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J. R. Sutton

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OVERGROWTHS ON DIAMOND.

By J. R. SUTTON.

THE AFFINITY BETWEEN DIAMOND AND CARBONATE OF LIME.

"Formerly the diamonds were picked out from the concentrates by means of the keen eyes of skilled natives, but the process has been vastly simplified . . . by the remarkable discovery made in 1897 by F. Kirsten of the De Beers Company, that of all the heavy constituents of the blue ground, diamond alone, with the exception of an occasional corundum and zircon, which are easily sorted out afterwards, adheres to grease more readily than to water. In this ingenious machine . . . the concentrates are washed over a series of galvanised-iron trays, which are covered with a thick coat of grease. The trays are slightly inclined downwards, and are kept by machinery in constant sideways motion backwards and forwards. So accurate is the working of this device that few diamonds succeed in getting beyond the first tray, and none progress as far as the third."

This account, which contains nearly all that is necessary by way of preface, is extracted from G. Herbert Smith's charming 'Gem Stones,' 1912, p. 148. Evidently the secret of the process, as Lawn has said, is surface tension. Common minerals can easily be wetted, whereas diamond cannot be; and because of the wetting the grease cannot touch the mineral surface, whereas it can touch the dry diamond.

According to G. F. Williams "only about one-third of 1 per cent. of diamonds is lost by the first table, and these are recovered almost to a stone when the concentrates are passed over the second table." ('The Diamond Mines of South Africa,' 1902, p. 380.)

J. Stewart reports further that for the six months July to December, 1909, out of 1,211,552 carats of diamonds recovered at the De Beers Company's pulsator all but 1,249 carats were caught on the first tables—an efficiency of 99.9 per cent.

But it is a curious fact that while diamonds of all kinds, including bort, from the blue ground adhere readily to the grease tables, those from the surface yellow ground are much less easily caught. Some years ago a

parcel of diamonds from the Wesselton Mine yellow ground was handed to me for examination. Some concentrates from the yellow ground had been passed over the grease tables with the following result:

	Carats caught.	Per cent.
First table	241	50·52
Second table	90	18·87
Third table, and final dry sorting of rejected concentrates	146	30·61
	<hr/> 477	<hr/> 100·00

That is to say, instead of a loss of between one-tenth and one-third per cent. (the values quoted above), only about a half of the diamonds were caught on the first table—a result scarcely better than an electrostatic separator would give. Clearly it was lucky that the grease tables were not thought of in the early days of Kimberley when nothing but yellow ground was being worked, for, had they been tried then, that excellent invention would probably have passed stillborn into oblivion.

In the matter of the anomalous behaviour of the yellow-ground diamonds the problem to be solved was unique inasmuch as there was no outside analogy for a guide. To begin with, there was nothing to show whether the surface of yellow-ground diamond was essentially different from that of blue-ground diamond, or whether the anomaly arose from some disturbing factor in the matrix. As to the former alternative, there was a prevalent belief that the surfaces of diamonds found in the early days of Kimberley were on the whole more brilliant than those obtained later, in the deep workings. As to the latter alternative, it appears that the soapy-feeling substance lining the blue-ground matrix of diamond has not quite the same constitution as adjacent blue-ground has. This point will be referred to again.

The first step in the attempt to solve the problem was made by screening the diamonds caught on the three different tables into series of sizes. From the results it was ascertained that, generally speaking, the larger diamonds tended to adhere to the grease on the first table better than the smaller ones did, those caught on the third table not often exceeding a quarter of a carat each. There was, moreover, a marked difference in the behaviour of the smaller diamonds with respect to the tables, for while those caught on the third table, or dry sorted afterwards, were largely of good shape with no specially great proportion of cleavages and splinters, those caught on the first table were mostly irregular or broken pieces. Hence it seems that a still larger quantity would have been lost by the first table if the normally great percentage of Wesselton cleavage were less. Two possibilities were thus suggested:

- (1) The larger diamonds stick better than the smaller ones do because

their weights being great relatively to their surfaces they travel more slowly in a given current of water, and so can sink mechanically more heavily into the grease. Here it may be noted that pieces of iron and heavy minerals sink into the grease not because of any attribute of surface tension, but because the current of water flowing over the tables is insufficient to overcome gravitation.

(2) Apart from that, some peculiarity of surface seemed to be involved whereby fractured faces were more adhesive than natural faces. On the other hand the sharp edges of the fractured faces can plunge mechanically into the grease with more facility than natural edges can.

Under magnification, however, no characteristic difference could be detected either between the surfaces of the diamonds taken from the different tables, or between the surfaces of the non-adhesive yellow-ground diamonds and the surfaces of ordinary adhesive blue-ground diamonds. Some specific gravity tests, also, reveal no differences worth mention.

Since only a few diamonds from the blue ground are normally lost by the first grease tables, it remained to examine typical specimens of blue and of yellow ground in order to determine whether any accountable peculiarities exist in the respective matrices which might be communicated to a diamond surface. Competent geologists are pretty unanimous that "the yellow ground, which may go down even to 70 ft., is simply blue ground in a weathered condition, and contains the same minerals in due proportion." (W. H. Penning, 'Gold and Diamonds,' 1901, p. 4.) But unanimity in the case of the diamond is never evidence, and, for the most part, judging by the strong family likeness of the various accounts, each high expert quotes without question from some higher expert. At any rate some samples of blue ground, yellow ground and so-called "limestone" from the original overburden, were obtained for testing purposes from the Wesselson mining area. So far as could be seen the samples of yellow ground were typical and clean. The blue ground had other matter mixed with it, which had probably been scraped up from the depositing floors by the shovel. It could only be guessed whether the "limestone" was an average sample of its kind. It was a spongy-looking stuff of rather low specific gravity (? altered blue ground, or dolomitic), and to casual inspection carried particles of yellow ground. Portions of each of the three kinds of ground were crushed, gently dried, weighed, treated with dilute acid, evaporated to dryness, and again weighed, with the following result:

	Weight before treatment.	Weight after treatment.	Loss. Per cent.
Blue . . .	10.000	9.225	7.75
Yellow . . .	10.000	8.650	13.50
"Limestone" . . .	10.000	9.975	0.25

In the acid the blue ground effervesced strongly, the yellow ground violently, the limestone scarcely at all. A sample of hard blue from De Beers Mine, tested at the same time, gave scarcely any effervescence, while some lumps of hard and soft limestone from Kenilworth effervesced violently, leaving no great proportion of insoluble residue, so that the effervescence of the blue ground may have arisen, at any rate in part, from an admixture of a foreign carbonate. Moreover, the substance (alluded to above) lining the matrices of sundry blue-ground diamonds effervesced very little.

These rough tests seemed to supply a clue worth following towards a solution of the problem. There is more carbonate of lime in yellow ground than there is in blue ground, and the question is, Will it, when it is plentiful enough, spread itself on a diamond surface in a crust capable of being wetted? Numerous experiments were accordingly made in the hope that premised feasible natural processes might to some extent be imitated in forming such a crust. Pastes were made of the blue ground, the yellow ground and the limestone, with hot and with cold water, in which small diamonds that had adhered normally to the first grease table were enclosed for some days. Sometimes these pastes were kept wet throughout, sometimes they were dried in gentle heat, and sometimes left to dry of themselves. Finally the enclosed diamonds were taken out and run over the grease tables at the pulsator. The results were only so far encouraging that neither the diamonds from the yellow paste nor those from the limestone paste showed any particularly marked inclination to stick to the grease. But, on the other hand, curiously enough, neither did the diamonds from the blue paste. Thus although all were originally normal first table captures, the act of putting them into the different pastes had for the most part destroyed their adhesive property.

Of course, only a soft and easily removable crust, at the best, can be deposited on diamonds by enclosing them for short periods in pastes of this kind. One effort was made to deposit a harder crust on four first table diamonds of about six carats each by placing them in four separate vessels with some blue, yellow, and lime ground respectively, well stirred with plenty of water, and leaving the water to evaporate slowly. This is a lengthy process, and was only partially successful. Scarcely any blue ground appeared to have attached itself to the diamond surface, though the lime and yellow were deposited in patches with some freedom. Upon roughly testing these diamonds for surface tension in water, it was found that those from the lime and yellow grounds gave much higher values per unit area of surface than those from the blue ground did, albeit a single test of this kind cannot be regarded as of much consequence. These same diamonds were afterwards passed over the grease tables: three adhered, and one, which had a fair coating of lime, rolled away.

The experiments were repeated with three good samples of virgin blue, yellow, and real limestone crust, obtained from the Kamfersdam Mine. In acid the blue gave no effervescence to speak of, while the yellow effervesced strongly, losing 20 per cent. of its weight, and the lime crust violently, losing fully 60 per cent. Pastes were now made as before of the virgin blue and of the lime crust in equal quantities, and ten first table diamonds, weighing on an average about a carat a-piece, were placed in each paste. The two lots of diamonds were chosen so as to be as nearly alike as possible. After the pastes had become quite dry they were broken, the diamonds were carefully extracted, soaked in water, and passed over the grease tables. Every diamond from the limestone paste rolled off as fast as the water could carry it; whereas nearly all the diamonds from the blue were caught.

Lastly, some third table and dry sorted diamonds, *i. e.*, diamonds which originally were not easily caught, or even not caught at all, by the grease, adhered quite well after having been cleaned in acid.

Reasoning from the above results, the following conclusions, *venio rogatum*, would seem to be justifiable:

Yellow ground contains more calcite than blue ground does.

Calcic carbonate in suspension, or solution, deposits itself readily in thin layers on a diamond surface, causing that surface to approximate to the consistency of the common minerals in the pulsator concentrates.

This deposit being more easily wetted than a bare diamond surface is, the surface tension in water is increased, and that in grease decreased accordingly. Hence the coated diamond behaves like an equal mass of limestone on the grease tables.

The above account is drawn with no material alteration from my report made at the time some years ago. This report had been put away and the details half forgotten, although the conclusions were alluded to in a recently published paper. But during the last few months the results appear to have received some extraneous confirmation perhaps sufficiently important to warrant the publication of them. This latter development will now be briefly described.

Now, it is to be noted that if calcite, or limestone, can be made to form a crust on a diamond by artificial means, it ought to do the same naturally, in propitious circumstances. So far as the Wesselton yellow-ground diamonds are concerned, since they do not always adhere readily to the grease tables, this would appear to have been proved, or at least made probable, by the experiments described above. But since calcite occurs in fair abundance in some specimens of blue ground, there ought to be cases here and there in which blue-ground diamonds had acquired a calcite coating. The chances would be, however, that even so it would not follow that the coating would survive the rough treatment of mining and winning to the

end at the grease tables. Moreover, should it be a thick coating and completely enclose a diamond, and survive intact, the diamond would certainly be rejected by the grease tables like the superfluous concentrates; or, in case of dry sorting, probably rejected as a valueless piece of white mineral. The chances are therefore not altogether favourable for the detection of a diamond with a thick coating. Nevertheless diamonds heavily coated with a more or less complete shell are occasionally found. They come mostly from the interesting Bultfontein Mine, doubtless partly because the prevailing striated surface of Bultfontein diamond holds the coating best, and partly because of the abundance of calcite there; but they are found occasionally at Wesselton and Dutoitspan.

A significant fact about these particular lime-coated diamonds from blue ground is that the coating is not aragonite. For when it is boiled with cobalt nitrate it remains uncoloured. It is evident, therefore, that the coating was acquired at a late stage in the history of the matrix, and at a low temperature.

Equally significant is the fact that calcite is not found inside cracked diamonds from the Kimberley area. The filling material has been taken from the cracks of many diamonds on the De Beers sorting tables and in no case has it been calcite. Usually it appears to be apophyllite,* and pectolite has been found. Hence it may reasonably be inferred that the cracking of the diamonds took place at a relatively early period, and that the cracks became filled with a zeolite, or something of that sort, before the calcite was introduced, or separated out, into the matrix.† Which is yet another argument against the popular delusion that cleavages among diamonds are due to explosion after the diamonds are taken from their matrix.

Occasional Dutoitspan rounded yellow diamonds are reported which have failed to adhere to the grease tables. They carry no obvious foreign coating any more than the Wesselton yellow-ground diamonds did, but presumably they carry a coating even though it be indefinitely thin. And it may be surmised that they come from the vicinity of local accumulations of calcite in the pipe rock. One typical specimen that had been rejected by all three tables adhered to the grease quite normally after immersion in a weak acid.

It may be of interest to quote here some remarks made by Boutan in his great work '*Le Diamant*,' 1886, p. 171. Speaking from actual experience of Kimberley as it was somewhere about 1884—*i. e.* at a time when the blue ground had been reached and was being worked, he says of the diamond:

"Il se présente sous bien des états divers de cristallisation, de couleur

* Cf. '*The Diamond Mines of South Africa*,' p. 507.

† Cf. F. P. Mennell, '*The Miner's Guide*,' 1909, p. 147; also P. A. Wagner, '*The Diamond Fields of Southern Africa*,' 1914, p. 75.

et de grosseur ; mais il est presque toujours enveloppé d'une mince pellicule calcaire, qu'on enlève avec les autres impuretés qui pourraient ternir sa surface en le laissant pendant quelque temps dans de l'acide azotique bouillant."

It is a curious statement to make, however, that diamonds fresh from the mine were almost always encased in a chalky envelope.* Certainly diamonds have always been put into acid—mostly aqua regia earlier, though hydrofluoric nowadays—before being sorted for shipment to London ; but, as one understood, rather to remove impurities from cracks than especially to clean their surfaces, though of course it would do that too. And yet one hesitates to question the word of so careful a writer as Boutan. Possibly the explanation of the difficulty is either that such diamonds as he had the opportunity of seeing were thus coated, or that he mistook the main purpose for which the acid was generally used. True or not, the copyists lost a chance in not repeating the statement and so passing it on by their unanimity to the realm of historical fact. It may be mentioned here that it is well known at the De Beers pulsator that diamonds which have been lying for many years in the blue ground on the depositing floors are very intractable on the grease tables. Probably the long-continued weathering has set calcite free, either from the blue ground itself or from the limestone underlying the floors, to form an incrustation on the diamond.

A clean diamond is not readily wetted by ordinary rain or river water. If it be immersed in such water it will come out dry saving where droplets can cling to irregularities upon its surface, and even these are easily shaken off. A triangular flake of diamond whose edges are 12 mm. and whose thickness is 1.25 mm. will float indefinitely upon a still-water surface. If the same flake be placed edge downwards in the water whose depth is about 6 mm., the lower edge will rest at the bottom of the water and the top corner will project slantwise through the surface, and remain so, provided that the surface is kept fairly quiet. This is the largest thin flake there has been the opportunity to try, though doubtless much larger ones would behave in the same way. Small diamonds of good geometrical form up to at least 0.1 carat each will float on water, even when it is gently agitated, like corks, partly because of the surface tension of the water, but chiefly because they are not readily wetted, whereas most common minerals of the same size will submerge at once.

A number of simple experiments have been made with the object of ascertaining whether the addition of freely soluble substances to water would modify the surface tension between diamond and water. Saturated solutions of the following compounds showed no appreciable difference :

* Cf. G. F. Williams, p. 208 : "All the crystals in the blue ground were encased in a smooth bed of the same material which did not adhere to the diamonds, so that their lustre, when extracted, was quite bright or glassy."

Alum, Epsom salts, sal ammoniac, common salt, saltpetre. Saturated solutions of the following increased the tension somewhat: Chloride of lime, borax, hyposulphite of soda. On the other hand, a solution of caustic soda wetted the diamond thoroughly. But of all the substances tried carbonate of soda proved by far the most effective. A diamond (crystal or bort) dipped into a saturated solution of carbonate of soda comes out wet and dries with a thick deposit of the substance. Even here, however, the wetting tends to be to a certain extent selective. The deposit as a rule dries thicker on the faces of the octahedron than it does on the edges; and, by the same token, thicker on the edges of the rhombic dodecahedron than it does on the faces. Some octahedra dry with their faces thickly coated (saving where deep triangular indentations interfere) and their edges scarcely dimmed, and some dodecahedra dry with their edges sharply outlined in white. This result may arise from faulty manipulation, or it may have been accidental to the limited number of stones treated; but it is curious that the observer occasionally comes across a diamond naturally coated on its octahedron faces with a black adamantine incrustation, while its edges are so clear that the colourless interior can be seen through them. On the other hand a bort incrustation favours the dodecahedron faces of Wesselson "black" (nearly opaque) diamond.

One other, minor, point: If a diamond be placed in a solution of carbonate of soda contained in a glass vessel, the soda, in spite of its affinity for the diamond, will crystallise out, as the water evaporates, by preference on the sides of the vessel above the water surface, while the diamond remains uncovered in the solution. But in a solution of cane-sugar crystallisation will begin on the diamond alone, and the latter after a time will appear as if enveloped in an extensive cloudy condensation. The reasons need not detain us.

COATED DIAMONDS: SOME OBSERVATIONS AND INFERENCES.

Diamonds with a black incrustation are common, especially at Wesselson. In the mines of the Kimberley area this incrustation is usually very thin, and under magnification is seen to consist of minute dull black specks more or less uniformly streaked over a somewhat rough and pitted surface—so thin indeed as to make the diamond look slaty-grey by reflected light and smoky-brown by transmitted light. Not improbably this coating is allied to the frequent black spots included in the body of spotted stones. Whether, so far as the Kimberley mines are concerned, it represents the remains of a thicker coating which has been lost either naturally or in the process of mining and winning is doubtful. Mr. P. Ross Frames, however, has obtained, at the Premier Mine, Pretoria, a small diamond from the midst of a lump of graphite, and at this mine diamonds with quite a thick, soft

black coating are sometimes found.* The black coatings of the Kimberley area diamonds may be amorphous or crystalline diamond, or even graphite like the Premier ones. It may be due to a temporary increase of temperature in past time. But a sufficiently great general increase of temperature is not very likely, if only for the fact that diamonds are found in intimate association with crystal garnet and coloured zircon. Of hoth the same may be said; and quite recently a lump of stewartite containing numerous grains of almandine garnet was found at Bultfontein. High temperatures would be expected to render the garnet vitreous and to blanch the zircon.

The black incrustation is more likely to be a late corrosive sort of deposit on the diamond, quite independent of the process of crystallisation and not defining its final phase. And this view is supported by a small broken lump found at Koffyfontein which at first sight resembles a fragment of coal, but on closer examination proves to be transparent diamond thickly incrustated with a very hard black adamantine coat. It cannot be denied that the fracture preceded the incrustation.

This Koffyfontein specimen, then, helps us to see that the black spots common in diamonds have not necessarily always been enclosed within rapidly and continuously crystallising diamonds; and still less are these same spots centres of crystallisation in a metastable medium, but rather are incrustations on temporarily quiescent diamond surfaces analagous to the lime coatings dealt with above. For, suppose some black incrustation to form spots on a diamond crystal, then a further stage of diamond crystallisation would determine the black spots as inclusions like other minerals, such as garnet, pyrites, etc., captured in the same way. And this no doubt explains the frequent colour effects in their vicinity revealed by the polariscope. Also it helps us to see that Dutoitspan rounded yellow diamonds, which are much less subject to strain and are less spotted than most other kinds, were probably formed more rapidly in one continuous process.

Haily, indeed, attributed the rounded form of some diamonds to rapid crystallisation:

“ Mais la formation du diamant ayant été précipitée, les faces ont subi des arrondissemens, comme cela arrive par rapport à une multitude de minéraux ” (‘ *Traité de Minéralogie*,’ 1801, iii, p. 290).†

Whole stones incrustated in precisely the same way are met with now and

* See P. A. Wagner, “ Note on Graphite-coated Diamonds from the Premier Mine,” ‘ *Trans. Geol. Soc. S.A.*,’ 1914; also ‘ *The Diamond Fields of Southern Africa*,’ p. 143.

† Antonio Magliabechi expressed the opinion that diamonds do not grow larger by lying in the earth, but that their magnitude and figure are assumed at once (see ‘ *Phil. Trans.*,’ No. 311, 1707). Leuwenhoeck gives reasons for thinking differently (*ibid.*, No. 324, 1709). But crystallisation, fast or slow, necessarily postulates a solvent.

again in the mines of Griqualand West. More important still, incrustated stones have been proved to exist inside larger ones. A good and typical instance was a Dutoitspan fragment of about two carats consisting of about a third of a whole white rounded diamond. Portions had split away from the original whole stone along two octahedral planes of cleavage, showing near the middle of the edge where the cleavage planes met a heavily incrustated little stone of fair form, as depicted on an enlarged scale in the annexed Fig. 1. The incrustation was at least as hard as ordinary diamond. Observed through what was left of the natural face the inside of the fragment appeared to be extensively blurred with large black blotches

FIG. 1.—Section of fragment showing position of inclusion. A. Incrusted inclusion. AB. Cleavage faces. BDB. Natural surface.

—an illusionary effect caused by refraction, for actually, saving for the incrustated inclusion, the specimen was quite without blemish. Soft graphite inclusions are plentiful enough in the holes so common in the cleavage surface of diamond.

Owing to the high refractive index and frequent rounded habit of diamond the true outlines of black spot inclusions are not always easy to make out, but frequently they seem to be shapeless. Sometimes they are mere flakes. They occur either singly or in groups. Jagersfontein diamonds are noted for the dense and solid appearance of their large black spots. At the other end of the scale of size are the smoky-brown clouds—the danger-signals of sensational literature, giving warning of impending

explosion!—clouds of tiny black discrete particles. One would like to understand how the internal black spots are aligned with respect to the space lattice, as to which there is a striking suggestion in the case of a coated Bultfontein “rounded octahedron,” within which at a depth of about a millimetre (as determined roughly by the focussing distance) under one face were three separate constellations of tiny black spots all lying in one octahedral plane of cleavage.* These constellations of spots were of additional interest because of the gorgeous chromatic display they gave under the polariscope, and also for their obvious relationship to the surface markings, for exactly over each constellation was a particularly well-defined indented triangle. Could the millimetre or so of the face have been cleared off, then without a doubt the new face would have had much the same sort of coated appearance as the existing natural face had.

I have observed the phenomenon of the superimposition of a deep indented triangle over a shallow-seated spot or spot area once or twice before, and thought that it could be explained as mere coincidence. The case of the above-mentioned Bultfontein stone nevertheless makes it pretty certain that spots may on occasion interrupt the orderly rate of crystallisation, and hence that they are not likely to be action centres of growth themselves.

It is quite on the cards that a competent study of the black incrustation and the black spots may yet explain a great deal that is yet unknown about the diamond macle and so justify the use of the name. For the majority of macles are spotted—some in the composition plane—as it is not quite accurately termed, seeing that the seam is not as a rule a plane at all—others in most remarkable streaks along the grain, and yet others in both ways together. The streaks running along the grain—*i.e.* in the dodecahedral cleavage planes—are very common in macles, and practically non-existent in simple crystals. Some macles display, indeed, saving for a comparatively clear space in their centres, almost as much streak as diamond. Granting, for argument, that the streaks are graphite, they show at least that macles must have grown in a more graphitic environment than simple crystals did. It is not meant by this that the graphite must have forced the mactling, for many macles are quite free from streaks and spots too, but that the two sorts of conditions were unlike under which macles and simple crystals came into being, conditions perhaps in which the production of graphite was more favourable than it was elsewhere. In this connection we may observe that the blue grounds of the Premier and Jagersfontein Mines are reported to yield a large percentage of macles and much graphite.

Falling within the category of coated diamonds, though not in the

* *Cf.* two observations of a similar kind made by Des Cloizeaux, cited by Boutan, p. 55.

market sense, are the occasional irregular crystals upon whose surfaces thick coatings of a kind of grey bort have been deposited. This bort might to all appearance have been put on in the form of a wet paste, with a spatula, and then dried hard. Such specimens as have come to light have never been completely covered by the bort, although there are pieces of the bort which look as if they may have diamond within. This kind of bort overgrowth is not commonly found on a natural crystal face, but rather on what appear to be faces of arrested growth, say on surfaces of attachment, and may be material which has flowed into and filled the interstices between the diamonds of a cluster, at any rate it simulates that effect. A Dutoitspan flat diamond which was found recently had such a surface of attachment covered with bort, and on the surface of the bort, which was much pitted, there were numerous tiny black particles—whether of graphite or of amorphous black diamond could not be determined—filling the pits. The bort overgrowth here spoken of forms a link between common grey bort and the cement-like stuff of the next section, merging by insensible gradations from the one into the other.

FIG. 2.—Hailstone structure of diamond. Surface of fracture showing alternate shells of diamond and grey cement.

THE HAILSTONE STRUCTURE.

Unequivocal proof that the crystallisation of diamond is by no means necessarily a rapid and continuous process is supplied by the diamonds which in a previous paper have been likened to hailstones.* Such diamonds are common enough, although they do not seem to have attracted much attention. Typically they consist of what looks like a kind of hardened and more or less porous paste, superficially not unlike Portland cement, alternating with layers or shells generally of curvilinear section (as sketched in Fig. 2) of clouded crystal diamond. Sometimes the core is diamond; now and then it is diamond with a small central spot of some cognate material; often it is an irregular lump of the cement alone so far as one can judge of its interior without breaking it open. When the outermost layer is cement the specimen is shapeless; when it is diamond it tends to a diamond contour—cube, octahedron, or dodecahedron—and it is usually

* "Some Controversial Notes on the Diamond," 'Trans. R.S.S.A.,' 1920, viii, p. 129.

much cracked. Naturally it is only in the broken specimens that the structure is revealed. The condition of the specimens indicates a higher co-efficient of expansion for the cement than for diamond; unless the cement is subject to secular shrinkage, which on various grounds is not altogether improbable. The colour of the cement varies from light to dark dirty-grey. It is much softer than diamond, writing a light grey streak on black amorphous bort. The denser pieces have a somewhat higher specific gravity than pure diamond; a lower specific gravity suggests porosity. Like diamond, the cement is insoluble in acids.

On account of the theoretical importance of these hailstone-like overgrowths I venture to attempt a description of some characteristic forms. The majority are from Bultfontein.

1. A broken piece showing an irregular core of light grey cement, surrounded by a thin shell of diamond, then a thin shell of cement, the whole enclosed in a thicker shell of diamond of irregular outline. Weight 4·5 carats.

2. An irregular lump showing no trace of crystal diamond. A crater-shaped hole in a projecting corner contains a tiny fragment of bright green mineral, probably chrome diopside. 0·5 carat.

3. A broken piece with a dark grey cement interior surrounded by a confused mixture of light grey cement and diamond. 0·7 carat.

4. A flat piece showing a centre of clouded crystal diamond surrounded by an inner ring of black crystalline diamond, and an outer ring of light grey cement. The original stone, of which this is a fragment, must have been roughly spherical. 0·5 carat.

5. A flat cleavage fragment showing a hexagonal flake of clouded and spotted diamond with an outer crystalline shell of a composition apparently intermediate between diamond and cement. This specimen is of further interest as showing dodecahedral cleavage with the dodecahedral striations. 1 carat.

6. A flat cleavage fragment in plan something like the section of a pear cut parallel to the stalk. This has a crystalline core surrounded by cement, then a thin crystalline shell, then a thicker shell of cement intersected by a portion of a very thin crystalline shell following the contour of the first for about a quarter of the way round its perimeter, and lastly, a crystalline casing. 0·2 carats.

7. A broken-off corner consisting of a black crystal interior surrounded by alternate shells of cement and diamond. Three more or less complete crystal shells and four cement ones may be counted. 0·2 carat.

8. A flat fragment consisting of a crystal central portion surrounded by four concentric shells of about 0·5 mm. thick, two of light-coloured cement and two of crystal. 3 carats.

9. A flat fragment broken from one end of what, to outside appearance, must once have looked like a cube of highly crystalline bort. A scraping of the broken face with a knife-blade indicates that it consists of numerous exceedingly thin successive overgrowths of bort and cement. 2 carats.

10. A somewhat hemispherical piece. The central crystal core is surrounded by no less than seventeen alternate concentric rings of light grey cement and black crystal diamond. 0·4 carat.

11. A pyramid consisting of a half of a "rounded octahedron." The edges, where dodecahedral striations would emerge on ordinary diamonds, are here of cement. Rather it looks like a piece of octahedral cement with projecting grey crystal bosses on the triangular faces, thus inclining the form to that of the plus and minus tetrahedral twin. 0·8 carat.

12. An irregular lump of cement to outside appearance. When first seen it was pitted with small elongated holes as though it had been prodded with the point of a penknife. At the time of writing it is scored over much of its surface with deep meandering cracks which either are (and look like) shrinkage cracks, or were there all the time, but hidden by being filled up with cement which afterwards fell out. 2·7 carats.

13. A fragment similar to No. 10, excepting that it has rather fewer shells, has an outer coat of shiny bort, and gives the impression that the fractured face showing the shells has been glazed over with a vitreous layer and polished. The outer contour is that of the cube carrying the usual well-defined square indentations. Unlike most hail-stone forms, which cleave in the dodecahedral plane, the fractured face of this specimen lies in the octahedral plane. 0·5 carat.

Mr. J. Parry has kindly analysed two small diamonds carrying this cement crust. It was not possible to separate the diamond from the cement, consequently the specimens had to be treated entire. They gave only the familiar indication for iron, and a rather stronger one for magnesia. The actual proportions of these elements in the cement itself cannot, of course, be determined until a large enough sample can be procured separate. Meanwhile it seems reasonable to infer that the comparative softness of the cement is due to the magnesia, seeing that a considerable admixture of iron with diamond (*e. g.* *stewartite*) does not diminish the hardness at all.

LAMINATED DIAMONDS.

Laminated diamonds are very common. In one sense they appear to be examples of the general phenomena of overgrowths, and for that reason are included in this paper.

Suppose a model octahedron of glass to be split parallel to a pair of opposite faces into a number of thin laminae; next the laminae to be sealed

together in their original positions by means of a transparent cement slightly harder (or slightly less solvent) than the glass ; and lastly the edges of the octahedron to be abraded (or dissolved) away. The layers of cement being more resistant than the glass will stand out in slight relief as the attack proceeds.

Next let the same octahedron of glass be split again into thin laminae parallel to another pair of opposite faces and the cementing and abrading (or dissolving) process repeated. We shall obtain another set of layers protruding in relief and intersecting the first at a constant angle.

Finally, let the series of operations be repeated for laminae parallel to the two other pairs of opposite faces. The whole octahedron will now be spaced out into a device of small octahedra, marking its faces with a network of flush interlacing equilateral triangles, showing in relief on the reduced edges.

Laminated diamonds are exactly like this. The laminae are sometimes as thin as paper ; more often they are in the vicinity of half a millimetre thick. They are not hemitropic. They alter the overall contour of a crystal very little, differing essentially in this respect from the macle, but on the other hand they modify the surface detail to some extent. The layers corresponding to the cement layers of the hypothetical glass model always protrude where they show themselves, and, as a rule, they may be easily felt with the finger-nail or with the edge of a knife. A formal analogy will be found in the octahedral structure of iron meteorites, wherein kamacite stands for the glass, and the less easily dissolved taenite for the cement.

The laminae scarcely ever manifest their existence save on the well-developed somewhat coarsely rilled faces of the rhombic dodecahedron or tetrahexahedron. On octahedron faces they are rarely seen, as also on the finely grained rounded edges of the octahedron (which are embryo dodecahedron and tetrahexahedron faces). On octahedron-dodecahedron combinations they may be traced all round a stone excepting where the octahedron faces interrupt. The intersections of the laminae with the octahedron faces, however, are often indicated by an array of indented triangles.

In the majority of cases only one set of parallel laminae appear on any one diamond. When two sets appear, intersecting on a solution face, one set is nearly always much more prominent than the other. An examination of a great number of laminated specimens has only determined a very few—and some of these doubtful—with more than two sets of laminae in one stone.

In Fig. 3 I have attempted to depict a laminated octahedron-dodecahedron combination from Wesselton, showing two sets of laminae. It is one of the rare cases in which the edges visibly cut the octahedron face. Though some relationship between the laminae and the indented triangles is shown, it is not so marked as in many other specimens, wherein, while

the edges themselves are not visible, their course is traced out by rows of little triangles, all much of a size, in a row.

On the rotating stage under the microscope the edges of the laminae give a singularly pleasing effect. They prove them to be more of the nature of steps down facing away from the shorter diagonals of the rhombic faces, than of definite protrusions; and their undeviating straightness, so different from the vacillating composition plane of the macle, contrasts sharply with the rippled surfaces they cut.

Geometrically, the shorter diagonal of a rhomb of a dodecahedron coincides with an edge of the derived tetrahexahedron. The same rule is approximately true for such diamonds as are of good symmetry, and are not

FIG. 3.—Laminated Wesselton diamond, enlarged.

laminated; but when diamonds are laminated the rule is varied, in that the tetrahexahedron edge tends to slant away from its geometrical position into parallelism with the edges of the laminae. This is, perhaps, the most important change made by the lamination on the aspect of a stone.

Fersmann and Goldschmidt have described ('Der Diamant,' 1911) three laminated diamonds, all Brazilian, namely: Crystal No. 26, an irregular lump of a weak violet colour, showing lamination in three directions; Crystal 32, a brownish regular dodecahedron, whose surface is covered by a delicate network formed of innumerable twin lamellae in four sets; and Crystal 33, a brown dodecahedron with coarse lamination. They argue that most diamonds may be presumed to be composed of such lamellae, and that the lamination is brought into view by the process of solution. They seem further to hold that hemitropic twinning is the cause of the phenomenon.

It is curious that their drawings of crystals 32 and 33 show the protuding edges of the lamellae as running nearly parallel with the edges of the rhombs, a feature not actually possible in nature. Indeed in this respect their version of the aspect of 33 differs absolutely from that of Rose and Sadebeck made some forty years earlier, and which they reproduce for comparison with their own.

Boutan also regards these laminated diamonds as macles by hemitrophy. He further regards Brewster's celebrated lens of diamond as having been cut from a multiple twin of this kind—a remote possibility, maybe, though not quite a probability, if only for the reason that a laminated stone is not likely to be transparent enough to serve as a good lens.

One reason against hemitrophy is that one sometimes comes across laminated stones which could just as well be called in the French way "macles by penetration," *i. e.*, tending to conform geometrically to the interpenetrating twins of the plus and minus tetrahedra; the lamination giving a terraced aspect to the blunt protruding pyramidal bosses very like the terraced diamonds from Jagersfontein in miniature. Another reason is that lamination is limited to four definite directions each of which is parallel to an octahedron face, so that in any laminated stone each multiple-twin set intersects another at a constant angle; and this is the case even when the specimen is a macle. But macles when they intersect one another are not limited to definite directions at all: their seams crossing almost at random much as irregularly twinned simple crystals interpenetrate.

Lamination has an intimate correlation with colour. With very few exceptions, all laminated diamonds, no matter where they come from, are coloured—brown, mauve, green, or blue-white. Slight lamination may also be seen once in a way on poor cape-white diamonds, and on poor yellow ones. Reflexively, nearly every brown, and nearly every mauve, dodecahedral diamond, either macle or simple crystal, whether the tint be light or dark, is plainly laminated.* So are most blue-whites when they are of a milky transparency or when their tint inclines to mauve. Lamination also occurs among the green diamonds from the Rand banket.

Hitherto I have only succeeded once in seeing signs of lamination in the interior of a diamond. This was in an ugly dark-brown brilliant in which the lamellae were marked out in alternating lighter and darker brown streaks. A fair inference seems to be that a diamond going in general through stages of growth and quiescence may, during the latter, become covered with colouring matter which is enclosed in a later growth. The apparent uniform tint of the final whole stone will be largely a refraction effect (like the grey

* The featureless brown diamonds of resinous lustre from South-West Africa do not show lamination so often as brown diamonds from other sources. For that matter South-West African diamonds seldom show any surface detail at all to speak of, saving either an exceedingly high polish or a roughening due perhaps to wind erosion.

colour imparted to coated stones by indefinitely thin layers of tiny black spots), and is the happier as the laminae are thinner. Thus the colouring matter is an overgrowth which establishes the lamination. There is no doubt that Heddle when he alleged the disseveration of "plate diamonds" ('Ency. Brit.,' 9th Ed., Art. "Mineralogy"), was confounding the mythical bursting of smoky stones with the lamination of brown ones.

[ADDENDUM.—While the above paper was going through the press I had the good fortune to see a most important specimen of diamond embedded in calcite, found by Mr. J. T. Vigne in the working over of some old Kimberley lumps. The diamond appears to be of about four carats, and the enclosing calcite perhaps five carats. The diamond has evidently not been squeezed into the calcite, but has acted as a nucleus upon which the latter has crystallised. Mr. J. Stewart has, also, given me a portion of a beautiful shell of calcite taken from a Wesselton blue-ground diamond. The interior faces of this shell have acquired, from their intimate contact with the diamond, an almost perfect adamantine lustre.]