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Diamonds delivered to the West Coast of southern Africa from erosion of Kaapvaal based kimberlites and lamproites

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Introduction

As an initial endeavour to quantify the mass of diamonds liberated from Cretaceous lamproites (var. Kaapvaal) and kimberlites on the Kaapvaal Craton, Wilson (1972) proposed that approximately 3 bn cts of diamonds had been released and transported by the Orange River. Gurney et al. (1991) speculated that around 1.5 bn cts reached the West Coast of which 90% to 95% are gem-quality stones. These authors assumed that some 50% of the diamonds were broken, abraded and lost in transport, particularly of the poorer quality diamonds, indicating significant upgrading. In addition to the Orange River, they also highlighted that several smaller coastal drainages were utilized in the diamond distribution. Separately Schneider (2009) suggested that 10 bn cts were eroded and that 3 bn cts had reached the Namibian coast. The Orange River drainage basin hosts several major diamond mines, and numerous smaller pipes and dykes that have been intermittently mined. Cretaceous diamond-bearing kimberlites (38) and lamproites (29) within this drainage basin were utilized to calculate the quantity of diamonds released during more accurately defined post-Gondwana erosion phases.

Post Gondwana landscape denudation

The subcontinent was uplifted after Gondwana breakup as part of the Kalahari epeirogeny, and this was maintained at high elevation since the Early Cretaceous, initiating harsh erosion of its Karoo cover. Hawthorne (1975) estimated that central South Africa since the emplacement of the Cretaceous kimberlites and lamproites had lost on average some 1,400 meters during this erosion phase.

Improved stratigraphic relationships and low-temperature thermochronometric data have been adopted as the main guide to adjust the level of erosion for these diamond-bearing bodies.

Hanson et al. (2009) characterized various crustal xenoliths within the lamproites and kimberlites, linking them stratigraphically to various Karoo formations that were once present but subsequently removed. Based on these data, they established that approximately 850 meters of the ~85 Ma kimberlites and 1,350 meters of the ~120 Ma lamproites in central South Africa have been eroded (Fig. 1). Kimberlites like Kaalvallei, Monastery, and Jagersfontein penetrated through the entire Karoo stratigraphy, while the Koffiefontein, Kimberley-cluster and Leicester kimberlites intruded through a reduced Karoo sequence where the basalts had already been removed. Consequently, an escarpment likely existed approximately 200 km west of the present Drakensberg basalt escarpment when kimberlites erupted, retreating at an average rate of 2 km/Myr.

Apatite Fission Track (AFT) and Apatite (U-Th)/He (AHe) analyses, along with the offshore sediment records, register substantial landscape denudation after Gondwana breakup, which was particularly intense during two phases of accelerated erosion in the Cretaceous. These phases coincided with the emplacement of lamproites (around 120 Ma) and kimberlites (around 90 Ma), respectively. During the Cenozoic no major cooling events were recorded suggesting significantly reduced erosion during this period, as evidenced by the presence of several Late Cretaceous sediment-filled craters in the region.

Erosion Model

The volume of the missing upper part of each diamond-bearing lamproite and kimberlite has been calculated with the understanding that the wall rock inclination is between 82° and 87° from the vertical, based on Hawthorne's kimberlite model (Hawthorne, 1975). Since the grades and density of most lamproites and

kimberlites are known it allows the carats of the eroded part of these intrusions to be approximated with a reasonable amount of confidence, based on certain assumptions.
Erosion of these Cretaceous intrusions within the Orange/Vaal River drainage basin therefore amounted to some 2,225.4 mil cts of diamonds with 136.7 mil cts coming from Lesotho and 2,088.7 mil cts from South Africa. The kimberlites contributed 1,336.3 mil cts (56%) and lamproites adding a further 889.1 mil cts (44%), and of these the five major mines in Kimberley accounted for 44% (973.2 mil cts), and Finsch contributed 17% (379.1 mil cts) of the total.

Reorganization of the drainage network since Gondwana breakup has led to shifts in diamond depocenters and placer development along the West Coast. After Gondwana breakup, there were two main westerly draining rivers in southern Africa—the Karoo and Kalahari Rivers (de Wit, 1999). The Karoo River, the upper part of which is now copied by the Vaal River and the Upper and Middle Orange River segments, flowed across the Karoo and exited into the ocean via southern Namaqualand. The Kalahari River drained southern Botswana and the north-western part of South Africa, mostly mirroring what is now known as the Molopo and Lower Orange Rivers. The Karoo River progressively shifted northwards between 100 and 85 Ma before it was captured by the Kalahari River somewhere in the Prieska area mainly due to the exhumation of the Doringberge from its Karoo cover and the asymmetric uplift of the subcontinent. The timing of this capture therefore separated the two episodes of accelerated erosion.

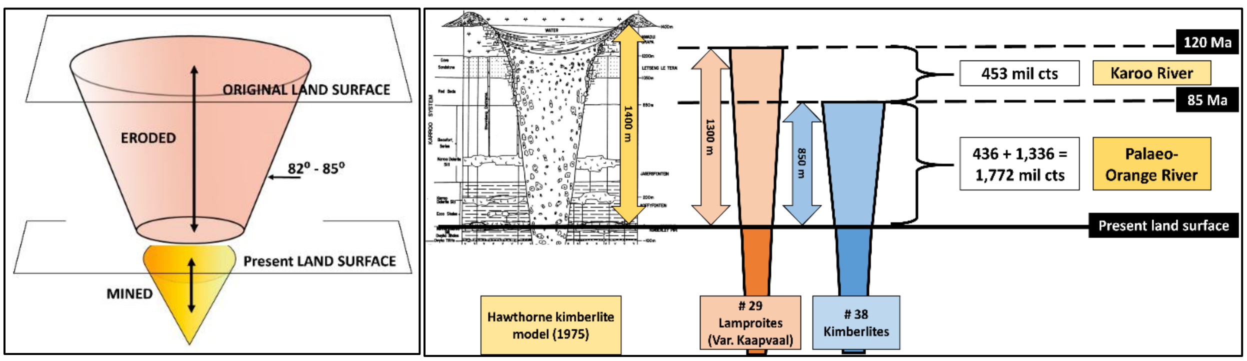

Figure 1. Simplified truncated cone for the tonnage calculations of eroded kimberlites (left), and revised erosion levels of the lamproites (~120 Ma) and kimberlites (~85 Ma) (right).

The older denudation phase led to the initial erosion of the lamproites by approximately 450 m, resulting in the release of 453 mil cts (Fig. 1). Since an estimated 50% were destroyed during transport only 227 mil cts would have reached the Atlantic Ocean via the Karoo River in the south. From the start of the second intense period of denudation, the Late Cretaceous kimberlites and the remaining parts of the lamproites were denudated by approximately 850 m, producing 1,336.3 and 435.6 mil cts respectively, and generating some 1,772 mil cts in total (Fig. 1). With 50% of these diamonds lost in transport, it would result in the delivery of approximately 886 mil cts to the West Coast in the general location of the present Orange River mouth. This is supported by $^{40}Ar/^{39}Ar$ analyses of clinopyroxene inclusions of detrital diamonds from the Namaqualand Coast, yielding eruption ages ranging from 117 to 120 Ma (Phillips et al., 2018), while most of those analysed from the Namibian coast originated from both the Cretaceous kimberlites and the older lamproites in roughly equal amounts (Phillips and Harris, 2009).

Older diamond-bearing kimberlites, such Venetia (Cambrian) and Cullinan (Proterozoic) mines would have generated 124 mil cts and 152 mil cts respectively with their projected levels of erosion. Since most of the erosion of these pipes occurred in pre-Dwyka times, many of these diamonds are likely locked up in pre-Triassic sedimentary rocks and particularly in south and south-westward flowing glacial sediments of the Dwyka Group. Some of the Cullinan diamonds were reworked from the Dwyka into upper Vaal River sediments, others were incorporated in the Dwyka eskers in the Lichtenburg/Ventersdorp fields or were upgraded into beach deposits associated with the Ecca shoreline around Schweizer Reneke and Wolmaransstad, and still others were added to the southern Namaqualand coastal deposits. Venetia's diamonds were likely transported by glacial activity via the Kalahari Basin to the south-west.

The number of large diamonds (defined as any diamond over 100 cts) produced from each of the 'big' five mines in Kimberley, Jagersfontein and Koffiefontein, as well as the tons hoisted over the corresponding period have been listed by Williams (1932). Using the ratio of big stones per tons hoisted, the number of large stones that were generated by the denudation of those kimberlites was estimated to be close to 15,500 of which the majority came from the De Beers (44%) and Dutoitspan (39%) mines. Erosion of the Lesotho kimberlites, such as Letšeng and Kao, would have delivered an additional 200 and 300 large stones respectively, thereby increasing the estimated number of large diamonds from the Cretaceous kimberlites released since emplacement to around 16,000.

Alluvial mining along the Vaal and Orange Rivers has so far registered close to 400 large stones, the largest of which was the 511 ct Venter diamond found near Kimberley. The biggest diamond recovered along the West Coast was a 246 ct yellow octahedron from the mouth of the Orange River and the biggest diamond from the Olifants River Mouth at De Punt was a 106 ct stone.

As shown the West Coast received approximately 1.12 bn cts of diamonds, of which some 200 mil cts or 18% have been mined from the rivers, the coast and off-shore, leaving a resource of just under 1 bn cts. However, many of those carats are locked up in Cretaceous off-shore sediments that have not been subjected to post-Cretaceous reworking and upgrading, and would therefore not be economic to mine. Finally, if 50% of the large stones are broken, the percentage of those recovered during mining compared to those produced is much lower than 17%, suggesting that breakage during transport is more common among big diamonds and probably more so among the purer CLIPPER stones.

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