. They are crystallised apparently in forms strongly suggesting the diamond, the faces being sometimes curved, and the octahedral forms apparently predominating. They are unattacked by acids, including hydrofluoric acid. They melt readily to glass in a crucible, and may thus be distinguished from diamonds. Most of them are so small as to be seen only with high powers, and they are then readily confounded with minute diamonds. They probably belong to the variety of garnet called 'demantoid,'¹ which is found in the diamond

¹ Rammelsberg, *Zeits. Deutsch. Geol. Gesell.* xxix. 1877, p. 819.

region of Sysstersk, Urals, imbedded in serpentine.¹ Other small garnets, again, of bluish-green colour, giving a chrome reaction, may belong to the variety named 'ouvarovite.'

The pyropes are about as abundant as in the garnet-bearing serpentines, and it is probable that many of these serpentines have been derived from a peridotite of similar nature to that now under consideration. These serpentines are related not merely in the occurrence of garnet, but also in the association of olivine, bronzite, diallage and sometimes perovskite, and even diamond.

Perovskite.—Perovskite is an abundant and characteristic mineral in the rock under consideration. It occurs in crystals, in crystalline aggregates, and in combination with ilmenite. It was isolated with the garnets from the other constituents by treatment with sulphuric and hydrofluoric acids, and submitted to blowpipe tests. Most of the mineral thus isolated was in the form of brownish-black cubical crystals, with octahedral truncations

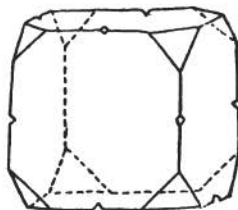


FIG. 19.—Perovskite

(fig. 19). These crystals were almost all of a nearly uniform size. In the thin sections the perovskite appeared as reddish-brown crystals or aggregates, deep yellow when thin, but sometimes nearly opaque, scattered abundantly through the ground-mass. In their deep colour and very high index of refraction they resembled the rutile grains of the crystalline schists, but were readily distinguished from that mineral or from zircon by their remarkably low power of double refraction. The colour in polarised light seldom rose above grey of the first order, and was sometimes as high as white of the first order. The characteristic optical properties therefore are an index of refraction nearly as

¹ Lösch, *Neues Jahrb.* 1879, p. 785; *Verhandl. der Russ. Miner. Gesell.* xiii. 1878, p. 432; xvi. 1881, p. 299.

high as rutile (over 2) and a power of double refraction about as low as zoisite ($\gamma - a = .005$). The low double refraction, together with the opacity often caused by inclusions of ilmenite or chromite, might in some cases cause it to be mistaken for a dark spinel or other isotropic mineral. In no case, however, is the perovskite isotropic. Extinction always occurs parallel to the diagonal of the cube. Pleochroism is extremely faint. The form and optical properties of the perovskite show that in all cases it belongs to the rhombic system, and is in the form of twins, or of aggregates of twins. The commonest form is that of interpenetrative twins, so crossed as to form a cube. The following are common forms as seen in ordinary light:—

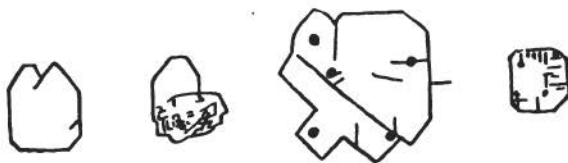


FIG. 20



FIG. 21

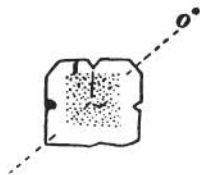


FIG. 22

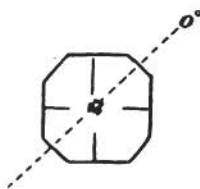


FIG. 23

FIGS. 20-23.—Twinned perovskite

A cleavage or parting occurs parallel to the cubic faces. Re-entrant angles usually divide the elements of the twins, but these are still better indicated by the optical characters of the mineral. The extinction is always parallel to the diagonal of the cube, as shown by the dotted lines in figs. 21, 22, and 23. The apparent cube appears to be composed of interpenetrating rhombic individuals, whose

basal pinacoids form the octahedral replacements of the cube. Very frequently four individuals are seen grouped to form a single square, dark lines dividing the deep yellow crystal. The entire cube would then be composed of six individuals.¹

A second kind of twinning is also common in this perovskite, producing the appearance with crossing nicols of a series of parallel alternately coloured bands, like the polysynthetic twinning in plagioclase feldspars. The bands are again often crossed at right angles, as in microcline. These lamellæ are parallel to the cubic faces of the compound twin. They are alternately pale greenish-blue and pale greenish-yellow, and are all simultaneously extinguished when they are turned at an angle of 45° to the nicols. The following are among the forms which are seen by the use of this apparatus:—

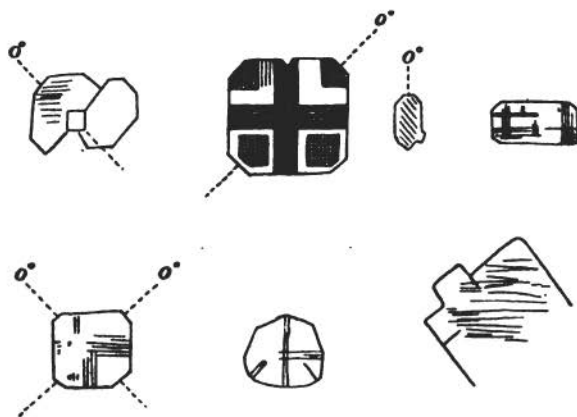


FIG. 24.—Twinned perovskite (crossing nicols)

It seems, therefore, that a series of rhombic prisms are twinned according to two laws at the same time, the apparent cubo-octahedrons being in reality compound

¹ See *Neues Jahrb.* 1878, p. 38.

twins. The following, fig. 25, represents diagrammatically this double twinning.

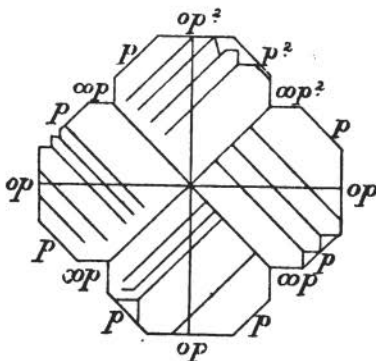


FIG. 25.—Twinned perovskite

We have here apparently a polysynthetic or parallel growth, and a simple interpenetrative twinning according to *P*. The optical peculiarities of perovskite have long been a subject of discussion, and diverse views are at the present time held as to the crystalline system to which it belongs. Some crystallographers¹ hold that perovskite is a regular mineral, with optical anomalies which are due to strain; while others² believe it to be a rhombic mineral, occurring in compound twins belonging to the class of 'mimetic' minerals.

The brighter colours of single lamellæ, and of certain portions of the compound crystals in the Kimberley rock, suggest that the very weak double refraction exhibited by the crystals, as a whole, may be due to the overlapping of two or more simple components producing a compensation; a weak double refraction belonging to the untwinned mineral. The re-entrant angles, so common in the Kimberley crystals, seem to have been rarely observed

¹ Klein, Zirkel, Ben Saude.

² Descloiseaux, Baumhauer, Groth, Von Koksharow, Tschermak, &c.

in the perovskites of other localities. The striation parallel to the cubical faces, extinguishing when the section is at 45° to the polarisers, occurs also on perovskite from Zermatt, from the Urals (where also all the crystals are penetration-twins), from the Tyrol, from Arkansas, from Wiesenthal (Erzgebirge), &c. The figures of perovskite grains out of the nepheline-basalt of the last locality, as given by Sauer,¹ are very similar to those given above from the Kimberley mineral.

Perovskite also occurs in the Kimberley peridotite in aggregates of crystals and in irregular grains. Very frequently these crystals or grains enclose one or more opaque black octahedral crystals of a titaniferous magnetite (or other spinellid). Often an octahedron or cube of perovskite will have a black grain in the very centre, and when an aggregate of such crystals occurs, each of its components may have a black grain in its centre.



FIG. 26.—Inclusions in perovskite



FIG. 27.—Titanic iron in perovskite

This is so common an appearance that one is led to suspect that the perovskite is a secondary mineral, made out of the older titanite through some reaction with the basic magma. While, generally, the titanite is in the form of small grains in the perovskite, as shown in the above figures, sometimes the perovskite forms a narrow fringe on one side of a larger mass of titanite, or makes a shell around it. Sometimes also a crack in a mass of titanite is filled with perovskite, as if by a secondary mineral.

That titanite is older than the perovskite is proved by the fact that while titanite occurs as an enclosure in the olivine, perovskite never does so.

¹ *Zeits. Deutsch. Geol. Gesell.* xxxvii. 1885, p. 447.

It is very common to find the small perovskite crystals surrounding a large crystal of olivine, as if attracted to it. The following figures are examples of this peculiarity :—



FIG. 28.—Perovskite surrounding olivine



FIG. 29.—o, olivine; r, rutile; s, serpentine; p, perovskite

The perovskite crystals lie on the outer sides of the olivine crystal, as if a later growth. In the same manner perovskite is attached to the outer surface of serpentine pseudomorphs after olivine. Fig. 29 shows such a case, and shows also in the serpentinised olivine secondary rutile needles growing out of a grain of titaniferous iron, as already described under olivine.

A similar grouping of small perovskite crystals, like a wreath, around the olivines has been noticed by Stelzner¹ in the melilite-basalt of Hammerer Spitzberg, near Wartenberg, Bohemia (the so-called 'nephelin-pikrit' of Bořický),² which is rich in perovskite.

Perovskite is one of the most characteristic minerals for the felspar-free basic eruptive rocks. As a rock ingredient it was first detected by Bořický³ in the above-named melilite-basalt of Wartenberg. Hussak⁴ proved its existence in the nepheline and leucite lavas of the Eifel; Stelzner⁵ showed that it was a constant constituent of melilite-basalts, and Sauer⁶ that it occurred very commonly in the nepheline and leucite-basalts of the Erzgebirge.

¹ *Neues Jahrb.* Beil. Bd. ii. 1883, p. 415.

² *Sitzber. der math.-naturw. Classe der böhm. Gesell.* Prague, 1876, p. 229.

³ *Loc. cit.*

⁴ *Sitzber. Akad. Wien*, lxxvii. 1878 (Abth. 1), p. 341.

⁵ *Neues Jahrb.* Beil. Bd. ii. 1883, p. 396.

⁶ *Erläuterungen zur geologischen Specialkarte des Königreichs Sachsen.* Section Kupferberg. Leipzig, 1882, p. 70.

Perovskite has not been identified in a peridotite until quite recently, when my friend, Dr. G. H. Williams, observed it in an eruptive peridotite—closely resembling the Kimberley rock—in the State of New York. It has probably been mistaken frequently for other minerals. The colour and form, the similarity to picotite, the included opaque grains, and the mineral associations, all indicate perovskite rather than zircon. Diller¹ has described, as probably anatase, certain yellowish, highly-refracting grains occurring around and penetrating ilmenite in an eruptive porphyritic peridotite in Elliott County, Kentucky. Through the courtesy of Mr. Diller and of Prof. A. R. Crandall, I have received specimens of this interesting rock, and find that these grains are identical with the perovskite of the Kimberley rock.² The same form, colour, and enclosures, the same twinning structure, the same high index of refraction and low power of double refraction, and the same mineral associations, occur in the Kentucky as in the Kimberley peridotite.

It is an interesting fact that, speaking generally, the titanium in acid eruptive rocks takes the form of sphene, in basic non-felspathic rocks of perovskite, and in rocks of intermediate basicity, the felspar-basalts, of ilmenite or titanite iron. An explanation is offered by an important experiment performed by Bourgeois,³ who was able to form artificial perovskite by fusing its elements with various silicates and basic rocks, and who found that below a certain point of acidity only perovskite was formed, while above that point only sphene was produced. With a titanite spinellid as the primary titanium mineral, the reaction of a basic magma would produce perovskite (as in leucite- and melilite-basalts and in peridotite), while the reaction of an acid magma would produce sphene (as in granite,

¹ *Amer. Journ. Sci.* xxxii. 1886, p. 124. [Mr. Diller has since withdrawn this opinion.]

² For a description of this rock see Section III.

³ *Ann. Phys. Chim.* xxix. 1883, p. 481.

and trachyte).¹ In both cases the titanite spinellid or ilmenite is surrounded or penetrated by the younger sphene or perovskite, silica being necessary for the formation of sphene out of titanite iron, but not for that of the more basic perovskite.

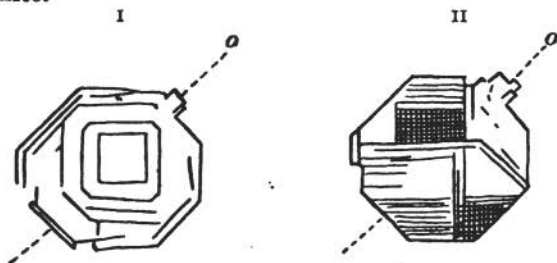


FIG. 30.—Perovskite. I, plain; II, polarised

The other minerals, which are to be found in examining the specimens from Kimberley, with the exception of the diamond, are less important.

Magnetite, *chromite*, *titaniferous-magnetite*, and *picotite*,—four isomorphous minerals with difficulty distinguished from one another²—occur in small grains or crystals scattered through the ground-mass. Chromite is, perhaps, the most abundant of the four, and is primary, while magnetite may in part result from the decomposition of the olivine. The chromite is abundant in minute octahedrons. It is a mineral to be expected in a magnesian rock, occurring in almost all serpentines. Picotite or pleonaste occurs in similar minute grains, the latter of a dark green colour in transmitted light. Both the chromite and the spinel-mineral are much smaller than the perovskite crystals.

Another black mineral in octahedrons occurs in association with rutile. Ilmenite proper is, of course, rhombohedral, and usually is in thin plates. This mineral may be the same that so often occurs in basalts, and was called 'trapp-eisenerz' by Breithaupt. In titaniferous magnetite

¹ Sphene also occurs in clauolite-syenite and phonolite.

² For some remarks on this point see Wadsworth, *Lithological Studies*, section vii.

of this character, in the nepheline-dolerite of Meiches, Knop¹ found 25 per cent. of titanite iron.

Ilmenite is in plates with a purplish metallic glance, as in Rowley Regis basalt; and also probably in grains.

Apatite.—In small hexagonal colourless crystals, with a high index of refraction and a low double refraction. The crystals are unusually short, and have a negative character. Sometimes the apatite is faintly pleochroic. It occurs in short crystals in the ground-mass, and also in long actinolite-like crystals, apparently as a contact mineral around enclosures.

Epidote is in pale yellow grains, with a high index of refraction and a weak yellow pleochroism, and is apparently a secondary mineral due to decomposition.

Orthite is one of the most interesting of the non-essential minerals. It was noticed in large rounded cleavable grains, as if a primary constituent. It has a chestnut-brown to yellowish-brown colour in transmitted light, and is pleochroic. The pleochroism is more marked than that of epidote, changing from light to dark brown. It has a very high index of refraction, so that its surface appears wrinkled or shagreened. The double refraction is not so high as that of olivine. It has an excellent cleavage parallel to the base, OP, and another parallel to $\infty P\bar{\infty}$. On the basal face or cleavage plane an axis appears in converging light not quite in the centre of the field, and this axis shows a hyperbola coloured green inside and red outside, as in epidote.² The plane of the optic axis is diagonal to the cleavage, and the character is negative. All these characters agree with those of orthite, although this is a new association for that mineral. Orthite occurs in many granitic and hornblendic rocks, as shown by Törnebohm,³ Sjögren,⁴ and others, and was found by Vom Rath⁵ in

¹ *Neues. Jahrb.* 1877, p. 696.

² Rosenbusch, *Mikrosk. Physiogr.* i. 1885, p. 496.

³ *Vega-Exped. Velensk. Iakttagelser*, Stockholm, iv. 1887, p. 124.

⁴ Stockholm, *Geol. Fören. Förhandl.* iii. 1876-77, p. 258.

⁵ *Zeits. Deutsch. Geol. Gesell.* xvi. 1864, p. 255.

tonalite, but seems not to have been previously observed in peridotite or serpentine.

Tourmaline, in strongly pleochroic short prisms, is a rare but interesting constituent of the rock, being especially abundant around certain inclusions of shale.¹ Its pleochroism changes from brown to light blue. This and other minerals in small quantities are best detected after treating the thin section with hydrochloric acid.

Sphene, or titanite, was rarely observed, only a few irregular grains being noticed. The finely fibrous form of sphene as a secondary mineral, known as leucoxene, also rarely occurs.

Tremolite has already been described, also *rutile*, as secondary minerals.

Serpentine and serpentinous minerals, as already stated, form a large part of the rock, resulting from the decomposition of olivine.

Talc.—Very minute scales of this mineral were noticed in the ground-mass, and, as a contact or alteration mineral, around certain enclosures. It was highly refracting, had a wavy sheen, high colour, and parallel extinction.

Calcite is abundantly present in this rock. Diopside can be seen directly altering into this mineral, but the quantity of diopside is so small that we must look elsewhere for the large mass of calcite that penetrates the rock. It is possible that some readily decomposed lime-bearing mineral, like melilite, originally furnished it; but it may be that, as Cohen² has suggested, the lime has filtered in from without. Calcite is said frequently to form a crust around the diamonds.

¹ It will be remembered that tourmaline is very often a product of contact metamorphism in an aluminous rock.—T. G. B.

² *Neues Jahrb.* Beil. Bd. v. 1887, p. 195. Cohen here holds, in opposition to Mouille and others, that the 'calc-tuff' encrusting the 'blue ground' at the diamond mines is not derived from the diamantiferous ground; but is a later deposit from brackish water during a depression in the Pleistocene Period.

Zeolites occur in cavities and cracks as a product of infiltration and decomposition. They are very rare in the hard rock here described, but nearer the surface of the mine they occur abundantly in the decomposed blue ground, sometimes forming rock-like masses. The principal zeolite is natrolite. Fibres of natrolite were seen in thin sections radiating inwards, with a more or less tufted arrangement, from the outer edge of a mass of calcite.

Chalcedony was observed in one instance filling a microscopic cavity in the rock.

Cyanite.—A microscopic mineral occurs in minute quantity in the peridotite, whose exact nature is uncertain, but whose optical characters seem to agree more closely with cyanite than with any other known mineral. It is particularly interesting, as forming usually a zone around enclosures of shale and other rocks, as if a contact mineral. It usually forms a fine compact crystalline zone, but sometimes the separate crystals are large enough to be separately studied under the microscope. It occurs in fibrous masses resembling cyanite or actinolite, and has the following properties: a high index of refraction, about equal to that of pyroxene; the double refraction low, being lower than in actinolite. It is very faintly pleochroic from pale blue to faint green, or, more accurately, pale lavender (corresponding to *a*) to pale greenish-lavender (corresponding to *t*). The fibrous structure is well marked in this mineral. It has two cleavages, one parallel to the fibres, and one at right angles to them, the latter often causing a separation, as in apatite. The crystals seem to be brittle, being often broken, as is so common in sillimanite. It has a large angle of extinction ($= 32^{\circ}$ — 35°). It is unattacked by acid. All these characters seem to be those of cyanite. It would be curious, however, to find cyanite forming contact zones around enclosures in a peridotite.

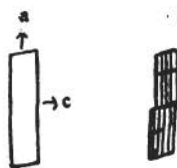


FIG. 31.—Cyanite ?
a, lavender; *c*, greenish

Diamond.—We have deferred to the last the consideration of the most interesting mineral in our rock. While the diamond is very difficult to observe in thin sections, it has been found abundantly in the decomposed portion of the peridotite. In practice it is obtained by the following process¹: The 'blue ground' is spread out upon the ground and exposed to the sunshine. After a period, dependent on the original condition of the rock, it has crumbled to a coarse powder, and is then placed in rotating washers, and all the lighter material washed away. The residue of chromic and titaniferous iron, garnet, pyroxene, &c., among which are the diamonds, is then picked over by hand, and the diamonds are separated. The number of diamonds thus obtained is something extraordinary. It is interesting also to find that they become more abundant the deeper they are from the surface, and where also the volcanic action was more intense. They are well crystallised in sharp octahedrons, also in dodecahedrons, at times. The crystallography of African diamonds² has been described by several mineralogists, and it is not to our purpose to enter upon that subject.

Carbonados and black diamonds are also common, not only in large crystals, but very abundantly as minute, almost microscopic, crystals. The abundance of these minute crystals is another proof that they are not enclosures brought up from some other matrix.

I feel some hesitation in describing certain small highly refracting crystals in the thin sections of the rock, which may possibly be referred to as diamonds. Former attempts to describe microscopic diamonds in rock sections have not been successful. Thus, Professor Jeremejew³

¹ T. Reunert, *Cape of Good Hope Official Handbook*, 1886, p. 213. Moule, 'Mémoire sur la géologie générale et sur les mines de diamant de l'Afrique du Sud,' *Ann. des Mines*, vii. 1885, p. 193.

² Among later papers are Kunz, *Proc. Amer. Acad. Sci. and Arts*, xxxiv. 1886, p. 250.

³ 'Mikrosk. Diamanteinschlüsse im Xanthophyllit der Schischimskischen Berge des Urals,' *Neues Jahrb.* 1871, p. 589.

thought he had found microscopic diamonds in xanthophyllite from the Urals, the diamonds, in the form of hexakistetrahedrons, being held to be very abundant; but Professor Knop,¹ after a very painstaking and convincing examination, proved the supposed diamonds to be merely holes in the xanthophyllite, the holes being probably negative crystals due to corrosion. By rubbing copper oxide on a dry slide he filled these holes with the black powder.

Another supposed discovery of diamonds in the matrix was announced by Fouqué and Lévy,² in 1879. They thought that they had observed numerous small diamonds in a thin section of the diabase, the so-called 'ophite andésitique,' which forms overflow sheets in the Karoo shales, and they published photographs of these supposed diamonds in sections. But, as they afterwards found,³ these also were only holes.

The very minute, isotropic, highly refracting crystals occasionally seen in a thin section of the Kimberley peridotite are certainly not holes, for they are sometimes of a faint yellowish, or, more frequently, bluish colour, and are often entirely embedded in the ground-mass. They never occur as enclosures in other minerals, but, like the perovskite, lie scattered in the ground-mass only; belonging, therefore, to a later generation of minerals than the olivine and bronzite. They are always in the form of entire crystals, even in the thinnest slide, as if they were too hard to be cut. The shape is that of an octahedron with rounded faces; tri-



FIG. 32.—Minute diamonds

¹ 'Ueber die Bedeutung der für Diamant gehaltenen Einschlüsse im Xanthophyllit der Schischimskischen Berge des Urals,' *Neues Jahrb.* 1872, p. 785.

² 'Note sur les Roches accompagnant et contenant le diamant dans l'Afrique Australe,' *Bull. Soc. Min. de France*, ii. 1879, p. 216.

³ *Neues Jahrb.* i. 1881, p. 194.

angular facets are also seen. (In some cases larger holes of the same octahedral shape may be observed in the section, as though a crystal had dropped out during the process of grinding.) Frequently these bodies seem to have concave faces, viz., as in fig. 32, ii. and iii.; this, however, is probably only an optical illusion. They sometimes have a decided yellow colour. They have a high index of refraction, and a dark rim around them. They are usually isotropic, but traces of weak double refraction in the centre of one of the crystals have been seen, a pale bluish colour appearing in certain positions, as if it were a crystal under strain. I

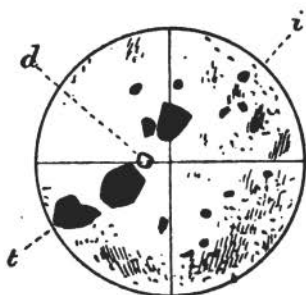


FIG. 33.—Microscopic section of the Kimberley peridotite. *i*, ilmenite; *t*, titanite; *d*, diamond (?)

I took some of the same rock from which the section was made, and after pulverizing it, separated the heaviest portion by means of Thoulet's solution. This was put upon a glass plate with a few drops of water, and then rubbed with a polished sapphire. The sapphire was clearly scratched. A photograph of one of these bodies (fig. 33) was taken by a friend, the supposed diamond lying between three crystals of titanite. Four of these supposed diamonds were seen in a single section of the rock.

I am not, however, prepared to state that these bodies are diamonds, not having been able to isolate them. Several colourless isotropic minerals appear in the rock, among which a colourless garnet, probably demantoid, occurs in small crystals and might readily be supposed to be a diamond.

Mr. Hedley, of the Colonial Exhibition, from whom I obtained my specimens, informed me that diamonds have been found in the rock as well as in the soft decomposed material; but as yet their detection under the microscope cannot be said to be free from doubt.

The larger diamonds from Kimberley have been the subject of study by several investigators. They have been found sometimes to have optical anomalies due to strain, so that they are not perfectly isotropic. Fizeau thought this strain to have been caused by the unequal distribution of heat during rapid cooling; but Jannettaz¹ holds that the strain is due to compressed gas in the interior of the crystal. The latter theory seems to be supported by the fact that the diamonds frequently crack or fly to pieces after having been taken from the mine. It is a phenomenon perhaps similar to that which occurs with the smoky quartz of Branchville, Connecticut, which, as Wright² has proved, is filled with liquid carbonic acid, and flies to pieces with a report when struck, as so well described by Hawes.³ The fact that fragments of the diamonds are often found separated in the mine has been used as an argument that the blue ground is not a volcanic rock but an aqueous mud derived from one. This argument falls to the ground on our knowing that the separation of these fragments is not due to a flow of the matrix, but to the bursting of the diamonds themselves on exposure to the atmosphere.

The Kimberley diamonds contain various enclosures,⁴ among which hematite is the most abundant. Zirkel,⁵ before the discovery of the South African diamond mines, gave a full *résumé* of the inclusions in diamonds. Schrauf⁶ has described a curious case of one diamond enclosed in another, a fact formerly mentioned by Kenngott.⁷ The researches of Harting⁸ upon inclusions in diamonds, as

¹ 'Sur les colorations du diamant dans la lumière polarisée,' *Bull. Soc. Min. de France*, ii. 1879, p. 124.

² *Amer. Journ. Sci.* xxi. 1881, p. 209.

³ *Ibid.* p. 203.

⁴ Cohen, *Neues Jahrb.* 1876, p. 752.

⁵ Zirkel, *Mikrosk. Beschaff. der Min.* 1873, p. 250 (gives literature).

⁶ Tschermak, *Min. Mitth.* 1873, p. 289.

⁷ *Wien. Akad. Sitzber.* x. 1853, p. 182.

⁸ *Verhdl. d. Kon. Institut. van Wetensch., Letterkunde &c. te Amsterdam*, vi. 1858.

well as those of Brewster, Petzhold, Wöhler and Desclois-eaux, Sorby and Butler, Damour and Dumas can only here be mentioned. The supposed discovery by Goeppert¹ of plants and organic cells in the diamond has not yet been verified.

The explorations of the last few years have placed it beyond question that the serpentine rock called 'blue ground' is in reality the matrix of the diamond. For a time it was thought that the diamonds were washed into the 'kopjes' from above, being mere alluvial deposits, as held by Mr. Cooper² and others; afterwards, and until the present time, the idea has been general that they were carried up from below along with other inclusions, and that their true matrix was some gneiss or itacolumite far below, from which they had become detached by volcanic agency. Others again, such as Döll,³ hold that while the serpentinous rock is the matrix of the diamond, the latter is a secondary mineral due to the decomposition of the rock.

But recent investigations seem to place it beyond question that diamonds are as much a part of the Kimberley rock as biotite, garnet, titanite and chromic iron and perovskite, and that, like these minerals, they may be considered as a rock ingredient. The fact that they continue just as abundant, if not more so, the deeper the mines are explored: that they are never found in, or especially associated with, the foreign inclusions of gneiss, granite, or sandstone: that they are distributed abundantly through all parts of the rock: and that in each of the four principal mines the diamonds have distinctive features of colour, lustre, and shape, are, with the microscopical evidence of the eruptive

¹ 'Ueber algenartige Einschlüsse in Diamanten,' *Breslau. Abhandl. der schles. Gesell. für vaterländische Cultur*, Abth. für Naturwissenschaften und Medicin, 1868-69, p. 61. He describes supposed algæ enclosed in diamonds, comparing them with *Eozoon* and *Oldhamia*, and names them '*Protococcus adamantinus*' and '*Palmogloeites adamantinus*.'

² Cooper, *Proc. Geol. Assoc.* iii. 1874, p. 336.

³ *Verhandl. geol. Reichsanstalt*, 1880, p. 78.

character of the rock, strong reasons for holding that the diamonds now lie in their original matrix.

Ground-mass.—All the above-described minerals lie, some of them porphyritically, in a ground-mass or base, which we may now examine. This is a more or less homogeneous serpentinous mass, which, by reason of the decomposition it has suffered, is very difficult to study. It is now mainly composed of a nearly isotropic serpentinous mineral mixed with calcite. By treating the slide with hot hydrochloric acid, the iron and calcite are dissolved away and the amorphous and more readily soluble portions of the ground-mass eliminated, so that traces of the original structure for the first time become visible. Forms of small prismatic crystals (possibly a pyroxenic mineral) can now be seen occasionally, and between them are traces of an isotropic substance which may indicate a non-crystalline base. Certain resemblances can be traced to the ground-mass of sundry decomposed basaltic or other basal rocks. The base now, however, is a greenish serpentinous substance full of calcite grains, flour-like grains of gibbsite, rounded dusty masses of ferruginous and kaolinic material, &c., the original structure being entirely lost through disintegration. Until fresher specimens are obtained it is impossible to speak with any confidence concerning the original structure of the ground-mass. In one case already mentioned, a brown glass was noticed enclosed in olivine. Any similar basic glass in the ground-mass has long since been entirely decomposed.

Fragmental Enclosures.—Fragments, both of the adjoining shale and diabase, and also of more deeply seated granite, gneiss, eclogite and other rocks, occur in the Kimberley peridotite. Those of shale are by far the most numerous, sometimes becoming so abundant as to form the greater portion of the rock.¹ A breccia of shale

¹ Nevertheless in a large specimen, given to me by Sir J. B. Stone, I could not with certainty identify any shale, even under the microscope, but fragments of a compact rock of peculiar structure were present. See *Geol. Mag.* 1895, p. 498. (It is represented on Plate I.—T. G. B.)

cemented by the serpentinous rock may then occur. The adjoining shale in place is a black bituminous rock full of pyrite, burning when set on fire. When kept, both unburned and burned specimens after a time become covered with alum. The fragments of shale in the peridotite are more compact and have lost their shaly character, their bituminous or carbonaceous matter and their sulphur. The microscope shows that they have also frequently been mineralogically altered by the heat of the lava; having lost the character of a shale and become filled with aggregates of micaceous minerals. Often the shale fragment is corroded away to a skeleton or shell, filled with the ground-mass (fig. 34). In another case a zone of grey kaolin-like



FIG. 34.—Shale fragment filled with the ground-mass



FIG. 35.—Shale fragment surrounded by calcite

substance occurred around the fragment, while calcite was outside of all (fig. 35).

These enclosures occur of all sizes, from fine powder to very large masses. The largest masses are seen only at the top of the mine, and are made of shale; they are called 'floating reef.' In regard also to smaller fragments, shale is most abundant at the top of the mine, and less abundant the deeper we penetrate. Rounded fragments of granite, mica-schist, and quartzite are found, though rarely, and fragments of diabase also occur. All seem to have been carried upwards.

Chemical Composition of the Ground-mass.—Almost all of the rock is soluble in acid, a small residue of garnets, biotite, bronzite, perovskite, ilmenite, chromite, &c., remaining. By repeated treatment with hydrofluoric and

sulphuric acid all the silicates except garnet are dissolved, which with perovskite forms the larger part of the residue.

The specific gravity of the rock was determined by the use of Klein's cadmium solution and Westphal's balance, and is somewhat less than the true specific gravity.

Two varieties were analysed¹ :—

I. The least decomposed rock, with few shale enclosures.

II. The more decomposed rock, with many shale enclosures (diamantiferous).

	I.	II.
SiO ₂ (with some TiO ₂)	33·00	34·80
FeO (including Al ₂ O ₃)	12·00	14·40
MgO	32·38	30·76
CaO	9·60	2·70
Na ₂ O	0·67	1·40
CO ₂	7·05	5·55
H ₂ O (carbonaceous matter, &c.)	6·00	10·60
	100·70	100·21
Spec. grav.	2·734	2·64–2·70

Since, in Analysis I. 8·97 of the CaO clearly belongs to the 7·05 CO₂, we get :

	III.	or, eliminating the calcite :	IV.
SiO ₂ , &c.	33·00	SiO ₂ , &c.	39·25
FeO, &c.	12·00	FeO, &c.	14·27
MgO	32·38	MgO	38·51
CaO	0·63	CaO	0·75
Na ₂ O	0·67	Na ₂ O	0·79
CaCO ₃ (calcite)	16·02	H ₂ O, &c.	7·13
H ₂ O, &c.	6·00		
	100 70		100·70

¹ The titanitic acid (at least 1 per cent.) was not separated from the silica, nor the alumina (which was in small quantity in Analysis I.) from the iron. The CO₂ was estimated directly in a CO₂ apparatus, using dilute acid. The carbonaceous (organic) matter and moisture were determined by ignition over a blast lamp, and from the total loss deducting the CO₂ already determined and correcting for the gain of oxygen by the FeO.

From Analysis IV. the amount of serpentine in the rock can be readily calculated. A typical serpentine¹ has the composition of

SiO ₂	MgO	H ₂ O
43·48	43·48	13·04,

the water being $\frac{2}{15}$ of the whole. In the Kimberley rock freed from calcite the water is only $\frac{1}{15}$ of the whole, so that we may conclude that about half of the rock is serpentine. The analysis shows that olivine forms the principal constituent of the remaining portion of the rock. The slight excess of silica beyond that required to form olivine,² (SiO₂ FeO MgO), (39·12 13·16 44·80), belongs to the biotite, bronzite and garnet present in small proportions.

The calcite, forming 16 per cent. of the rock, is probably, with most of the serpentine, the result of the decomposition of the ground-mass. Unless we assume that the lime is derived from without, which would be difficult to explain,³ it has come from the decomposition of certain lime-bearing minerals. With the exception of chrome-diopside—which is present only in small quantity—the porphyritic crystals are practically free from lime. It may have come from diopside, melilite, or some other lime-bearing mineral in the ground-mass. The small percentage of alumina and the mineral associations exclude felspar as a constituent.⁴ Calcite frequently occurs in serpentine, and is generally regarded as the result of the decomposition of a pyroxenic mineral.⁵

¹ Rammelsberg, *Zeits. Deutsch. Geol. Gesell.* xxi. 1869, p. 97; *Mineral. Chemie*, Leipzig, Theil ii. 1875, p. 506.

² Stelzner, 'Ueber den Olivin des Melilithbasaltes vom Hochbohl,' *Neues Jahrb.* i. 1884, p. 271.

³ Surely not; because, where volcanic action has been, springs with CaCO₃ are common.—T. G. B.

⁴ It would equally exclude nepheline.—T. G. B.

⁵ Doelter, *Ueber das Muttergestein der böhmischen Pyropen*; Tschermak, *Min. Mitth.* 1873, p. 13, and other references.

(It is so sometimes, but it is often infiltrated from without, as in the so-called ophealite formed from brecciated serpentine.—T. G. B.)

The extreme basicity of the rock, the abundance of the calcite as a decomposition product, the high magnesia and low alkali, the presence of biotite, and more especially of perovskite, point to the possible presence of nepheline or melilite in the ground-mass. All these characters occur in melilite-basalt.¹ Traces of a mineral giving rectangular sections occur in the ground-mass, which possibly are to be referred to melilite or nepheline, but its altered state prevents this suggestion from being confirmed with the present material. In melilite-basalt, as in the Kimberley rock, the pyroxene is chrome-bearing, the perovskites surround the olivine 'einsprenglinge,' garnets may occur, and the augite may be replaced² by biotite.³

The composition of the whole rock, characterised by a low amount of silica and a high amount of magnesia, together with much lime and little alkalies, may be compared with that of certain garnetiferous olivine serpentines.⁴ Among unaltered rocks the only ones that show similar relations between the silica and magnesia are dunite,⁵ olivinfels,⁶

¹ Stelzner, 'Ueber Melilith und Melilithbasalte,' *Neues Jahrb. Beil.* Bd. ii. 1883, p. 369.

² Törnebohm, 'Melilitbasalt från Alnö, Stockholm,' *Geol. Fören. Förhandl.* vi., 1882-83, p. 240.

³ Professor Rosenbusch, to whom these proofs have been submitted, remarks that it would have been a great satisfaction to Prof. Carvill Lewis if he had lived to know that in the State of New York dykes of Alnöite are now known to exist in the vicinity of dykes of the Kimberlite character.—T. G. B.

⁴ Compare serpentine from Zöblitz (Lemberg, *Zeits. Deutsch. Geol. Gesell.* xxvii. 1875, p. 532) with the following composition:

SiO ₂	Fe ₂ O ₃ + Al ₂ O ₃	MgO	CaO	H ₂ O
39.27	8.98	38.78	1.16	11.81

Compare, also, analyses of many serpentines quoted in Wadsworth, *Lithological Studies*, 1884, table 4.

⁵ Dunite from the Vosges (Tschermak, *Min. Mitth.* 1875, p. 187); New Zealand (*Zeits. Deutsch. Geol. Gesell.* xvi. 1864, p. 341); North Carolina (*Amer. Journ. Sci.* xxxiii. 1862, p. 199), &c.

⁶ Olivinfels from Steiermark (Tschermak, *Min. Mitth.* 1872, p. 79); from Norway (Kjerulf, *Verhandl. Geol. Reichsanstalt*, 1867, p. 71), &c.

and chassignite¹ (an olivine meteorite). The structure of the Kimberley rock, as will presently be shown, differentiates it from these, which are all holocrystalline. The rock now described appears to differ from any heretofore known. Picrite-porphyrite is practically a felspar-free melaphyre, or, perhaps in deference to its hornblende, it may be called the effusive form of the rock named camp-tonite by Rosenbusch. Picrite-porphyrite is also an augitic rock, and contains less magnesia than the Kimberley rock. Limburgite, the neovolcanic equivalent of picrite-porphyrite, is likewise an essentially augitic rock, being a non-felspathic basalt,² and is also much poorer than the Kimberley rock.

There appears to be no named rock-type having at once the composition and structure of the Kimberley rock. For this reason, as also on account of its importance as the matrix of the diamond, it is now proposed to name the rock *Kimberlite*.

Kimberlite may be described as a porphyritic volcanic peridotite of basaltic structure, or, according to Rosenbusch's nomenclature, the palæovolcanic 'ergusform' of a biotite-bronzite-dunite, being an olivine-bronzite-picrite-porphyrite rich in biotite. Had it less olivine and more rhombic pyroxene it could be classed among the picrite-porphyrites, and be called a saxonite-porphyrite. As it is, it is more nearly related to a dunite-porphyrite. Prof. Judd has described a porphyritic dunite, but that is a holocrystalline deep-seated rock of entirely different structure from the rock under consideration. In fact Kimberlite is a rock *sui generis*, dissimilar to any other known species.

Three varieties of Kimberlite may be distinguished:

¹ Vauquelin (*Ann. Phys. Chim.* i. 1816, p. 49); Damour (Paris, *Comptes Rendus*, lv. 1862, p. 591); Tschermak (*Wien. Akad. Sitzber.* lxxxviii. 1883 (Abth. i.), p. 361).

² This must be understood in the sense that felspar has not yet separated from the glassy basis. From the chemical composition of the rock, it is reasonable to conclude that limburgite, with a different environment, would appear in the form of a picrite; *i.e.* a rock containing some felspar, but not so much as in a dolerite.—T. G. B.

(1) *Kimberlite proper*, a typical porphyritic lava ; (2) *Kimberlite breccia*, the same lava broken and crushed by volcanic movements and crowded with included fragments of shale ; (3) *Kimberlite tuff*, being the fragmental and tufaceous portion of the same volcanic rock. These varieties pass by insensible gradations one into another, so that no sharp line can be drawn between them, and all occur together in the same neck or crater. The Kimberlite breccia forms by far the greater portion of the rock, and is rich in diamonds. It is traversed by dykes of Kimberlite proper, and contains streaks and patches of softer 'soapy' material, which appears to be the Kimberlite tuff. The deeper portions of the Kimberlite breccia become more compact as though passing gradually into Kimberlite proper. The so-called 'blue ground' has also been analysed, but being so thoroughly altered, the analyses are of small scientific value.

Perhaps the most interesting chemical observation concerning this 'blue ground' was that made by Sir H. E. Roscoe. He found¹ that on treating it with hot water an aromatic hydrocarbon could be extracted. By digesting the 'blue ground' with ether, and allowing the solution to evaporate, this hydrocarbon was separated and found to be crystalline, strongly aromatic, volatile, burning with a smoky flame, and melting at 50°C.

Structure.—The structure of Kimberlite, to which subject we may now proceed, is its distinguishing and characteristic feature, differentiating it from ordinary serpentines and peridotites, if not from all other terrestrial rocks. The structure can only be compared with that of certain meteorites.

It may be described as a porphyritic brecciated structure. While evidently the structure of an eruptive rock, it at the same time shows clear proof of mechanical disturbances during or after its cooling. According as the por-

¹ Manchester, *Lit. Phil. Soc. Proc.* xxiv. 1835, p. 5.

phyritic or the brecciated structure happens to predominate in the section under examination, the observer varies in his opinion as to whether the rock is a lava or a tuff.

Cohen, Hudleston, Moulle, and others, believed it to be an igneous tuff, while Dunn, and Maskelyne and Flight considered it to be an eruptive gabbro-like rock.

When comparatively free from enclosures the porphyritic structure may be as distinctly shown as in a basalt. The greater mass of the porphyritic crystals (the 'einsprenglinge') are the olivines, which often have distinct crystalline form. These are, as already stated, more frequently rounded and like the olivines in basalts, and may show the action of a corrosive magma. Biotite, bronzite, garnet and other substances also form comparatively large crystals, usually rounded, and, with the olivines, lie separately in a more or less isotropic ground-mass made mainly of a serpentinous mineral. The rock therefore is not holocrystalline, but belongs to the class of volcanic or effusive rocks ('erguss-gesteine'), characterised by idiomorphic porphyritic crystals floating in a ground-mass.

That the rock was a true igneous lava, and not a mud or ash, is indicated by the following facts:—

1. The minerals and their associations are those characteristic of eruptive ultra-basic rocks.
2. The porphyritic crystals are idiomorphic as in volcanic rocks.
3. The corrosion cavities ('einbuchtungen') in the porphyritic crystals are due to solution by the hot magma.
4. The character of the bronzite and diopside is similar to that in meteorites and eruptive rocks, but not in metamorphic or plutonic rocks.
5. The occurrence of a ground-mass and of traces of glass.
6. The traces of a second generation of minerals (pyroxene?) in the ground-mass.
7. The occurrence of fragmentary enclosures of the adjoining rock and of deep-seated rocks, and the evidence of alteration by heat which these enclosures exhibit.

8. The traces of a fluidal structure shown on polished specimens.
9. The identity of the rock with one in Kentucky, which is a true eruptive dyke, and with others in the Vaal River, which also form dykes.

That it is not a tuff is shown by the entire absence of stratification, of clayey or ashy bands, of water-worn fragments, of cementing material, and by its geological position: not as an overflow mud deposit, but in the very neck of a volcano.¹

The brecciated structure of the rock is shown not only in the abundance of angular fragments of shale it contains, but also in the broken and angular character of many of the porphyritic crystals in it, and the mechanical manner in which they seem to have been sometimes pushed together.

Yet the structure is not a purely mechanical one, such as is the case with certain ancient rocks which have been subjected to heavy pressure. A so-called mechanical-porphyrific structure is well known in deep-seated peridotites,² being particularly well marked in the variety named olivinfels. These, as Brögger³ and Reusch have shown in Norway, are often so crushed as to resemble a sandstone. Here, however, under the microscope the so-called 'cataclastic' structure,⁴ or 'mörtel-structur,'⁵ whereby the outer portions of the crystals are smashed into a mosaic-like band (as in 'augengneiss,' &c.) can always be seen. No traces of this cataclastic structure occur in the Kimberley peridotite. The olivines have no mosaic borders or ends, no 'eyes' of them are made, and their rounded form is certainly

¹ (But suppose the rock were an agglomerate? This appears to me equally consistent with all the reasons given above, except, perhaps, 8 and 9, of which the former is very dubious, but the latter no doubt is weighty, because an agglomerate does not usually have a dyke-like habit.—T. G. B.)

² Rosenbusch, *Mikrosk. Physiogr.* ii. 1887, p. 273.

³ *Neues Jahrb.* 1880, ii. p. 187.

⁴ Kjerulf, Christiania, *Nyt. Mag. Naturvid.* xxix. 1885, p. 215.

⁵ Törnebohn, Stockholm, *Geol. Fören. Förhandl.* v. 1880-81, p. 233.

not due to pressure. The brecciated structure, therefore, whatever its cause, is not due to pressure.

Several causes may produce brecciation in a volcanic rock. It may be due :—1. To the rapid cooling and consequent shrinking and cracking of a fluid lava ; 2. To the contact of the moving lava with the adjoining rock which is carried along with it and broken up to form a so-called friction breccia ('reibungsbreccia'); 3. To subsequent explosions and movements in the crater of the volcano. It is quite possible that in the present instance all three of these causes may have operated.

As to the first cause, the words of Dr. Wadsworth,¹ if applicable, seem prophetic. After explaining the brecciated character of meteorites as due to rapid crystallisation, he says: 'If we could find rapidly cooled, unaltered terrestrial peridotite rocks, I should expect to find in them the chondritic structure, the same as the Estherville meteorite possesses the structure of an unaltered terrestrial peridotite, and the meteoric pallasites possess that of the terrestrial ones.' Roth² speaks of the formation of lavas and slags which fall apart on cooling.

The second process, which causes a 'friction breccia,' is well known in many volcanic districts. It is seen on approaching the vent of the volcano. Naumann³ has given some excellent examples of this in Saxony, where in the border between porphyry and shales, great masses of the breccia, the so-called 'Brockengesteine' is formed, and the mass of the enclosed slates may predominate over the mass of the porphyry.

The third process, the result of successive explosions in the same crater, is also common in volcanic districts. In this case, not only are fragments of the adjoining rock enclosed in the lava, but the older and hardened magma itself is broken up and imbedded afresh in the new erup-

¹ *Lithological Studies*, 1884, p. 111.

² *Allg. und chem. Geol.* Berlin, ii. 1883, p. 207.

³ *Lehrbuch der Geognosie*, Leipzig, i. 1858, p. 917.

tion. In this case the old lava forms the larger part of the breccia, and the final composition and structure is not unlike that of a tuff. It is of course just this material which, when ejected in the form of dust or mud, does make the stratified ashes called tuff. - This kind of breccia occurs in the Euganean Hills,¹ in Italy,² and perhaps in Wales.³

According to Chaper,⁴ who has studied the geology of the Kimberley mines, the eruption has taken place at many successive periods; all his observations pointing to a series of eruptions, between each of which there was time for the volcanic mass to consolidate. He says that the great irregularities so puzzling to the miners are thus explained, and that at Bulfontein and Du Toits Pan it is possible to make out a chronology of the various eruptions.

If this last is the principal cause of the breccia it is no wonder that the rock should so closely resemble a tuff. It is, of course, difficult to draw the line between a brecciated lava and a tuff, but in this instance everything points to its lava-like character. The tuff would lie outside of the volcano, the brecciated lava in its vent. The conception of a true porphyritic lava, afterwards broken by paroxysmal eruptions, seems perfectly to explain the nature of the remarkable rock which is now under discussion. Certain so-called 'soapy' bands in the mine probably represent the true tuff. Just as the limburgite of the Kaiserstuhl district alternates with beds of tuff, so here it is probable that

¹ Reyer, *Fisik der Eruptive; Die Euganaen*. [It is often very well exhibited in the dykes of basalt cutting through lower carboniferous rocks near Burntisland, Scotland. See, for other cases, *Proc. Geol. Assoc.* vii. No. 2. - T. G. B.]

² The piperno.

³ Bonney, *Quart. Journ. Geol. Soc.* xxxv. 1879, p. 311. [It may also be produced by more solid parts of the lava being ruptured and swept along by the onward pressure of the more liquid mass, the result being often called a fluxion-breccia.—T. G. B.]

⁴ *Bull. Soc. Min. de France*, ii. 1879, p. 195. 'Sur les mines de diamant de l'Afrique Australe.'

Kimberlite tuff occurs together with the Kimberlite breccia.

A comparison of the Kimberlite with known ashes or tuffs, Professor Rosenbusch having kindly placed his collection at my service for this purpose, has failed to establish any analogy with them, and I am compelled to differ from Professor Cohen and others who speak of it as ash, mud, or conglomerate, and to regard it as a true eruptive lava.

The structure of the African Kimberlite is equally shown in the Kimberlite from Elliott County, Kentucky, and with that from Syracuse, New York. I have compared the Kentucky rock with the African rock directly. Dr. Williams has published a photograph of that from Syracuse.¹ In mineral composition, in eruptive character, in structure, in enclosures, the three rocks are identical. As the Kimberlite of Kentucky and New York State occurs in dykes, not volcanic vents, it becomes all the more certain that the porphyritic structure is an original one characteristic of the rock.

Although, as already stated, the peculiar character of Kimberlite is shared by no other terrestrial rock, it is of high interest to find that in structure it resembles meteorites of similar composition. Attention has already been called to the likeness of some of its minerals to those in meteorites, and its chemical composition has also been shown to be closely related to that of the olivine meteorite called chassignite.

If we were to replace the ground-mass of Kimberlite by native iron, we should get a rock nearly allied in both structure and composition with the well-known class of meteorites known under the name of chondrites. These meteorites are both porphyritic and brecciated, and when the breccia structure is well developed it has given rise to the same

¹ For notes upon specimens afterwards obtained from these localities by Professor Lewis, see Section III.

discussion as Kimberlite, as to whether they are tuffs or lavas. Haidinger was one of the first to describe the so-called meteorite-breccias, and to show that not only are angular fragments of other rocks frequently enclosed in the olivine rock, but that the meteoric rock itself is often broken into angular and rounded fragments cemented together, as if a volcanic tuff. Tschermak¹ holds to the tuff-like character of certain meteorites, yet remarks that— 'There occur passages into the tuff structure, so that the same stone may be designated by one observer as crystalline, by another as clastic.' Another structure in these olivine meteorites is the occurrence of rounded masses of olivine or of olivine and enstatite, called the chondritic structure. The origin of this has given rise to much discussion. A chondrus may consist of a single optically continuous mass of olivine, or it may be polysomatic, that is, due to a number of individuals.

Polysomatic chondri of olivine occur in the Kentucky Kimberlite. The olivines are laid together, as if in a mosaic, the whole forming an irregular sphere. This is identical with a granular chondrus in a meteorite from Seres figured by Tschermak.² Glass which occurs in these chondri occurs also in a chondrus from Kimberley.

¹ *Die mikrosk. Beschaff. der Meteoriten*, Stuttgart, 1885, p. 3.

² *Ibid.* (Plate VIII. fig. 2.)

SECTION III

KIMBERLITE FROM THE UNITED STATES

BY PROFESSOR T. G. BONNEY

Two rocks from the United States, specimens of which were in Professor Carvill Lewis' collection at the time of his death, present, as will be seen hereafter, a very close macroscopic and microscopic resemblance to the diamond-bearing rock from South Africa. One occurs at Syracuse, New York; the other about six miles south-west of Willard, in Elliott County, Kentucky. For the most recent information relating to the former rock we are indebted to the late Professor G. H. Williams; the latter has been described by Mr. J. S. Diller.

1. *Rock of Syracuse, New York.*¹—There are two types of this rock, according to Professor G. H. Williams; one of these is a very dark green, almost black, rock, with minute specks of glistening mica, occasional larger plates of a brass-yellow mineral (4×6 mm.), and a few small masses of a lighter green more compact serpentine with a sharp crystal form. The other is paler in colour, composed of a dense

¹ Literature.—G. H. Williams, *Science*, March 11, 1887; *Amer. Journ. Sci.* xxxiv. 1887, 137; *Bull. Geol. Soc. Amer.* i. 1890, p. 533. He cites Vanuxem (*Third Annual Report*, 1839, and *Final Report on Geol. of Third District of New York*, 1842); Lewis Beck (*Report on Mineralogy of New York*, 1842); T. S. Hunt (*Mineral Physiography and Physiology*, 443-447); and *Amer. Journ. Sci.* ii. xxvi. 1858, 237; *Geological Hist. of Serpentes* (*Trans. Roy. Soc. Canada*, i. 174); and J. D. Dana (*Manual of Geology*, p. 233, third edition), as referring to it more or less in detail.

compact base containing numerous lighter spots, with a sharp crystal outline, thus producing a porphyritic structure. Some singular blood-red patches are scattered through this rock. The first type, under the microscope, appears as a medium-grained aggregate of brown mica, of octahedral crystals of two minerals—one yellow and transparent, the other black—of green or colourless serpentine, and of carbonates. Through this matrix occasional larger crystal forms are scattered. In spite of nearly all the substance of the rock being secondary, these preserve the shape of crystals. Among the minerals present Professor Williams identifies olivine or enstatite; the latter being completely, the former mostly, replaced by serpentine. The mica is the peculiar brown biotite, well known to be characteristic of eruptive peridotites, without a definite crystal form, and often with a bleached peripheral zone. Of the octahedral minerals, the opaque are usually chromite, but a few may be magnetite, the transparent are proved to be perovskite.

The second type of this rock, under the microscope, is identical with the former, except as regards structure. The ground-mass is finer grained, thus throwing the characteristic crystal forms of the olivine and enstatite into sharp relief; the octahedral crystals are much smaller than in the other rock and are confined wholly to the ground-mass; the brown mica is less abundant. 'The persistence of structure in this rock, in spite of the profoundest chemical changes, is remarkable. In one porphyritic specimen, the ground-mass is almost all carbonate, the mica has become quite colourless, and the olivine crystals are changed to a perfectly isotropic, colourless substance, enclosing the sharpest possible rhombohedra of dolomite; in fact none of the original components remain, except the chromites, and yet the structure is just as sharp and characteristic as in a specimen,' of which Professor Williams gives a figure.

The rock, when Professor Williams wrote his earlier paper, was no longer visible, being concealed beneath

a lawn and a street. His description was founded upon observations made and specimens collected, about 1887, by Professor Oren Root, who found it to be associated with shales and limestone belonging to the Onondaga salt-group, and considered it, for reasons which he gives, to be intrusive in them.

In a later paper¹ Professor Williams adds some interesting details. In cutting some deep sewers, 'two admirable sections' had been exposed. In these it was seen that the serpentine formed a dyke, cutting perpendicularly across the nearly horizontal strata of limestone, forcing its way in places between them, and, in one of the exposures, considerably disturbing those in its immediate vicinity. Much of the serpentine was full of angular fragments of other rocks embedded in it, sometimes at least one-third of the face of a block being occupied by fragments. Most of these, but by no means all, are bits of the adjacent limestone. One, for instance, is a large fragment of black shale (probably Utica shale), which here is over 1,000 feet below the surface. Another is a fragment of an acid crystalline rock, granite or gneiss, which must lie over 2,000 feet below the surface. Granitic and syenitic fragments were also mentioned by the earliest observers. All of the included limestone fragments show signs of contact metamorphism, and the new minerals, thus produced, have a zonal arrangement.

Professor Williams is of opinion that the eruptive rock, which is now represented by the serpentine, must have differed much from its present composition as represented in analyses furnished by Professor James Ball, which he quoted in the earlier memoir. The specimen consisted of carbonate of lime 84.77, carbonate of magnesia 2.73, and serpentine 62.5. The composition of the last was as follows :—

¹ *Bull. Geol. Soc. Amer.* i. 1890, p. 533.

SiO ₂	.	.	.	.	.	.	40·67
Al ₂ O ₃	.	.	.	.	.	.	5·18
FeO	.	.	.	.	.	.	8·12
MgO	.	.	.	.	.	.	32·61
H ₂ O	.	.	.	.	.	.	12·77
							99·30

(2) *Rock of Elliott County, Kentucky* :—

This rock occurs between Isom and Critche's Creeks, near Fielden Post Office, six miles south-west of Willard, in Elliott County, Kentucky. Mr. Diller describes it at some length in the 'Bulletin of the American Geological Survey,'¹ and, more shortly, in the *American Journal of Science*.²

It was discovered by Professor A. R. Crandall, who states that it has a very limited extent laterally, and so readily disintegrates as not to form a noticeable feature in the topography. 'It appears to extend in two diverging lines from Critche's Creek into the valley of Isom's Creek, with several minor offshoots of undetermined, but doubtless limited, extent, possibly no more than wedge-like projections from the main dyke between the strata of the coal measures, which make up the whole height of the hills of this region. The whole length of the dyke in its greatest surface extension appears to be less than a mile, with a width of from a few feet to 50 feet or more.'³ The rock, according to Mr. Diller, is compact in structure, dark greenish in colour, with a specific gravity of 2·781, having embedded in it many grains of yellowish olivine, uni-

¹ No. 38 (with map and illustrations).

² Vol. xxxii. p. 121. See, also, *Science*, 1885, p. 65.

³ This statement is mainly an inference, as pointed out by Mr. Diller, from the presence of pyrope and ilmenite in the soil. The visible outcrops of the rock are only five in number—three of them in a line about three furlongs long; the others being about five furlongs away in opposite directions from one end of it, which happens to be the spot where the rock is in best preservation; they are more or less oval in shape.

formly distributed throughout the mass. These, however, occasionally disappear, and the whole is serpentine. This olivine and the serpentine together form nearly 75 per cent. of the rock. Besides them other minerals appear in the hand specimen, the most important being pyrope and ilmenite; a few scales of biotite may be observed. Near the exposed surface the rock becomes yellowish, due to the oxidation of the iron, and softer, so that it readily disintegrates.¹ The garnet and much of the ilmenite withstand the atmospheric influences, and are found quite fresh and abundant in the sand resulting from the disintegration of the peridotite. The specimens from some localities are quite free from included fragments, while those from another 'are full of fragments of shale, which have been greatly indurated and metamorphosed in the operation.' In the best preserved specimens (which also are free from rock fragments) Mr. Diller estimates the composition to be as follows :—

Primary minerals	Per cent.	Secondary minerals	Per cent.
Olivine . . .	40	Serpentine . . .	30·7
Enstatite . . .	1	Dolomite . . .	14
Biotite . . .	1	Magnetite . . .	2
Pyrope . . .	8	Octahedrite ² . . .	1·1
Ilmenite . . .	2·2		
Apatite . . .	trace		

He gives a figure of a microscopic section from which it would appear that the larger included minerals are somewhat irregular in outline, size, and distribution. The olivine grains are generally irregular in form, varying from 0·1 to 1·5 mm. in diameter, and penetrated by many fissures. Occasionally, however, they occur in short prisms, terminated by brachydomes, the usual planes being suppressed. The structure of the matrix appears to be fine-granular. The alteration of the olivine to serpen-

¹ Compare the 'yellow ground' of the mines at Kimberley.

² A synonym of anatase (TiO₂); and corresponding with the perovskite of Williams.

tine takes place rapidly in the cross fractures approximately parallel to the base, but very slowly along the numerous minute fissures in the prism zone. Cleavage parallel to the brachypinacoid is barely discernible. Magnetite is excluded in the usual manner, and in some cases dolomite appears as an ultimate product of alteration. The enstatite has an irregular (corrosion) border. The biotite is dark coloured, is strongly dichroic, and is sometimes surrounded by a secondary border of biotite (differing in optical properties) and of magnetite. The pyrope occurs in spherical and ellipsoidal grains, varying from 1 to 12 mm. in diameter, of a clear, deep-red colour, its specific gravity being 3.673. It is often surrounded by a border, the outer band of which is commonly rendered opaque by a dark powder, the inner one being a greyish or reddish-brown colour, generally fibrous in structure (the substance named kelyphite by Schrauf, but shown by Lasaulx to be a mixture of several minerals, chiefly of the pyroxene and amphibole groups). Of the other minerals, the octahedrite occurs in yellowish clouded grains, ranging in size from .004 to .06 mm. in diameter. The dolomite is irregularly distributed. Of the serpentine there are two forms.

This peridotite cannot be seen in contact with the adjacent sandstone and shale; but within a short distance from it both appear to be indurated, and the latter in some cases to be converted into a kind of spilosite. The fragments of shale included in the peridotite are always surrounded by a border of colourless mica, its scales being intricately intermingled, and have undergone other mineral changes, generally on a minute scale. On a review of the whole evidence, Mr. Diller concludes that 'the peridotite is a truly eruptive rock, which has been forced up through the carboniferous strata.'

At the end of the paper Mr. Diller gives a series of analyses of the adjacent sedimentary rocks, of the peridotite, and of the minerals contained in it.

The following represent the peridotite :—

	I.	II.
SiO ₂ . . .	29·81	29·43
TiO ₂ . . .	2·20	1·48
P ₂ O ₅ . . .	0·35	trace
Cr ₂ O ₃ . . .	0·43	0·14
Al ₂ O ₃ . . .	2·01	2·36
Fe ₂ O ₃ . . .	5·16	.....
FeO . . .	4·35	9·06
MnO . . .	0·23	.....
NiO . . .	0·05	0·60
CaO . . .	7·69	6·94
MgO . . .	32·41	31·66
K ₂ O . . .	0·20	0·65
Na ₂ O . . .	0·11	0·78
H ₂ O (at 110°) . .	8·92	10·90
CO ₂ . . .	6·66	5·65
SO ₃ . . .	0·28	0·30
Total . . .	<u>100·86</u>	<u>100·15¹</u>
S.G. . . .	2·781	2·697

To these notes may be added a few remarks on the specimens which I find in Professor Lewis' collection :—

The hand specimen [436] labelled 'From James Street, Syracuse, N. Y. (G. H. W. col. Feb. 1888)' is a dark-coloured rock of a greenish tint, slightly mottled in one or two places with a yellower green hue, compact in structure, dull, but with fairly numerous rather rounded spots, up to about one-sixth of an inch in diameter, with a more glistening lustre. The specimen is traversed by a thin whitish vein. In fracture and general aspect it resembles a serpentine, or something between a serpentine and a diabase, except for the slight irregularity in the 'por-

¹ Including 0·20 of sulphides.

phyritic' structure. A slice has been prepared for microscopic examination; but here, as in the case of the others mentioned below, a brief notice will suffice, after Professor Lewis' elaborate description of the Kimberley rock, for the general resemblance is very strong. In this slice we find a number of grains, rather variable in size and form, some approaching idiomorphic, others rounded or apparently broken, but all serpentised. Most of them were formerly olivine, but it is possible that enstatite also may have been present. There are various differences of detail in the colour and minuter structure of the serpentine, in the distribution and arrangement of the iron oxide, and the like; but on them it is needless to dwell. These larger grains are scattered about in a more or less granular matrix, apparently identical with that of the Kimberley rock, in which serpentine and a carbonate, probably calcite with some dolomite, are important constituents. One part of the slice suggests the presence of fragments of a peridotite rock, embedded in a matrix of similar condition; but whether this is significant of a pyroclastic structure or of a fluxion breccia is open to question. Here, also, is a small 'patch' of rather rounded mineral fragments, which seem to be a felspar.

The rock from Kentucky is represented by the following specimens:—

(a) [435, 1.] 'Dyke I., Elliott Co. (Crandall).' A rock resembling that from Syracuse in colour and aspect, but the fracture is a shade rougher, the rounded spots run to a slightly larger size, being not seldom about one-fifth of an inch in diameter; they are less lustrous than in the other case, and of a yellowish-green colour (similar to that in the mottling of the other specimen and resembling that of olivine), and thus lighter than the matrix. Except in this respect the two specimens are very similar. Microscopic examination shows that this rock closely resembles one of the best-preserved specimens from Kimberley. The olivine

F

generally is more rounded than in the last case, and a considerable amount of the original mineral still remains, especially in the larger grains; that is, they are about half olivine, half serpentine, exhibiting the usual structure. There is one grain which appears to be a monoclinic pyroxene, containing two or three flakelets of a micaceous mineral; also, a small grain of the usual brownish mica, a garnet with the outer zone of rich brown kelyphite, already described, with two others--which possibly may be the same mineral more completely altered--and two or three smaller deep-brown grains resembling chromite. One or two irregular patches, consisting of a carbonate and some small minerals (zeolites) are very like the irregular cavities in some scoriaceous rocks, when these become converted into amygdules. I suspect the presence of a small rock fragment consisting of little roundish grains of olivine (or possibly malacolite) in a minutely granular matrix, of which I can hardly venture to say more than 'probably basic igneous.'

(b) [495, 2.] The label with this specimen (a printed one on thick paper) is partly effaced by rubbing; it has the words 'Kentucky Geological Survey . . . and Bureau of (? emigration). Frankfort, Kentucky, U.S.A.' (the effaced part being apparently a date, perhaps 1886). It is not distinctly stated to be from the above locality, but I think there can be no doubt on that point. It is practically identical with the last-named, except that the yellowish-green spots run a shade larger, occasionally almost one-quarter of an inch. Under the microscope the rock appears very similar to the last described, but the olivine is rather more serpentinised; garnet as before; one or two patches of calcite with a tuft or two of an acicular zeolite, suggestive of cavities of some kind; part of the matrix is tinged with green, this apparently being due to the presence of minute scales of a chloritic mineral.

(c) [497.] This specimen bears the label, 'Elliott Co., Ky. (Diller).' The matrix is slightly more compact than in the case of the last two the yellowish spots are not quite

so frequent, or so large generally, though one, which shows a moderately good cleavage and is apparently olivine, attains to quite a quarter of an inch. It has a distinctly rounded outline. Mica also is more plentiful in this specimen, occurring generally in small rounded flakes; but these in one or two cases are about one-fifth of an inch in diameter. It is distinctly brown in colour. In microscopic structure the rock is like the last, but without any garnet or spots suggestive of filled-up cavities; there are also one or two semi-opaque grains; minutely granular in structure; which are possibly fragments of some rather compact and decomposed rock.¹

The above hand specimens from both Syracuse and Elliott Co. are perhaps a little more like a porphyritic igneous rock than those which I have seen from Kimberley, owing to the absence of distinct rock fragments and the more uniform size of the included minerals; and the same may be said of their microscopic structure. They are very like serpentine, but the points to which attention has been called produce a difference—marked, though not easily expressed in words—from the normal specimens of that rock. This also is very perceptible in looking at the thin slices with the unaided eye or with a common pocket lens, when they are held up to the light. The rather rounded outline of the enclosures, their unequal size and distribution, give them a fragmental, rather than a normal porphyritic, aspect. I believe that had I been asked to guess what the rocks were, from the evidence of the hand specimens and from this mode only of studying the slices (*i.e.* without actually using a microscope), I should have answered 'probably a non-scoriaceous unstratified tuff.'

¹ See Plate II. for a figure of a portion of this specimen.

NOTE

THE portions of Professor Lewis' manuscripts which, as explained in the Preface, have not been printed, brought out more clearly one point in regard to the origin of the diamond than is done in the two papers included in this work, though I remember he laid stress on it in giving a summary of the second paper at Manchester. This was the intimate connection of peridotite (or serpentine) with the diamond, which he regarded as being in the relation of cause and effect, at least in South Africa and in Kentucky, where carbonadoes occur under similar conditions. This will appear from the report of his paper printed in the 'Geological Magazine' (1888, pp. 129-131). It may suffice to quote the concluding sentence: 'All the facts thus far collected indicate *serpentine* in the form of a decomposed eruptive peridotite as the original matrix of the diamond.' Professor Lewis, I believe, thought that, owing to the basic nature of the peridotite, the carbon in the sedimentary rock with which it came into contact was less likely to be oxidised than it would be by more acid intrusives, but this opinion, so far as I know, is not expressed in his published papers.

I may add that in 1896 the workings in the De Beers Mine had reached a depth of over 1,500 feet. They have ceased to work the diamond-bearing rock by excavating it vertically downwards from the top of the 'pipe,' but sink shafts through the 'country rock' (shale, quartzite, and 'melaphyre'), from which they drive levels into the pipe itself, removing its contents by means of these, as it were,

layer by layer. While the last sheets of this book were in the press Sir J. B. Stone, M.P., F.G.S., sent me a collection of specimens which he had recently received from this mine, among which were pieces of the diamond-bearing rock, of which the deepest was labelled 1,400 feet, and I saw blocks from nearly as far down in a collection shown to me by Mr. W. Crookes, F.R.S. A particularly well-preserved specimen which he has lent to me for study came from 1,320 feet.

He has also favoured me with a copy of a section representing the workings in this De Beers mine. The shaft has reached a depth of quite 1,500 feet, and from it the lowest level is being driven. The section of the 'country rock,' outside the 'pipe' containing the diamond-bearing breccia, is as follows: (1) superficial debris, (2) basalt, (3) black shale, (4) 'melaphyre,' (5) quartzite, (6) 'slate'—probably only a hard shale, (7) quartzite and 'slate.' Dykes (probably basaltic) pierce into (5), through (6) and (7). The 'melaphyre' (4) is about four hundred feet thick. The area of the workings is twenty-two acres. It is the least of the four mines mentioned on page 1; Du Toits Pan, the largest, being forty-five acres. Since Professor Lewis wrote, another important mine (the Wesselton) has been opened; it is included within the same circle as the last-named.

T. G. B.

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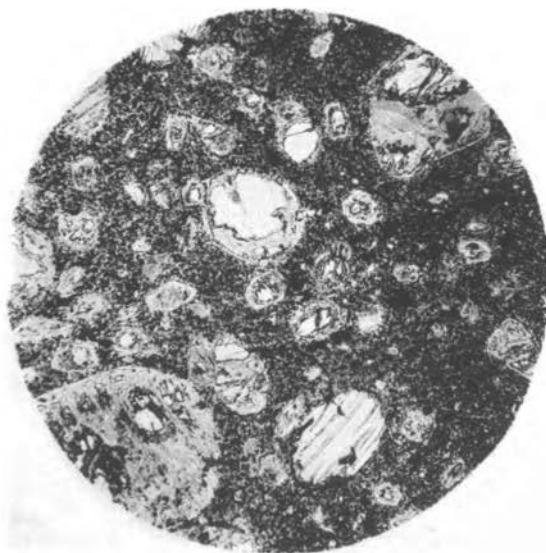
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PLATE II.—Microscopic Sections of Kimberlite.



(1) THE KIMBERLEY ROCK.



(2) THE NORTH AMERICAN ROCK.

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