FOURIER TRANSFORM INFRA RED SPECTROSCOPY OF THE LARGE DIAMONDS RECOVERED FROM THE STAR KIMBERLITE AT FORT À LA CORNE, SASKATCHEWAN

by

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May 25, 2010

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REPORT TITLE	**Fourier Transform Infra Red Spectroscopy of the Large Diamonds Recovered from the Star Kimberlite at Fort à la Corne, Saskatchewan**
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PUBLISH DATE	**May 25, 2010**
REPORT NUMBER	**SG-Report-006**

SUMMARY

The most common diamonds (over 95 percent) in nature are Type I diamonds. Type I diamonds are so named due to the presence of nitrogen in their crystal structure. However, the majority of large diamonds, greater than 300 carats, are Type II diamonds.

Shore Gold Inc. has recently conducted a study of the occurrence of Type II diamonds from the 5 kimberlite lithologies at the Star Kimberlite in the Fort à la Corne area. This information is important for predicting the occurrence of large, and potentially high value, diamonds in the Star Kimberlite.

The Fourier Transform Infra Red (FTIR) results obtained in this study showed that Type IIa diamonds were found in three of the kimberlite lithologies at Star, of which the most abundant kimberlite lithology is the Early Joli Fou (EJF) which contained 24.57 percent Type IIa diamonds above 2.7 carats. The overall Type IIa diamond content for the Star Kimberlite was 26.15 percent for diamonds greater than 2.7 carats.

ACRONYMS AND ABBREVIATION

cpht	Carats per hundred tonnes
EJF	Early Joli Fou Kimberlite
FTIR	Fourier Transform Infra Red
LJF	Late Joli Fou Kimberlite
MJF	Mid Joli Fou Kimberlite
Star	Star Diamond Kimberlite deposit (515000E, 5897000N)
Type I	Diamonds containing nitrogen in their crystal structure
Type IIa	Diamonds with no detectable nitrogen in their crystal structure
Type IIb	Diamonds with no detectable nitrogen in their crystal structure but do contain boron making them semi conducting and sometimes blue in colour.

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1. INTRODUCTION

The most common diamonds (over 95%) in nature are Type I diamonds [Ref 1]. Type I diamonds are so named due to the presence of nitrogen in their crystal structure [Ref 2]. However, the majority of the large diamonds, greater than 300 carats, are Type II diamonds. Type II diamonds have no detectable nitrogen in their crystal structure. Type II diamonds are split into two categories: Type IIa which contain no detectable nitrogen and Type IIb which contain no detectable nitrogen but do contain boron making them semi conducting and sometimes blue in colour. The top 10 largest known rough diamonds in the world (as researched by Ray Ferraris, Letšeng Mine) are:

1. The Cullinan (3106 carats)
2. The Excelsior (995 carats)
3. The Star of Sierra Leone (969 carats)
4. The Incomparable (890 carats)
5. The Orlov (788 carats)
6. The Millennium Star (777 carats)
7. The Woyie River (770 carats)
8. The Golden Jubilee (755 carats)
9. President Vargas (727 carats)
10. The Jonker (726 carats)

Of these top 10 diamonds, as far as the author is aware, all are Type II[♣]. The largest Type I diamond is the Kimberley Octahedron which weighs 616 carats and is the 14th largest diamond ever recovered (as researched by Ray Ferraris, Letšeng Mine).

Type II diamonds are clear-white, blue or brown in colour. The Cullinan and Excelsior diamonds are both clear coloured as seen in Figure 1 while the Incomparable diamond, as seen in Figure 1, is an example of the brown colouring that Type II diamonds are commonly known for. Type I diamonds have a range of colours from clear white to black as well as different intensities of yellow, green, orange and red.

A distinctive characteristic of Type II diamonds is their absence of a crystallographic shape. Type II diamonds have an amorphous appearance as seen in Figure 1. In contrast, Type I diamonds are usually associated with crystal shaped such as an octahedron, dodecahedron, macle or cube. Figure 2 is an example of two octahedral, clear, Type Ia diamonds.

[♣] The large diamonds from Cullinan mine, Elandfontein and Jagersfontein mine are Type II diamonds. The shapes and colours of the remaining diamonds fit the profile of Type II diamonds.

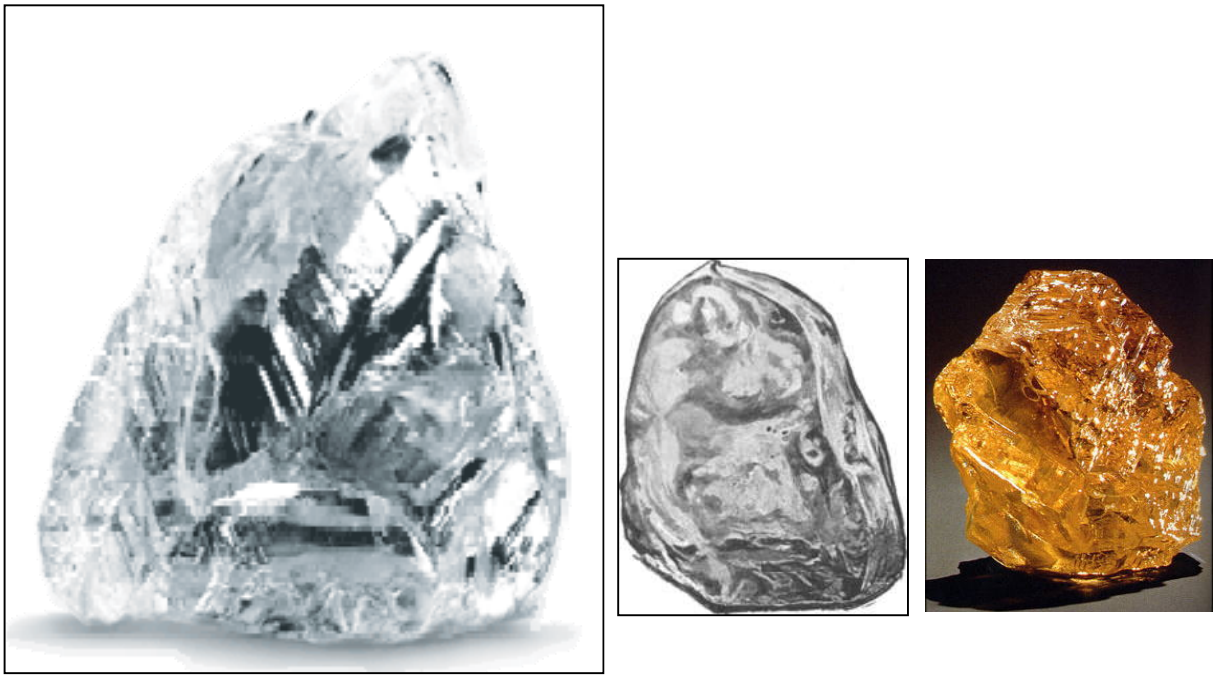

Figure 1: Three famous large diamonds from left to right, The Cullinan, The Excelsior and The Incomparable.

Figure 2: Two Type 1a, clear, octahedral diamonds from the Star Kimberlite.

The two diamond mines in the world that presently produce the largest diamonds are the Cullinan Mine in South Africa and Letšeng Mine in Lesotho. The largest diamonds from both these mines being classed as Type II. At present the diamond top size at Cullinan Mine is 32 mm as determined by the crusher spacing and the diamond top size at Letšeng is 45 mm [Ref 3].

In the Fort à la Corne area there are a number of diamond deposits, the most extensively explored being the Star Kimberlite. Advanced exploration and reserve estimation has proven that the Star Kimberlite will be a viable source of diamonds and has produced a number of high interest diamonds from exploration thus far. The presence of a significant population of Type IIa diamonds from exploration indicates a high probability for the occurrence of large, high value, diamonds during mining. Furthermore, the occurrence of large diamonds has the potential to increase the present dollar price per carat.

From the geology of the Star Kimberlite, it is known that there have been 5 different volcanic events that have each transported diamonds to the surface. Each eruptive event carries a unique diamond population resulting in a unique grade, diamond size frequency distribution and proportion of Type II diamonds. The 5 kimberlite lithologies present at Star in order from the oldest to youngest are [Ref 4]:

- The Cantuar Kimberlite
- The Pense Kimberlite
- The Early Joli Fou Kimberlite
- The Mid Joli Fou Kimberlite
- The Late Joli Fou Kimberlite

The diamond grade and diamond size distribution for each kimberlite lithology at the Star Kimberlite is known. This report documents the occurrence of Type IIa diamonds in the larger (>2.7 carats) diamond size fractions at the Star Kimberlite in Fort à la Corne.

2. OBJECTIVE

The objective of this investigation is to obtain information on the percentage of Type IIa[♦] diamonds occurring in each kimberlite lithology in the Star Kimberlite at Fort à la Corne.

[♦] FTIR spectroscopy was conducted on all the large (>2.7 cts) diamonds and no Type IIb diamonds were identified.

3. THE DIAMONDS

A total of 260 diamonds with a mass greater than 2.7 carats, were used in the study as listed in Table 1. These diamonds were all recovered from the Star Kimberlite during the underground bulk sampling phase of the evaluation.

Table 1: The 260 diamonds greater than 2.7 carats recovered during the bulk sampling phase on the Star Kimberlite

Kimberlite Lithology	Number of Diamonds
Cantuar	59
Pense	24
Early Joli Fou	175
Mid Joli Fou	2
Late Joli Fou	0

The largest Star diamond was recovered from the Cantuar kimberlite. This diamond weighs 49.1 carats and is a brownish, Type IIa stone with a number of flaws. On examining this diamond, it is found to be broken and forms part of a larger stone (Read, G. pers comm.). Figure 3 is a photograph of this diamond (# 016755) along with two other brownish, Type IIa diamonds from the Cantuar kimberlite. Additional photographs of the diamonds appear in the Appendix.

Figure 3: The 49.1 carat, brown, Type IIa diamond and two smaller brown, Type IIa diamonds recovered from the Cantuar Kimberlite at the Star Kimberlite.

4. DIAMOND TYPING

Diamonds are categorized by the presence of nitrogen in their crystal structure. Type I diamonds have nitrogen and are the most common diamonds, whereas Type II diamonds (Type IIa and Type IIb) have no detectable nitrogen in their crystal structure. Type I diamonds are further classified according to the aggregation state of the nitrogen in the crystal structure. Type Ia diamonds are natural diamonds with aggregated nitrogen. Type Ib diamonds are synthetic diamonds with un-aggregated nitrogen.

Diamond Typing is carried out using Fourier Transform Infra Red (FTIR) spectroscopy. The carbon absorption band for diamond occurs between the wavenumbers 2660 cm^{-1} to 1330 cm^{-1} and the nitrogen absorption band occurs between the wavenumbers 1300 cm^{-1} to 1100 cm^{-1}. The diamond Type is determined by the nitrogen absorption band on the FTIR spectrum. Figure 4 shows a typical FTIR spectrum for a Type IIa diamond from the Star Kimberlite. The red column, highlights the area where nitrogen absorption would occur if there was any. Figure 5 shows a typical FTIR spectrum for a Type Ia diamond from the Star Kimberlite. The red column highlights the nitrogen absorption band and the two peaks in this band are associated with the two aggregation states of the nitrogen in the diamond [Ref 2].

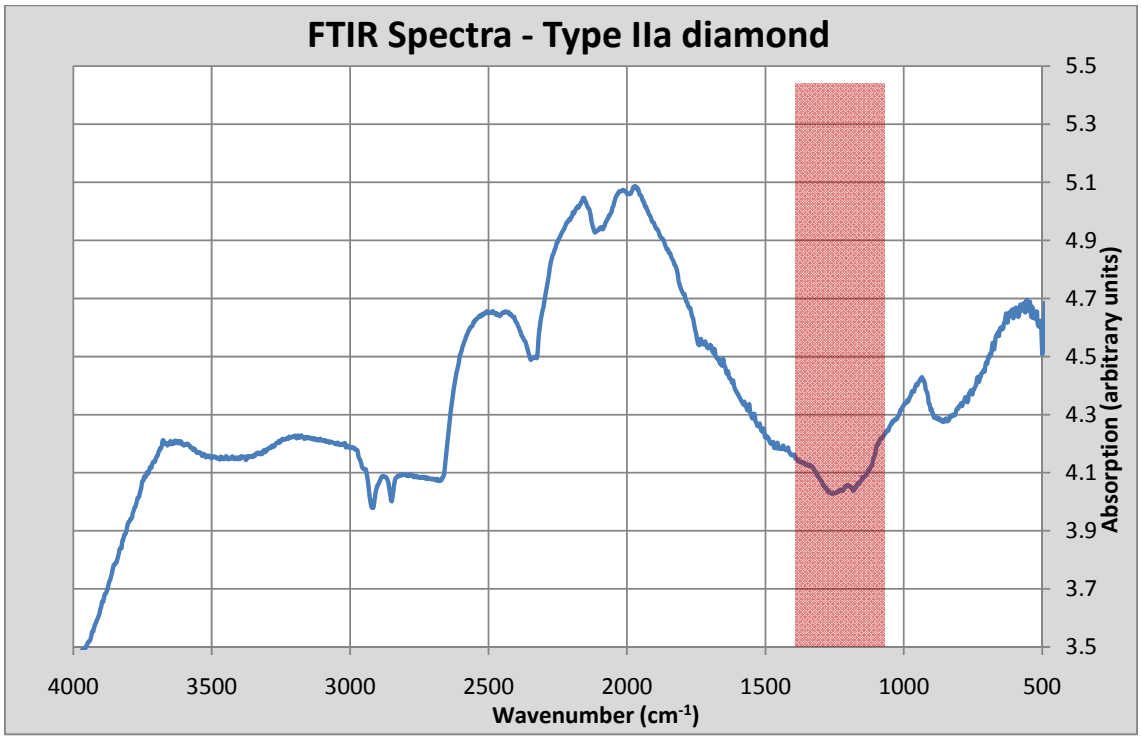

Figure 4: The FTIR spectrum of a Type IIa diamond from the Star Kimberlite.

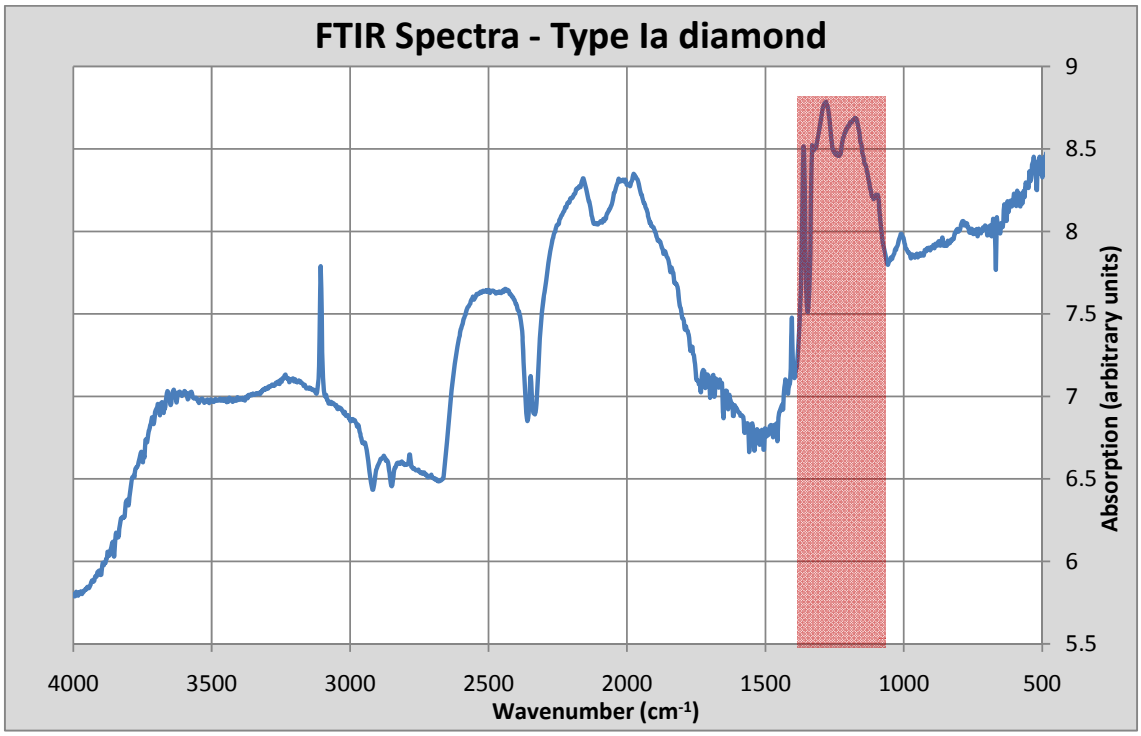

Figure 5: The FTIR spectra of a Type Ia diamond from the Star Kimberlite.

5. EXPERIMENTAL METHOD

The FTIR measurements were carried out on a Bio-Rad Digilab FTS-40 IR spectrometer at the University of Saskatchewan. This spectrometer irradiates a relatively large area of the diamond with Infra Red light and then collects the scattered and reflected light in a parabolic lens which then focuses the signal to the detector (Deuterated Triglycine Sulfate Pryoelectric Bolometer).

Initially a background spectrum was recorded in order to remove the effects of air, moisture and the internal configuration of the spectrometer. Each diamond was individually mounted into a sample holder and placed inside the FTIR unit. The FTIR unit was set to scan between the wavenumbers 500 cm^{-1} to 4000 cm^{-1} and each diamond was scanned 128 times. The algorithm inside the spectrometer then subtracted the background from the response signal.

6. RESULTS

The EJF is the most dominant kimberlite lithology at Star and accounts for approximately 59 percent of the entire deposit. During the exploration study, a total of 175 large diamonds (>2.7 carats) were recovered from this kimberlite. The FTIR analyses of these diamonds are documented in Table 2. Of the 175 diamonds tested, 43 were classified as Type IIa. Of the 43 Type IIa diamonds, 11 were brownish in colour while the remaining 32 diamonds were clear to grey depending on the number of inclusions present.

Table 2: The FTIR results for the +2.7 carat diamonds recovered from the EJF kimberlite.

Size	Number			Percentage
(carats)	Type Ia	Type IIa	Total	Type IIa
> 2.7 ≤ 3	18	4	22	18.18
> 3 ≤ 4	46	13	59	22.03
> 4 ≤ 5	27	9	36	25.00
> 5 ≤ 6	13	6	19	31.58
> 6 ≤ 7	11	1	12	8.33
> 7 ≤ 8	3	1	4	25.00
> 8 ≤ 9	3	2	5	40.00
> 9 ≤ 10	2	0	2	0.00
> 10	9	7	16	43.75
TOTALS	**132**	**43**	**175**	**24.57**

The Pense kimberlite accounts for approximately 10 percent of the Star Kimberlite. The FTIR analysis of the diamonds recovered from the Pense kimberlite are documented in Table 3. Of the 24 diamonds recovered, eight were classified as Type IIa. Of the 8 Type IIa diamonds, only 1 was brownish in colour while 6 of the remaining 7 diamonds were clear. The seventh Type IIa diamond was slightly grey due to inclusions.

Table 3: The FTIR results for the +2.7 carat diamonds recovered from the Pense kimberlite.

Size	Number			Percentage
(carats)	Type Ia	Type IIa	Total	Type IIa
> 2.7 ≤ 3	1	0	1	0.00
> 3 ≤ 4	5	4	9	44.44
> 4 ≤ 5	6	2	8	25.00
> 5 ≤ 6	0	0	0	NA
> 6 ≤ 7	1	1	2	50.00
> 7 ≤ 8	0	1	1	100.00
> 8 ≤ 9	0	0	0	NA
> 9 ≤ 10	1	0	1	0.00
> 10	2	0	2	0.00
TOTALS	**16**	**8**	**24**	**33.33**

The Cantuar kimberlite accounts for approximately 8 percent of the Star Kimberlite and is thought to be the first volcanic event that occurred at Star [Ref 4]. This kimberlite body is situated at the base of the deposit. The FTIR analysis of the diamonds recovered from the Cantuar kimberlite are documented in Table 4. Of the 59 diamonds recovered, 17 were classified as Type IIa. Of the 17 Type IIa diamonds, 3 were brownish in colour. The large, 49.1 carat brown diamond was recovered from this kimberlite. The two smaller diamonds possibly represent fragments of a larger stone weighing in excess of 12.7 carats since their FTIR spectra were very similar. Of the remaining 14 Type IIa diamonds, 11 were clear with minor inclusions while the last 3 were light grey due to inclusions.

Table 4: The FTIR results for the +2.7 carat diamonds recovered from the Cantuar kimberlite.

Size	**Number**			**Percentage**
(carats)	**Type Ia**	**Type IIa**	**Total**	**Type IIa**
> 2.7 ≤ 3	3	1	4	25.00
> 3 ≤ 4	15	3	18	16.67
> 4 ≤ 5	14	4	18	22.22
> 5 ≤ 6	3	3	6	50.00
> 6 ≤ 7	0	0	0	NA
> 7 ≤ 8	1	3	4	75.00
> 8 ≤ 9	2	2	4	50.00
> 9 ≤ 10	2	0	2	0.00
> 10	2	1	3	33.33
TOTALS	**42**	**17**	**59**	**28.81**

The Mid Joli Fou (MJF) and Late Joli Fou (LJF) account for approximately 16 percent of the Star Kimberlite. Although the MJF kimberlite produced 2 diamonds greater than 2.7 carats in the bulk sampling phase, neither diamond was a Type IIa or a Type IIb. In the bulk sampling phase, only a small tonnage of the LJF kimberlite was sampled and no diamonds above 2.7 carats were recovered.

The total FTIR analysis for the Star Kimberlite is given in Table 5 and this combines all the Type IIa results from the 5 kimberlites.

Table 5: The FTIR results for the +2.7 carat diamonds recovered from the Star Kimberlite.

Size	Number			Percentage
(carats)	Type Ia	Type IIa	Total	Type IIa
> 2.7 ≤ 3	23	5	28	17.86
> 3 ≤ 4	66	20	86	23.26
> 4 ≤ 5	47	15	62	24.19
> 5 ≤ 6	17	9	26	34.62
> 6 ≤ 7	12	2	14	14.29
> 7 ≤ 8	4	5	9	55.56
> 8 ≤ 9	5	4	9	44.44
> 9 ≤ 10	5	0	5	0.00
> 10	13	8	21	38.10
TOTALS	**192**	**68**	**260**	**26.15**

The cumulative FTIR results for the large, Type IIa diamonds from the Star Kimberlite and Letšeng mine [Ref 3] were calculated as seen in Table 6. The cumulative percentage of Type IIa diamonds for the Star Kimberlite and Letšeng mine were then compared as shown in Figure 6.

Table 6: The percentage Type IIa diamonds from Letšeng mine and the Star Kimberlite.

Size	Letseng			Star		
(carats)	Type IIa	Total	Percentage Type IIa	Type IIa	Total	Percentage Type IIa
> 2.7	87	298	29.19	68	260	26.15
> 3	74	244	30.33	63	232	27.16
> 4	52	153	33.99	43	146	29.45
> 5	40	97	41.24	28	84	33.33
> 6	29	66	43.94	19	58	32.76
> 7	26	52	50.00	17	44	38.64
> 8	18	32	56.25	12	35	34.29
> 9	15	26	57.69	8	26	30.77
> 10	13	19	68.42	8	21	38.10

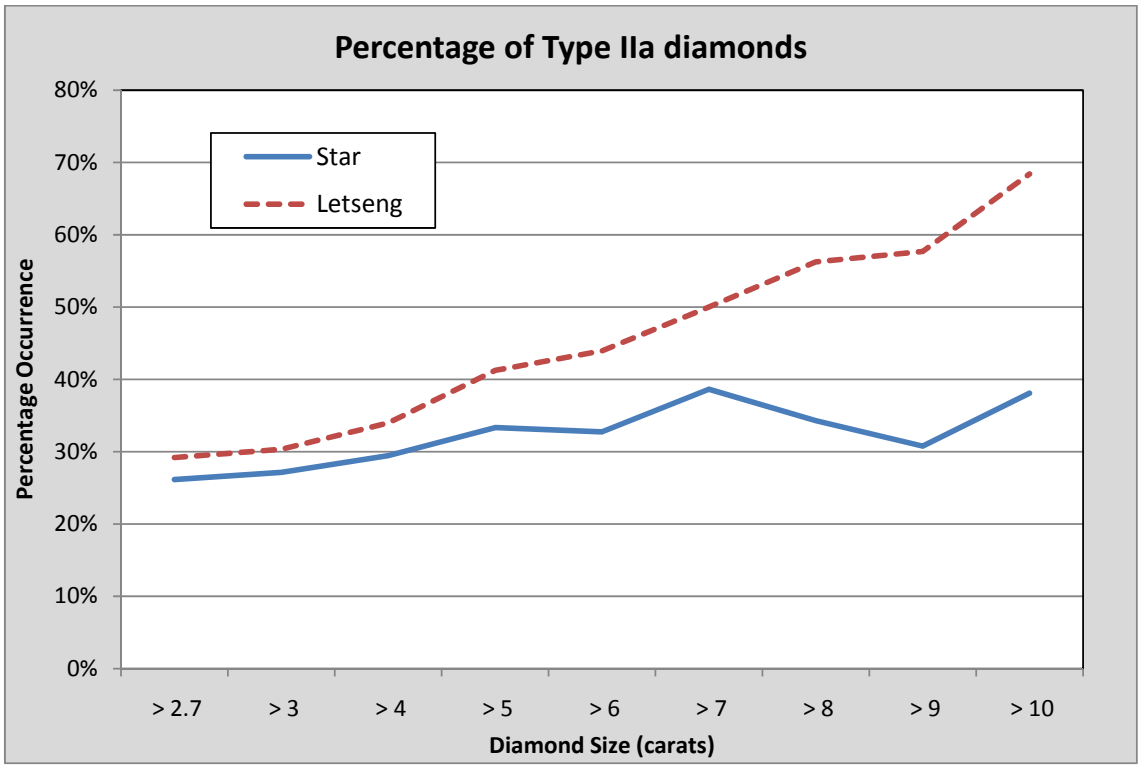

Figure 6: A comparative study of the percentage of Type IIa diamonds greater than 2.7carats for the Star Kimberlite and Letšeng diamond mine.

7. DISCUSSION

Although Type Ia diamonds are the most common diamonds in nature, Figure 6 shows explicitly that the abundance of Type II diamonds increases with increasing diamond size. The presence of Type II diamonds increases the probability of large diamonds occurring in the kimberlite.

In this FTIR study of the larger diamonds from the Star Kimberlite, a significant number of Type IIa diamonds were identified in all the major kimberlite lithologies. Furthermore, it is estimated that the broken 49.1 carat diamond may have been part of a far larger diamond, possibly in excess of 100 carats.

Large diamonds fetch significantly higher prices than small diamonds. Small diamonds (diamonds less than 10.8 carats) are sold in parcels with a dollar price per carat determined for the entire parcel. Diamonds greater than 10.8 carats are usually sold individually, by tender. In recent years both Cullinan mine and Letšeng mine have profited from the sale of large diamonds. The more famous diamonds being:

Cullinan Mine

Year	Carats	Value US$ (million)	Name
2008	26.58	9.49	Star of Josephine
2009	507	35.3	Cullinan Heritage
2009	168	6.28	Special white diamond

Letšeng Mine

Year	Carats	Value US$ (million)	Name
2006	603	12.4	Lesotho Promise
2007	493	10.4	Letšeng Legacy
2008	478	18.4	Light of Letšeng

Of interest is the fact that Letšeng mine has a very low grade for a diamond mine. The total resource grade for Letšeng is 1.7 carats per hundred tonnes (cpht) as reported in the Gem Diamonds Annual Report for 2009 [Ref 5], but due to the presence of large Type IIa diamonds fetching very high prices, the average dollar price per tonne of ore is economic at $29.8 dollars per tonne. Figure 6 shows a comparative plot for the Star Kimberlite against Letšeng mine and, although Star plots lower on the graph, the grade of the Star Kimberlite is at least 7 times higher and thus further increases the probability of the occurrence of large diamonds positively impacting the dollar value per tonne of ore.

8. CONCLUSION

The results of the FTIR analysis show that Type IIa diamonds were found in three of the five kimberlite lithologies at Star. The most abundant kimberlite lithology being the EJF which contained 24.57 percent Type IIa diamonds above 2.7 carats. The overall Type IIa diamond content for the Star Kimberlite was 26.15 percent for diamonds greater than 2.7 carats.

9. ACKNOWLDGEMENTS

A thank-you to Prof. R. Sammynaiken at the University of Saskatchewan for allowing Shore Gold Inc. to use the facilities for this research. The author would also like to thank Jason Maley for conducting the many tedious FTIR measurements.

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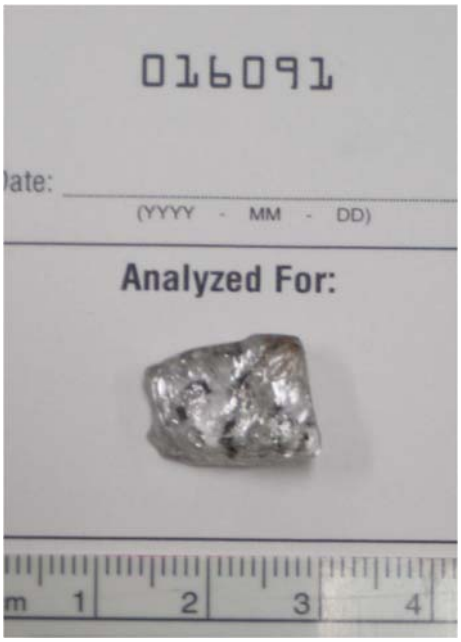
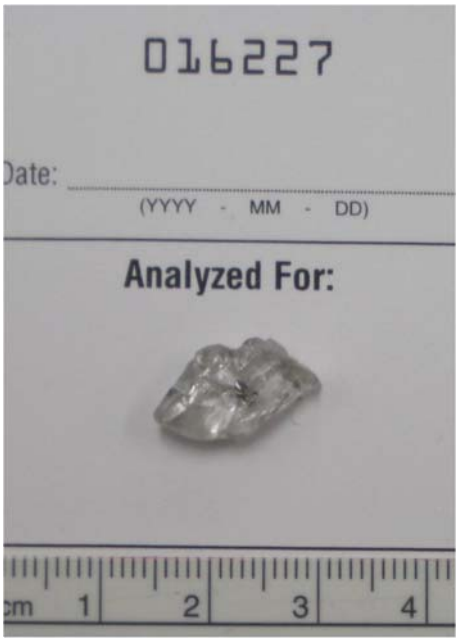
APPENDIX

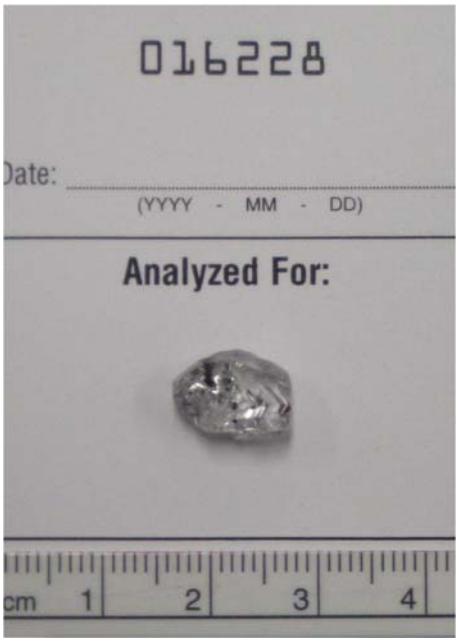
Photographs of the Large diamonds Recovered from the Star Kimberlite

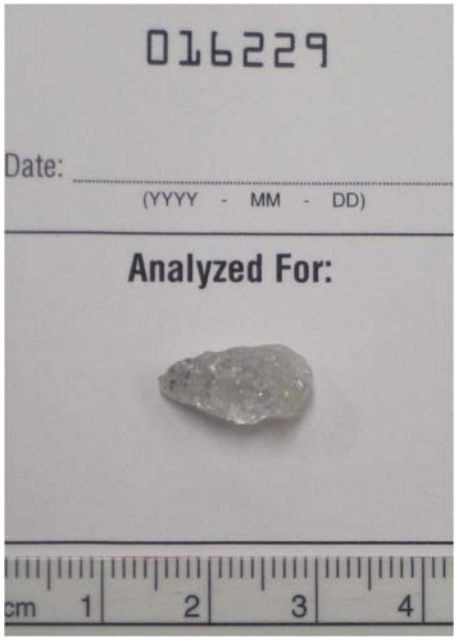
Early Joli Fou

Clear-white, Type IIa diamonds

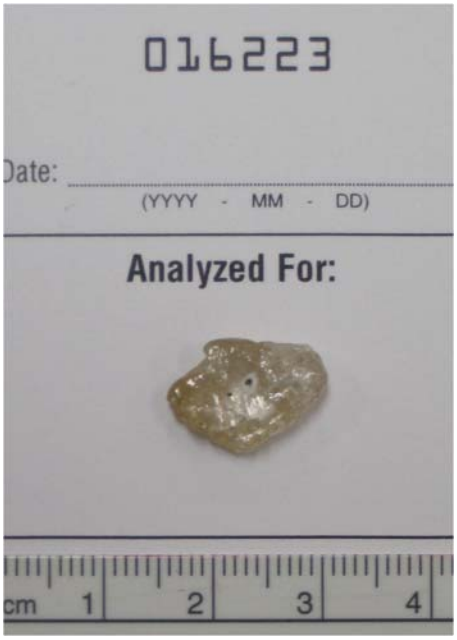


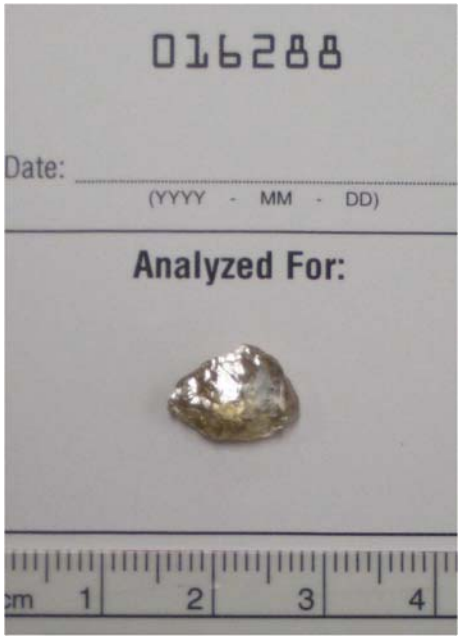






EJF - Brownish, Type IIa diamonds

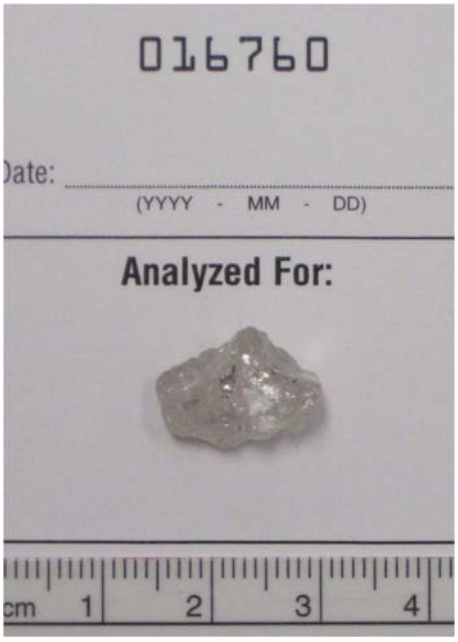


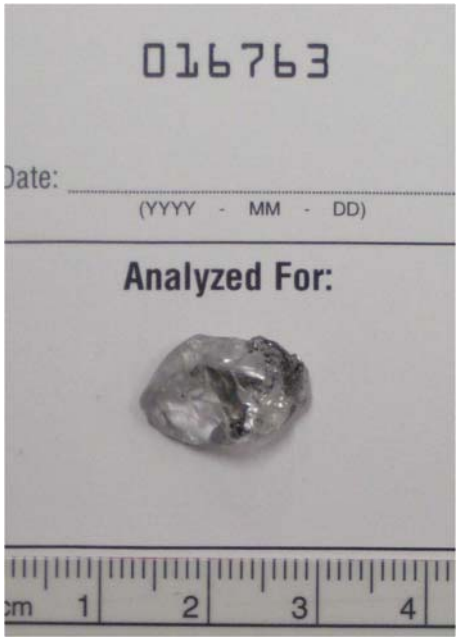


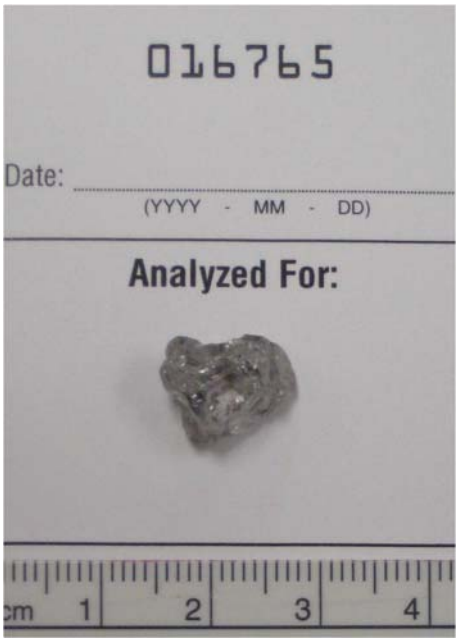
Cantuar

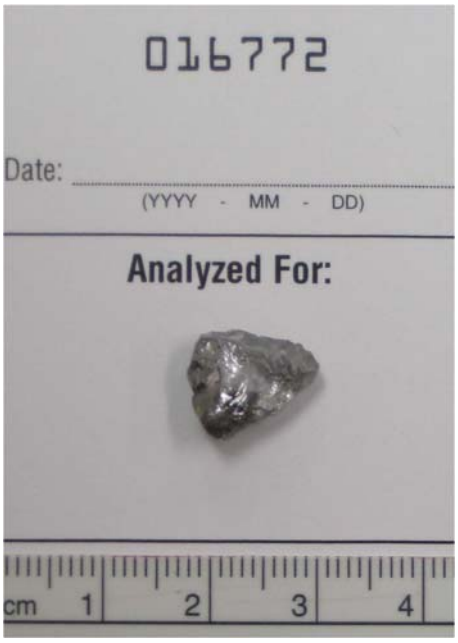
The three brown diamonds recovered from Cantuar are given in Figure 3 in the text.

Cantuar - Clear-white, Type IIa diamonds



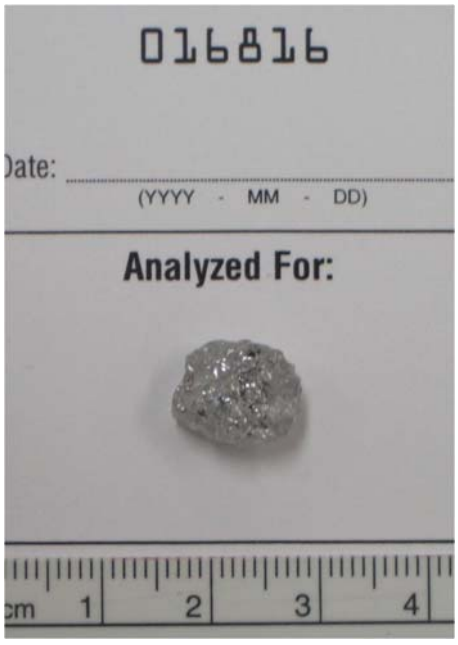


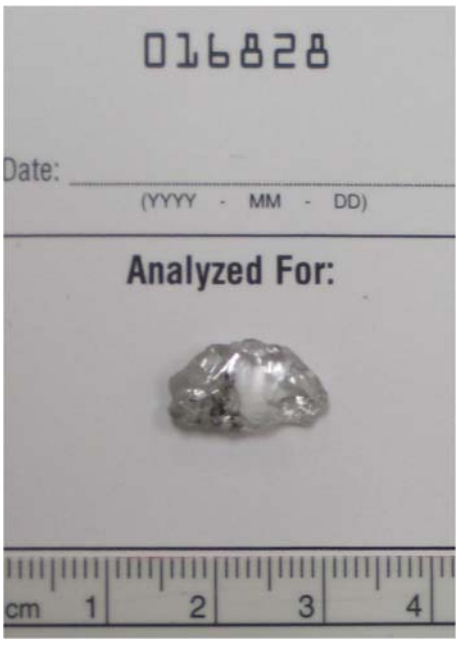


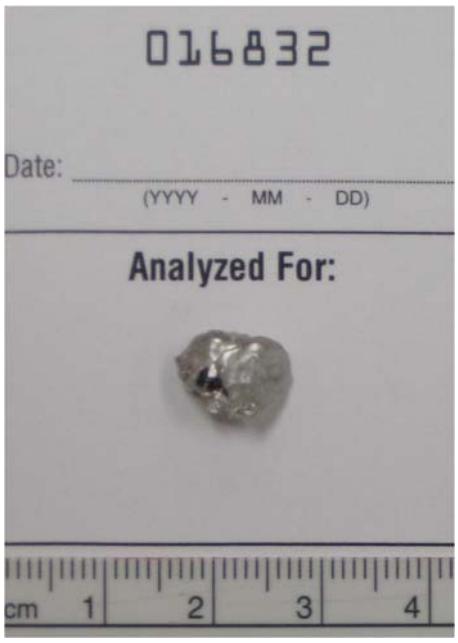


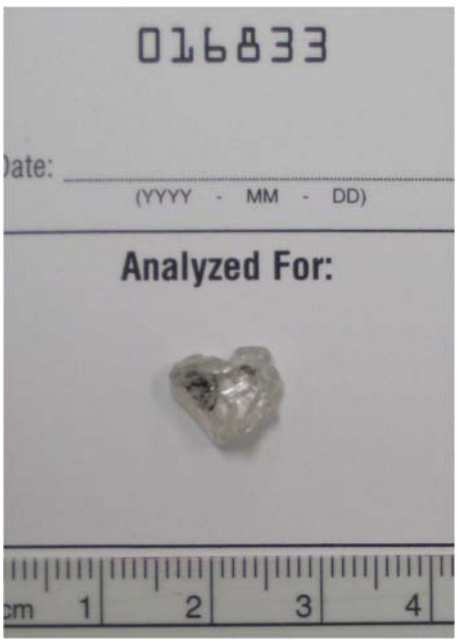
Pense

Clear-white, Type IIa diamonds









Pense - Brownish, Type IIa diamonds