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On a recent Hypothesis with respect to the Diamond Rock of South Africa.

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[Read February 15th, 1883.]

THIS paper forms part of a communication recently made to the Geologists' Association, with some additional matter relative to certain criticisms passed upon Mr. Dunn's hypothesis as to the origin of the diamonds.

It is taken for granted on this occasion that the leading geological facts are known, I will merely, therefore, draw attention to a generalised section of Kimberley Mine, where one side represents the wall or reef bounding the pipe itself, and is thus constituted:—

Red Sand	8 ft.
Concretionary Limestone	5 ,,
Yellowish Fissile Shale	20 ,,
Black Argillaceous Shale	10 ,,
Two thin bands of Black Dust in Shale	1 ,,
Black Shale	236 ,,
Total	275 ft.

Then comes a band of andesitic dolerite, below which I at present possess no precise information.

The edges of these shales, as is well-known, are more or less turned up in contact with the material in the pipe, of which the following is a restored section—

Red Sand	3 ft.
Concretionary Limestone	15 ,,
"Yellow Stuff"...	30 ,,
Blue Stuff	282 ,,
Total	330 ft.

The excavations are no doubt deeper now, but I await further information on this point. It would seem that the concretionary or tufaceous limestone is three times as thick over the diamond rock as it is over the shales, from which we may infer that the diamond "marl," as it was once called, is richer in available lime than the more argillaceous shales.

The yellow stuff is merely a surface variety of the blue unaltered diamond rock, and it contains abundance of the larger pieces of shale and rounded rock fragments, such as are found in the friable matrix of this curious breccia.

The "blue stuff" is the genuine diamond rock, uninfluenced by superficial agencies, and if in any way altered, such alteration must be due to causes altogether unconnected with the surface; it is in fact a green earthy breccia containing fragments of shale, and various minerals of which the glistening plates of Vaalite are perhaps the most conspicuous. The minerals found in the diamond rock are so well known to most of us that I need not mention them here. Mr. Davies tells me that the bronzite grains which occur are in a condition much resembling those of meteorites.

Before proceeding any further to describe or theorise on the diamond rock, I ought to say a few words about the numerous doleritic rocks which pervade the shales or Karoo beds, both as dykes and sheets, and thus constitute an important geognostic feature which must be duly taken into account if we wish to understand the phenomena of the diamond rock itself. These doleritic rocks are probably for the most part known as basalts, and some of them help to form the walls of the other mines, to a greater extent than at Kimberley. All these rocks are described by MM. Fouqué and Lévy as having an ophitic structure; a term which puzzled and misled me for some time, until Mr. J. J. Harris Teall pointed out that those authors apply the term to a rock entirely composed of crystalline constituents in which the felspars are elongated in a certain direction, and in which the pyroxenic constituent has consolidated after the felspar.

I. The first group comprises the andesitic dolerites (or diabases ?). A sheet occurring in the shales on the north side of Kimberley is quoted with the following composition : magnetite rare, oligoclase, augite not plentiful ; chlorite and globular quartz as secondary products. Such a rock is probably what some people would call an augite-andesite, chiefly made up of oligoclase.

Other rocks of this class are quoted between Kimberley and the Vaal, differing from each other chiefly in the size of the crystals and in the secondary products, some of which are stated to be epidote, and even serpentinite.

II. The second group comprises the labradoric dolerites (or diabases), with which we may associate the anorthic dolerites.

1. A specimen of the reef at Old de Beers is described as a labradoric dolerite with peridote ; pretty much what we should call an olivine basalt, rather a common type of rock.

2. Next comes the labradoric dolerite with diallagic pyroxene, which we should probably call gabbro. Such a rock occurs on the Karoo plateau north-east of Beaufort West, consisting of diallagic pyroxene and large crystals of labradorite moulding the pyroxene, black mica in the pyroxene.

3. Lastly there occurs a class of rocks similar to the preceding, but containing olivine more or less intact, and various secondary products ; some of these are described as handsome types of peridotic rocks.

All these varieties of dolerite are found as "pebbles" in the diamond rock itself, to the consideration of which we must now return. I was inclined to think that we might regard the matrix or magma in which these various rocks and minerals are found as chiefly a mixture of talc and serpentinite, more or less adulterated with argillaceous dust and particles derived from the trituration of the shales, so that it would not be easy to obtain a pure substance for analysis. A specimen of the general mass, with the pieces of shale picked out as much as possible, was found to lose 6¾ per cent. in ignition. A small quantity of this loss may be set down to carbonic acid.

The softness of the rock suggests that talc enters largely as an ingredient. When Messrs. Maskelyne and Flight * examined specimens

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* Q. J. G. S., Vol. xxx. (1874), pp. 406 *et seq.*

of it, they came to the conclusion that the matrix consisted largely of an altered bronzite-like mineral which had the composition—

Silica	53·46
Alumina	·95
Ferrous Oxide	8·77
Magnesia	25·92
Lime	2·54
Water...	8·36
	100·00

But for the considerable amount of ferrous oxide this would nearly correspond to a mixture of talc and serpentinite. Call it what we choose, the matrix or magma is a hydrated ferro-magnesian silicate. The lime present may be in part derived from the shales, and partly from the doleritic rocks which furnish so many of the " pebbles " found throughout the mass. To these I must now direct attention.

" Pebbles."—Several specimens were shown to me some time ago by Mr. Davies of the British Museum. I shall mention only one—a hard yellow, speckled rock, consisting mainly of serpentinised enstatite and crystals of bronzite : it is from the yellow layer.

Mons. Chaper brought away with him lately a large collection of the rocks included in the diamond breccia : these were also reported on by MM. Fouqué and Lévy. Excluding the shales, the larger fragments belong to ophitic dolerites and rocks of the serpentine group, the smaller ones to felspathic and amphibolic rocks : it is rare to find clastic rocks other than the shales.

In the *serpentine* group we have—(1.) Rock consisting of serpentinite, with enstatite and olivine occurring as a " pebble " in the diamond breccia of Du Toits Pan.

(2.) Rock containing large crystals of olivine transformed into bastite and serpentinite occurring as a " pebble " in the diamond breccia of De Beers.

(3.) Rock consisting of serpentinite and talc, along with enstatite and magnetite occurring as a " pebble " in the diamond breccia of Bultfontein.

Next follows a large list of *doleritic* " pebbles " of various kinds, similar to the rocks already mentioned and partly described. These are the most numerous.

But we have not yet done with all the curiosities of the diamond rock. I say nothing about pieces of ostrich eggs and other things which have fallen, along with the sand drift, into cracks, as these are accidental.

But pieces of coaly matter, and I believe compressed plant stems, derived in all probability from the Karoo beds, have been noticed in several cases. One of these coaly pieces is in the British Museum, and in the same place are to be seen some well-preserved fossil shells, which were exhibited by Mr. Davies before the Geologists' Association, and commented on by Mr. Etheridge. Like the other curiosities, they were most probably derived from the Karoo beds. People have at different times spoken of shells being found in the diamond stuff, but Mr. Davies has the credit, it seems to me, of having been the first to establish the fact beyond a doubt.

It is evident that some of the rocks contained in the breccia are fragments derived from the various *dolerites* already mentioned, most of which go by the name of basalt, whilst others are clearly gabbros. The more purely magnesian varieties of " pebbles " belonging to the *serpentine* group, of which I have just quoted several examples, must be derived from a rock whose original condition it is almost impossible to diagnose; the remarkable enstatite-bronzite rock originally described by Maskelyne belongs here.

The parent rock of this group may, in composition, somewhat resemble the stony meteorites, whilst in a hydrated form it has probably supplied the talcose* and serpentinous matter constituting the bulk of the matrix or magma of the diamond breccia itself. It is not a little singular that no rock belonging to the magnesian group is quoted in Fouqué and Lévy's table as occurring *in situ*, although there are plenty of all kinds of doleritic rocks with or without olivine. By the magnesian group I mean rocks mainly composed of ferro-magnesian unisilicates and bisilicates, such as enstatite, bronzite and olivine, with the equivalent hydrates, serpentinite, bastite, the altered bronzite, and perhaps talc.

That the whole of this matrix or magma once flowed is certain, and that it flowed upwards is equally clear from the turned-up ends of the " reef " in all the mines, whether that reef consists of shale or dolerite. It is also equally certain that the diamonds occur in this and *in no other rock*, the various basalts and gabbros being just as free from marketable diamonds as the shales themselves.

From what has been said, it is impossible to doubt the eruptive character of the diamond rock; though whether the singular breccia which now plugs the old duct at Kimberley was ever, in that portion of its course, in a state of igneous fluidity, as an ordinary lava-pipe

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* Bronzite, according to Maskelyne and Flight

might be, is by no means clear. Mons. Chaper believes that the course of several eruptions may be traced in the diamond rock of Kimberley, and that this fact is more obvious in the "yellow stuff" than in the "blue stuff." Whether such be the case or not, we must admit that the condition of the included fragments in the breccia, and especially of the shale, looks as though they had not been subjected to any intense heat, otherwise one would expect them to be fused at the edges, and more effectually incorporated in the general magma. And yet a most tremendously powerful expansive force must, during the period or periods of activity, have been perpetually urging the mixture upwards as the only direction in which it could find relief. I know of no force capable of doing this so likely as superheated steam. Indeed, there is no agency which seems to fulfil the conditions now exposed at the diamond mines, but water-gas at a moderate heat and under enormous pressure. How the action was originally set up, and whether it had any resemblance to that of mud volcanoes, it is not easy to say.

The very exceptional composition of the breccia, both of the matrix and the included fragments, may give us some inkling of the direction in which the problem will ultimately be solved. I have already stated that those samples of the matrix examined by myself consist mainly of a soft hydrous magnesian silicate. The alumina which it contains is probably —in part at least—the result of comminuted shale. The source of the lime, much of which now exists in the form of secondary products such as carbonates, is not quite so obvious. The shales themselves may contain a fair proportion of lime; and whatever they contain is sure to find its way into the diamond rock, which has invaded them in the manner we have seen. But there is another source from which the very considerable quantity of lime existing in the diamond rock may have been derived, viz. from the trituration and partial absorption of the numerous fragments of labrador dolerite, including, of course, the gabbros. These rocks, as we know, permeate the shales in all directions, and would yield, besides alumina, abundance of lime, much of which has speedily become carbonate. It is from this source that part of the lime in the tufaceous layer has been derived.

But after all the bulk of the matrix is made up of a hydrous magnesian silicate, the altered bronzite of Maskelyne. Here is the chief character in this motley piece, and what is its history? We seem to obtain a clue in the pseudo-pebbles of serpentinised olivine-enstatite rock to which I have already alluded. That some rock of this class supplied much of the material now constituting the matrix of the diamond breccia is more than probable.

But then comes the difficulty: we all know the intimate connection which exists between serpentinite and olivine, and how it is held by many that serpentine is largely derived from hydration of olivine rock; and with olivine we may associate the bisilicate, enstatite, which, like all magnesian silicates, seems unable to resist the attacks of water. That we can trace in the diamond rock of South Africa a very considerable element, representing generally what I may term an olivine-enstatite rock which has undergone alteration, is pretty certain: but the difficulty which presents itself to me is this, viz. what are the conditions under which the product now plugging the old pipe at Kimberley became hydrated?

I must confess to being very much in the dark on this point, more especially when I remember the enormously high temperature which would be necessary to produce igneous fluidity in rocks consisting of such refractory minerals. For this reason I cannot think that the hydration was effected where we now see the rock, but that it took place lower down, and possibly long before the eruption which produced the mixture we now know as the diamond rock. All the evidence at present accessible seems to indicate that somehow or other, and possibly on several occasions within a limited period, there burst through the shales, and through the dolerites permeating the shales, a magnesian silicate with its constitutional water as a gas in a state of extreme tension, and that this material carried along with it portions of the various rocks it met with on its way upwards.

Such seems to be a not improbable account of the mode of occurrence of the singular and unique breccia, to which it would be quite impossible to assign any petrological name, and which may be described simply as the diamond rock of South Africa, being, to the best of my knowledge, entirely *sui generis*.

The possible Origin of the Diamonds.

Finally we must consider how a rock such as we know this to be, generated under conditions which we can partly understand, is likely to have been the original home where the diamond was elaborated. The undoubted facts of the case are that a mixture held in a base consisting chiefly of magnesian silicate has been forced through both dolerites and shales by an action which in a certain sense may be regarded as hydrothermal; *i.e.* to say, it has been due to the expansive power of water-gas acting under irresistible pressure from below, and apparently at a moderate temperature. This extraordinary flow has brought along with it and partly incorporated into itself the débris of various rocks, much of which now appears as the "floating reef" of the miners or as "pebbles." We must not suppose that this has been derived merely from the walls of the existing pipes, for it is found abundantly in the very centre of the once fluidal column, pointing to the probability of that column having passed through both shales and dolerites at greater depths.

As the depth of the mining operations at Kimberley increases we shall obtain more accurate information on these points, and possibly the ramifications of this elliptical pipe may be traced so as ultimately to set all doubts as to its origin at rest.

Meanwhile we must again ask ourselves, do the conditions, so far as we know them, appear likely to have produced the diamond *within the rock itself?* So many other crystals, such as magnetite, ilmenite, garnet, bronzite, &c. occur, some of which may have been derived from the rocks passed through, that the same origin might be claimed for the diamonds, viz. that they came, as Professor Ramsay supposed, from some metamorphic rock at a great depth below. It should be stated here that small gneissic fragments are found in the diamond rock.

In Mr. Dunn's third contribution to the Quarterly Journal of the Geological Society, he drew attention to the carbonaceous character of the shales forming the reef at Kimberley, and perhaps some persons then learnt for the first time that these black shales were carbonaceous. But nearly ten years ago Mr. Paterson* had pointed out that on one side of the Kimberley Mine were being drawn out buckets of carbonaceous shale, and on the other side buckets of green marl. He also observed that the marl or "stuff," *i.e.* the diamond rock, was richer opposite the shales. He stated that burning removed the element of blackness in the shales, and that an oily scum might be found on the water of the wells sunk in these shales.

It may perhaps be a mistake to suppose that there is any great difference in the diamond yield opposite special portions of the shales, as alleged by Mr. Dunn in his last paper, but there can be no question as to the general correctness of Mr. Paterson's statement. Unquestionably Kimberley Mine, which is largely within shale, is far richer than the others, and this circumstance does seem to point in the direction of a connection between the carbonaceous shales and the diamonds. But if the shales really have

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* Proc. Geol. Assoc. Vol. III. p. 77.

supplied the carbon, which has yielded the diamond in the manner I am about to suggest, such carbon has most probably been derived from shales occurring at greater depths. I am not aware how deep the shales are known to extend, though Mr. Oats in a very recent communication to the Geological Society[*] states that so far as he knows, they do not occur below 270 feet, whilst the "ground" is successfully worked for diamonds at a depth of 350 feet. Mr. Dunn's suggestion that below the shales the rock may cease to be diamantiferous was likely to cause some uneasiness, and it seems to have been Mr. Oats' object to show that there was no cause for alarm. The latter maintains that the carbonaceous shales have nothing to do with the origin of the diamonds.

It is true that certain objections to the diamond rock itself having been the birthplace of the diamonds are based upon the imperfect condition of many, I should perhaps say of most, of the crystals. The stones are often broken, as though they had been shattered by some agency; and it is said that the corresponding pieces are never found in the vicinity of the principal stone. It is not difficult to believe that the shattering is simply due to the molecular strain which is known to have caused not a few of these "dry diggings" diamonds to "explode" spontaneously after capture. Some may have exploded at the moment of birth, others according as the pressure varied in the ascending column of viscous matter. I think, therefore, the argument has weight in so far as it indicates that the stones, in the majority of cases, were not generated in the *exact spots* where they are now found. Each diamond was born lower down, and on its way upwards, if it had become broken, the pieces would be separated. Such a result is exactly what we should expect from the rise of the viscous fluid in the pipe. This view is not inconsistent with the origin of the diamond within the rock itself on the basis already suggested, provided the carbonaceous shales or similar beds occur at still lower depths. This may be taken for granted so long as pieces of the shale continue to be found in the diamond breccia.

Notwithstanding the assumption on the part of Mr. Oats, there does therefore seem a possibility that the diamonds in this rock are the result of reactions which have taken place between the hydrocarbons in these or similar shales, and the hydrous magnesian silicate under peculiar conditions of temperature and water-gas pressure.[†]

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[*] Abstract 429, p. 26 (1883).

[†] In a recent issue of the *Chemical News* (Vol. 46, p. 105) there is a short article "On the origin and formation of the Diamond in nature." The author, who makes no allusion to the South African Diamond Rock, believes, from the analogy of silica

The conditions under which this was effected may have been somewhat as follows:—It has long been known that water gas under great pressure and at a moderately high temperature will dissolve both silica and alumina, and that, on withdrawing the solvent or lowering its solvent action, the gaseous solution nearly always yields a crystalline solid. But note the difference between these oxides and carbon, viz. that all attempts to effect a solution of solid carbon have hitherto failed. Hence we must look for some compound of carbon which is likely to give the desired results.

Now the old chemists had suggested that the diamond was originally derived in some way from a hydrocarbon: Liebig, for instance, thought by a slow process of decomposition in a fluid rich in carbon and hydrogen. That we should look to the hydrides rather than to the oxides of carbon to provide us with the pure element, both in its amorphous and crystalline form, seems to have been the notion of most chemists: I mention this because in the discussion on the reading of Mr. Dunn's third paper before the Geological Society Professor Seeley threw out a hint that "carbonic acid might have been carried down by water and then decomposed by the heat of the volcanoes, so that the carbon, when liberated, might become crystallised." There are also other combinations of carbon which suggest themselves: for instance, in the preparation of pure amorphous carbon in organic chemistry the vapour of carbon tetrachloride is passed through a hard glass tube containing metallic sodium heated, with exclusion of air. But carbon tetrachloride savours more of the chemist's than of Nature's laboratory; I merely quote the practice as showing that the affinity of certain metals for one of the elements of a gaseous compound of carbon is, under certain conditions—one of which must always be the entire absence of free oxygen—so powerful, that the carbon, being left in the lurch as it were, and not having anything wherewith to ally itself, must needs be deposited in the solid form. I may also mention here a curious fact lately alluded to by Mr. Teall—that graphitic carbon is deposited in the cells of the slag which is derived from spiegeleisen, but not from that derived from other kinds of pig iron.

There has been so much said for and against the success of Mr. Hannay's attempts to make diamonds, that I cannot quote the case with

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being so soluble in highly heated water under pressure, that the same law may apply to carbon, though he adduces no instance of carbon having been so dissolved. In this way he concludes that the diamond has been formed by the solvent action of highly heated water or water gas, aided by enormous pressure, on the carbonaceous matter of fossils contained in the sedimentary rocks, followed by slow cooling.

absolute confidence; but there is no doubt that in all such experiments the fundamental method is to obtain nascent carbon under peculiar conditions. This is most likely to be effected in nature by the attraction of some metal for the hydrogen of a hydrocarbon, a result of the great affinity of hydrogen for the metals, and notably for *magnesium*. We were then told that when the carbon is thus set free in the presence of a stable compound containing nitrogen (the conditions being a red heat and a high pressure), the carbon is so acted on by the nitrogen compound that it is obtained in the clear and transparent form of the diamond. I admit that there is a vagueness about the latter series of reactions which is not altogether satisfactory, but in some such direction as this we may believe that chemists look for the synthesis of the diamond. Whether the result be diamond or graphite would seem to be in a great measure a question of pressure and consequent condensation.*

If we now return to the South African rock, it certainly does appear that many of the conditions of this synthesis have existed in the juxtaposition of the shales and the magnesian silicates which form so considerable a portion of that extraordinary medley. There could have been no lack of hydrocarbons, and where organic matter has decomposed there should at least be a sufficiency of compounds containing nitrogen. The reducing power of the gases resulting from the distillation of so much coaly matter would be certain to effect the reduction—if only temporary—of sufficient oxide to the metallic state, and this is what we require for decomposing a sufficient quantity of hydrocarbon in order to obtain pure nascent carbon. This element would find itself subject to enormous pressure, due to the expansive force of steam, and had no choice but to assume the crystalline form.

In concluding this brief and imperfect notice of a very interesting and much debated subject, I must admit that further evidence is greatly to be desired. In the first place, we require more accurate and less contradictory statements regarding the mode of occurrence of the Diamond Rock itself; and, secondly, we require confirmation of the actual synthesis of crystalline

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* In his paper read before the Royal Society (Proc. Roy. Soc. Vol. XXX. p. 450) it appears that bone oil was the nitrogenous compound employed by Mr. Hannay in his synthesis of the diamond. The following ingredients were used:—Three grammes of metallic lithium were heated in closed tube with a mixture consisting of 90 per cent. bone oil, and 10 per cent. paraffin spirit. Bone oil, it should be remembered, is obtained by the distillation of bones and other animal matters, and contains, amongst other substances, a variable series of nitrogenised hydrocarbon compounds.

carbon, together with some indications of the analogies and differences attendant on the genesis of graphite and of diamond. All these may be forthcoming in due course, and when they are so forthcoming it will be possible to treat the subject in a more satisfactory manner than can be done with the materials now in our possession; but according to our present lights we must regard the Diamond Rock of South Africa as a boiled plum-pudding rather than a baked one.

APPENDIX.—July 9, 1883.

The third meeting of the Central Diamond Mining Company was held at Kimberley, on May 28, 1883. There is a full report in the local papers. Not much additional information is obtained as to the nature of the Diamond Rock, though "prospecting" had been pushed as low as 530 feet on the south side of the mine. Nothing is stated as to results, but, since the chairman predicted a tremendous future for the Kimberley Mine, we may conclude that these were not unsatisfactory.

A gentleman well-known at Kimberley mentioned to me some time ago that the Diamond Rock had been proved at a depth of about 500 ft., whilst workings in open day were carried on as low as 400 ft. Between 400 ft. and 500 ft. a considerable change comes on in the character of the Diamond Rock, which is described as being more "sandy" and yet containing good diamonds at the greater depth. The "hard rock" or dolerite still continues to form the wall or reef it is presumed, and it gains more on the diamond stuff than do the shales, so that the area of the pipe contracts considerably at these depths.

The same gentleman also observed with regard to the diamonds, that they varied much in different places, each having its own style. There are no yellow diamonds in what he describes as the more "sandy stuff," but where the green breccia prevails the diamonds are often coloured.

At Bultfontein the diamonds are small, white, and striated. At Kimberley the faces of the octahedria are usually not curved. All have the little triangular marks.

When the diamonds are broken, sometimes, though rarely, the corresponding fragment has been found within a few feet.