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On the unusual characteristics of the diamonds from Letšeng-la-Terae kimberlites, Lesotho

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ABSTRACT

The Letšeng-la-Terae kimberlites are situated 3100 m above sea level in the Maloti Mountains of Lesotho, southern Africa. The principal economic bodies are two Late Cretaceous, low grade, 1–3.5 carats/hundred ton (cpht), kimberlite pipes that host high-value diamonds realising US$ 2000–2500/carat ($/ct) in 2008 terms. Locally, the larger kimberlite body is referred to as the Main Pipe (17.2 ha) and the smaller one is called the Satellite Pipe (5.2 ha). These pipes, and their associated eluvial and proximal alluvial deposits, are renowned for yielding large, "D" colour, gem quality diamonds, including +100 carat (ct) stones. Earlier artisanal effort (1959–1977) and formal mining (1977–1982) produced 335,000 carats (cts), including the 601 ct *Lesotho Brown* in 1968. In 2003, Letšeng Diamonds Limited re-commenced mining operations and had produced 265,000 cts by the end of July 2008, including 24 +100 ct diamonds, the largest of which was the 603 ct *Lesotho Promise*.
We report here on the unusual characteristics of the Letšeng diamond population that include:

i. 75% gem quality that is more commonly associated with alluvial diamond deposits,
ii. large average stone size of ca. 1 carat/stone (ct/stn) that is also more typical of certain alluvial diamond placers,
iii. high-yielding, rounded to flattened irregular, resorbed dodecahedral shapes (Main Pipe 67% and Satellite Pipe 87%) with subordinate dodecahedral macle (Main Pipe 32% and Satellite Pipe 12%) and broken (ca. 1%) forms. In both pipes the octahedral component is virtually absent (<0.1%),
iv. economically favourable colour mix (ca. 33% white colour diamonds in both pipes),
v. abundance of nitrogen-free, "D" colour, Type IIa diamonds that dominate the internationally recognised "special" stone size fraction which covers all diamonds larger than +10.8 cts (Main Pipe 32% and Satellite Pipe 51%).

During 2008, these larger, "special" diamonds commanded prices in excess of US$ 15,000/ct, contributing ca. 75% of the revenue generated by the Letšeng mine. Furthermore, of the 24 +100 ct diamonds recovered between November 2003 and July 2008, 18 (75%) were Type IIa "D" colour diamonds that also fetched prices mostly in excess of US$ 25,000/ct. Therefore the Type IIa diamonds boost significantly the revenue per unit measure (in this case, the US$/ton) of the Letšeng-la-Terae pipes, making these low grade kimberlites economic to mine.

1. Introduction

The Letšeng-la-Terae kimberlites, discovered in December 1957, are situated some 3100 m above sea level in the Maloti Mountains of the Kingdom of Lesotho in southern Africa (Bloomer and Nixon, 1973; Fig. 1). These two pipes, and their associated pre- and post-emplacement dykes, are part of the Late Cretaceous (ca. 90 Ma) Group 1 kimberlite occurrences comprising the Lesotho Kimberlite Province that is affiliated to the Kimberley and Gordonia Kimberlite Provinces of South Africa (Skinner and Truswell, 2006). At Letšeng-la-Terae, the kimberlites intruded close to the eastern edge of the Kaapvaal Craton and are currently preserved in Jurassic-age (ca. 183 Ma) basalts of the Lesotho Formation, Drakensberg Group (Duncan and Marsh, 2006). Locally, the larger kimberlite body is referred to as the Main Pipe (17.2 ha) and the smaller one is called the Satellite Pipe (5.2 ha; Fig. 2).

After discovery, Letšeng-la-Terae was declared a Government digging in 1959 and artisanal mining occurred up until 1968. Their

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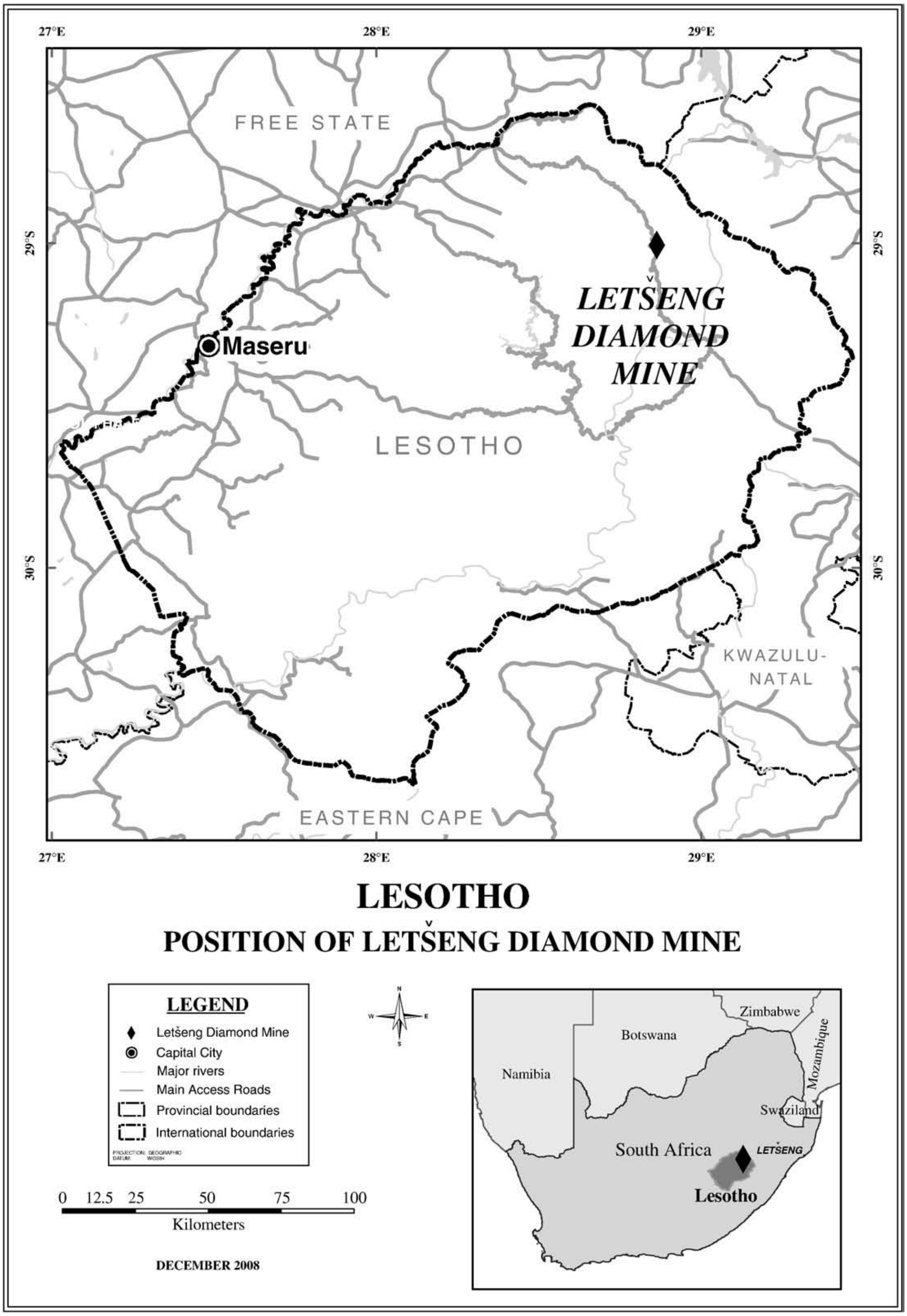

Fig. 1. Locality map of the Letšeng Diamond Mine, Lesotho, southern Africa.

efforts, which yielded some 62,000 carats (cts), were directed at the eluvial sediments overlying both the Main and Satellite Pipes, and in the proximal alluvial deposits draining these bodies via the Patiseng and QaQa streams, respectively (Bloomer and Nixon, 1973). By that time, it was already known that Letšeng-la-Terae produced large diamonds, many of which were white, high quality stones and included the 601 ct *Lesotho Brown* (Bloomer and Nixon, 1973). Between 1968 and 1972, the pipes were explored systematically and then later, from late 1977 to 1982, were mined formally, when 272,840 cts were recovered from 9.4 million tons of kimberlite drawn mainly from the Main Pipe (Whitelock et al., 2004; Palmer et al., 2007). Some 21 years later, in 2003, Letšeng Diamonds (Pty) Ltd re-commenced formal mining and had, by the end of July 2008, produced ca. 265,000 cts from the kimberlite pipes and remnant alluvials, including the 603 ct *Lesotho Promise* (2006) and the 493 ct *Letseng Legacy* (2007).

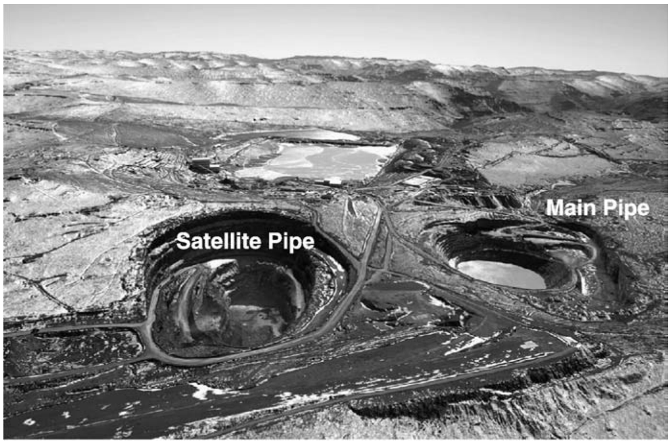

Fig. 2. Oblique aerial view north-eastwards over the Satellite Pipe (5.2 ha) and Main Pipe (17.2 ha) at Letšeng-la-Terae. Note sub-horizontal basalt flows of Jurassic-age Lesotho Formation in background through which Letšeng kimberlite pipes intruded 91 Ma ago.

Although the Letšeng pipes are low grade, with diamond content ranging from 1–3.5 carats/hundred tons (cpht), both bodies are economic because they host high-value diamonds, the revenue of which raise positively the value per unit measure of kimberlite (in this case, the US$/ton). Significantly, during 2008, Letšeng rough diamonds achieved prices in the order of US$ 2000–2500/carat ($/ct) on a tender system in Antwerp. Such average prices are the highest realised for a kimberlite run-of-mine production globally in 2008 terms. Moreover, these pipes, and their associated eluvial and proximal alluvial deposits, are renowned for yielding large, +100 carat (ct) diamonds — the majority of which have been "D" colour, potentially flawless stones. Up until July 2008, at least 26 +100 ct diamonds had been recovered — the two largest being the 601 carat (ct) *Lesotho Brown* from the Main Pipe found in 1968 (Bloomer and Nixon, 1973) and, more recently in 2006, the 603 ct *Lesotho Promise* from the Satellite Pipe.

We present here aspects of the characteristics of the Letšeng diamond population, many of which are deemed unusual in a kimberlite context. These include the high percentage of gem quality diamonds, the large average stone size, distinctive shape, exceptional colour mix and the abundance of Type IIa stones, that all contribute significantly to these two low grade kimberlite pipes being economic to mine. Our findings lend further support to the importance of the inherent revenue (in this case, US$/ton) rather than the grade per se in determining the economic potential of diamondiferous kimberlites. Our provisional findings are drawn from detailed daily production and tender sales records, as well as our ongoing diamond studies since Letšeng Diamonds (Pty) Ltd re-commenced operations at Letšeng-la-Terae in 2003 (alluvials) and early 2004 (kimberlite pipes).

In 2003, only diamond size and numbers were recorded from the alluvial returns and these could be confidently assigned back to their respective points of origin in either Main Pipe (Patiseng Stream) or Satellite Pipe (QaQa stream). Subsequently diamond size and also diamond shape, colour and Type II studies have been primarily focussed on the kimberlite diamond population since pipe mining re-commenced in 2004. Moreover the data and observations presented here are drawn from a working mine perspective that, as yet, have not been followed through with detailed academic studies.

1.1. Previous work on the Letšeng-la-Terae diamonds

Interest in the Letšeng-la-Terae diamonds was generated by the artisanal results in the 1960s, particularly the finding of the 601 ct *Lesotho Brown* (Bloomer and Nixon, 1973) and also the report of an ca. 527 ct stone for which no published account has, to date, been found. Harris (1973) first reported the virtual absence of octahedral stones and the dominance of rounded, irregular and commonly flattened dodecahedral forms in the Letšeng-la-Terae diamond population. He also pointed out the prevalence of brown and faint yellow colours with an "absence of colour" (i.e. white colours) in the larger stones from both Main and Satellite Pipes (Harris, 1973). The incidence of small Type IIa stones (0.05–0.15 carats per stone size range) was also recognised previously but hitherto had only been reported on briefly (cf., Robinson, 1979; McDade and Harris, 1999; McKenna, 2004; Robinson et al., 2004; Bowen et al., 2007).

Table 1
Accuracy of the visual recognition of Type IIa diamonds at Letšeng confirmed with a Bruker FTIR spectrometer.

Visual identification of type IIa diamonds				FTIR confirmation by Bruker	
Size	Potential type IIA STONES	Total per size	% of size	Confirmed	Visual accuracy
2 ct	34	186	18.28%	33	97.06%
2.5 ct	13	54	24.07%	11	84.62%
3 ct	22	91	24.18%	21	95.45%
4 ct	12	56	21.43%	12	100.00%
5 ct	11	31	35.48%	11	100.00%
6 ct	3	14	21.43%	3	100.00%
7 ct	8	20	40.00%	8	100.00%
8 ct	3	6	50.00%	3	100.00%
9 ct	0	2	0.00%	0	0.00%
10 ct	2	5	40.00%	2	100.00%
+10.8 ct	13	19	68.42%	13	100.00%
TOTAL	121	484	25.00%	117	**96.69%**

Overall 96% accurate in a subset of 484 diamonds over 11 diamond size classes from 2 cts through to +10.8 cts.

2. Methods used

At Letšeng, the diamonds are concentrated from kimberlite crushed and processed through a 350 ton/h Dense Media Separator (DMS) Plant with 800 mm cyclones (size range 2–45 mm) and then recovered through wet X-Ray (Flowsort) units before being dried and finally hand-sorted in a high-security Recovery. The diamond production is recorded daily for both alluvial and kimberlite mining and the number of records exceeded 3500 as at end July 2008. These include the number of stones and carats (1 ct = 0.2 g) per diamond size class (using the "De Beers standard" sieves) and the number and size of Type IIa diamonds. Diamond colour, shape and breakage (not

Table 2
Letšeng colour classification based on Gemological Institute of America (GIA) colour grading (Liddicoat, 1993).

GIA colour	Rough colour description
White through yellow	
D	Colourless
E	Near colourless
F	
G	White
H	
I	Off white
J	
K	Light yellow
L	
M	Medium yellow
N	
O–R	Yellow–light to medium cape
S–Z	Yellow (Cape)–light yellow fancy
Brown	
H	Top–top light brown
I	Top light brown
J	
K	Light brown
L	
M	Medium brown
N	
O–R	Brown
S–Z	Dark brown

discussed here) studies are carried out regularly, particularly where the origin of the material studied can be determined accurately.

Although the mining and treatment process commonly involves a blending of kimberlite from the two pipes, the diamonds reported on here are only those where the origin could be traced back to either the Main Pipe or the Satellite Pipe. Similarly the +100 ct diamonds reported here from the alluvial deposits could be traced back to their source pipes. Furthermore, our access to the full size range of diamonds recovered at Letšeng over the last 4.5 years has been a decided advantage in our studies, particularly with the Type IIa investigation.

With respect to the Type IIa diamonds (cf. Robertson et al., 1934; Meyer, 1985) at Letšeng, we have developed a visual identification system that has proved 96% accurate (Table 1). Initially, 484 diamonds drawn from 11 size classes were visually identified into Type IIa and Type 1 categories that were then tested in a Bruker FTIR Spectrometer. A Swiss Gemmological Institute (SSEF) Type II Spotter was used to confirm the Bruker results which demonstrated 96% accuracy in the visual identification of Type IIa diamonds (Table 1). This Swiss Gemmological Institute (SSEF) Type IIa spotter has been retained on-site for ongoing quality control and the checking of difficult decisions. This visual technique (96% accurate) focuses on:

- Shape or morphology. Type IIa diamonds come in a range of elongated, distorted or irregular shapes. On the rare occasion that a Letšeng Type IIa diamond displays some octahedral form, this feature is confined invariably to a single face.
- Colour. Type IIa diamonds can be almost any colour with the exception of yellow, due to the absence of nitrogen. At Letšeng, Type IIa diamonds are either top white colours (D, E, F or G) or any shade of brown (Liddicoat, 1993; Table 2). Interestingly, most Letšeng pink and brownish-pink stones are also Type IIa diamonds.
- Quality. Whilst Type IIa diamonds come in a range of qualities from low cleavage (any rough diamond that must be split into smaller pieces by cleaving, laser or sawing, prior to polishing; Liddicoat, 1993) to high quality gem, most Letšeng large (+5 ct) stones are of

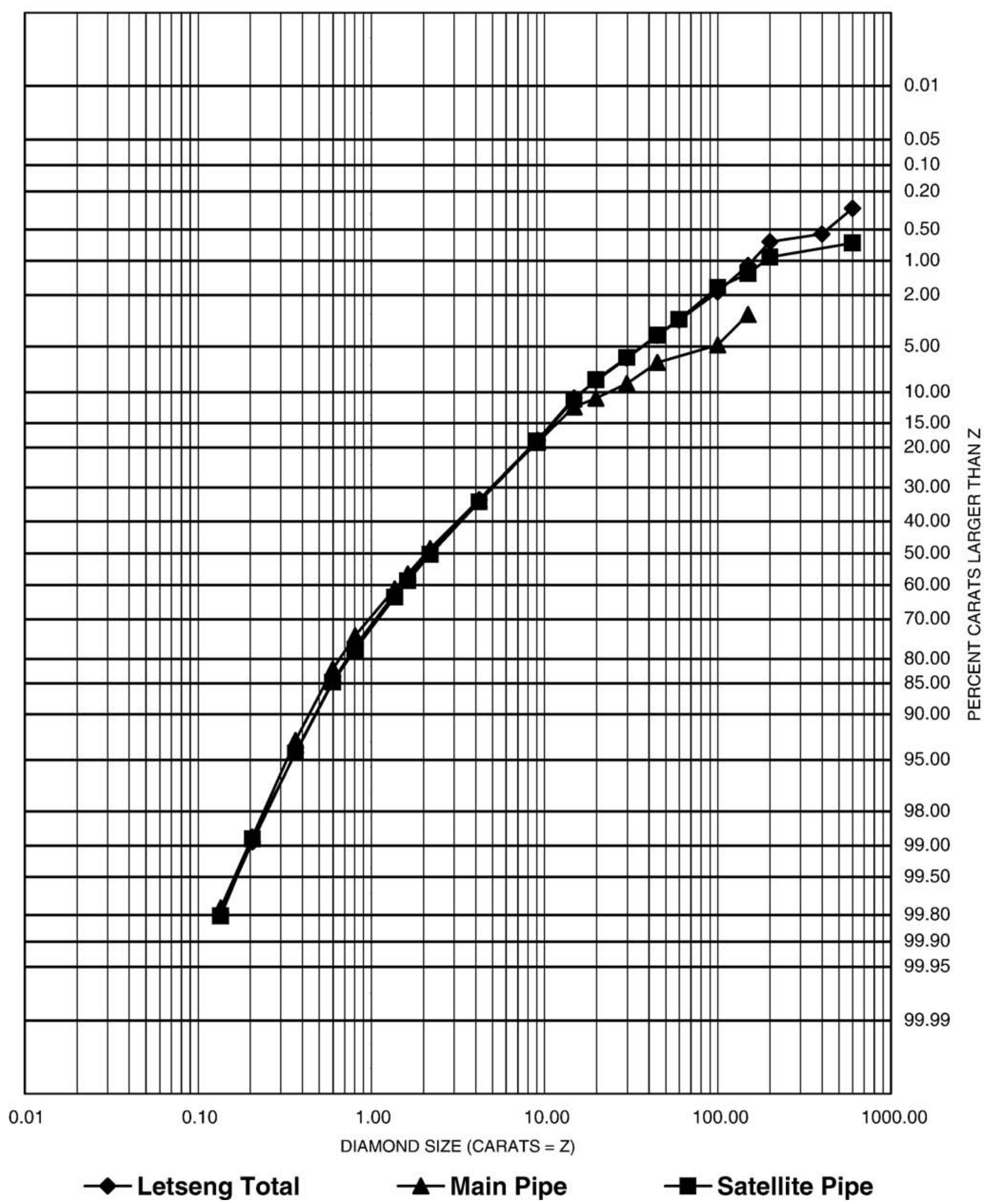

Fig. 3. Size frequency distribution of diamonds (log scale) from the Main Pipe, Satellite Pipe and Letšeng total production (March 2004–May 2008). Sample size = 198,647 cts. The average size of the recovered Letšeng diamonds is ca. 1 carat per stone (cts/stn) at a bottom cut-off of 2 mm. The *X*-axis is diamond size in carats (= *Z*) on a log scale and the *Y*-axis represents the percentage carats of the diamond population larger than any particular value of the diamond size represented on the *X*-axis (= *Z*).

Table 3
Combined table for Main and Satellite Pipes showing percentage breakdown of diamond shapes, colour distribution of diamonds and percentage of Type IIa stones per diamond sieve class (n = stones).

Diamond characteristics	% Main Pipe	% Satellite Pipe
Diamond shape	n = 19,061	n = 1635
Dodecahedral	67%	87%
Dodecahedral macle	32%	12%
Broken	0.9%	1%
Octahedral	0.1%	0%
Diamond colour	n = 22,068	n = 16,185
White	33%	33%
Yellow	29%	41%
Brown	33%	15%
Grey/Boart	4.8%	10.9%
Fancy	0.2%	0.1%
Diamond size class	n = 15,924	n = 6648
+10.8 cts	32%	51%
5–10 cts	28%	41%
2–4 cts	20%	29%
3–6 grainer	18%	21%
+5 to +12 sieve	19%	25%

exceptional gem quality. Generally, inclusions are uncommon in the Letšeng Type IIa diamonds and are mostly graphite. Additional natural damage comprises ruts and cracks that may be filled with kimberlite or, on some of the larger diamonds, with calcite.

- Cleavage. The Letšeng Type IIa diamonds generally display excellent cleavage, commonly breaking along mirror-like surfaces, whereas the Type I diamonds tend to cleave in a series of microscopic steps. Consequently, a significant proportion of Type IIa diamonds are broken, whether naturally or during the liberation processes associated with the treatment of the Letšeng kimberlite.
- Fluorescence. All the large stones (+5 ct) at Letšeng are subjected to long-wave ultraviolet testing in a standard diamond industry UV light as the absence or presence of fluorescence impacts on the down-stream value of that diamond. The majority of Type IIa diamonds do not fluoresce hence their colour remains constant, regardless of the type of artificial light or sunlight used to view them, thereby enhancing their value. On rare occasions, a weak white fluorescence has been detected in a diamond normally identified as a Type IIa stone at Letšeng.

3. Results

3.1. Diamond quality

The quality of the diamonds recovered from the Letšeng pipes averages 75% gem, well above the global average for kimberlites. The bulk of the non-gem stones comprise mainly cleavage and dark browns (15%–20%) with rejections and boart running at 5%–11%. Rejections are defined as "rough diamonds of poor quality from which only a low polished yield can be expected; includes small, misshapen, broken, poor colour and low clarity diamonds" (Liddicoat, 1993).

3.2. Diamond size

Based on our ca. 200,000 cts study from both pipes, the average stone size for Letšeng is ca. 1 carat per stone (ct/stn; Fig. 3). This is approximately an order of magnitude greater than the average stone size for the majority of the world's kimberlites and is more comparable to some large-stone, alluvial diamond placers, e.g. along the Lower Orange River in southern Africa (cf., Van Wyk and Pienaar, 1986). Initial sampling at Letšeng showed a limited fine and ultra fine

Fig. 4. Examples of resorbed Letšeng diamonds showing low relief surfaces: A. Resorbed diamonds, the majority of which display low relief surfaces (LR). The largest diamond is 105 cts. Bar scale 10 mm. B. Low relief surfaces on a well resorbed, rounded 12 ct diamond. Bar scale 10 mm. C. A rounded resorbed 40 ct diamond showing low relief surfaces. Bar scale 10 mm. D. An irregular dodecahedral 123 ct diamond showing low relief surfaces. Bar scale 15 mm.

diamond population (<2 mm). Therefore the bottom screen size in the recovery plant at Letšeng has been set at 2 mm which is larger than most kimberlite mines in the world. This deficiency of small diamonds in the Letšeng population would thus have a limited influence on the size frequency distribution evident in the +2 mm population (Fig. 3). Size frequency analyses (using "De Beers standard" diamond sieve class sizes) show remarkable similarity between the Main and the Satellite Pipes (Fig. 3).

3.3. Diamond shape

Whilst the dodecahedral form is the dominant diamond shape at Letšeng (Main Pipe 67%; Satellite Pipe 87%), the classic rounded dodecahedron is uncommon (<10%), with the remainder (>90%) being irregular and elongated (Table 3). Likewise the rare presence of the octahedral form (<1%) and, to date, the absence of the cubic form, is deemed unusual in a general kimberlite diamond population. The

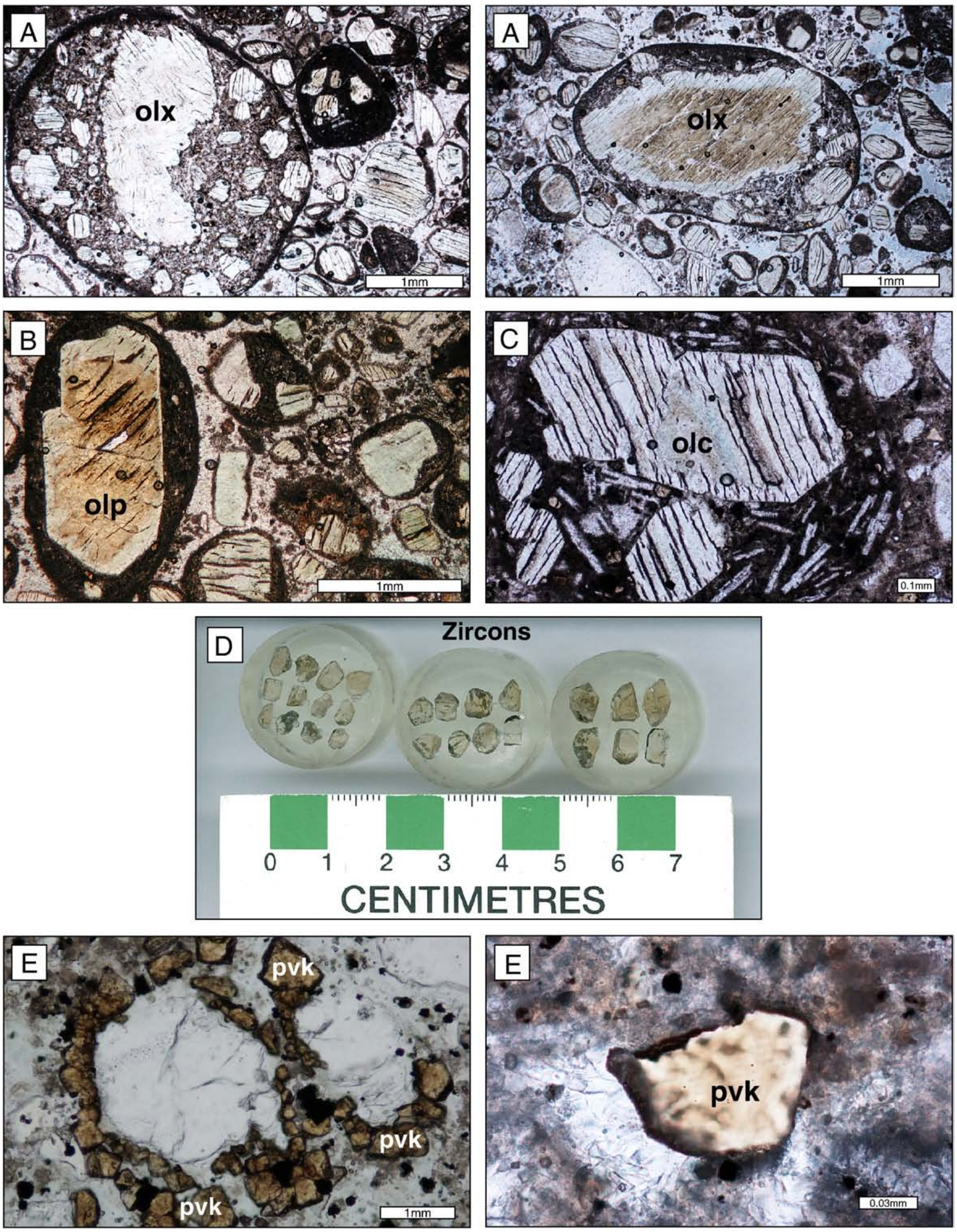

Fig. 5. A. Olivine xenocrysts (olx) showing serrated "saw tooth" texture along the grain margins. B. Coarse euhedral olivine phenocrysts (olp). C. Complex-shaped olivine phenocrysts (olc) are common in the Letšeng kimberlites. D. Kimberlitic zircons are coarse and have been dated at 91 Ma (Appleyard, 2006). E. Coarse perovskite (pvk) grains are abundant in the Letšeng kimberlites.

macle (twinned) form is relatively common (Main Pipe 32% and Satellite Pipe 12%), an observation also noted earlier by Harris (1973). Significantly the Letšeng macles display highly resorbed shapes and therefore, strictly speaking, are part of the dodecahedral population (Table 3). Minor broken forms make up the balance of the shapes in the Letšeng diamond population.

The low grade of the Letšeng pipes and the predominant irregular dodecahedral form exhibited by the Letšeng diamonds are attributed to resorption (Robinson, 1979), the degree of which is, as yet, to be ascertained. However Nowicki et al. (2008) rate the Letšeng diamonds as having a very low Preservation Index (PI) value of 0.01 which highlights the high proportion of dodecahedral forms. Our data supports their view in that 99% of the diamonds in both Main Pipe and Satellite Pipe are dodecahedral (resorbed) forms (Table 3). We speculate that these resorption conditions were responsible for development of low relief surface textures (Fig. 4; Robinson et al., 2004) and the lack of octahedral forms, as well as the dissolution of the fine and ultra fine diamond suites (<2 mm). Significantly, our preliminary petrographic studies provide supporting evidence for resorption of other mantle-derived minerals, notably olivine xenocrysts which are relatively fine-grained (predominantly <3 mm) and exhibit serrated "saw tooth" texture along their margins (Fig. 5). The overall low proportion of olivine xenocrysts (<10 modal%) also supports that there has been resorption. There is petrographic evidence for advanced fractionation of the kimberlitic melt which promoted the growth of the both coarse-grained (average 0.5 mm in size), euhedral and sometimes complex-shaped olivine phenocrysts, as well as coarse-grained spinel, perovskite and zircon in the Letšeng kimberlites (Fig. 5). This suggests that it is during this period of kimberlite melt fractionation that the bulk of the diamond resorption is likely to have occurred. Investigations into the nature of the Letšeng kimberlites are ongoing.

3.4. Diamond colour

Although earlier work suggested a dominance of white colours in both pipes (Robinson, 1979; Robinson et al., 2004), our results, which are based on a larger population, indicate that brown stones (Fisher, this issue) are prevalent in the Main Pipe (ca. 33%) and that light yellow is the prevailing colour in the Satellite Pipe (ca. 41%; Table 3). Nonetheless, we still found an unusually high percentage (ca. 33%) of white stones in both pipes.

Fig. 6. Selected Type IIa diamonds from Letšeng, including the 603 ct *Lesotho Promise*. Note the rounded, irregular dodecahedral form and the exceptional "D" colour typical of white Type IIa diamonds from Letšeng. Characteristically, the Type IIa diamonds do not fluoresce and have significantly different (no nitrogen) spectral peaks compared with Type I diamonds.

Table 4
Percentage of diamond type in the +100 ct size class, Letšeng ($n=24$ stones).

Diamond type	Diamond colour	Percentage
IIa	White	75%
IIa	Brown	4%
I	White	9%
I	Yellow	4%
Boart	Grey/black	8%

3.5. Type IIa diamonds

The most unusual, and the most economically important, characteristic of the Letšeng diamonds is the abundance of Type IIa, nitrogen-free, "D" colour, gem quality stones. Earlier studies, which were restricted to the smaller size fractions (mostly 0.05–0.15 cts/stn size range), indicated that Type IIa stones comprised 12–15% of the Letšeng diamond population (McDade and Harris, 1999; McKenna, 2004). However, with access to the full size range of diamonds produced at Letšeng since 2003, our studies show that Type IIa diamonds are a major component of the larger size fractions, in particular those sizes greater than +10.8 cts (Fig. 6; Table 3). In a diamond context, the 10.8 ct weight for a stone is the threshold that is rounded up to the 11 ct diamond size class which is the entry level into the so-called "special" diamond size classes.

Overall, the Main Pipe diamond population has ca. 19% and the Satellite Pipe ca. 25%, Type IIa diamonds. In the largest size fraction, the Type IIa stones in the Main Pipe comprise ca. 32% of the +10.8 ct diamonds whereas in the Satellite Pipe this runs at ca. 51% (Table 3). Significantly, of the 24 +100 ct diamonds recovered between November 2003 and July 2008, 19 were Type IIa stones with 18 of these white, "D" colour, gem quality stones and the remaining one stone a top light brown colour (Table 4). The balance of the +100 ct diamonds comprised two white Type I stones, one Type I yellow diamond and two grey/black boart fragments (Table 4). These large Type IIa and Type I diamonds were confirmed on-site using the Swiss Gemmological Institute (SSEF) Type II Spotter owned by Letšeng mine.

The Type IIa white diamonds of Letšeng regularly command high prices with stones in the +10.8 ct size fraction often exceeding US $25,000/ct. A noteworthy example was the US$58,000/ct achieved for a Letšeng Type IIa white 27.62 ct diamond in the first quarter of 2008. As the +10.8 ct size fraction makes up ca. 75% of the revenue for the Letšeng Diamond Mine, the contribution by the Type IIa diamonds is clearly substantial.

4. Conclusion

The combination of the unusual characteristics of the Letšeng diamonds, most notably the abundance of large, high quality Type IIa stones, rather than the grade per se, makes these two kimberlite pipes a viable economic mine in the comparatively remote and climatically harsh setting of the Maloti Mountains in Lesotho.

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