

# INVESTIGATION OF THE MINOR ELEMENTS IN DIAMOND

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## ABSTRACT

The methods and results of emission spectrographic analysis of thirty-three diamonds are described. Thirty elements were analyzed for and thirteen were detected among the thirty-three diamonds. The elements Al, Si, and Ca form a persistent group which appeared as minor elements in every specimen. The elements Al and Si exhibited 'sympathetic' variation in each diamond. Absorption spectra in the ultra-violet region revealed the presence of a type 2 diamond which was found to be the purest of the thirty-three diamonds. Diamonds from some of the geographical localities show similarities in minor element content. The elements Fe and Ti tended to be present in the colored diamonds. A minor correlation was made between the crystal habit and the simultaneous presence of Ag and Ti. No correlation was observed between minor element content and fluorescence phenomenon.

## INTRODUCTION

The primary objective of this investigation was to carry out a semi-quantitative analysis, based on emission spectra, of the impurities present in certain diamonds. An attempt has been made to correlate the information so obtained with the color, crystal habit, fluorescence, x-ray pattern, and geographical location of the diamonds. The results are also discussed on the basis of the two established types of diamonds.<sup>1</sup>

At the suggestion of Amos J. Shaler, J. K. Smit and Sons, Inc., kindly placed certain diamonds at the disposal of the writer for research purposes. It was decided to cleave the diamonds, using one half for emission spectra work, and to retain the other half for non-destructive observational purposes.

<sup>1</sup> Robertson, R., Fox, J. J., and Martin, A. E., Two types of diamond: *Phil. Trans. Roy. Soc. (London)*, **A 232**, 463 (1933).

There are very few references<sup>2,3</sup> in the literature to the impurities which occur in the diamond. These references are incomprehensive in scope. This lack of information might be due to the difficulty in obtaining good specimens for research purposes, especially when they are to be partially destroyed to secure certain data.

The diamonds used in this investigation are considered to be quite a representative group, as they range from colorless to colored, and from those perfect in form to those quite imperfect.

#### DESCRIPTION OF DIAMONDS

In the original lot of diamonds submitted for this investigation there were 138 stones from 15 different localities. The quantities and localities are tabulated in Table 1. From this quantity the writer was privileged to

TABLE 1

Name	No. of Stones in Original Lot	Weight in Carats*	No. of Stones Selected for Analysis
Angola	10	2.90	4
So. W. African Alluvial	5	1.13	2
Dark Brown Premiers	10	1.55	2
Congo Octahedrons	10	3.21	2
Sierra Leone	10	3.48	3
Brown Congo	10	2.75	2
Premier Black Ballas	10	2.95	1
Brazilian (Venezuela)	13	1.16	4
Brazilian Ballas	5	0.70	2
Kimberley	5	1.85	2
Carbonados (Brazil)	10	1.65	3
Brazilian (Bahia)	10	1.77	2
Congo Cube	10	2.83	2
French Guinea	10	2.55	2
West Africans	10	1.80	—
Total	138	32.28	33

\* 1 carat = 0.200 gm. Av. wt. per stone = 0.235 ct.

select an average of two stones from each locality for use in the investigation. Particular care was taken by the staff of J. K. Smit and Sons, Inc., to assure validity of the sources of the diamonds. All of the diamonds are

<sup>2</sup> Among them the writer found:

Wild, G. O., and Klemm, R., *Mitteilungen über Untersuchungen an Mineralien: Centr. Mineral., Abt. A.* 321 (1925).

<sup>3</sup> Walter, B., Eine charakteristische Absorptionserscheinung des Diamanten: *Ann. Physik.*, **42**, 505 (1891).

from famous diamond producing regions in South America and Africa. The approximate geographic locations are shown in Fig. 1.

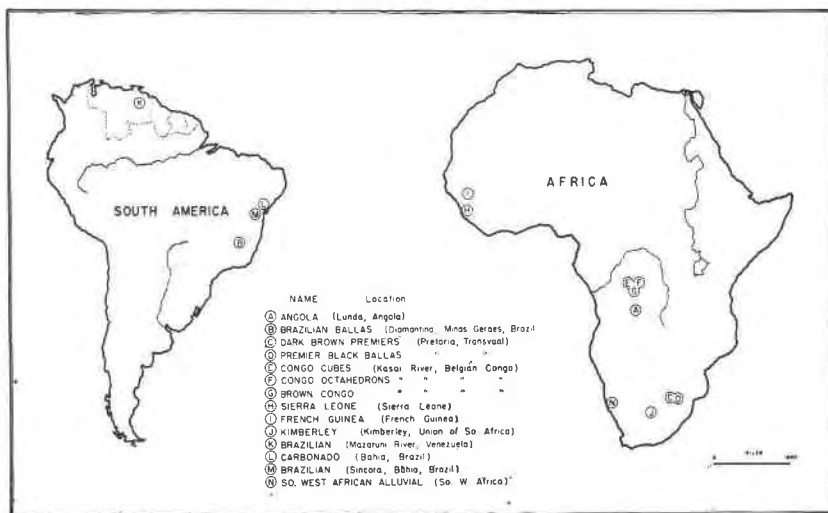


Fig. 1. Map showing approximate geographic locations of diamonds used in this investigation.

The choice of the representative stones from each locality was made with the intent to select individual stones that possessed dominant characteristics of certain types such as color, perfection of form, obvious lineage structure,<sup>4</sup> etc. The purpose of this choice was to see if any correlation could be found between these features and the data obtained from the emission spectra.

The colors of all the diamonds described below will be found in Table 2.

From Figs. 2 and 3 it will be seen that the various morphological features common to the diamond are well represented in the group. Nos. 1-4 are all highly twinned and were selected mainly on the basis of their imperfection of form and obvious evidence of lineage structure. Lineage structure is a common, though rarely mentioned, characteristic of diamond crystals. Attention was focused on this feature because of the importance it seems to have played in the extensive work carried out by Robertson, Fox, and Martin.<sup>5</sup> Diamonds 5 and 6 were selected on the

<sup>4</sup> Buerger, M. J., Lineage structure of crystals: *Zeits. Krist.*, **89**, 195 (1934).

<sup>5</sup> Robertson, Fox, and Martin have established the existence of two types of diamond as based on the positions of absorption bands in the infra-red and ultra-violet regions of the spectrum. They found the common, or type 1 diamond, to have an absorption band at  $8\mu$  in the infra-red region and complete absorption at  $3000 \text{ \AA}$  in the ultra-violet. The rarer,

basis of perfection as fine octahedra. Likewise 9 and 10 were chosen as representatives of the octahedral habit, though from a different locality. Specimens 7 and 8 were interesting in so far as they were single crystals, colored, transparent, and apparently free from inclusions. The Sierra Leone diamonds, Nos. 11, 12, and 13, constitute a group from a single locale in which various habits and colors were represented. The brown Congos, Nos. 14 and 15, exhibited cleavages which showed excellent lineages, quite similar to those seen on galena cleavages. These stones were also colored. Number 16 was a grayish translucent diamond highly twinned with many steps present on the surface. Diamonds Nos. 17-20 were transparent, colored specimens. Numbers 21 and 22 were nearly spherical in shape and possessed much pitting or etching on the surface. The Kimberley stones, Nos. 23 and 24, were colorless. Both specimens exhibited very few natural faces, these few, however, indicated a dodecahedral habit. The carbonados, Nos. 25, 26, and 27, were selected because they were totally opaque and lacked any visual evidence of crystallinity. Diamonds Nos. 28 and 29 were clear transparent specimens each slightly colored. Both were distorted crystals, No. 28 being a distorted dodecahedron and No. 29 a distorted octahedron. Numbers 30 and 31 were chosen because of their color and cubic habit. Number 31 was a penetration twin. The French Guinea diamonds, Nos. 32 and 33, were cleavage fragments with only a few natural faces. No particular habit could be assigned to these specimens. Both appeared to have a slight pinkish tint.

A. F. Williams<sup>6</sup> has been in a unique position to observe many hundred thousand carats of diamonds. Referring to the color of diamonds he says:<sup>7</sup>

"The color of diamond is generally referred to as white or colorless, but as a matter of fact, this is one of the rarest colors found among diamonds . . . ."

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or type 2 diamonds, have no band at  $8\mu$  and exhibit complete absorption at  $2250 \text{ \AA}$ . They observed that a crystalline condition which was indicated by fine oscillation lamellae was more particularly associated with type 2 diamonds. The writers also state that 2 was more nearly isotropic optically than type 1, but specific gravity, index of refraction, dielectric constant, Raman effect, and fluorescence phenomenon showed no difference between the two types.

Another feature which they found common to the type 2 diamonds was a marked photoelectric effect. This same effect they observed to be very feeble in the type 1 diamonds. Robertson, Fox and Martin offer an explanation of the difference in transparency of the two types as derived from a consideration of the various modes of vibration of C against C in the diamond structure. They advance arguments against the assumption that the type 2 owes its properties to common impurities.

<sup>6</sup> Williams, A. F., *The Genesis of the Diamond*, Ernest Benn, Ltd. (London), p. 475 (1932).

<sup>7</sup> *Ibid.*, p. 467.

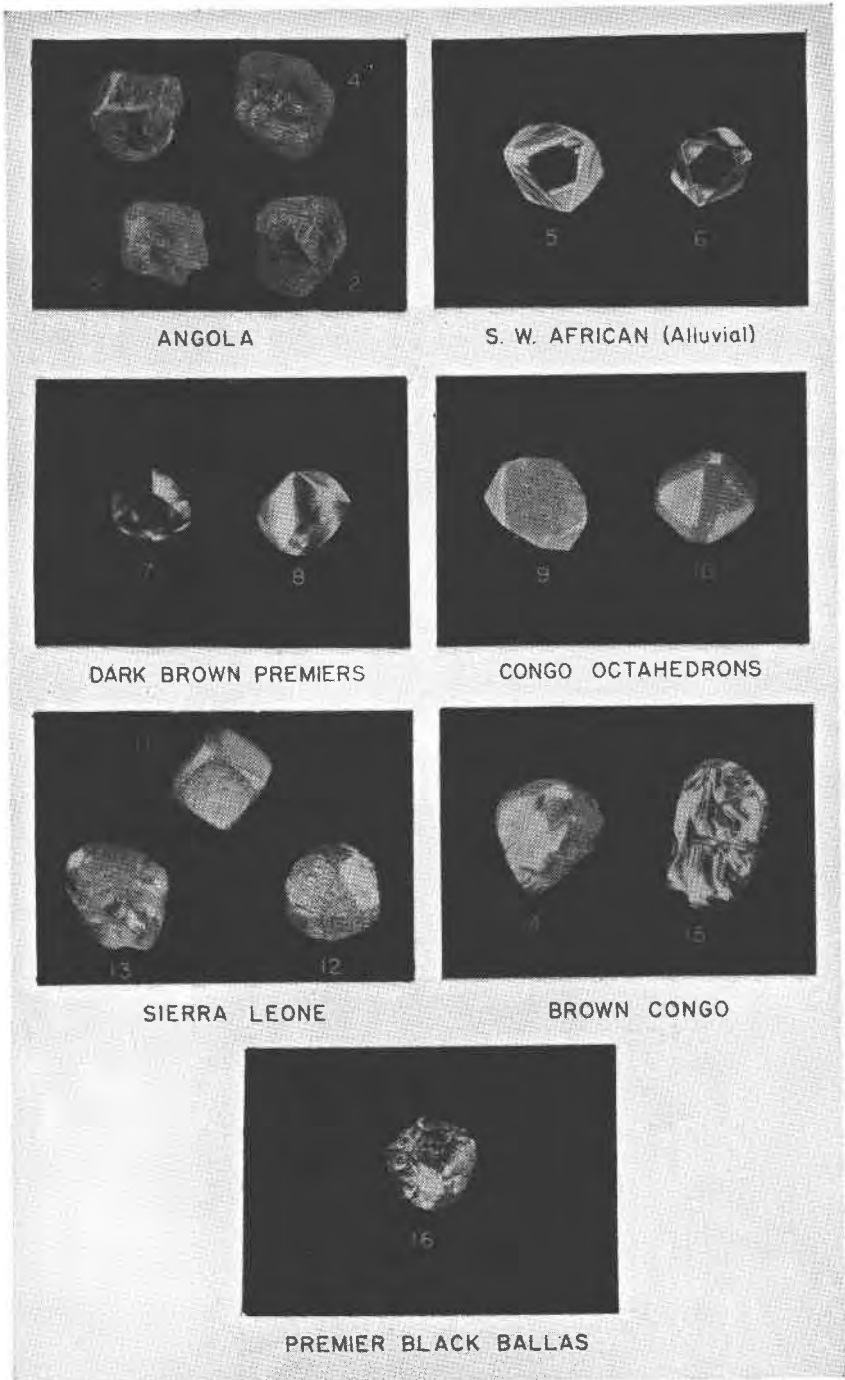


FIG. 2. Photographs of diamonds. X 4.

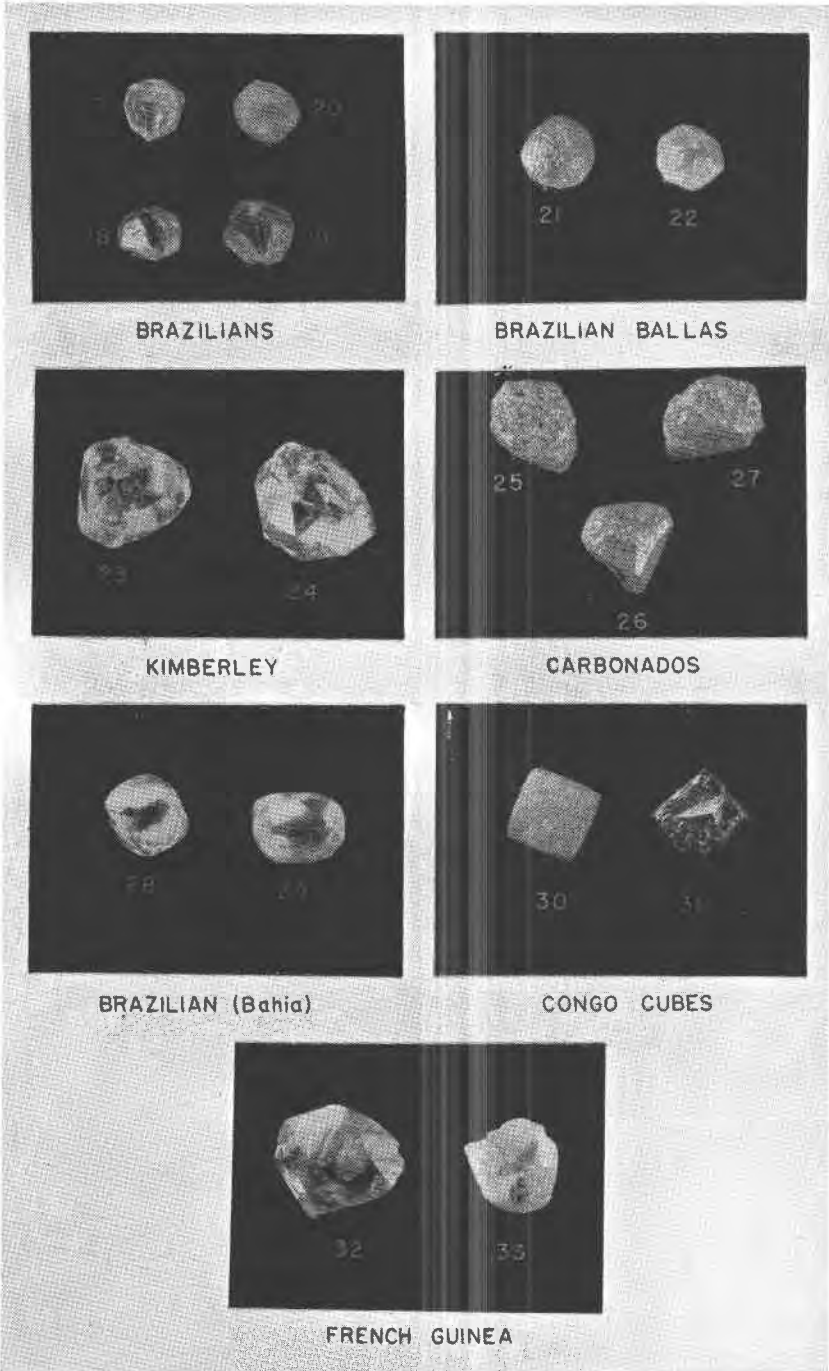


FIG. 3. Photographs of diamonds.  $\times 4$ .

TABLE 2

Diamond No.	Color	Diamond No.	Color
1	colorless	18	very pale green
2	colorless	19	pale yellow
3	white	20	pale yellow
4	colorless	21	pale yellow
5	pale yellow tint	22	white
6	very slight yellow tint	23	colorless
7	brown tint	24	colorless
8	light brown tint	25	dark brown
9	clear colorless	26	black
10	grayish	27	black
11	dark green opaque	28	very pinkish tint
12	deep green	29	very pale green tint
13	dark green	30	yellow
14	brown	31	dark yellow green
15	slight yellow tint	32	light pinkish tint
16	dark gray transparent	33	light pinkish tint
17	clear very pale yellow		

## METHOD OF PREPARING SAMPLES

Each of the diamonds selected weighed approximately 50 mg. Only a fraction of each stone was necessary for the spectrum analysis. Consequently every diamond was photographed for record purposes and then cleaved in half. One half of each stone was powdered for spectrographic examination because a single fragment would not stay in the arc long enough for satisfactory excitation. The powdering process consisted in shattering each stone by percussion. Although diamond is the hardest known mineral, a sharp blow will cause it to break into many small pieces. Each cleavage fragment was placed in an improvised mortar which was constructed as follows. Two cold-rolled steel slugs, which were  $1\frac{1}{4}$ " diam. and  $3/32$ " thick, held the diamond between them. The slugs were then placed on a short steel cylinder of slightly smaller diameter. A steel envelope was slipped over this assembly and another cylinder was inserted at the top. A few sharp blows on the top member reduced the diamond to powder. The envelope prevented the powder from shooting out laterally. The powder was then carefully gathered and cleaned. Two new slugs were used for each specimen.

Before the crushing process both the steel slugs and the fragment had been thoroughly treated with organic solvents to remove any grease or oils that may have been on them due to handling. After the crushing process the powder was placed under a magnet to remove any loose iron.

The powder was then subjected to vigorous acid treatment in order to remove any impurities that might have accumulated on the surfaces of the shattered particles. After moderate warming, the acid solution was diluted and decanted. This was followed by washing with distilled water, alcohol, and ether. All of the wet processes were carried out in small glass vials.

#### SPECTROGRAPHIC APPARATUS AND TECHNIQUE

The apparatus used for this investigation was the 21 foot, 30,000 lines per inch, Wadsworth grating spectrograph of the Cabot Spectrographic Laboratory at the Massachusetts Institute of Technology. The region of the spectrum examined ranged from 2800 to 4600 Å. This range was selected because it includes the major portion of the sensitive lines of the elements which preliminary examination showed to be present in the diamond. The dispersion of the spectrograph in this region is 2.46 Å per millimeter. The spectra were registered on Eastman commercial film and developed for 6 minutes at 18–20°C. in D-11 developer, diluted 1:1.

A 220 volt D.C. source with resistance and inductance in series was used for excitation purposes. The 220 volt supply gave a steady discharge and resistances were arranged in stages which permitted current increases from  $3\frac{1}{2}$  to  $7\frac{1}{2}$  to 12 amps. Each sample was ignited at a current of  $3\frac{1}{2}$  amps and electrode separation of 5 mm. The sample was burned under these conditions for 30 seconds, then increased to  $7\frac{1}{2}$  amps for 30 seconds, and finally to 12 amps for 60 seconds. The progressive increase in current helps to completely vaporize all elements present in the sample and consequently register their line spectra.



FIG. 4. Cross-section of cathode.

National Carbon Special Spectrographic Carbons of  $3/16$ " diameter were used as electrodes. The upper electrodes or anodes were approximately 20 mm. in length. The cathodes were of the same length but they were shaped as illustrated in Fig. 4. This shape minimizes the wandering of the arc and also helps to retain the unvaporized portion of the sample until the last stages of burning.



A new cathode and anode were used for each sample. The carbons were free of all impurity under the conditions of the investigation and showed no contamination on the test plates which were taken of sample electrodes. A special drilling tool was employed to shape the cathodes and precautions were taken to see that no contamination occurred from this source. The composition of the drilling tool included iron, manganese, chromium, and a trace of nickel. However, these elements did not appear at all when sample electrodes were burned in the arc as mentioned above.

#### CHOICE OF SPECTROGRAPHIC METHOD

The arc is especially suitable for the examination of non-conducting material such as diamond. The energy produced in the arc is high enough to excite the spectra of most elements in sufficient intensity. The obvious advantage however, of the arc method over other methods of excitation, is that the sample need not be treated according to more or less complicated chemical procedures. This feature alone eliminates the possibility of contaminating the sample with impurities which frequently occur in reagents even of analytical quality.

As a means of determining the minor constituents in a non-conducting solid such as diamond, it was of great advantage to employ the cathode-layer or "Glimmschicht"<sup>8</sup> technique. This is a special application of the carbon arc method. By means of the cathode-layer method, smaller quantities of most elements present in the powdered substance can be detected, than with the spark or other arc methods in spectrum analysis. The great sensitivity of the cathode-layer method is the primary reason for its choice in this investigation. In addition, this method requires only a minute quantity of material for maximum sensitivity. Only 7 mg. of finely powdered substance was used for the analysis of each sample.

An attempt was made to establish the presence or absence of thirty different elements. They are listed in Table 3 along with the most sensitive line and the checking line for each element in the spectral region 2800-4600 Å.

#### RESULTS OF SPECTROGRAPHIC ANALYSIS

It is important to emphasize the fact that this analysis is only semi-quantitative in nature. No effort was made to determine the absolute quantity of the concentration of impurities present in the diamonds. The

<sup>8</sup> Strock, L. W., *Spectrum Analysis with the Carbon Arc Cathode Layer* ("Glimmschicht"), Adam Hilger, Ltd., London (1936).

analysis is qualitative in nature with a visual estimation of the relative line blackenings. The symbols used to represent the different relative quantities are explained in Table 5, and they are purely arbitrary. The sensitivity varies from element to element, and  $L$  in the case of one element may represent 0.1%, while in another it may be about .01%, these figures being typical for quartz. Taking into consideration the conditions of excitation, exposure, amount of sample, etc., it may be said that the limits of sensitivity of the minor constituents in diamond are comparable to those of quartz.

TABLE 3

Element Sought	Most Sensitive Line	Check Line	Element Sought	Most Sensitive Line	Check Line
Aluminum Al	3961.53	3944.03	Magnesium Mg	2852.13	3096.92
Antimony Sb	3267.48	3232.52	Manganese Mn	4030.76	4033.07
Arsenic As	2860.46	2898.73	Nickel Ni	3414.77	3524.54
Barium Ba	4554.04		Potassium K	4047.22	4044.16
Beryllium Be	3130.42	3131.06	Rubidium Rb	4215.58	4201.81
Bismuth Bi	3067.73	2897.98	Scandium Sc	4246.85	3613.8
Calcium Ca	4226.73	2899.78	Silicon Si	2881.59	3905.52
Chromium Cr	4254.34	4274.80	Silver Ag	3280.67	3382.89
Cobalt Co	3453.51	3405.12	Sodium Na	3302.94	3302.34
Copper Cu	3247.55	3273.96	Strontium Sr	4607.34	4077.71
Germanium Ge	3039.08	3269.50	Tin Sn	3262.33	3034.12
Gold Au	3122.8		Titanium Ti	3349.41	3371.46
Iron Fe	3719.94	3734.14	Tungsten W	4008.76	4294.62
Lead Pb	4057.83	3683.47	Zinc Zn	3345.51	3302.56
Lithium Li	4602.99	3232.67	Zirconium Zr	3391.98	3438.23

The spectra of the diamonds were registered on two plates. A portion of one of the plates is shown in Fig. 5. This figure represents a region of the spectra which includes Si, Ca, Al, and Fe lines. However, the most sensitive lines for Si, Ca, and Fe happen to occur in other portions of the spectra, as indicated in Table 3. This figure serves to show the way certain elements made their appearance in the spectra, and also gives an idea of the dispersion of the instrument.

All of the data derived from the emission spectra of the 33 specimens are tabulated in Table 4. The elements are arranged with those appearing most frequently to the left, and those appearing least frequently to the right. Thirteen of the thirty elements sought for made their appearance during the analysis.

The four elements Al, Si, Ca, and Mg constitute a persistent group which appears in each of the 33 specimens (with the exception of Nos. 23 and 32, in which Mg was not detected). These elements are abundant

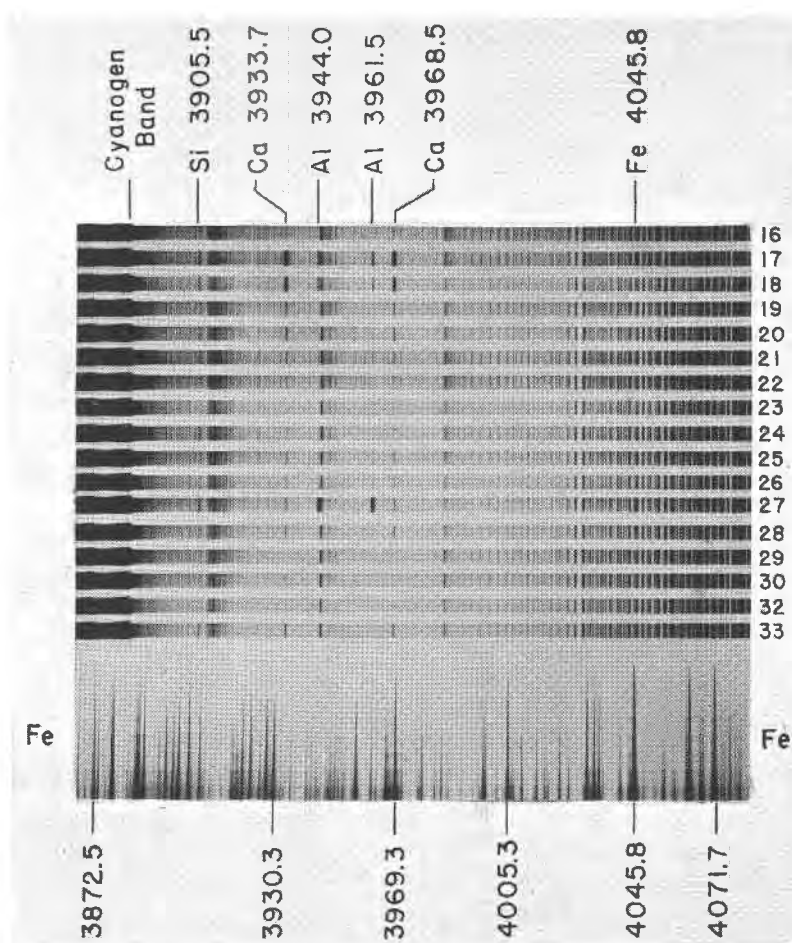


FIG. 5. Portion of spectrographic plate.

in nature and also sensitive to detection by the spectrograph. Al and Si appear to act as a pair of elements which exhibit "sympathetic" variation in each diamond. That is, when Al is large, then Si tends to be large, and when Al is small, Si also tends to be small. The other minor elements,

TABLE 4

Geo-graphic Location See Fig. 1	Diamond No.	Al	Si	Ca	Mg	Cu	Ba	Fe	Sr	Na	Ag	Ti	Cr	Pb	Special Effects
A	1	M	T	M	T	M	L	T	S	T	A	A	S	A	F Z
	2	M	S	M	S	L	M	M	A	T	T	A	A	A	
	3	S	vT	M	T	M-	A	S	S	T	T	T	T	A	
	4	S	T	L	T	S	M	A	A	A	A	A	A	A	
N	5	T	T	S	T	S	M	A	A	A	A	A	A	A	F F
	6	S	M	M	S+	S	L	A	M	A	A	A	A	A	
C	7	M	M	vL	L	S	M+	T	T	A	A	A	A	A	F Z
	8	S	S	M	M	S	M	A	A	A	A	A	A	A	
F	9	S	T	M	S	T	A	T	A	A	T	A	A	A	F Z
	10	S	vT	L	T	T	M+	A	T	A	A	A	A	A	
H	11	M	M+	L	M	S	M+	M	A	T	A	S	A	A	
	12	M+	vL	vL	L	A	L	S	A	S	A	A	A	A	
	13	L	M-	vL	M	T	L	M	L	T	A	S	A	A	
G	14	L	M	S	S	T	A	A	A	A	A	T	A	A	F
	15	M	L	M	L	L	A	M	A	T	M	A	vT	S	
D	16	T	S	S	M	A	A	A	A	A	A	A	A	A	F Z
K	17	vL	L	vL	L	T	vL	M	M	T	A	A	T	A	F Z
	18	vL	L	vL	L	L	vL	M	L	T	T	A	T	A	
	19	S	S	L	T	T	M	A	A	A	A	A	A	A	
	20	S+	M	L	S	S	L	A	A	A	A	A	A	A	
B	21	M	M	M	S	S	L	A	S	A	A	A	A	A	F F
	22	M	S	M	T	T	A	A	A	A	A	A	A	A	
J	23	S	T	S	A	T	M	A	A	A	A	A	A	A	F
	24	M	L	S	M	S	M	S	A	A	T	A	A	A	
L	25	M	M	M	M	S	A	S	T	A	A	A	A	A	
	26	M	M	S	M	T	A	S	A	A	T	S	A	A	
	27	vL	L	M	M	L	M	L	M	A	A	M	S	A	
M	28	M	S+	M	T	T	A	M	A	A	A	A	A	A	F F Z
	29	S	T	S	T	A	A	A	A	A	A	A	A	A	
E	30	S	T	S	T	T	A	A	A	A	T	T	A	A	
	31	M	S	M	S	T	L	M	M	A	T	T	A	A	
I	32	S	T	M	A	T	A	T	A	A	A	A	A	A	
	33	M	M	M	S	T	A	A	A	T	T	A	A	A	

Abbr. vL=very large  
 L=large  
 M=medium  
 S=small  
 T=trace

vT=very small trace  
 A=absent  
 F=fluoresced  
 Z=zoned

Cu, Ba, Fe, Sr, Na, Ag, Ti, Cr, and Pb show no tendency to persist through all the diamonds, nor is there any sympathetic variation as exhibited by Al and Si.

In some cases an association can be drawn relating the minor element content and geographical location. For example the diamonds from location *K* are divided according to their minor constituents into two pairs, Nos. 17, 18 and 19, 20. Numbers 5 and 6 differ appreciably only in the Sr content. From location *H*, Nos. 11 and 13 are likewise quite similar except for the Sr content. The reason for striking differences between many members from the same geographic region may be that they came from different mines or diggings in that particular locality.

The only correlation which could be observed between color and minor element content concerns the two elements Fe and Ti. Examination of Tables 2 and 4 reveals a tendency for the diamond to be colored when these elements appear individually or simultaneously. However, many other factors affect the color of a substance much more strongly than minor element content. These will not be discussed in the present paper.

A study of the association between minor element content and morphology reveals that diamonds of perfect form, for example Nos. 5 and 6, contain as much minor element content as many of the less perfectly formed diamonds (Nos. 23, 24, etc.). The correlation of habit with impurity content concerns only cubes and octahedra. The octahedra show an absence of Ag and Ti, while the cubes show these two elements to be present. Silver has previously been associated with crystal habit, as shown by Frondel, Newhouse, and Jarrell.<sup>9</sup>

It is unfortunate that approximately 20 elements are not easily detected by the spectrograph. Among those whose presence or absence would be of great interest are B, O, N, P, S, the halogens, etc.

#### ULTRA-VIOLET SPECTROSCOPY OF DIAMOND

The variations in minor element content as determined by the emission spectra did not suggest a means of distinguishing between the two types of diamond without further information. Robertson, Fox, and Martin<sup>5</sup> have established, among other tests, that the absorption characteristics of the diamond in the ultra-violet region of the spectrum are a criterion for distinguishing between the two types of diamond. The more common or type 1 diamonds exhibit complete absorption at 300 Å, and the rarer or type 2 diamonds absorb at 2250 Å. In so far as one-half of each of the

<sup>9</sup> Frondel, C., Newhouse, W. H., and Jarrell, R. F., The spatial distribution of minor elements in single crystals: *Am. Mineral.*, **26**, 197 (1941).

diamonds was retained, it was possible to use them for ultra-violet absorption measurements.

The purpose of this test was to ascertain whether or not both recognized types of diamond were present in the lot under investigation. If both types were found, then further inspection of the emission data might reveal differentiating characteristics.

The apparatus used for the absorption work consisted of an iron spark as the source of ultra-violet light, and a Hilger Spekker to provide a small concentrated image at the slit of a Hilger Medium Quartz spectrograph. The spectra were recorded on Eastman Process plates. The diamonds were mounted at the slit with a masking arrangement which permitted only light that had passed through the diamond to fall upon the slit. The transmission ability of each diamond so mounted was tested by removing the plate holder and viewing the visible spectrum which was present. Due to the irregular shape and size of some of the diamonds, it was very difficult, and in some cases impossible, to mount the specimen so that adequate light was transmitted for photographing. Even though most of the diamonds possessed an octahedral cleavage, the surface irregularities opposite the cleavage caused them to act as an imperfect lens. Consequently the optic axis of the instrument was disrupted. Diamonds possessing two more or less parallel sides could be mounted and their spectra satisfactorily photographed. Such was the case with Nos. 1, 4, 5, 6, 9; and 29. The absorption spectra of 1, 4, 5, 6, and 9 exhibited a sharp absorption edge at about 3000 Å. The spectra of No. 29 extended to about 2500 Å.

The fact should be kept in mind that this was carried on at ordinary temperatures and that a continuous source of illumination was not used. The test was only qualitative, but nevertheless it qualifies No. 29 as being a type 2 diamond. Nos. 1, 4, 5, 6, and 9 are the common or type 1 diamonds.

Examination of the emission spectra shows that No. 29 is an unusually pure diamond. Traces of two elements and small quantities of two others are all that are indicated, these four elements being members of the persistent group, Al, Si, Ca, and Mg. On this basis it might be predicted that No. 16 is also a type 2 diamond. The surface irregularities of No. 16 prohibited an examination of its absorption spectra.

#### X-RAY EXAMINATION

Single crystal rotation patterns were taken of diamonds Nos. 5, 6, and 9. These specimens were chosen because they possessed quite perfect form and had different impurity content. Numbers 6 and 9 provide a

wide contrast in their content of the heavy elements, Sr and Ba. The patterns were closely examined for spots which would suggest the presence of a superstructure, especially in No. 6. No evidence was found in the specimens examined.

#### FLUORESCENCE

All of the diamonds in this analysis were examined for fluorescence. It was found that 17 of the 33 diamonds fluoresced under the ultra-violet

TABLE 5

Diamond No.	Fluorescent Color and Special Effects
2	Light blue inner and outer zone, dark band between
4	Zoned similar to No. 2
5	Yellow
6	Yellow
8	Zoned, yellowish-green outer zone, darker inner zone
10	Octahedron with light colored inner zone
15	Dark blue fluorescence
16	Light inner zone, outer band non-fluorescent
17	Light blue outer region with central dark zone
18	Light blue
19	Yellowish-green
20	Light greenish
21	Brilliant light blue
22	Brilliant light blue
23	Dark yellowish-brown, weakly fluorescent
28	Light blue
29	Light blue band with darker inner zone

light of a mercury vapor lamp. A double 986A red-purple Corex filter, which has a transmission peak at approximately 3650 Å was used. The diamonds which fluoresced are indicated in Table 4, and the fluorescent effects are listed in Table 5. One of the most striking observations made in this test was the evidence for the existence of 'zoning' or zonal growth in seven specimens. These zones were observed as a distinct band of one fluorescent color completely surrounding a central area of quite different fluorescent color. This effect was best noted on the {111} faces which resulted from cleaving the diamonds, as mentioned earlier in the paper. The effect might not have been observed had it not been for the presence of this fresh cleavage surface. The central area in diamonds 2 and 29 was a very distinct triangle. The presence of a triangle on the {111} face would suggest that the early growth of the specimen was octahedral. Its

later growth was also octahedral, but apparently distorted. Upon examination of Tables 4 and 5, there does not seem to be any correlation between the fluorescent effect and the impurity content of the diamonds exhibiting this property. Diamonds which do not fluoresce seem to contain as great a minor element content as diamonds which do exhibit this phenomenon.

Authors of the paper describing the two types of diamond state that fluorescent phenomena is common to both types. On the basis of the data from the emission spectra, this might suggest that fluorescence in the diamond could be partially attributed to the members of the persistent group Al, Si, Ca, and Mg.

H. W. Lindley<sup>10</sup> observed in many yellow diamonds from Southwest Africa, a zonal banding parallel to the octahedral faces. He also observed that crystals showing a strong pale blue fluorescence are more transparent than others to ultra-violet light. This observation is confirmed by the findings of this investigation which shows that No. 29 fluoresces pale blue and is quite transparent to ultra-violet light.

#### NEUTRON BOMBARDMENT

With the possibility in mind that some unusual effect might be induced, the entire collection of diamond fragments (Nos. 1-33 inclusive) was exposed to bombardment by stray, slow neutrons from the M. I. T. Cyclotron for approximately 48 hours. Observations made immediately after removal, and again at three and six days after removal from the cyclotron, revealed no change in appearance of the diamonds. This work was carried out with the collaboration of Dr. Clark Goodman of the Physics Dept. at M. I. T.

#### SUMMARY

1. The emission spectra in the region 2800-4600 Å of 33 diamonds have been recorded. The data so obtained have been discussed on the basis of geographic location, form, color, x-ray pattern, and fluorescence.

2. Analysis was made for thirty elements, and thirteen elements appeared among the thirty-three specimens. They were Al, Si, Ca, Mg, Cu, Fe, Ba, Sr, Na, Ag, Ti, Cr, and Pb. A persistent group of elements, Al, Si, and Ca, was detected in every diamond. The elements Al and Si exhibited 'sympathetic' variation.

3. Absorption spectra in the ultra-violet region have been photographed for six of the diamonds. Five of these were found to be the common or type 1 diamond, and one was the rarer or type 2 diamond (No.

<sup>10</sup> Lindley, H. W., Wachstumserscheinungen am Diamant: *Fortsehr. Min. Krist. Petr.*, **21**, 71 (1937).



29). This diamond proved to be the purest of the lot on the basis of the emission spectra.

4. The diamonds of cubic habit revealed the presence of Ag and Ti, whereas these elements were not detected together in the octahedral diamonds.

5. The elements Fe and Ti tended to be present in the colored diamonds.

6. Similarities were observed in the emission spectra of diamonds from some of the geographical localities.

7. Seventeen of the diamonds exhibited fluorescence. No correlation could be observed between this phenomenon and the minor element content of the specimens. Seven of the fluorescent diamonds showed a zoning effect.

#### ACKNOWLEDGMENTS

The writer is indebted to several persons without whose help this investigation would have been impossible. In the first place the writer wishes to express his gratitude to Amos J. Shaler and J. K. Smit and Sons, Inc., for supplying the diamonds and later cleaving them. Mr. Shaler was also kind enough to assist in preparing the samples for the emission spectrographic analysis. Grateful acknowledgment is made to Prof. M. J. Buerger not only for suggesting this work but for many helpful discussions and for critically reviewing the manuscript. Professor W. H. Newhouse kindly permitted the writer to use the facilities of the Cabot Spectrographic Laboratory. The writer wishes to express his appreciation for advice given by R. F. Jarrell concerning the spectrographic analyses.