CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

OTTAWA

[redacted]

Mines Branch

COPY NO. 07

CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

OTTAWA

MINES BRANCH INVESTIGATION REPORT

IR 71-83 December 1971

EXAMINATION OF A BULK SAMPLE OF KIMBERLITE FOR DIAMOND CONTENT

by

R. A. Wyman and F. H. Hartman

Mineral Processing Division

Note: This report relates essentially to the samples as received. The report and any correspondence connected therewith shall not be used in full or in part as publicity or advertising matter.

COPY NO.

Mines Branch Investigation Report IR-71-83

EXAMINATION OF A BULK SAMPLE OF KIMBERLITE FOR DIAMOND CONTENT

by

R. A. Wyman* and F. H. Hartman**

- - -

SUMMARY OF RESULTS

An eight-ton bulk sample of kimberlite from northern Ontario was crushed and screened and the screenings were subjected to various concentration procedures. However, the mineralogical and X-ray examination of concentrate from the 20 to 35-mesh fraction failed to reveal any diamonds.

---

*Head, and **Research Scientist, Industrial Minerals Milling Section, Mineral Processing Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

CONTENTS

TABLES

INTRODUCTION

For many years, isolated occurrences of diamonds have been reported over the wide range of central North America that was once covered by the continental glaciers. On the assumptions that diamonds were actually carried to their various locations by the advancing glaciers and were dropped when the ice retreated, their probable origin would be in western Quebec.

As a result of a project of the Geological Survey of Canada (G.S.C.) which involved the investigation of heavy minerals in an esker near Kirkland Lake, Ontario, a kimberlite dyke was found in the Upper Canada Mine[1]. This kimberlite is similar to those in Siberia and South Africa from which diamonds have been recovered, therefore, it was decided to search the material very closely for diamonds, and, to this end, an arrangement was made between Upper Canada Mines Ltd., the G.S.C., and the Mines Branch.

It was decided to follow the South African sampling procedure on a 100 to 120-cu-ft 8-ton bulk sample that had been taken on February 5-7, 1969, at Upper Canada Mine, in the presence of a Mines Branch observer to reduce the possibility of "salting".

BULK SAMPLE

The sample was loaded into drums which were immediately locked and sealed for transfer to the Mines Branch[2]. The sample arrived intact at the Mines Branch together with a small amount of additional mine rock, packed separately, to act as control material.

PROCESSING METHODS EMPLOYED IN AFRICA

A study of the available information, including a verbal report by Dr. H. A. Lee on his inspection of prospecting methods for diamonds, as practiced in certain parts of South Africa, indicated that both "soft" and "hard" ground are worked. The "soft" ground is usually prospected by taking 10-cu-ft samples from which a specified screen fraction is removed. This is further reduced by jigging, slow-moving ball milling, and washing. Any diamonds present are detected by further sizing, by grease tabling, or by skin flotation. "Hard" ground is tested somewhat similarly but requires careful comminution.

The mining of soft ground is usually by a bulldozer, shovels, and loaders. Hard ground requires blasting before loading. If workings are underground, the usual extraction methods are applied. Comminution is accomplished with jaw, cone, and roll crushers followed by tube milling and screening. Despite their hardness, diamonds are so brittle as to require very careful handling during comminution.

Concentration methods depend chiefly upon the characteristics of diamonds, especially specific gravity (3.5) and surface properties. Cyclones, jigs, heavy-media separation (both wet and dry), rotary pans, and attrition milling are generally used to eliminate the bulk of the material mined. Some magnetic separation may be applied. Because, on average, there is just one part of diamond per 21,000,000 parts of feed, the various separation steps are usually expressed as "concentration ratio".

After the concentrate has been reduced to a minimum practical bulk, there remains the problem of isolating any diamonds present. Originally this was done chiefly by hand sorting. Later, the fact that diamonds would adhere to grease, while other constituents of the concentrate would not, was utilized. Recently, electrostatic separation and selective sorting by X-rays have been applied to the isolation of diamonds.

COMPOSITION OF FEED

The approximate mineral composition and distribution of feed are shown in Table 1.

TABLE 1*

Composition of Feed

Composition	Wt %	Sp gr	Hardness	Magnetic	Other
Olivine	31	3.27 to 3.37	6.5 to 7.0	weak	0.3 to 12.00-mm grains
Phlogopite	25	2.78 to 2.85	2.5 to 3.0	weak	0.5 to 1.0-mm grains (0.05 in matrix)
Carbonates &	35	2.71 to 2.90	3.0 to 4.0	?	
Serpentine		2.50 to 2.65	2.5 to 4.0	?	
Magnetite &	5	5.17 to 5.18	5.5 to 6.5	yes	0.1-mm grains
Chromite		4.10 to 4.90	5.5	weak	0.1-mm "
Perovskite	4	4.0	5.5	no	0.05-mm "
Pyrope	T_r	3.73	6.5 to 7.0	weak	2.0-mm "
Clinopyroxine	T_r	3.2 to 3.3	5.0 to 6.0(?)	no	
Amphibole	T_r	2.9 to 3.4	5.0 to 6.0	weak	
Apatite	T_r	3.17 to 3.23	5.0	weak	
Pyrhotite	T_r	4.58 to 4.64	3.5 to 4.5	yes	
Diamond	?	3.53	10	no	brittle

*From Reference(1)

POSSIBLE BENEFICIATION METHODS

Grain size of mineral constituents may be rulled out as a beneficiation aid because diamonds can exist at any size. Specific gravity differences and magnetic differences appear to be exploitable. The hardness factor cannot be directly exploited because of the brittleness of diamonds, although careful grinding might allow removal of soft minerals as fines. Accelerated weathering of the kimberlite would help if it could be induced.

EXPERIMENTAL PROCEDURES APPLIED

Various experiments were applied to one of the drums of sample. Many of the results were negative but they served to indicate the most appropriate methods for this particular operation. The areas covered were:

heating and quenching;

freezing and thawing;

high-intensity ultrasonic exposure under wet conditions;

heat and humidity;

mild acid attack.

Virtually no disintegration was developed from numerous heat-quench sequences. A series of thirty freeze-thaw cycles, with the specimens wet on freezing, failed to produce any break down of the exposed material. Exposure to ultrasonics dislodged a few chips and powder, probably exploiting cracks already induced by blasting. Exposure to infrared heat in a high-humidity atmosphere for 100 days resulted in minor disintegration: some cracks were formed, with one or two small chips dropping off, and the specimens turned "rusty". Exposure to mild HCl (pH6), for 60 days produced minor pitting, one or two small chips, and some powder.

According to Table 1, about 60% of the mineral content is relatively soft. The possibility of applying careful comminution to eliminate most of this was considered. At the same time, it might have been possible to remove some of the hard and relatively coarse olivine.

Contents of the experimental drum were reduced, in stages by jaw crusher, to pass a half-inch screen. The resulting size distribution is shown in Table 2.

TABLE 2

Size and Distribution of Heavy Minerals

Fraction	Wt (%)	Sink* (%)	Distribution Heavy Minerals (%)
Minus 1/2 in. Plus to 3/8 in.	20.9	3.5	13.0
3/8 " to 3 mesh	15.6	3.2	9.0
3 mesh to 4 "	11.9	0.0	0.0
4 " to 6 "	9.1	5.0	8.1
6 " to 10 "	12.8	6.1	14.0
10 " to 20 "	9.4	7.0	11.8
20 " to 35 "	6.5	10.6	12.1
35 " to 65 "	5.9	11.3	12.0
65 " to 150 "	4.2	12.4	9.3
150 "	3.7	16.3	10.7
Totals	100.0	5.6	100.0

* % Sink in liquid having a sp gr of 2.96

Table 2 shows that, below 4 mesh, the heavy mineral content increases as size become smaller. Nearly half of the material is plus 4 mesh and could be discarded, or set aside, with a loss of about 22% of the heavy mineral content. Nearly 50% of the heavy minerals are in 34.5% of the material between 6 and 65 mesh.

The 1/2-inch to 4-mesh material was used to test the "grinding" premise. According to Table 1, the soft minerals are also of low specific gravity so that heavy liquid separation at 2.96 specific gravity should provide a measure of grinding success. Both wet and dry grinding sequences were tried on a roughly comparable basis. For Stage 1, the feed was allowed to self-grind. For Stages 2 and 3, a light load of 1-inch porcelain balls was used approximately in the proportion of 1 lb balls to 2.5 lb feed. For the 4th Stage, this ratio was retained for the dry grinding, which had produced far less size reduction than the wet, but was altered to a 1:1 ratio for the wet grinding. This was done because the treatment in Stages 1 to 3 had not produced the expected differential grinds and it was thought desirable to

observe the effect of a heavier ball load. All trials were run in a large porcelain jar mill revolving at 60 rpm. The results are given in Table 3.

No pronounced tendency towards differential grinding was demonstrated. The plus 4-mesh remaining after Stage 4 had become rounded and "smooth" but was of essentially the same composition as the feed.

TABLE 3

Grinding Trials

Stage	Screen Fractions	Wet			Dry		
		Feed: 0.5-inch to 4-mesh (3hr, 75%S, no balls)*			Feed: 0.5-inch to 4-mesh (3hr, no balls)		
		Wt (%)	Sink (%)	Dist (%)	Wt (%)	Sink (%)	Dist (%)
1	Plus 4 Mesh	84.3	-	-	92.3	-	-
	4 to 20 "	5.3	5.2	51.6	6.1	6.1	62.3
	20 " 150 "	0.3	25.9	15.0	0.4	27.3	17.8
	Minus 150 "	10.1	1.8	33.4	1.2	10.2	19.9
		100.0	3.5	100.0	100.0	7.8	100.0
		Feed: plus 4-mesh from Stage 1 (1hr, 75%S, 1 lb balls: 2.3 lb feed)			Feed: plus 4-mesh from Stage 1 (1 hr, 1 lb balls: 2.5 lb feed)		
		Wt (%)	Sink (%)	Dist (%)	Wt (%)	Sink (%)	Dist (%)
2	Plus 4 Mesh	61.0	-	-	78.5	-	-
	4 to 20 "	13.0	5.0	42.9	9.9	5.4	58.6
	20 " 150 "	1.4	20.6	19.3	1.1	13.7	16.8
	Minus 150 "	8.9	6.4	37.8	2.8	8.0	24.6
		84.3	6.5	100.0	92.3	6.6	100.0
		Feed: plus 4-mesh from Stage 2 (1.25 hr, 75%S, 1 lb balls: 2.5 lb feed)			Feed: plus 4-mesh from Stage 2 (1.25 hr, 1 lb balls: 2.6 lb feed)		
		Wt (%)	Sink (%)	Dist (%)	Wt (%)	Sink (%)	Dist (%)
3	Plus 4 Mesh	46.6	-	-	66.5	-	-
	4 to 20 "	7.5	2.7	44.1	8.6	12.6	73.3
	20 " 150 "	0.6	20.9	28.4	0.8	17.1	10.0
	Minus 150 "	6.3	2.0	27.5	2.6	9.6	16.7
		61.0	3.2	100.0	78.5	12.3	100.0
		Feed: plus 4-mesh from Stage 3 (1 hr, 75%S, 1 lb balls: 1 lb feed)			Feed: plus 4-mesh from Stage 3 (1.75 hr, 1 lb balls: 2.5 lb feed)		
		Wt (%)	Sink (%)	Dist (%)	Wt (%)	Sink (%)	Dist (%)
4	Plus 4 Mesh	38.4	-	-	55.7	-	-
	4 to 20 "	5.1	5.0	38.5	7.6	1.6	19.9
	20 " 150 "	0.6	19.6	18.1	0.8	18.5	27.8
	Minus 150 "	2.5	11.2	43.4	2.4	13.2	52.3
		46.6	8.0	100.0	66.5	5.6	100.0

* %S = Solids. Sink (%) = Portion sinking in a liquid having sp gr of 2.96.
Dist (%) = Distribution of Sink portion.

With the exception of olivine, the grain size of constituent minerals shown in Table 1 is generally so small that their libertation would require secondary reduction to a small size. However, in diamond recovery practice, all minus 5/8-inch material is treated. Therefore trials were made of gravity concentration with all sizes of the feed.

Wet jigging was applied to all fractions between 0.5 in. and 10 mesh. Though most of the heavy mineral that sunk in heavy liquid (2.96 sp gr) reported in the hutch (heavy) product much of it went out with the overflow. The series was repeated in an air jig (dry) with similar results. Wet tabling was used for fractions below 6 mesh and air tabling for fractions down to 65 mesh. (Air tabling is not practical for material below 35 mesh because of dusting). Tabling results, as shown in Table 4, were not definitive but they were more positive than jig results. Wet tabling gave sharper separations than did dry tabling in all comparative trials.

TABLE 4

Experimental Tabling Results

Screen Fraction	Product	Wet			Dry		
		Wt(%)	Sink(%)*	Dist(%)	Wt(%)	Sink(%)*	Dist(%)
Minus 6 to Plus 10 mesh	Light	50	4.6	29	63	6.2	67
	Heavy	50	11.3	71	37	5.2	33
	Totals	100	8.0	100	100	5.8	100
10 to 20 mesh	Light	69	4.1	29	65	9.0	61
	Heavy	31	21.9	71	35	10.5	39
	Totals	100	9.7	100	100	9.5	100
20 to 35 mesh	Light	73	7.2	34	72	9.5	54
	Heavy	27	36.4	66	28	20.5	46
	Totals	100	15.1	100	100	12.6	100
35 to 65 mesh	Light	70	6.7	25	74	7.7	43
	Heavy	30	47.2	75	26	29.6	57
	Totals	100	18.8	100	100	13.4	100
65 to 150 mesh	Light	66	10.0	25			
	Heavy	34	56.6	75			
	Totals	100	26.0	100			
150 mesh	Light	87	12.0	51			
	Heavy	13	79.0	49			
	Totals	100	20.5	100			

* % Sink in 2.9 sp gr heavy liquid

Larger-scale wet tabling was tried with a Holman diagonal deck table on feed fractions between 6 and 35 mesh. Separations were not as sharp as those obtained with the laboratory-size table.

Both wet and dry magnetic-separation trials were made. Diamonds, if present, should remain with the non-magnetics. Non-magnetic material would not necessarily represent the heaviest mineral content (see Table 1). Wet separation was made with the Jones high-intensity equipment, taking several magnetic cuts at increasing field strength. Dry separation was made with Exolon equipment using from 1 to 3 passes. For purposes of comparison, results from tabling 20 to 35-mesh "heavy fraction" are shown in Table 5.

TABLE 5

Wet Vs Dry Magnetic Separation

	Wet		Dry		
	Wt(%)	Sink(%)*		Wt(%)	Sink(%)*
Mags, 0-amp	6.2	40.0	Mags	16.6	15.0
Mags, 5-amp	47.0	15.6	Midds	29.8	50.0
Mags, 10-amp	13.1	53.0	Non Mags	53.6	34.3
Mags, 25-amp	11.8	59.0			
Non Mags	21.9	20.2			
Totals	100.0	28.1		100.0	35.8

* % Sink in 2.9 sp gr heavy liquid.

Because the weight % non-magnetics was considerably less for the multi-stage wet separation, multi-stage dry runs were performed as indicated in Table 6.

TABLE 6

Multi-Stage Dry Magnetic Separation

Run No.	5		2		4		3	
Feed Size	20 to 35-mesh		20 to 35-mesh		10 to 20-mesh		10 to 20-mesh	
	Wt(%)	Sink(%)*	Wt(%)	Sink(%)	Wt(%)	Sink(%)	Wt(%)	Sink(%)
Mags	66.0		58.7		57.2		47.3	
(Midds)								
Non-Mags	14.7		15.7		35.3		35.8	
Mags	1.2		3.8		2.0		3.2	
(Midds)	16.4				4.1			
Non-Mags	1.7		5.7		1.4		7.0	
	100.0				100.0			
Mags			1.1				1.6	
Midds			13.3				3.8	
Non-Mags			1.7				1.3	
			100.0				100.0	
Combined N-Mags	16.4	28.6	23.1	14.1	36.7	28.5	43.1	16.3

* % Sink in 2.96 sp gr liquid.

Less non-magnetics resulted from 20 to 35-mesh than from 10 to 20-mesh feed. Less non-magnetic was obtained from 2 than from 3 cycles. At least 2 cycles appeared necessary because a single cycle gave a mixed middling. Non-magnetics do not necessarily represent a heavy mineral concentration. Therefore, to obtain the maximum concentration of potential diamond-bearing material, a combination of magnetic separation and tabling seemed necessary.

The combination gravity-magnetic system was tried on three feed sizes, 6 to 10-, 10 to 20-, and 35 to 65-mesh. In each case, heavy concentrate was first removed by tabling. Table heavies were subjected to multi-stage magnetic separation, and the non-magnetic material was separated into sink and float products by heavy liquid (3.3 sp gr); see Table 7. Report No. MP-MIN-1548, by Ore Mineralogy Section, indicates

that the principal constituents of the sink products are barite, olivine, pyrite, and celestite, with minor garnet, pyroxene and tennantite.

It is interesting to observe (from Table 7) that table concentration and magnetic separation became sharper as feed size became smaller and that the final heavy-liquid fraction became greater in the same order.

TABLE 7

Gravity and Magnetic Concentration

Feed Size	6 to 10-mesh	10 to 20-mesh	35 to 65-mesh
Table type	Wilfley	Deister	Deister
% Heavy	32.5	27.7	13.9
Exolon N. Mags(%)	3.27	1.77	
Jones N. Mags(%)		0.79	0.45
Heavy liquid Sink(%)	0.017	0.027	0.21
Concentration ratio	6123:1	4822:1	512:1

BULK TREATMENT

Phase 1

The bulk treatment for six drums of sample was based on the results of experimental work done on the first drum of sample. The nature and results of the Bulk Treatment-Phase I are presented in Table 8.

TABLE 8

Bulk Concentration - Phase 1

Drum No.	2	3	4	5	6	7
Wt Contents (lb)	707.5	801.0	740.5	696.5	794.5	738.5
Wt 20 to 35 mesh (lb)	36.0	54.0	44.0	32.0	46.5	31.5
Exolon (3 cycles): Wt Non-Mags plus Midds (lb)	12.9					
Exlon (2 cycles): Wt Non-Mags plus Midds (lb)		17.9	11.7	12.7	13.0	9.6
Wt Deister heavy (lb)	3.14	5.44	3.94	2.54	3.71	2.23
Exolon (2 cycles): Wt Non-Mags (lb)*	0.23	0.72	0.17	0.24	0.17	**
Concentration	36.0:0.23	54.0:0.72	44.0:0.17	32.0:0.24	46.5:0.17	31.5:2.23
Conc Ratio	157:1	75:1	259:1	133:1	273:1	14:1

* Samples sent to G. S. C. for examination.
** Special processing by G. S. C., see Table 9.

Phase 1 products sent to the G. S. C. were subjected to further concentration and final examination by D. E. Lawrence. The concentration consisted of Franz magnetic separation, treatment of the Franz non-magnetics by heavy liquid, sp gr 3.3, and superpanner concentration of the heavy-liquid sink portion. The light fraction from superpanning was examined under the microscope. No diamonds were found. For Drum No. 7, (Deister table heavy) the G. S. C. used a more elaborate approach that consisted of separation in 2.8 sp gr heavy liquid followed by acid attack on the heavy portion in an effort to dissolve olivine. The undissolved material was then subjected to the Franz magnetic separator, 3.3 sp gr heavy liquid, and superpanner sequence. The results of this concentration are shown in Table 9.

TABLE 9

Concentration by G. S. C. - Phase 1

Drum No.	2	3	4	5	6	7
Wt of sample (lb)	0.23	0.72	0.17	0.24	0.17	2.23
Wt 2.8 sp gr heavy (lb)						1.25
Wt after acid attack (lb)						0.67
Wt Franz non-mags(lb)	0.20	0.20	0.14	0.22	0.12	0.04
Wt 3.3 sp gr heavy (lb)	0.04	0.06	0.02	0.05	0.06	0.03
Wt superpanner light(lb)	0.024	0.004	0.005	0.001	0.009	0.001
Total Concentration	36.0:0.024	54.0:0.004	44.0:0.005	32.0:0.001	46.5:0.009	31.5:0.001
Concentration ratio	1500:1	13500:1	8800:1	32000:1	5167:1	31500:1

Phase 2

Because the processing in Phase 1 demonstrated that magnetic separation could be employed to effect the necessary concentration, the tabling was eliminated for Phase 2. Therefore, Phase 2 consisted of stepwise jaw crusher reduction of six drums of sample to pass one-half inch, and concentration by magnetic separation of the 20 to 35-mesh fraction. Phase 2 results are given in Table 10. The final non-magnetic portions were sent to the G. S. C. for evaluation. Arrangements were made by G. S. C. to have the the final concentrate examined under soft X-ray by the Non-Destructive Testing Section of the Physical Metallurgy Division. Because only a gram or two of material could be examined with this facility, the smallest possible final concentrate had to be submitted.

TABLE 10

Bulk Concentration - Phase 2

Drum	Wt of 20 to 35-mesh fraction (lb)	Wt final non-mags		Concentration	Concentration ratio
		lb	g		
8	37.6	0.06	27	37.6:0.06	627:1
9	40.7	0.10	45	40.7:0.10	407:1
10	39.1	0.06	28	39.1:0.06	652:1
11	44.3	0.06	26	44.3:0.06	738:1
12	32.0	0.11	50	32.0:0.11	291:1
13	36.6	0.11	48	36.6:0.11	333:1

Phase 3

This involved the comminution by stepwise jaw crushing to pass a half-inch screen, and magnetic concentration of the 20 to 35-mesh fractions for the remaining nine drums of sample. Again the final non-magnetic portions were sent to G. S. C. and then to Physical Metallurgy for soft X-ray examination. For Phase 3 concentration, 7 cycles of magnetic separation were employed for each drum using Exólon and Dings equipment. The results are shown in Table 11.

TABLE 11

Bulk Concentration - Phase 3

Drum	Wt of 20 to 35-mesh fraction (lb)	Wt final non-mags		Concentration	Concentration ratio
		lb	g		
14	35.5	0.06	29	35.5:0.06	590:1
15	53.5	0.06	28	53.5:0.06	892:1
16	50.0	0.07	30	50.0:0.07	715:1
17	41.7	0.08	35	41.7:0.08	521:1
18	37.5	0.06	28	37.5:0.06	625:1
19	46.5	0.10	46	46.5:0.10	465:1
20	37.2	0.07	34	37.2:0.07	532:1
21	33.0	0.11	49	33.0:0.11	300:1
22	39.5	0.09	39	39.5:0.09	438:1

DISCUSSION

No diamonds were detected, by either mineralogical or X-ray examination in any of the concentrates made in this investigation. Though only the 20 to 35-mesh fraction of the original sample was processed, it was decided, on the basis of negative results obtained, that the amount of work required to process the remaining bulk was not justified. The investigators spent some 1560 man-hours on this project exclusive of the preparation of final report. To similarly process the remaining bulk would at least triple the amount of time already devoted to the project.

Considering that diamonds occur in South Africa in the proportion of 1 to 21,000,000 parts, there may be some question as to whether the current assessment method was adequate. From more than eight tons of sample, concentrate from roughly 1000 lb was examined very intensively for diamonds. The Mineral Processing Division is currently not well equipped either to process such large bulks or to assess the concentrates therefrom rapidly enough to meet the needs of diamond prospecting. If prospecting service is to be undertaken the necessary man-power and facilities would have to be acquired.

CONCLUSION

Mineralogical and X-ray assessment failed to indicate the presence of diamonds in concentrates obtained by various beneficiation methods from a bulk sample of kimberlite.

REFERENCES

(1) Lee, H.A., and Lawrence, D.E., "A New Occurrence of Kimberlite in Gauthier Township, Ontario", G.S.C. Paper 68-22, 1968.

(2) Bartley, C.M., "Field Work Sampling of Kimberlite Dike at Upper Canada Canada Mines, Ltd., Dobie, Ontario, February 5-7 1969", Mineral Processing Division, Mines Branch, MPI 69-18, 1969.

RAW:FHH/ec