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DIAMONDS FROM EXPLORATION TO MANUFACTURING

20 - 30 JUNE 2022

OVERBERG GEOSCIENTISTS GROUP

MINE AND FIELD VISITS

JULY 2022

Programme & Abstracts Volume

Overberg Geoscientists Group (OGG), South African Diamond Producers Organisation (SADPO), & Geological Society of South Africa (GSSA)

Diamonds from Exploration to Manufacturing

Introduction - Presented by a team of prominent local and international experts, this online Diamond Course is being offered from 20[tt] to 30[th] June 2022 under the auspices of the OGG, SADPO, and GSSA. It will provide participants with a unique opportunity and exposure to the latest developments in diamond exploration, geophysics, structural studies, kimberlite petrology and mineralogy, diamond formation, mantle indicator and fine diamond applications. It further covers the full ambit of primary (kimberlites and lamproites) and secondary (land and marine based alluvial) diamond deposits, including the evaluation, mining and exploitation, processing and diamond recovery from these deposits, as well as marketing and sales.

It is pitched at fourth-year University students, researchers, and industry professionals looking to update their knowledge of this fascinating industry.

The content, structure and timing of the June 2022 online Course are presented below, along with details of the mine and alluvial field trips scheduled for July 2022, and a comprehensive set of Abstracts of the online presentations, and mine and fieldtrip guides.

Background - The last half century has seen a massive shift in geological thinking and technological innovation and developments all facets of diamond exploration, mining, processing, recovery, manufacturing, marketing and sales. Recently synthetic gemstone diamonds have taken a place alongside natural gemstone-diamonds and jewellery, offering branded diamond jewellery ranges.

However, in spite of the above technology driven progress, the diamond sector has not seen a new world-class (Tier-1) discovery since 1991. Existing mines have mostly transitioned to underground operations with concomitant reduction of mined product. The famous pink-diamond producer Argyle Diamonds, closed in November 2020, and several other small operations and projects have closed. World natural rough diamond production has dropped by 30% since 2017 (152 m to 107m carats in 2021), paving the way for the growth of synthetic gems or laboratory growing diamonds to increase market share.

In a positive move to possibly start countering falling natural diamond supply, in late-2021 both De Beers and Rio Tinto announced they would pursuing new exploration ventures in Angola, and in January 2022 De Beers advertised for an in-country *Exploration Programme Manager* in Botswana.

Recently announced US embargoes against the sale of diamonds by Russian company ALROSA, the world’s largest producer of rough goods, approximately 30% of total production and marginally ahead of Botswana in previous years, is adding to uncertainty in the rough and polished diamond market.

In this context, the Overberg Geoscientists Group (OGG) in conjunction with invited diamond researchers and industry experts, including Herman Grutter of SRK Canada, the South African Diamond Producers Association (SADPO) representing the South African Small and Junior alluvial and kimberlite producers, and the Geological Society of South Africa (GSSA), is offering an eleven-part virtual presentation series covering the full spectrum of diamond exploration, evaluation, mining, processing and recovery, manufacturing, and marketing.

The presenters of the online Short Course include local and international experts from the full spectrum of diamond industry disciplines, with Paul Zimnisky, leading international diamond market analyst out of New York, presenting the opening keynote address.

Online Zoom Short Course (20th – 30th June 2022)

1. Introduction to the diamond industry
2. Diamonds and their origin
3. Diamond exploration
4. Kimberlites and lamproites
5. Mantle Indicators as applied to diamond exploration
6. Micro/macro diamond relationships
7. Alluvial diamond deposits
8. Mining and recovery methods
9. Diamond valuation and project evaluation
10. Current and Future Trends
11. Discussion + Concluding Remarks

Mine and Field Trips (July 2022) - These trips during in July 2022 which could change in the event that Covid challenges and lockdowns necessitate a change of dates. Participant numbers are limited and a first come first serve situation will apply.

1 **Gauteng and North West Province:**
Cullinan Diamond mine (Petra Diamonds) (Anton Wolmarans) – *(Wednesday 20 July 2022)*
Helam Fissure diamond mine (Swartruggens) (Jim Davidson) – *(Thursday 21 July 2022)*

2 **Northern Cape Mine and Field Trips:**
Kimberley Mine Museum & Nodule Dumps (Jock Robey) – *(Thursday 14 July 2022)*
Middle Orange River (MOR) alluvial operations (Lyndon De Meillon) - (*Friday 15 July 2022)*
Blue Rock diamond mine (Ulco, Ghaap Plateau) (Jock Robey) – *(Saturday 16 July 2022)*

The Gauteng and North West Province trips run over two consecutive days out of Johannesburg/Pretoria, whereas the **Northern Cape trips** cover three consecutive days out of Kimberley. Participants must make their own travel and arrangements to Cullinan and Helam, and travel and accommodation to Kimberley. The organisers will assist with overall arrangements, recommend suitable accommodation in Kimberley, advise on meeting points, and provide documentation for the Mine and Field excursions. The Helam mine trip is restricted to 10 persons, and the other trips to 20.

Personal Protective Equipment (PPE) - Mine and field trip participants must also please arrange their own PPE equipment, with the exception of the Cullinan mine visit.

With thanks,

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Petra Diamonds

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Acknowledgements and Thanks

The Organisers of the Online Diamond Short Course, Mine Trips, Field Excursions, and Tender House Visits, extend their thanks and acknowledgements to All of the Following, and those companies and individuals who may have slipped past the list below:

- The Sponsors who have so generously supported this event, including the individuals who helped facilitate the sponsorship
- The dedicated staff and assistants of the Geological Society of South Africa (GSSA), and in particular Lully Govender and Marliese Olivier.
- The staff and geologists of Cullinan mine (Petra Diamonds) and Helam Mining for facilitating mine trips to these two localities
- Gert van Niekerk (Chairperson), Rosalind Hansen and the SADPO Team for assistance with accommodation and arrangements in the Northern Cape
- Jock Robey for his support with tours of the Kimberley Mine Museum, Kimberley mantle nodule dumps, and BlueRock mine visit
- Jahn Hohne (CEO) and Ekapa Minerals (Pty) Limited for supporting a welcoming function at the Kimberley Club
- Daniel Nathan and his Team at the Alexander Bay Diamond Company tender house

Online Zoom Presentation Program				
Part-A 20 - 24 June 2022 *NY-New York; Sal-Salvador (Brazil); Vanc-Vancouver; Kings-Kingston (Canada); Per-Perth (Australia)*				***Page***
Monday 20		**Introduction to the diamond industry - 2022**		
1	*14.00-15.00 (RSA)* *8.00-9.00 **(NY)*** *5.00-6.00 (Vanc)*	The status of the international diamond market, and immediate and longer term outlook	Paul Zimnisky (*Diamond Analytics)*	***8***
2	*15.00-16.00 (RSA)* *10.00-11.00 **(Sal)*** *6.00-7.00 (Vanc)*	An overview of the Brazilian diamond sector	Ken Johnson *(Lipari Diamonds)*	***9***
3	*16.00-17.00 (RSA)* *8.00-9.00 **(Vanc)***	Overview of the Canadian diamond sector	Brooke Clements *(Craton Minerals)*	***10***
4	*17.00-18.00 (RSA)* *9.00-10.00 (Vanc)*	Characteristics, origin and evolution of diamond	*Fanus Viljoen (Univ. Johannesburg)*	***12***
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8	*(Moved to Thurs 23)*			
9	*(Moved to Friday 24)*			
	Q+A, discussion			
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10	*14.00-15.00 (RSA)* *5.00 - 6.00 (Vanc)*	Geophysical systems and techniques applied to diamond exploration	Gavin Selfe (*Geofocus*)	***24***
11	*15.00-16.00 (RSA)* *9.00-10.00 (Kings)*	Tectonic controls on diamond formation and preservation on cratons: Slave Province, NWT, Canada.	Herb Helmstaedt (*Queens University*)	***26***
12	*16.00-17.00 (RSA)* *7.00-8.00 (Vanc)*	Classification of kimberlites and lamproites, and related resource definition and estimation	Johann Stiefenhofer *(Anglo American)*	***28***
13	*17.00-18.00 (RSA)* *8.00-9.00 (Vanc)*	Geology of Angolan kimberlites, & their diamond quality compared to other regional production	Herman Grutter *(SRK)*	***34***
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14	*14.00-15.00 (RSA)* *5.00-6.00 (Vanc)*	Indicator minerals and microdiamond techniques applied to diamond exploration	Hilde Cronwright *(MSA Group*)	***31***
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16	*16.00-17.00 (RSA)* *7.00-8.00 (Vanc)*	Pyroxene geotherms and the lithospheric thermal state	Herman Grutter *(SRK)*	***33***

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17	*14.00-15.00 (RSA)* *5.00-6.00 (Vanc)*	Cr-pyrope garnets re-purposed as lithosphere proxies	Herman Grutter *(SRK)*	***33***
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		Technology innovation driving change and trends in the diamond industry	John Bristow *(GDN)*	***66***
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Examples of large and exceptional Investment diamonds

Red Cross diamond - a cushion-shaped, 205.07-carat, fancy-intense-yellow diamond, cut from a 375 carat rough stone which sold for $14.3 million at Christies 11 May 2022 auction. The rough stone was found in 1901 in a De Beers mine in South Africa. As well as ranking among the largest diamonds in the world, a striking feature is its pavilion, which naturally bears the shape of a Maltese cross. This stone was first sold on April 10, 1918, at a Christie's Auction in London. It was offered by the Diamond Syndicate in aid of the British Red Cross Society and Order of St John, and fetched £10,000 -- approximately £600,000 ($740,000) in today's money. At the 1918 auction, London residents sold precious household items to help the war effort. Those proceeds, 10,000 pounds (now $12,350), helped the British Red Cross Society with their war charity and support efforts and was bought by the London jewellers S. J. Phillips. It was sold again by Christie's in Geneva in 1973, fetching 1.8 million Swiss francs, before being offered by the auction house for a third time in May 2022. This large and special diamond, an investment stone, has now had a 104-year history with Christie's Auction House.

The Rock diamond – a pear-shaped, 228.31-carat, G-colour, VS1-clarity diamond, which sold for $21.9 million at the Christie’s Magnificent Jewels Auction in Geneva on 11 May 2022. This price was below the previous record for a white diamond, a 163.41-carat stone sold for $33.7 million by Christie’s in 2017. This exceptional diamond was mined from the Cullinan diamond mine.

THE STATUS OF THE INTERNATIONAL DIAMOND MARKET, AND IMMEDIATE AND LONGER TERM OUTLOOK

Paul Zimnisky, CFA
(Paul Zimnisky Diamond Analytics, USA)

The commencement of production of multiple new commercial-scale diamond mines pushed global diamond output to a multiyear high of over 150 million carats in 2017. However, in the subsequent years, depletion of legacy mines along with no new significant sources of additional production – compounded by the impact of the COVID-19 pandemic– led to a decline in global diamond production to a multi-decade low of under 120 million carats in 2020 and just ~125 million carats in 2021. With very limited sources of new commercial supply expected to come online in the 2020's, production is forecasted to remain in a 120-130 million carat range for most of the remainder of this decade.

While an oversupplied market was arguably the primary fundamental driver of apathetic diamond prices for most of the last decade, what is currently a more properly supplied market is structurally supportive of positive price fundamentals –as evidenced in 2021 and early-2022 when rough diamond prices as measured by the Zimnisky Global Rough Diamond Price Index made a new all-time high – surpassing the previous high set in early-2011.

Looking forward, while the supply side of the equation is expected to remain supportive of price fundamentals, which should allow for incremental demand to drive diamond prices higher, diamond demand growth will likely be subject to macro-economic volatility as the global economy adjusts to a waning of record stimulus while facing generational inflationary pressures.

On a more micro level, the diamond industry will continue to be sensitive to the re-emergence of competition from experiential consumer discretionary spending, sufficient industry marketing, e.g. via the Diamond Producers Association, and the impact of lab-grown diamonds.

Paul Zimnisky *– Paul Zimnisky, CFA is a leading global diamond industry analyst based in the New York City metro area specializing in global diamond supply/demand fundamentals and the companies operating within the industry. His research and analysis on the diamond industry is used by financial institutions, management consulting firms, private and public corporations, governments, intergovernmental organizations and universities. He has a monthly subscription-based diamond industry research report called "State of the Diamond Market," a proprietary rough diamond price index called the "Zimnisky Global Rough Diamond Price Index" and a regular podcast called the "Paul Zimnisky Diamond Analytics Podcast." Paul is a contributor to industry leading trade journals and he is regularly interviewed and quoted by prominent media outlets including: The New York Times, The Wall Street Journal, Reuters, The Financial Times and Bloomberg. He is often invited to speak at institutional investor and industry conferences around the world and has given keynote presentations on the diamond industry in North America, South America, Europe, Africa and Asia. Prior to his work as an independent diamond industry analyst, Paul worked in the financial markets industry for over 10 years in capacities including buy-side analyst, high-frequency trader and exchange-traded fund developer. Paul is a graduate of the University of Maryland's Robert H. Smith School of Business with a Bachelor of Science in finance. He is a CFA charter holder and a member of the CFA Society of New York. He can be reached at paul@paulzimnisky.com and followed on Twitter @paulzimnisky.*

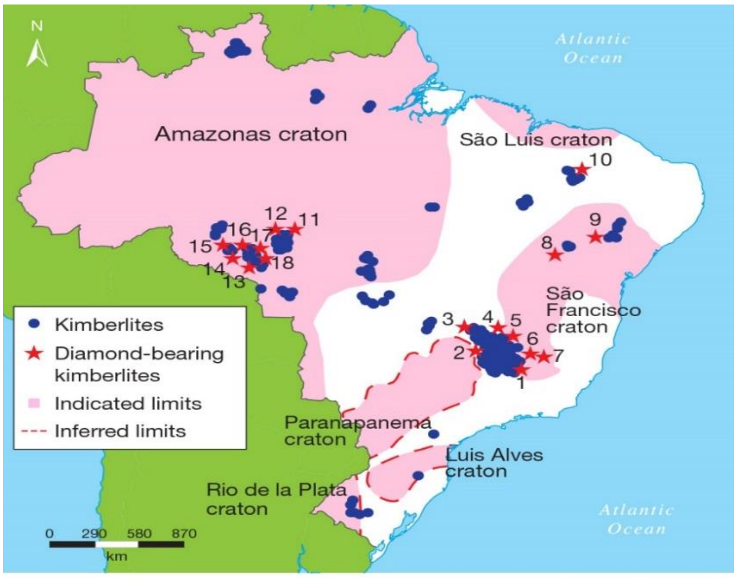
AN OVERVIEW OF THE BRAZILIAN DIAMOND SECTOR

Ken Johnson + Paulo Donatti
(Lipari Diamond Mines Ltd.)

Prior to the discovery of diamonds in South Africa in 1867, Brazil was the world's largest diamond producer for almost 150 years. All of the historical production was derived from alluvial deposits, despite the fact that there are now over 1,340 kimberlites discovered.

The Braúna mine is the first kimberlite deposit to be put into commercial production, with an annual production of approximately 230,000 carats per year. Following the success of Lipari's Braúna development, diamond explorers and producers are now starting to look at Brazil as a prospective area for diamond exploration.

There is an industry waiting to be developed here, it just needs investment and know-how. This will be the focus of the June 2022 online conference presentation.



Diamond-mineralized kimberlites:
(1) Canastra 1, (2) Romaria, (3) Três Ranchos 4, (4) Tucano, (5) Abel Régis, (6) Cana Verde, (7) Maravilhas, (8) Salvador, (9) Braúna 3, (10) Moana 11, (11) Juína 5, (12) Collier 4, (13) Carolina 1, (14) Comet 1, (15) Cosmos 1, (16) Cosmos 2, (17) Cosmos 3, (18) Tumeleiro 3.

Ken Johnson – *Ken completed a BSc degree in geology at University of Windsor, Canada. He is a highly experienced geologist and mining executive with over 30 years of experience as a diamond explorer and miner, with extensive diamond experience in Canada, Central Africa, South Africa, and Brazil. He is a founding Director of Lipari Mineração, owner and operator of the Braúna diamond mine in Bahia, Brazil. The Braúna mine is the first kimberlite diamond mine developed in Latin America and currently accounts for approximately 80% of Brazil's diamond production by volume.*

José Paulo Donatti-Filho *(Geology & Exploration Manager) – Paulo has 16 years of diamond exploration industry experience, was instrumental in the development of Brazil's Braúna diamond minel, and has gained international experience exploring for kimberlites in Canada (Fort a la Corne diamond district, Saskatchewan), and Project evaluations and field trips to kimberlite deposits in Brazil, South Africa and Botswana. He earned his PhD in kimberlite geology from the State University of São Paulo (2011) and associated research at the State University of Campinas, and carried out kimberlite research at the University of Western Australia and the University of Alberta in Canada.*

HISTORY AND FUTURE OF THE CANADIAN DIAMOND BUSINESS

Brooke Clements
(Craton Minerals Ltd)

The Canadian diamond business has contributed immensely to the economy, mining sector and the well-being of those living in the mining regions. Canada has produced over 270 million carats of diamonds since 1998 from seven mines with a value of over $35 billion CDN.

The initial discovery of diamonds in the Canadian Northwest Territories ("the NWT") in 1991 and the subsequent exploration, mining and business successes is an inspiring story. A new industry was created, the economy of the NWT was transformed and the imagination of the world was captured. It took vision, hard work, utilization of the latest scientific principles, timely investment and supportive government and communities to make the dream of Canadian diamonds a reality.

Because of the discovery of diamonds in alluvial deposits and glacial drift, principally in the United States, and the presence of several stable Archean cratons, there was speculation since the late 1800s that diamond fields similar to those in South Africa could be present in North America.

Principally from the 1970s through the 1990s, a number of companies explored for diamonds in the United States. The states of Michigan, Wisconsin, Minnesota, Montana, Colorado, Wyoming, Arkansas and Kansas saw significant exploration activity. The writer estimates that over US $200 million was spent on diamond exploration during this period and that over 100 kimberlites and lamproites were discovered. There have been two modest attempts at diamond mining in the United States: Prairie Creek in Arkansas and Kelsey Lake in Colorado. Approximately 90,000 carats were produced from Prairie Creek, including a 40carat stone, the largest verified diamond from the United States. Kelsey Lake produced approximately 11,000 carats between 1996 and 2001.

The first published account of serious diamond exploration in Canada was of an expedition into the James Bay region of Quebec in 1910. The modern era of diamond exploration is thought to have commenced in the 1960s with programs undertaken by De Beers and Selco Exploration Company. Kimberlite discoveries were made in Quebec, Ontario, British Columbia, Alberta, Saskatchewan and Nunavut in the 1970s and 1980s. One of these discoveries, Victor in Ontario, was mined by De Beers from 2008 to 2019.

In 1981, geologists Charles Fipke and Stuart Blusson, initially working with Superior Oil and Hugo Dummett, and Falconbridge, with technical guidance from Dr. John Gurney, started an exploration journey that would take them 900 kilometres and lead to the discovery of the Lac de Gras diamond district in the NWT. They followed high-interest indicator minerals picked from esker and till samples they collected, studying abrasion characteristics and mineral chemistry. Fipke, Blusson, Dummett and Gurney all contributed to diamond exploration efforts in the United States as well. The first mining claims were acquired in 1989 by Dia Met Minerals. A joint venture was formed between BHP, Dia Met, Fipke and Blusson in 1990. The first kimberlite in the NWT was discovered by drilling in September 1991 and Dia Met reported the recovery of 81 diamonds from a 59kilogram kimberlite sample in November.

The 1991 announcement set off a diamond rush unlike anything the world had ever seen and will likely never see again. Almost immediately, crews went out in the short arctic days in helicopters to stake claim blocks surrounding the discovery. By the end of 1992, at least 50 companies had acquired approximately 8 million hectares of claims. By 1994, 20 million hectares were under claim, about 80% of the Archean Slave craton. The NWT discovery suggested that other Precambrian cratons in Canada could host economic diamond deposits as well. Diamond exploration fever spread to the rest of the country and by 2020, over 900 kimberlites had been discovered in five provinces and two territories. Over $3.5 billion Canadian was spent on diamond exploration between 1991 and 2021 and seven diamond mines were opened in two territories (the NWT and Nunavut) and two provinces (Ontario and Quebec). Today, four diamond mines are producing with one of these scheduled to close in 2025 (Diavik).

All of the Canadian diamond developments to date have been on the traditional lands of indigenous people. Impact Benefit Agreements spell out how employment and economic benefits generated from the mining projects are shared with the affected communities. Many indigenous people work at the mines and successful indigenous businesses have been created to service the mines and support exploration programs.

The longevity of the Canadian diamond business is uncertain. Without significant new reserves, diamond mining in the country may cease in the 2030s. Canada now has a new generation of highly trained geologists, engineers, environmental scientists and miners with expertise in diamond exploration, mining and reclamation and working under difficult arctic conditions. This fraternity is ideally suited to ensure that the Canadian diamond business remains healthy for at least another generation. Three of the four producing mines, Renard, Ekati and Gahcho Kué, are working to extend their lives by increasing their reserves, and Ekati is looking at mining under water at the base of open pits that have already been mined.

There are currently six off-mine site projects in Canada with undeveloped diamond resources that could be put into production in the future. Exploration activity has decreased dramatically since the peak in the 2000s, but there are still opportunities to make new discoveries. All of the proven economic diamond districts were discovered as a result of traditional indicator mineral sampling programs. It's possible that the "easy ones" have been found. There is potential for new districts to be discovered buried underneath glacial cover using the latest geophysical technology or as a result of new interpretation of extensive proprietary and published exploration datasets.

It is worth noting that since the first diamond discovery near Kimberley, South Africa in 1869, new kimberlites have been discovered over a timespan exceeding 100 years in southern Africa.

Brooke Clements *– BSc Geology (Indiana University), MSc Economic Geology (University of Arizona). Brooke is currently President and CEO of Craton Minerals Ltd., a private diamond exploration company focused on discovering North America's next diamond district, and President of the consulting firm JBC Ventures Ltd. Previous positions include President, Peregrine Diamond Ltd. (2007-2015), Vice President, Exploration, Ashton Mining of Canada Inc. (1998-2007) and Regional Manager, Exmin Corporation (1982-1997). Brooke led the teams that discovered the Renard (Ashton) and Chidliak (Peregrine) diamond districts in Quebec and Nunavut respectively. Brooke also contributes to the Sheahan Newsletter, a monthly compilation of the latest literature related to kimberlites, diamond and the diamond business. A free subscription to the newsletter is available by contacting konsult@compuserve.com.*

CHARACTERISTICS, ORIGIN, AND EVOLUTION OF DIAMOND

Prof Fanus Viljoen
(University of Johannesburg)

Having formed at depths of more than 150 km below the Earth's crust, diamonds are transported to the surface in kimberlite and lamproite volcanoes. They occur in these magmatic rock types as discrete crystals with octahedral, cubic and rounded dodecahedral forms, while microcrystalline aggregates such as framesite, ballas and boart may also occur. The primary growth forms of octahedral and cubic crystals form at relatively higher (octahedral) and lower (cubic) crystallisation temperatures respectively, while the rounded dodecahedral form of diamond is a consequence of resorption in the magmatic host during transport to the Earth's surface. Single crystal diamonds grow slowly, under conditions of low carbon supersaturation, whereas fibrous coats and polycrystalline aggregates grow much faster under conditions of carbon supersaturation.

Diamonds may contain a variety of mineral inclusions, notable among them are olivine, garnet, pyroxene, spinel and sulphides. Based on the study of these inclusions, it is clear that diamonds crystallise primarily in high pressure magnesian (peridotitic) and more iron-rich (eclogitic) rock types. The peridotitic substrate in which diamonds crystallise is highly depleted, and likely formed as a residue in the early Earth as a consequence of the extraction of komatiites to the Earth's surface (probably through the melting of primordial mantle in ascending mantle plumes). This highly depleted variant of peridotite is known as harzburgite, and only occurs in regions of the Earth which have been preserved since the Archean. These old, cold, and very thick regions of peridotitic lithosphere underlies the oldest parts of continents and are commonly known as cratons. In contrast, eclogites are considered to be the high-pressure equivalent of subducted oceanic crust, and this rock type only started to form in the late Archean to early Proterozoic post 2.5 billion years, at which stage subduction became an important part of the Earth's dynamics.

Radiometric dating of mineral inclusions in diamonds clearly demonstrate that most diamonds are substantially older than their kimberlite and lamproite magmatic hosts. Harzburgitic garnets in diamonds are commonly older than 2.5 billion years, while eclogitic diamonds may be younger, with ages typically on the order of <2 billion years.

Thermo-barometric study of coexisting inclusions has confirmed conditions within the diamond stability field. Most diamonds record formation along 35-45 mW/m^2 geotherms and at pressures and temperatures of 45-75 kbar and 950˚C to 1350˚C respectively.

Nitrogen is the most abundant substitutional impurity in diamond, with concentrations normally ranging from undetectable amounts lower than 20 ppm to more than 2500 ppm. Nitrogen is the basis of the commonly used type I (nitrogen present) vs type II (nitrogen absent) classification. Type I diamonds are further subdivided on the basis of the form of nitrogen aggregation, and type II diamonds on the absence (IIa) or presence (IIb) of boron. Type I diamonds are subdivided according to whether the nitrogen is single substitutional (Ib) or aggregated (Ia). Single substitutional nitrogen is typical of synthetic diamonds, while most natural diamonds contain aggregated nitrogen due to extended residence in the mantle subsequent to diamond crystallisation.

The carbon isotopic composition of diamonds worldwide shows a marked mode at -5‰ to -6‰ with a tail to beyond -30‰. Peridotitic diamonds span a narrow range around -5‰ and eclogitic diamonds span a wider range to at least -30‰. This difference is commonly interpreted as reflecting different sources for the carbon e.g. mantle carbon in the case of peridotitic diamonds and subducted, biogenic carbon for eclogitic diamonds. In the case of peridotitic diamonds, and at least some eclogitic diamonds, crystallisation may be linked to the passage of C-H-O fluids through the lithosphere, in which carbon species CO_2 and CH_4 play a major role.

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***Prof Fanus Viljoen** – BSc Hons (Stell), MSc Geochemistry (UCT), PhD Geochemistry (Wits). Following 24 years with De Beers as a research geologist, Fanus joined the University of Johannesburg in 2008 to take up the DSI/NRF Research Chair in Geometallurgy. His research interests involve the study of kimberlites, diamonds, and mantle xenoliths, as well as applied mineralogy, with a view on the effect of ore mineralogy on the efficient recovery of metals through metallurgical processing. He is the author and co-author of 90 scientific articles in international journals, has a B2 scientific rating from the South African National Research Foundation, is an elected member of the Academy of Science of South Africa, and a Fellow of the Geological Society of South Africa.*

A CATALOGUE AND INSIGHT INTO THE WORLD'S LARGEST DIAMONDS

Ray Ferraris
(QTS Kristal)

"Bigger is better" very simply describes this paper. Humans delight in creating records in terms of size or value and diamonds are the perfect vehicle for this. From the earliest chapters of Indian history, size and value of diamonds was important and this is still true today. In 1905 the discovery of the fabulous Cullinan diamond changed the way large diamonds were recorded as this was the ultimate benchmark.

Diamonds that were seen as large in India, Brazil and South Africa were suddenly dwarfed by the giant 3,106 carat Cullinan; for people that are unsure of how to measure this amount; think of 621 grams! In the ensuing years, many large diamonds were discovered mostly in Africa; particularly in South Africa, Congo, Sierra Leone, Angola, Lesotho and Botswana, followed by Brazil. While the earlier large stone recoveries were in India, Brazil and South Africa; the more recent recoveries were almost all in Africa.

Lists or catalogues of large diamonds mostly have the Cullinan on top of the list, although some catalogues have the Sergio as number 1. The Sergio weighed a gigantic 3,167 carats (633 grams) and was found above ground in the State of Bahia, Brazil in 1895. It is a carbonado and is believed to be of meteoritic origin. Please note that the author does not include carbonados in this catalogue.

Up until the discovery of large diamonds in Kimberley, South Africa in the 1880's, the largest recorded stones were the 793 carat Koh-i-noor and the 410 carat Regent, discovered in India. From 1905 with the discovery of the Cullinan, most of the recorded large stones were from Brazil or South Africa. In 1945 the Woyie River at 770 carats was discovered in Sierra Leone. The next major discoveries were in the 1960's with important stones found South Africa, Lesotho and Sierra Leone; including the Lesotho Brown (601 carats) and the Kimberley Octahedron (616 carats). During the 1970's, Sierra Leone discovered the Sefadu (620 carats) and the Star of Sierra Leone (969 carats). In the 1980's, the most important stones were the Incomparable from the Congo (890 carats) and the Golden Jubilee (755 carats) and Centenary (599 carats) from South Africa. The 1990's saw the discovery of the Santo Antonio (602 carats) from Brazil and the Millennium Star (777 carats) from the Congo. After an 8-year hiatus in large stone discoveries; the Wynn Diamond (581 carats) was found in Brazil in 2002.

The year 2006 led to a new chapter of discoveries, almost exclusively from 3 mines; namely Letseng, Cullinan and Karowe; which have produced 17 out of the largest 24 diamonds recorded from 2006 to date. This chapter has seen many long-held records of large diamonds being broken with the Karowe Mine leading the way, having produced 8 of the 24 largest diamonds in the last 16 years; followed by Letseng with 6 and Cullinan with 3. Karowe discovered the Sewelo which weighs 1,758 carats, the unnamed Clivage at 1,174 carats and the Lesesdi La Rona at 1,109 carats. The largest stone recovered by De Beers is the unnamed Jwaneng diamond at 1,098 carats. The largest stone discovered by Letseng is the Lesotho Legend at 910 carats, while the largest stone found by Petra at the Cullinan Mine is the Cullinan Heritage at 507 carats.

This catalogue includes stones that have been documented over the years. However, it must be noted that there are many undocumented stones that were seen as inferior qualities and therefore not recorded, while there are also stones that were stolen and smuggled out of countries like Angola and the Congo, never to join the mainstream production of recorded large stones.

There are many generalised catalogues that include all stones regardless of colour, quality, Type, etc.; however, the author prefers to have designated categories, which creates a more meaningful understanding of these carbon giants of nature.

In recent times much research has gone into the crystallization and causes of these giants, mostly Type IIa stones; notably by Evan M. Smith, Steven B. Shirey, and Wuyi Wang. Their significant findings created the acronym "CLIPPIR" (Cullinan-like, Large, Inclusion-Poor, Pure, Irregular, and Resorbed). Linking CLIPPIR diamonds to a catalogue would be an obvious next step.

As new recovery methods become available such as the Tomra XRT recovery and large stone recovery circuits, we are likely to continue finding these giants. Many believe that Karowe has the greatest chance of breaking the record set by the Cullinan; but who would bet against Cullinan, Jwaneng or Letseng breaking the record… Twenty years ago stones larger than 300 carats were celebrated; in today's world we now await the plus 1,000 carat stones…

Ray Ferraris *– Ray is Independent Valuator with more than 40 years of experience in all aspects of rough diamonds, specialising in Valuation and Marketing or Tender preparation. He is a licensed South African Diamond Dealer, whose specialties include run of mine (ROM) valuations, large Type IIa diamonds and Noble Fancy Coloured diamonds. Studies include diamond breakage/damage assessment including process causes and reverse valuations to indicate value loss. Other specialities include diamond training, assessment of diamond features, diamond population studies, Diamond Chain of Custody, etc. Ray has worked for De Beers and Rio Tinto Diavik and consulted for many mines including Letseng, Karowe, Kao, Meya and many smaller operations. Besides his De Beers training, he has completed the GIA Polished Diamond Grading and the Rio Tinto Business Leadership Development Programme at Duke University.*

ORIGIN OF LARGE IRREGULAR GEM (CLIPPIR) TYPE II DIAMONDS AND PROXIES FOR PREDICTING THEIR OCCURRENCE IN KIMBERLITES

Andy Moore and Herb Helmstaedt^*
*(*Consultant, ^Queens University)*

Large, irregular N-free (Type II) gem diamonds such as the 3016 carat (ct) Cullinan (Cullinan mine, South Africa), 1109 ct Lesedi-la-rona (Karowe mine, Botswana) and the 603 ct Lesotho Promise (Letseng mine, Lesotho) can have a major impact on the economics of kimberlites. The occurrence of such stones in the Letseng-la-tera (Letseng) mine results in an average diamond value of over $3000/ct, making this locality, with a grade of 2.5ct/100t, the world's lowest grade economic kimberlite (Bowen et al., 2009). Smith et al. (2016) have coined the acronym CLIPPIR (Cullinan-like, Large, Inclusion-poor, relatively pure, irregularly shaped and resorbed) for this high value diamond population.

Currently, it is necessary to take expensive large bulk samples to determine the presence/absence and proportions of these CLIPPIR Type II stones and a proxy, analogous to the G10 garnets for P-type diamonds, would be invaluable for investigating kimberlite economic potential. Two very contrasting models have been proposed for the Type II CLIPPIR diamond population:

1. These diamonds are linked to the megacryst suite, and are thus of lithospheric provenance (Moore, 2009 & 2014; Moore and Helmstaedt, 2018)
2. They crystallized from sub-lithospheric, metallic melts (Smith et al. 2016).

The first model implies that prediction of the presence of these stones requires an understanding of the origin of the megacryst suite. The second requires an understanding of sub-lithospheric processes and mineralogy. Our presentation highlights evidence supporting a link to the megacryst suite rather than the sub-lithospheric model.

An important observation is that N-free (by definition, Type II) diamonds occur in eclogitic (E-type), peridotitic (P-type) and sub-lithospheric diamonds, as exemplified by inclusions from the Cullinan pipe (Korolev et al. 2018), (Fig. 1a). These collectively provide a section across the mantle from beneath the transition zone and across the lithosphere, with C-isotopic signatures ($\delta\ ^{13}C\ ^{o}/_{oo}$) consistently clustering around mantle values close to -5. These signatures differ markedly from the light C-isotopic signatures of the CLIPPIR Type II diamonds from this locality (Fig. 1a, lower pane, Milledge et al., 1983). In the Letseng kimberlite (Fig. 1b, lower pane), the inferred CLIPPIR diamonds also have a range to very light C-isotopic signatures which are markedly different from that of the associated P- E- and sub-lithospheric stones, failing to provide support for a link between these latter three parageneses and the Letseng CLIPPIRs. Further, inclusions of breyite (the intermediate pressure polymorph of $CaSiO_3$) are often uncritically assumed to represent inverted davemaoite (formerly CaPv), and thus evidence for a lower mantle provenance (Fig, 1c). However, breyite can crystallize directly from Ca- and carbonate-rich systems at lithospheric P-T conditions (Anzolini et al., 2016: Moore and Helmstaedt, 2019).

A further problem with the sub-lithospheric model for Type II CLIPPIR diamonds is that many of the N-free stones, inferred to represent CLIPPIRs by Smith et al (2016), are notably rich in inclusions (Fig. 2) (conflicting with their own definition) that are very similar to those documented from sub-lithospheric diamonds from the Juina alluvials (Brazil). This suggests that the inclusion-bearing stones studied by these authors are not CLIPPIRs.

Polycrystalline framesite diamonds, collectively and at individual localities, are characterized by a unique, wide range in C-isotopic signatures, which closely overlaps that shown by the Cullinan and Letseng CLIPPIR diamonds (Fig. 3), pointing to a genetic link. Inclusions in framesite diamonds have been ascribed to the websterite paragenesis but, as we will demonstrate, are more likely related to the megacryst suite. We will discuss possible proxies for predicting the presence or absence CLIPPIR diamonds.

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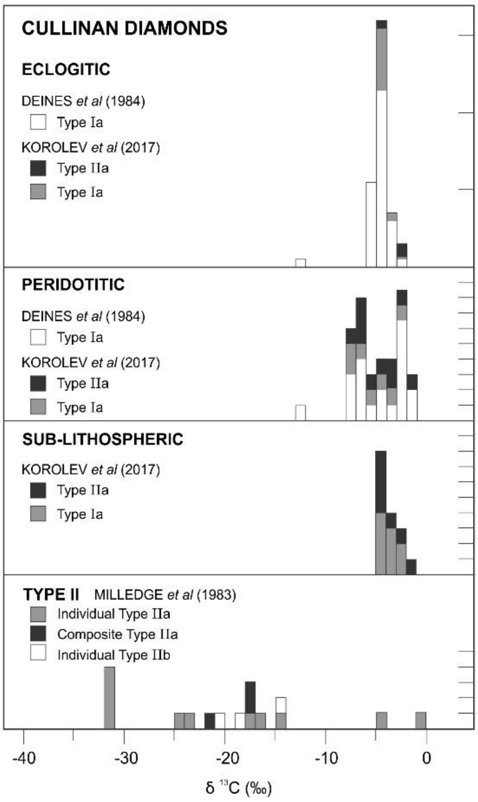

Fig 1a

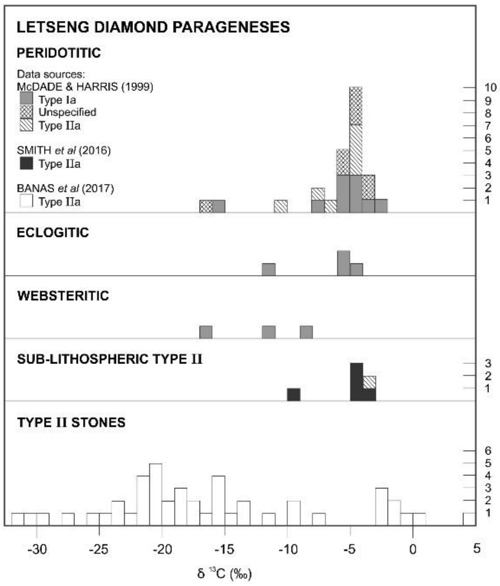

Fig. 1b

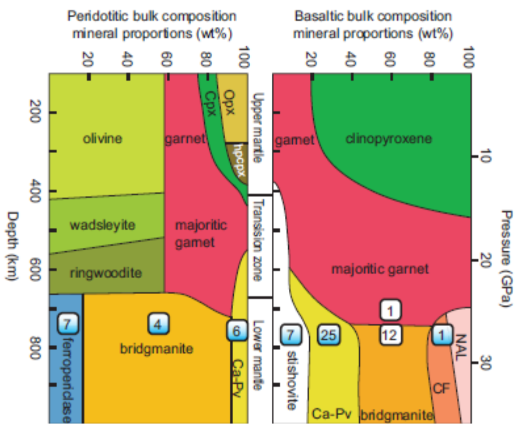

Fig. 1c

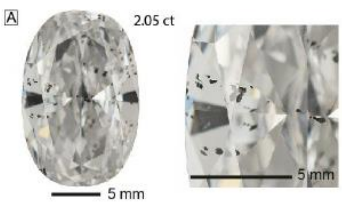

Fig. 2

Fig. 1. C-isotopic signatures of diamond parageneses from the Cullinan (1a) and Letseng (1b) kimberlites and P-T stability fields of lithospheric and sub-lithospheric phases (1c).

Fig. 2 N-free diamond with sub-lithospheric inclusions (from Smith et al., 2016.)

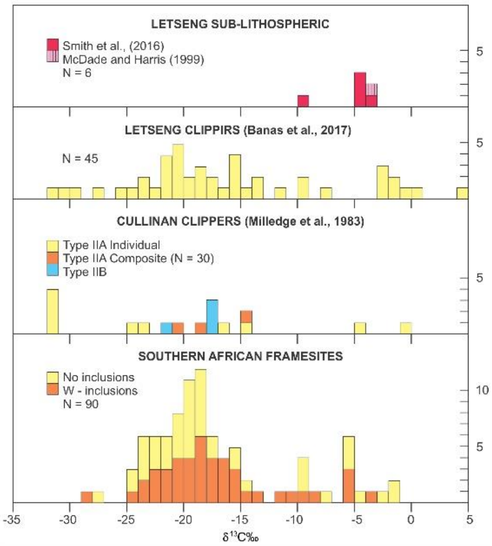

Fig. 3a Fig. 3b

Fig. 3a. Polycrystalline framesite diamond, curtesy of James St. John, Ohio State University, Newark.
Fig 3b. C-isotopic signatures of polycrystalline framesite diamond diamonds compared to CLIPPIR diamond populations from Cullinan and Letseng.

Dr Andy Moore *has a PhD and MBA from the University of Cape Town. He has over 40 years of kimberlite exploration experience in southern Africa, largely focussed on terrains blanketed by Kalahari Formation cover. Missing the economic Murowa kimberlite in Zimbabwe by some 10 km underlined the wry comment by Wolfie Marx (a classmate and fellow prospector) that diamonds take forever to find…. However, the experience opened a window on the fascinating interface between kimberlite exploration and geomorphology and, in turn, to linked faunal and floral evolution and distribution. Further insights are that the majority of kimberlitic olivines are cognate phenocrysts rather than mantle-derived xenocrysts, and that the large, irregular gem quality Type II diamonds are simply flamboyant megacrysts, with a lithospheric provenance.*

Prof Herb Helmstaedt *has degrees from the University of Munich, Germany (Dipl. Geol.), and the University of New Brunswick, Canada (PhD). His involvement with upper mantle studies began during his post-doctoral research at Lamont Doherty Earth Observatory of Columbia University, New York, in 1968/1969. He worked for the Geological Survey of Canada and taught at McGill University before settling at Queen's University, in Kingston, Canada, in 1974. His main research interests are all things upper mantle, the structural and tectonic settings of mineral deposits, including diamond, and the Precambrian geology of the Canadian Shield. From 1994 to 2004, he was involved with the Canadian LITHOPROBE Program and served as transect leader of the Western Superior Transect. His most recent publication is a book: The Slave Province, Canada - Geological Evolution of an Archean Diamondiferous Craton, published as Geological Association of Canada Special Paper 51, in 2021.*

PINK-GEMS AND PURPLE-HEARTS FROM THE KAO DIAMOND MINE TREASURE TROVE, LESOTHO

Debbie Bowen and John Ward
(Namakwa Diamonds)

The Kao main kimberlite pipe, at 19.8 ha, is the largest of the 5 Cretaceous-age kimberlite pipes known in the Maloti Mountains of northern Lesotho, southern Africa, despite the 750+m of erosion since its emplacement some 95 million years ago. Although known to be diamond-bearing since its "discovery" in 1955, the Kao main pipe is a marginal primary kimberlite deposit that was only developed into a commercially viable diamond mine in March 2012 by Storm Mountain Diamonds (Pty) Ltd (SMD) in a joint venture with the Government of Lesotho, following 2 years of development from 2010 to 2011.

From March 2012 to March 2022, SMD has recovered just under 7 million stones (stns) with a total mass of almost 2 million carats (cts) from about 37 million tonnes of kimberlite sourced from the 4 major economic units that comprise the bulk of the Kao main pipe. Type-IIa white diamonds were first recovered at Kao in late 2012, followed by the first pink stones in late 2013 – all of which have been Type-IIa diamonds to date. In contrast, the purple stones are all Type-I diamonds and have been known since 2008, prior to SMD's operations.

From January 2014, the post-boil sales records show that the Type-IIa stones (white, brown and pink colours) and Type-I purple diamonds make up only 3% of the total Kao production although this percentage increases almost 7-fold in the overall +10.8 ct and above size classes. Of this, the Type-IIa pinks comprised only 0.2% of the carats, but generated some 22% of the overall revenue in that period. Furthermore, the Kao production for the sales is sub-divided into a higher revenue, "Singles" (i.e., diamonds sold individually) class and a "Non-Singles" batch for each sale. Since January 2014, some 37% of the total revenue has come from the "Singles", of which the Type-IIa pinks contributed ca.57% of revenue from 23% of stones and 10% of carats.

The Type-IIa pink "Singles" display colours from faint pink through to fancy intense vivid pink, with a range in stone size from 0.51 cts/stn to 47.83 cts/stn. The intensity of the pink colour (derived from stress imparted on these 'super-deep" stones) can over-ride the more classic "size of stone" influence on the revenue. The sales revenues (USD/ct) reflect a broad range of pink values from about $2,500/ct at the bottom end to ca.$500,000/ct at the top end, the latter being a stone that was less than half the size of the largest pink recovered to date. In contrast, the Type-I purple diamonds are generally smaller, mostly <5 cts/stn, with a maximum to date of 28 cts/stn.

Until now the most valuable Type-I purple diamond recovered was the 3.06 ct "Purple Princess" that achieved just under 50% of the USD/ct of the top pink diamond. In the elite "plus 1 million USD per stone" class, the Type-IIa pinks again dominate with 55% of the stones (30% of carats) having generated 73% of the revenue in this highest value sales class but with no contributions from the Type-I purple diamonds.

Since the first discovery of Kao pinks, marked by the 36ct "Pink Storm" in December 2013, these top gems in 5 carater to +45 carater size classes have been recovered at an annual average of around 11 stones per year (range 6 to 16 stns/yr). At $15+M, the "Pink Storm" still holds the record total sales value for a single stone from Kao Mine. From the mining and mapping records maintained regularly since January 2014, the Type-IIa pinks occur in 2 of the 4 economic kimberlite units whereas the Type-I purples are found in 1 unit. Moreover, fewer Type-I purples have been recovered, and more intermittently so, than the Type-IIa pinks, which may in part be a consequence of the lower tonnes processed from GK.

Salient features of the 4 economic kimberlite units mined at Kao, together with some diamond type characteristics, are summarised below (Note: the nomenclature is drawn from historical records and current on-site mine usage with grades given in carats per hundred tonnes, cpht, at a Bottom Screen Size of 1.6 mm):-

- **Unit 4 = GK**: Youngest eruptive phase of mostly volcaniclastic kimberlite at ca. 7 cpht and hosting a noticeable content of mantle xenoliths and large garnet megacrysts. The Type-IIa pinks commonly display a more intense purplish-pink hue and includes the highest USD/ct pink recovered to date from Kao at ca. $500,000/ct. GK is also the principal host of the Type-I purples and has yielded 37.5% of the elite “plus 1 million USD per stone” Type-IIa pink stones to date. GK does not appear to contain Type-IIa white and/or brown stones.
- **Unit 3 = FK**: Largest preserved eruptive phase of mostly volcaniclastic kimberlite running at ca. 6.5 cpht and hosting 62.5% of the elite “plus 1 million USD per stone” Type-IIa pinks to date. This unit also contains Type-IIa white and/or brown diamonds.
- **Unit 2 = LQ**: Second phase, transitional with a combination of eruptive and intrusive sub-units at ca.4.5 cpht, containing Type-IIa white and brown diamonds but no Type IIa pinks to date.
- **Unit 1 = K6**: First phase of eruptive volcaniclastic kimberlite with 2 grade-distinct sub-units, averaging ca. 17 cpht and containing gem quality Type-I white, light yellow and fancy yellow stones but no Type IIa diamonds.

The FK and GK economic kimberlite units, which host the high value Type-IIa pinks and Type-I purple diamonds, constitute some 90% of the current planned remaining life of Kao Mine. Given the lateral and vertical recoveries of these top revenue stones over the last 10 years, it is anticipated that Kao Mine will continue to be a regular and prominent producer of these rare, fancy-coloured natural diamonds into the foreseeable future.

Debbie Bowen *- Debbie holds a GIA Graduate Diamonds Diploma and GIA Alumni Association Membership, and is a highly experienced rough diamond valuation expert with lengthy experience in Diamond Tender marketing and sales. She joined Namakwa Diamonds in 2011 and accepted the position of Namakwa Diamonds Group Valuations & Marketing Manager in February 2014. Prior to this she held the position of KAO/SMD Diamond Resource Manager, was the Diamond Recovery Manager at Letšeng Diamonds for 7 years, and Mineral Resource GeoLab Supervisor for Namdeb (Namibia) for 10 years.*

*J**ohn Ward -** John holds a Doctorate in Geology (PhD from the now UKZN) and has worked in about 26 countries, 20 of which were in Africa, mainly on alluvial and kimberlite diamond projects ranging from greenfields exploration through to large-scale mine production operations. Apart from his current consulting, John has also worked for a major, and two junior diamond companies and is the recipient of two medals (Oliver Davies medal and Henno Martin medal) for his contribution to academic and economic geology in southern Africa. He is a Life Fellow of the Geological Society of South Africa, a Life Member of the Geological Society of Namibia and SASQUA respectively, and a SAMREC Competent Person in primary and secondary diamond deposits.*

OVERVIEW OF DIAMOND EXPLORATION TECHNIQUES AND CHALLENGES

Mike De Wit
(University of Stellenbosch)

A summary is provided on basic exploration philosophies and approaches with the objective of finding and evaluating diamond bearing kimberlites. The focus will be on risks versus costs and what appropriate avenues should be followed in the exploration pipeline - from target selection to evaluation.

Of particular importance are the early stages of any exploration program with an emphasis on appropriate sampling procedures during the initial work programs. Getting it wrong up front will lead to an expensive and unsuccessful project. However, get the basics right and it will lead to success, which can either be walking away from areas that are negative with confidence, or progressing a project further down the pipeline.

Discussions will be on soil/stream sampling, geophysical work, drilling and eventual evaluation sampling. The importance of geomorphology and pedogenesis will be highlighted as these have a major impact on the results of any sampling program.

This presentation will also provide the background to subsequent presentations dealing with the multifaceted components of diamond exploration and project evaluation.

Typical assemblage of kimberlite indicator minerals (KIMS)

Michiel ('Mike') C. J. de Wit *– Mike holds MSc degrees in geophysics and sedimentology from the Universities of Pretoria and Reading (UK) respectively, and a PhD degree from the University of Cape Town. He has some 40 years of exploration experience primarily in the diamond industry, having begun his career as an exploration geologist for the Geological Survey in South Africa prior to joining De Beers, where he worked for 29 years. He managed various exploration programs for De Beers in Africa which led to a number of kimberlite discoveries, including holding the position of general manager for De Beers in the DRC. Since leaving De Beers Dr de Wit worked on a number of diamond and base metal projects junior exploration and mining companies in southern Africa including Botswana.*

HISTORY AND DISCOVERY OF BOTSWANA'S WORLD CLASS DIAMOND MINES

Mike De Wit
(University of Stellenbosch)

Bechuanaland/Botswana has a long and colourful history in exploration and mining. Here these activities are subdivided into three phases: pre-historic, historic and modern. Quarrying stone in Botswana was ongoing 500,000 years ago during the Early Stone Age (ESA). Actual mining of stones probably only started during the Middle Stone Age (MSA) i.e. post 250,000 BP, and the first prehistoric hard rock mining of specularite and limonite, likely started during the Late Stone Age (LSA) 20,000 to 2,000 BP. In eastern Botswana iron and copper were mined from AD 800 onwards; the mining of gold started in the 13th century.

Historic mining started with the re-discovery of gold close to Francistown in 1865 and lasted until the 1950s. Rumours of diamonds in Bechuanaland had already surfaced in the 1880s, and it was Ngamiland, in the northwest, that was first explored systematically for diamonds and gold between 1896 and 1899. A joint initiative between Anglo American and De Beers started serious prospecting parts of eastern Bechuanaland between 1932 and 1938; and in 1938 the first diamond finds in Bechuanaland were reported.

Modern exploration and mining in Botswana started with the signing of an agreement in 1959, allowing Consolidated African Selection Trust Ltd (CAST) into the Bamangwato Tribal Reserve. CAST found a few diamonds in the Motloutse River, but concluded that these were reworked and dropped the exploration rights. De Beers believed that these diamonds had come from west of the Motloutse headwaters, across the watershed in the Kalahari.

This ultimately led to the discovery of the Orapa kimberlite field in 1967, a year after Botswana became independent. This discovery triggered a major exploration boom across Botswana adding important diamond-bearing kimberlites such as at Letlhakane (1968), Jwaneng (1973), Gope (1981) and Lerala (1991).

Michiel ('Mike') C. J. de Wit *– Mike holds MSc degrees in geophysics and sedimentology from the Universities of Pretoria and Reading (UK) respectively, and a PhD degree from the University of Cape Town. He has some 40 years of exploration experience primarily in the diamond industry, having begun his career as an exploration geologist for the Geological Survey in South Africa prior to joining De Beers, where he worked for 29 years. He managed various exploration programs for De Beers in Africa which led to a number of kimberlite discoveries, and assumed responsibility for all De Beers programs in Africa, including general manager for De Beers in the DRC. Since leaving De Beers, Dr de Wit has worked on a number of diamond and base metal projects in Africa including Botswana.*

GEOPHYSICAL SYSTEMS AND TECHNIQUES AS APPLIED TO DIAMOND EXPLORATION

Gavin Selfe
(Geofocus)

Some new developments in the field of diamond exploration, including diamond alluvials, will be reviewed. These include low frequency ground penetrating radar (GPR) for palaeo-channels beneath cover, as well as the explosion in the myriad uses for drones.

Real-life examples will be given of drone magnetic surveys for kimberlites and alluvials, as well as GPR surveys over river channels.

A general review of the traditional uses of gravity, EM and magnetics will also be given, with real-life data examples. The more novel use of audio-magnetic tellurics (AMT) will be discussed briefly, as this technique, often dubbed 'the poor man's seismics' is playing more and more of a role, and its usage is burgeoning across the spectrum of mineral exploration.

Downhole geophysical logging, and the practical use thereof, will also be discussed with real life examples.

Practical examples of modern drone and GPR uses are shown in Figures 1 and 2 below.

Figure 1 – The drone revolution. The usage of drones in diamond exploration is booming.

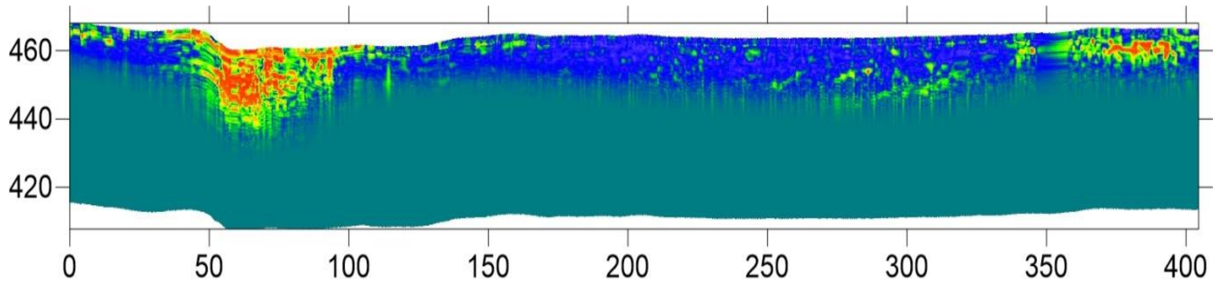

Figure 2 – River gravel mapping using ground-penetrating radar (GPR).

Gavin Selfe *– Gavin graduated from the University of the Witwatersrand in 1987 with a BSc Honours in Geology and Geophysics. He spent 15 years with the De Beers and Anglo American Group companies then started his own consultancy, and now has 34 years of experience as a geophysicist in minerals exploration, much of it with diamonds. He is a director and owner of GeoFocus, in partnership with Bjorn Havemann, a South African company that provides geophysical services and consulting to the mining, exploration and geotechnical industries.*

TECTONIC CONTROLS OF DIAMOND FORMATION AND PRESERVATION ON CRATONS: WITH SPECIAL REFERENCE TO THE SLAVE PROVINCE, CANADA

Herb Helmstaedt
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Comparisons of primary diamond deposits on different cratons have shown that diamond-forming processes have operated world-wide, but their timing is craton-specific. Yet on all cratons, the formation and preservation of primary diamond deposits is intricately related to the tectonic history of the craton as deduced from an integration of the surface geological record and its geophysical structure with the information gained from its kimberlite or lamproite-borne upper mantle sample, including diamonds. Area selection and subsequent diamond exploration require an intimate knowledge of the entire craton history which, for most cratons, may be discussed in five stages.

Stage 1	**Earliest subcontinental lithosphere development** with depleted roots and harzburgitic P-type diamonds. Proto-continental nuclei.	>3 Ga
Stage 2	**Amalgamation of early nuclei** and formation of first E-type diamonds. First detrital diamonds appear in sedimentary record and primary igneous rocks. Early roots must survive accretion of Neoarchean greenstone terrains, various "granite blooms" and other diamond-unfriendly events. **Cratonization**, greatest extent of Archean cratons.	~3 Ga ~2.5 Ga
Stage 3	**Post-Archean break-up of Archean cratons,** fragments become involved in Proterozoic (and Phanerozoic) orogenic events and supercontinent cycles. Archean craton roots are affected again by various mantle root-friendly or unfriendly tectonic and magmatic events, either diminishing diamond content of lithospheric source rocks or enhancing it by the addition of Proterozoic E-type or, more rarely, by lherzolitic P-type diamonds.	<2.5 Ga
Stage 4	**Archean cratons may be intruded by one or more generations of kimberlites or lamproites.** Such events may be accompanied or preceded by metasomatic alterations within or below the diamondiferous lithospheric roots. They may also be preceded by growth of late-stage amber or fibrous diamonds (Type-Ib). Sub-lithospheric diamonds may be picked up by kimberlites at this stage.	kimberlite or lamproite emplacement
Stage 5	Includes all geological **factors controlling the preservation of diamondiferous kimberlites or lamproites** and the dispersal of indicator minerals.	Post-emplacement

The Slave Province is a composite Archean craton consisting of a Paleo- to Mesoarchean nucleus (ca. 4.03-2.85 Ga), the Central Slave superterrane (CSST), with remnants of a quartzite-dominated late Mesoarchean cover sequence, to which juvenile Neoarchean supracrustal terranes were accreted between about 2.738 and 2.62 Ga. The entire province was affected by a post-tectonic granite bloom between 2.605 and 2.58 Ga, and cratonization followed between 2.5 and 2.4 Ga.

Diamond production from Slave Province mines is bimodal, consisting mainly of lithospheric P-type and E-type diamonds, with minor sub-lithospheric diamonds and late-stage fibrous overgrowths. P-type diamonds are concentrated in depleted parts of Mesoarchean lithosphere under the CSST that are tectonically buried under the eastern Neoarchean accreted terranes. Isotopic evidence for Mesoarchean ages of these diamonds (Aulbach et al.,2009; Westerlund et al., 2006) suggests early crust-mantle coupling which is corroborated by detrital diamond occurring in 2.96 Ga metasediments of the Central Slave Cover Group (e.g., Jackson, 1997). Significant Neoarchean diamond-forming events have not been recognized to date.

Cratonization of the province was followed by a ca. 200 m.y. magmatic hiatus, after which Paleoproterozoic mafic magmatism (beginning at 2.23 Ga) led to breakup of the Neoarchean precursor craton of the Slave Province at *ca.* 2.03 Ga. Deposition of passive margin sequences along the rifted craton margins was followed by collisional and transpressional orogenic activity along the margins, culminating in the incorporation of the province into Laurentia at about 1.84 Ga.

Alkaline Paleoproterozoic magmatism may have caused pervasive metasomatism under the southwestern part of the CSST, but numerous pre-Laurentia mafic dyke swarms did not have widespread deleterious effects on the P-type diamond content under the rest of the CSST. E-type diamonds are mostly post-Archean and were emplaced by a Paleoproterozoic subducted slab recognized on LITHOPROBE seismic reflection sections. Underplated from the west, this slab is thought to have protected the overlying remnants of the depleted Mesoarchean lithospheric root from further thermal erosion.

The Mesoproterozoic Mackenzie plume profoundly modified the lithosphere under the northern part of the Slave Province, negatively affecting diamond potential north of Contwoyto Lake. Eocambrian and Phanerozoic kimberlite events are unlikely plume-related, as plumes of that age were not recognized within and around the Slave Province.

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CLASSIFICATION OF KIMBERLITES AND LAMPROITES AND RELATED RESOURCE DEFINITION AND ESTIMATIONROCKS

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Kimberlites and lamproites represent a small but distinct sub-group of rocks in Earth's geological history. Geologists have argued and debated over their origins for many decades. Kimberlites, lamproites and the related rocks represent the products of small-degree partial melts within the earth, with the depth of melt separation having a significant influence on the character of the final volcanic product, similar to the broader lamprophyre clan. Kimberlites and lamproites represent the deepest known melts from within the Earth and remain the only rock types able to host economic primary magmatic diamond mines dominantly within cratonic areas of the Earth's crust. The economic importance of these rocks has resulted in significant scientific study over the past decades, with great progress being made in understanding their evolution. However, many unanswered questions remain, not least of which due to the absence of modern-day kimberlite eruptions. Kimberlite lavas and scoria cones are exceptionally rare in the rock record, understandable in view of the ultramafic nature of the rock which will readily alter and degrade at the earth's surface. Our view of kimberlite formation is therefore likely biased towards diatremes due to their better preservation potential compared to positive topographic features such as scoria cones and lava flows.

Another area of intense debate swirled around the physical emplacement mechanism of kimberlites and lamproites as the magmas neared the earth's surface. Early researchers vigorously defended their favourite models, usually focussed around either the gas-driven or hydrovolcanic (phreatomagmatic) endmembers of volcanic processes. Examination of the modern volcanic rock record suggest that mono- and polygenetic alkali basaltic eruptions represent the most likely analogues to kimberlite volcanoes. These alkali basaltic vents, and indeed almost all volcanoes, exhibit a range of both gas- and magma-water driven explosive processes within the same vent system, suggesting that single-process emplacement models such as those historically proposed for kimberlites and lamproites are at best unrealistic and at worst misleading. An extensive range of magma compositions have been identified in the earth's rock record, but the key volcanic processes remain present despite these differences, as shown by many investigations into modern and ancient eruptions and their products. The use of standard volcanic terminology is therefore best suited and preferred in the description of kimberlite and lamproite vent systems.

Kimberlites can typically be divided into an upper crater zone, a central diatreme zone and a root zone which can be located anywhere from just above the feeder dyke up into the base of the diatreme. The range in kimberlite shapes, sizes, internal morphology and key features suggest that the influence of host-rock geology, structure, hydrology, climate and magma volume on kimberlite emplacement vary significantly within and across continents, a feature also observed in modern volcanoes across the world. The seminal work by Smith in 1983 revealed that the petrographic differences evident between micaceous and poorly micaceous kimberlites were also reflected in the isotopic differences of their source regions. However, the origin and formation of these micaceous (Group II) kimberlites or orangeites have been another area of contention. Pearson et al. (2019) has recently proposed that Group II kimberlites could more accurately be described as carbonate-rich olivine lamproites (CROLs) based on isotope and geochemistry data. Although available studies suggest that lamproites may exhibit some distinct morphological features compared to kimberlites, at least some of these are likely related to the environment of formation and the reader would be well-advised to retain an open mind regarding the key features of lamproites.

A solid understanding of volcanology is essential if the emplacement and formation of a kimberlite or lamproite is to be successfully analysed and understood. Although identification of the various lithological units in a pipe using accepted geological principles is important, greater in-depth knowledge of volcanism is required to explain and understand the diamond grade and revenue trends in a kimberlite or lamproite. This can be a difficult step, particularly if the work is largely undertaken on drill core without essential 3D exposure. Important areas of focus for geological model construction should be whether the vent or pipe can be considered monogenetic or polygenetic, the existence of a lacustrine basin in the crater (or not), zones of potential grade dilution and the reasons for their existence, zones of possible grade enrichment and their lateral continuity based on geological process identification (important in the resource estimation process), depth of the crater zone, location of the crater-diatreme interface, extent and likely dimensions of the diatreme zone, and indications of any geological change or heterogeneity with depth in the pipe (analysis and interpretation of the main volcanological eruptive processes and the country rock will provide some clues).

The creation of geological models is a key step in the resource definition process, and it starts with the information described in the previous paragraph. When constructing such models, it is worth emphasising that the most robust and reliable geological models are those that are built using multiple levels of data – visual geology, quantifiable volcanological parameters such as clast size and dilution, geochemical data, metallurgical parameters, and structural information. The final model validation should be undertaken using the diamond data. The validation step is complete when the model can successfully account for the trends and features observed in the diamond data. Some geological parameters can be correlated with diamond grade and size and others with diamond assortment. The most useful and robust geological models will be the ones that can be used to proactively predict diamond grade and revenue changes in a resource, rather than attempting to account for the multitude of textural and small-scale variations commonly encountered in a vent system. Overly detailed models can be impractical, both from a resource estimation as well as a mining perspective. That said, it is usually better to err on the side of caution and rather include more detail initially, at least until the geology is understood with some degree of confidence, but this is very much experience-driven.

An appropriately scoped and optimised grade sampling programme is the key to any successful resource definition campaign, whether early in the life of a new deposit discovery or as part of a resource extension phase on an existing mining operation. It is unfortunately also the one area where shortcuts are frequently taken for various reasons. Where this is the case, the outcome is easy to predict – block estimates which create the illusion of confidence, but which bear no resemblance to actual grades, whether for long-term planning or SMU definition. Unfortunately, the impact of these decisions will only become evident years into the future when remedial action is either very expensive or impossible from a practical perspective. The presence of sampling failures will, however, be readily apparent as soon as the resource estimation process commences (and even earlier for those experienced in these matters), but the warnings are not always acted upon. Poorly executed sampling and insufficient communication of resource risk remain the biggest threats to the financial viability of any resource project.

Kimberlites, lamproites and the mantle inclusions which they carry continue to reveal a fascinating insight into the geology of the deep earth while at the same time providing disproportionately large economic benefits compared to their small volume in the rock record. There is still much to learn and understand about these unique and complex rocks. Interested readers are referred to the small sample reference list below as a starting point and are encouraged to embark on their own journey of discovery and learning!

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KIMBERLITE INDICATOR MINERAL AND MICRODIAMOND TECHNIQUES AS APPLIED TO DIAMOND EXPLORATION

Hilde Cronwright
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Diamond exploration usually starts with historical accounts of diamonds found in a particular area or drainage. Once a kimberlite is discovered prospective investors need an accredited laboratory to perform independent testing to confirm if the kimberlite is diamondiferous. The MSA Group Analytical Services Laboratory ("MSA") has two kimberlite evaluation procedures, Heavy Mineral Analysis ("HMA") and Microdiamond Analysis ("MiDA"). Both methods have been accredited by SANAS according to ISO/IEC17025 quality standard since 2012. MSA offers geological exploration and analytical testing services to assess kimberlite petrology, recover kimberlite indicator minerals ("KIMs") and test the mineral chemistry to evaluate diamond potential of the kimberlite sampled. MSA can assist clients by performing desktop studies, do site visits, map outcrop and sample material for testing to ensure that an auditable sample chain of custody is adhered to.

Heavy mineral concentrates are prepared from either stream sediment, soil, or drill core samples. Individual concentrates are visually sorted by experienced MSA Mineral Analysts to recover KIMs such as garnet, spinel, ilmenite, and chrome diopside, also called the "pathfinder minerals" for kimberlite. Each grain needs to be examined to visually distinguish genuine KIMs from other unrelated heavy background minerals like magmatic spinel and ilmenite or metamorphic garnet. Surface texture analysis of KIMs can provide valuable information of transport distance if the primary kimberlite source is not yet located (e.g. highly abraded vs fresh, angular grains with diagnostic remnants of their kimberlite affinity). MSA reports the KIM sorting results, garnet colours and/or surface texture analysis data for each sample with an interpretive HMA report.

The mineral chemistry of individual KIMs is tested by electron microprobe ("EMP") to provide genetic information if indicators are of kimberlitic origin or from non-kimberlitic ("NK") crustal sources. The colour of peridotitic garnets (like mauve, cerise, pink and red) vary with the average chromium content which are related to the crystallisation condition (e.g. depth, temperature, composition) of the garnet in the mantle. The low CaO/high Cr_2O_3 mineral chemistry of some peridotitic garnets, classified as G10D garnet, is highly indicative that the kimberlite sampled the mantle in the diamond stability field. Chrome-poor (< 1% Cr_2O_3) orange and pink garnets can be megacrystic, peridotitic or eclogitic. If they are tested to contain relatively low TiO_2 and Na_2O > 0.07% concentrations it is possible that an eclogitic source was sampled (which is rare but often a source of unusually high diamond grade). Analysing the mineral chemistry of KIMs can help to rank and prioritise individual targets for further exploration activities.

Once a kimberlite with positive diamond potential has been identified, microdiamond analysis ("MiDA") is a very cost-effective first stage approach to a) confirm whether newly discovered kimberlite body (dyke or pipe) is barren or diamondiferous, b) characterise diamond crystal features like colour, crystal shape and inclusions and c) model a preliminary diamond grade if sufficient microdiamonds are recovered. MiDA can evaluate and rank targets before more costly bulk-sampling is carried out or recommend a "walk-away" decision early on.

To test the MiDA content, it is recommended to process at least 200 kg of a kimberlite bulk-rock or drill core sample (drilled with a tungsten-carbide drill bit to avoid contamination by industrial/synthetic diamonds). The MiDA sample is processed by an approved subcontractor (Min-Met Equipment) by caustic fusion ("CF") dissolution. The resulting residue contains only diamonds and refractive oxide minerals and is visually sorted by MSA Diamond Analysts to recover all microdiamonds down to a minimum size of 75 microns. MSA operates the only MiDA facility in Africa and has consistently recovered over 97% of quality control ("QC") spikes (sized synthetic diamonds added before fusion). The MiDA laboratory was initially operated in partnership with SGS South Africa (from 2006) and since 2016 with Min-Met Equipment.

The microdiamonds recovered are described in terms of colour, clarity and crystal morphology and are weighed and securely stored on sample cards. The crystal classification and description information can be used to fingerprint diamond populations sampled by the kimberlite and can provide an indication of the expected characteristics of macrodiamonds (e.g. gem quality, semi-gem or boart). If a sufficiently large number of microdiamonds are recovered (generally more than 1 stone per kg kimberlite processed) the size frequency distribution ("SFD") can be modelled from the microdiamond data to predict a possible macro diamond grade and large stone frequency distribution estimation.

Applications:

- Karowe microdiamond modelling to predict macro diamond grade estimation
- Analysis of MiDA's by FTIR to determine Type IIa population
- Application of the microdiamond technique by diamond junior companies to assist in making relatively quick technical and economic decisions

Hilde Cronwright *– Hilde completed a BSc Honours degree in Geology at the University of Pretoria and BSc Honours in Chemistry at UNISA. Hilde is a geologist and chemist with over twenty years' experience in analytical testing of geological samples, gained while employed at The MSA Group and the Council for Geoscience Analytical Laboratory. Hilde is the Laboratory Manager and Technical Signatory of The MSA Group Analytical Services.*

KIMBERLITIC INDICATOR MINERAL AND MICRODIAMOND TECHNOLOGIES IN PRE-MINING ASSESMENT OF PRIMARY DIAMOND DEPOSITS

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Roughly 60% of over 6,000 known kimberlites contain diamonds, but only 1-2% of these contain diamonds in sufficient quantity and quality to support economic development. Some 98.5 wt% of global natural rough diamond production is known to derive from diamond-bearing peridotite, eclogite and websterite/pyroxenite rock types of deep lithospheric provenance; a sub-lithospheric (i.e. asthenospheric) genesis has recently been confirmed for the remaining ~ 1.5 wt% of production. Mineralization models for primary diamond deposits accordingly focus on specialised discrimination of lithospheric diamond host rocks, and the efficiency of their entrainment, preservation and transport to surface. Since commercial (macro)diamonds are very rare (grades are <0.01 to 1 g/ton) and require costly bulk samples to evaluate, the diamond industry has developed robust technologies to recover and analyse mantle-derived kimberlitic indicator minerals (KIMs) and microdiamonds (Mida) from workable 8 to 20 kg samples to aid in the pre-mining assessment of primary diamond deposits.

The current lecture series covers the development and real-world application of these KIM-Mida technologies. John Gurney and Mineral Services are acknowledged here (and in the lectures) for presenting a public interface to these powerful technologies, and for disseminating the basic tenets that today underpin pre-mining assessment of primary diamond deposits.

The titles, length and bullet-point intended coverage of individual lectures are summarized below

Presentation #15: [60 minutes] Mantle Indicators 101: Which ones are used and for what purpose
- Lithosphere, asthenosphere, diamond stability field
- Mantle rock types - peridotite, eclogite, pyroxenite, megacrysts
- Major- and minor-element mineral chemistry of olivine, garnet, chromite and ilmenite
- Relevant mention of KIM preservation, grain size(s), diamond-indicator xenocryst compositions and kimberlite-distinctive phenocryst compositions
- Focus on industry applications using only compositional data from microprobe analysis
- Diagrams contain comprehensively updated diamond-inclusion data

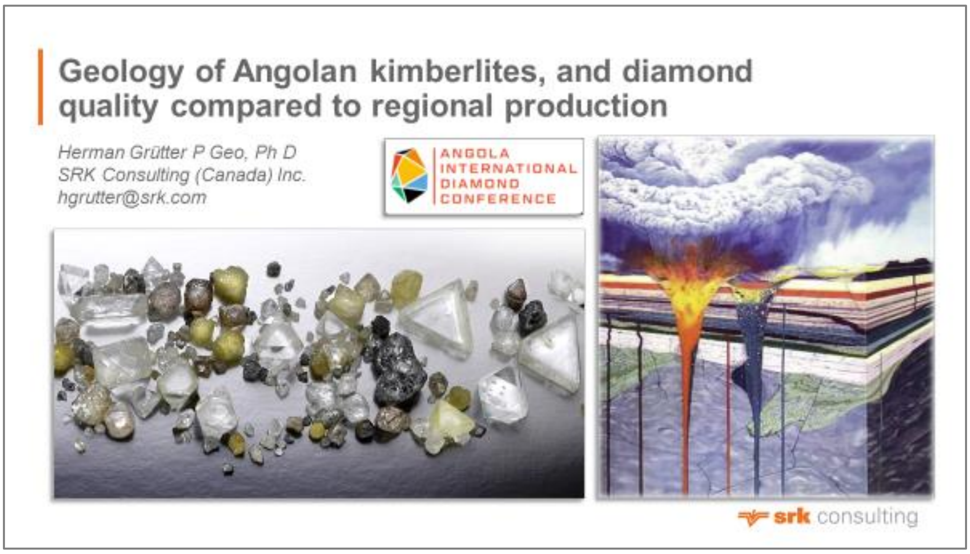
Presentation #16: [45 minutes] Thermometry, pyroxene geotherms and lithospheric thermal state
- Traditional mantle xenolith thermobarometry; cold vs elevated geotherms
- Single-orthopyroxene thermobarometry & geotherms
- Single-clinopyroxene thermobarometry & geotherms; accuracy & precision
- Single-clinopyroxene application: very slow lithosphere cooling – Ontario, Canada
- Mn-in-pyrope thermometry: xenocryst entrainment – Ontario, Canada
- Single-cpx application: fast lithosphere heating & loss of diamond root – Coromandel, Brazil
- Comment on "mantle plume" involvement in the genesis of kimberlite melts

Presentation #17: [45 minutes] Cr-pyrope garnets re-purposed as lithosphere proxies
- Melt-depletion and secular evolution of planet Earth
- Cr-pyrope mineralogy & composition vectors
- L, H and D-type mantles; geologic age of cratonic roots
- Cr/Ca-in-pyrope barometry - pure, simple & effective
- Cr/Ca-in-pyrope barometry - Cleve-01, Chompolo & Sekameng
- Cr-Ca attributes of Slave craton lithospheric domains

Presentation #18: [45 minutes] Examples of current use and interpretation of indicator data sets
- Safartoq, west Greenland: Open-file clinopyroxene & Cr-pyrope data
- Chidliak, Baffin Island: Fingerprinting of Cr-pyrope populations
- Angola: Comments on published clinopyroxene & Cr-pyrope data

Presentation #19: [45 minutes] Benchmarked microdiamond grade estimates using microdiamond data
- Context: Sichel (1973) Statistical valuation of diamondiferous deposits, J SAIMM 235-243
- Application: Letseng-la-Terai diamond populations
- Current micro-/macro-diamond benchmarks for grade range 0.03 to 6.8 ct/tonne
- Example benchmarked macrodiamond grade estimates, including errors

Presentation #13: [40 minutes] Geology of Angolan kimberlites, and diamond quality compared to regional production



This unique perspective on Angolan kimberlite geology and diamonds in the SADEC context was originally presented in Saurimo on 25 November 2021, at the invitation of the Angolan Ministry of Mineral Resources, Oil and Gas (MIREMPET). The Short Course version has updates and provides better resolution and colour rendering than the recorded version currently available on Youtube.

Dr Herman S Grütter *– BSc Hons (UCT), PhD (Cambridge, UK). Herman is a technical, numerate earth scientist with 25+ years' corporate, consulting, R&D, Chief Geologist and VP-level credentials built around value-accretive geoscience practice in global rough diamond ± porphyry Cu-Au projects. He is conversant with NI 43-101, SAMREC and JORC reporting and with Mining Analyst-style due diligence, specializing in pre-resource to feasibility-level diamond projects. From 2006 to 2012 he provided M&A-supportive techno-economic analysis for BHP Billiton covering almost all currently known diamond deposits; also for over 50 pre-resource diamond projects scattered across the globe. Dr. Grütter was integrally involved in corporate-level disposals of three diamond deposits at transacted values of C$9m+ (2011), US$500m (2012) and C$107m (2018). Further details at LinkedIn, over here:* [*https://www.linkedin.com/in/herman-grutter-phd-pgeo/*](https://www.linkedin.com/in/herman-grutter-phd-pgeo/)

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ALLUVIAL DIAMOND DEPOSITS OF NORTH-WEST PROVINCE DIAMOND 'TRIANGLE': DEPOSITION AND REWORKING OF DIAMONDS IN GLACIAL AND MARINE DEPOSITS OF THE KAROO SUPERGROUP

Pierre de Jager
(Consultant Geologist)

The apices of the well know ***diamond-triangle*** of the North West Province (NWP) are defined by the small farming towns of Wolmaransstad, Bloemhof and Schweizer Reneke. Diamonds were discovered in the area in 1912, and since then the *diamond-triangle* has produced more than 5 million carats, by mostly small-scale alluvial mining operators (historically referred to as '*Delwers'*).

The area is renowned for its consistent production of high-quality gem diamonds (85%), as well as coloured diamonds (pink, blue and orange stones). Previous studies of the deposits of the diamond triangle and their diamondiferous nature have been undertaken by Marshall (1987) and Dlakavu (2021). Precambrian rocks belonging to the Ventersdorp Super group (~2.7 Ga), Archaean greenstones of the Amalia belt, and Archaean granites, form the pre-Dwyka topography. The Precambrian rocks represents the southeastern margin (edge) of the Cargonian Highlands, which historically formed the high lying areas to the north and northwest of the younger country rocks (Carboniferous Dwyka diamictites and Permian Ecca sediments) comprising the ***diamond-triangle*** (see Figure 1 below).

This area (***diamond-triangle***) is flanked to the west by the Harts River glacial valley which is of Carboniferous age and cuts into Cargonian Highlands, and a glacial outwash plain to the south and south-east (area stretching towards the Vaal River), with glacial streams, kames and kettle structures. Permian Ecca Group rocks overly the Dwyka Group close to the Cargonian Highland and pinch-out against the Precambrian Ventersdorp Super group.

Middle Ecca sediments overly the Dwyka diamictites, comprising ancient beach deposits on and against the flanks of the Cargonian Highland, represented almost entirely by a secondary regolith gravel from roughly the 1350 masl to 1400 masl, grading into primary Middle Ecca beach deposit. This regolith gravel covers almost the entire Cargonian Highland area from Wolmaransstad northwest to Schweizer Reneke, and south-west to Christiana.

The Boesmanland/Harts River flexure axis (Du Toit, 1910) forms the watershed between the Harts River drainage towards the west, and the Vaal River drainage towards the east. The axis appears to have been stable since the Permian (horizontal Ecca beds in the area). The widespread and deeply weathered saprolite, which may equate with the African Surface *sensu stricto* of Partridge and Maud (1987), together with the associated shallow water table along the axis, confirms the long-lived tectonic stability.

Evidence of diamonds in the Carboniferous glacial Dwyka sediments and Permian marine Ecca sediments suggests that diamonds recovered from the ***diamond-triangle*** area and deposits are from older pre-Carboniferous diamondiferous kimberlites (see Table 1 below), and were transported from north-east interior to the southwest by Pre-Karoo fluvial systems and Dwyka glaciers (see Figure 1).

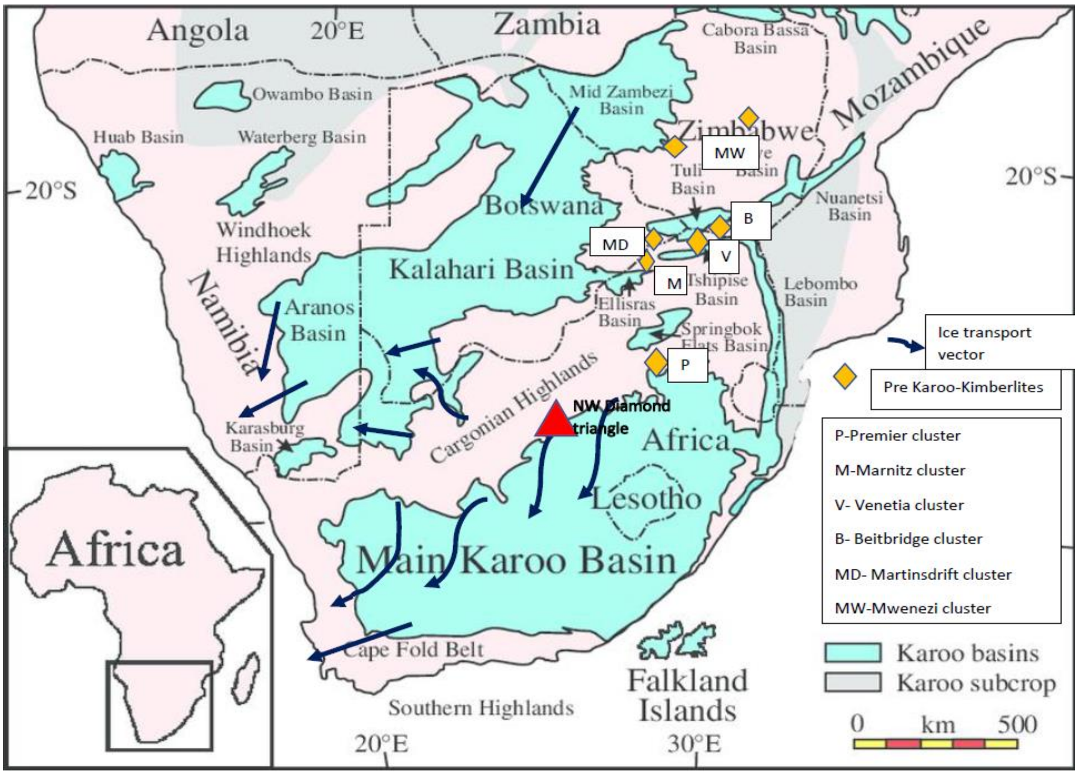

Figure 1. The NWP diamond-triangle (in red) and pre-Karoo kimberlite positions relative to the Cargonian Highland, Carboniferous Dwyka ice transport vectors, and Karoo Basin.

Reworking of the Dwyka glacial sediments during the Ecca regression (and transgression) phases produced a considerable amount of heavy minerals, including diamonds, garnets, ilmenite, spinel, and other heavy minerals, that were deposited in a beach deposit with no or very low intertidal zones. This setting and process also gave rise to the extensive high quality (reworked) diamond bearing beach-deposits that produced a well sorted, high quality alluvial gemstone diamond population since 1912. The famous heavy mineral deposits of Bothaville, Carolina and Delmas (Behr, 1964) are further examples of ancient beach-facies reworking of heavy minerals and coincide with the study area.

Previously, Du Toit (1954) noted a correlation between alluvial diamonds in the Carboniferous glacial sediments in western Brazil and Bolivia, and Tompkins and Gonzaga (1989) described the derivation of diamonds from glacial outcrops in Brazil. Von Gottberg (1970, 2006) argued that Dwyka rocks in the area under discussion are the source of the alluvial diamonds in the NWP ***diamond-triangle***. Harger (1909), Moore and Moore (2004), Van Der Westhuizen (2012), Bosch (2017), and Dlakavu (2021) have demonstrated far reaching evidence for secondary Dwyka glacial sources playing a key role in the development of land-based and marine (West Coast) diamond deposits in southern Africa.

The Cargonian Highland remnant represents the African surface (Partridge and Maud, 1987), and consequently the adjacent Karoo sediments of the diamond triangle were subjected to a long period of chemical surface weathering (regolith). The extensive high-quality alluvial diamond deposits of the NW Province ***diamond triangle*** which have been exploited since 1912 are interpreted as hidden primary Ecca marine sediments in a regolith remnant at the Permian-Carboniferous interface (see Table 1 below) which overlie the Proterozoic and Archaean rocks of the Cargonian Highland.

	Kimberlites	Author(s)	Age (Ma)
Post Ecca	Orapa	Haggerty et al., 1983	93
Kimberlites	**Initiation of Orange River Fluvial system**	Ward and Bluck, 1997	**100**
	Barkley west, Koffiefontein,De Beers	Phillips et al., 1998	118-117
	Sandrif, Finch, Lace, Star, Voorspoed	Phillips et al., 1998	135-120
	Swartruggens, Klipspringer	Westerlund et al,. 2004	144
	Dullstroom	Jelsma, 2004	165
	Dokolwayo	Allsopp and Roddick, 1984	200
	Jwaneng	Kinny et al., 1998	243
	Ecca Group	Hartzer et al., 1998	280-260 Ecca
	Dwyka Group	Hartzer et al., 1998	312-280 Carboniferous
Pre Dwyka	Beit bridge cluster	Kramers and Smith, 1983	430
Kimberlites	The oaks kimberlite cluster	Phillips et al., 1998	505
	Venetia cluster	Allsopp., et al 1995	519
	Mwenezi cluster	Phillips et al., 1997	533
	Premier group	Allsopp et al., 1977	1180
	Maartinsdrift group	Jelsma, 2004	1650
	Wits conglomerates	Smart et al., 2016	>2 900 Archaean

Table 1 – Summary ages of kimberlite intrusives in southern Africa in relation to the alluvial diamond deposits of the NWP *diamond-triangle*.

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Pierre de Jager – *Pierre obtained a BSc Honours from Nelson Mandela University (University of Port Elizabeth) and has pursued a career which includes diamond exploration with De Beers Consolidated Mines (4 years), geophysics with J.C.I (2 years), mine geologist at Kloof Gold Mine for G.F.S.A. (2 years), group geologist for Multi Gold Holdings (2 years), and exploration geologist with Rand Mines (1 year) He has been self-employed since 1989, initially owned and operated alluvial diamond mining projects in the Northern Cape, and has subsequently become a highly knowledgeable consultant alluvial diamond consultant geologist with over 20years experience in the Middle Orange River, North West Province diamond-triangle, DRC (eg. Kasai terraces and river diversions for Namakwa Diamonds), Angola, Sierra Leone, and Cameroon, and other areas of southern Africa.*

ALLUVIAL DIAMOND DEPOSITS OF THE LOWER-VAAL, RIET, AND MIDDLE ORANGE RIVERS : THEIR CHARACTERISTICS, DIAMONDS, AND MINING

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South Africa is endowed with remarkable geological, geomorphological and climatic conditions which liberated diamonds from numerous Cretaceous and older, kimberlitic sources and concentrated diamonds in Karoo basins, paleo-river systems (eg. Molopo, Harts, Riet, Vaal, Orange, and others), and in west coast marine placer deposits. These ancient riverbeds and marine deposits of the Northern Cape Province (including the West Coast marine deposits) and North West Province, and elsewhere, still contain millions of tonnes of low-grade diamond bearing gravels. The gravels yield exceptional high-value gemstone diamonds, as they have done since the discovery of the first diamond in an alluvial setting at De Kalk on the Orange River between Hopetown and Douglas in 1866.

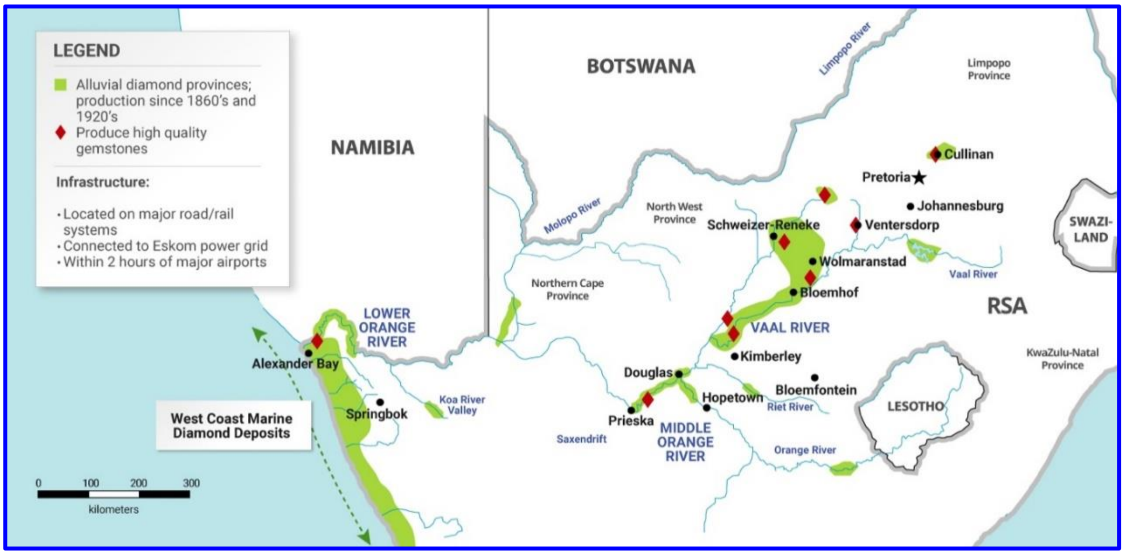

Figure 1 – Alluvial diamond deposits of South Africa

Geology and diamond population's – Overall the alluvial diamond deposits of South Africa (Figure 1) represent the highest and most consistent value per carat diamond supply in the world, with some areas averaging upwards of US$7000 per carat. Table 1 shows a comparison of some of the average ROM US$ per carat values for deposits in South Africa.

Riet River alluvial deposits represent a series of overlapping splay deposits formed where the proto-Riet exhumed a narrow gorge cut through a Ventersdorp quart-porphyry dome by Dwyka age glaciers. Deposits close to the gorge exit were characterized by exceptionally large boulders, very low grades, and yielded some large and exceptional diamonds, probably sourced from kimberlites such as Koffiefontein, Jagersfontein and the Kimberley area. Grades decrease downstream and most of these deposits have been mined out.

Studies of the alluvial deposits of the Orange River between *Hopetown and Douglas* have shown that the source of the diamonds in the section between Hopetown and Douglas, upstream of the confluence, are most likely the kimberlites in Lesotho. This is borne out by the high proportion of exceptional D-colour Type-II diamonds, with average USDollar per carat values in excess of US$7000 per carat in today's market (Figure 2), and rare pink stones which are characteristic of the Lesotho diamond mines, particularly the Kao kimberlite. The grade (carats per hundred tonnes) in this area can only be described as ultra-low and varies between 0,1 and 0,2 cpht. The location of the deposits along this stretch of the river is strictly controlled by a series of gorge and splay features and the availability of Carboniferous Dwyka diamictite clasts play a key role in diamond concentration.

The Orange River between *__Douglas and Prieska__* is characterized by a gradient that is less (flatter) than that between Hopetown and Douglas. Large incised meanders with an average amplitude of about 6 km with a wavelength of 13 km are typical (Gresse, 2003). About 33kms downstream of the confluence, McCarthy (1983) identified a large drainage from the north which introduced considerable volumes of banded ironstone into the Orange River deposits. The added mass and high SG of the banded ironstone added to the bedload and increased the ability of the system to trap and retain diamonds.

Several terraces have been preserved along this stretch of the river, with the highest situated on the farm Waaihoek, on the edge of the Ghaap Plateau at +200m above the current river. There are also terraces at +110m, + 70 m and +20 m. Differences in the composition of the sediments in these terraces reflect their provenance and has a direct correlation with grade (Gresse, 2003). Grades in the area value between 0,2 and 1 cpht, depending on elevation and trap-sites present, with average diamond values vary between about US$1800 and +US$3500 per carat, depending on the terrace elevation and whether the Vaal or Orange River was the dominant diamond source system at the time (Figure 2).

Figure 2: Exceptional rough diamonds from the proto-Vaal and Middle Orange River alluvial gravel terraces, Northern Cape Province, RSA (2006 – 2009)

Technology driving efficiency – The primary challenge in mining these deposits is that the grades (expressed as carats per hundred tonnes - cpht) can best be described as ultra-low, hence delineation, evaluation, and successful exploitation is challenging. Prospecting, mining, processing and recovery methods have advanced rapidly in recent years, as generations of local Small and Junior alluvial diamond miners ('Delwers'), and a number of Small kimberlite mine operators, have developed the skills and experience to unlock value from these varied deposits which produce exceptional diamonds.

The ability to observe and understand the geological subtleties of these deposits has played a key role in their exploitation. In the past 30 years the role of detailed geological investigations by the likes of McCarthy (1983), numerous comprehensive Technical Studies and CPR's by listed companies who have entered the business at times, and the authors of this abstract, have added value to the sector. Regrettably very little of this modern information is readily available in the public domain or easily accessible through the Council for Geoscience, hence disadvantaging new entrants.

Modern equipment and technology, including large-scale earthmoving equipment is aiding economies of scale required to mine the remaining low-grade deposits. Many deposits are covered by hard-pan calcrete that requires drill and blasting or large dozers to rip and break calcrete to expose underlying gravels. The development of mobile (in-pit) screens now makes it possible to screen out 60-70% of the ROM material at the mining face thereby reducing transport costs and rehabilitation costs. High frequency scalping screens, allow efficient de-sanding of gravel product before processing through the concentration plants.

The value of large and exceptional diamonds found in the study area outweigh the value of the smaller diamonds by an order of magnitude, hence a bottom cut-off of 6mm is used thereby reducing feed to processing plants (typically rotary-pans), with considerable efficiency and cost benefits. At 6mm, approximately 75% of the overall diamond content (mainly small diamonds) are screened off, representing only about 5-7% of the value (De Meillon, PhD in preparation).

Table 1 – Modern technology applications for alluvial diamond mining

	Equipment	Applications
1	Digital Elevation Modelling	Recognition of regional/local terrain features, 'splays', gradients, prioritization of targets areas of local 'heavy mineral' concentration
2	Drone Surveys	Delineation of structural controls, deflation (Rooikoppie) deposits; rapid/accurate surveys and monitoring of mined areas, resource depletion, rehabilitation
3	Geographical Information Systems (GIS) + Databases	Cost effective large multi-data storage and management, mapping, delineation, and interpretive tool
4	3D-Modeling packages	Rapid and effective delineation of geological and bedrock controls that create localized areas of diamond concentration
5	Reverse-Circulation Drilling	Resource delineation, stripping, mine-planning; identification of bedrock features, delineation of bed-rock features, scours, plunge-pools, and other concentrating features
6	In-Pit Screening Units	Efficient removal of gravel 'oversize' at the mining face reduces handling/transport, water use; 'enhances' grade and cost savings
7	High-frequency scalping (screening), de-sanding	Efficient removal of -3 to 6 mm fraction has revolutionized the industry; allows mining of ultra-low grade, high diamond value deposits; enhances processing efficiencies, reduces water use and costs
8	X-Ray Recovery systems eg, Bourevestnik (BV) systems (Russian)	Primary diamond and tailings reprocessing for efficient large and small diamond recovery; modular containerized units; high security; minimal diamond breakage
9	X-Ray Tomography Mineral Particle Sorters (XRT)	Efficient recovery of large and exceptional Type-IIa and IIb diamonds; minimizes diamond breakage; key reason for so many large stones recovered in the past 10 years
10	AI* CCTV Security and Site-Monitoring Technology (AI* – Artificial intelligence)	Local, remote monitoring of sensitive mining, processing, final recovery operations; monitoring of access routes to guard against incursions + crime; reduces product shrinkage; powerful management tool.

Bulk X-Ray machines and X-Ray transmission (XRT) plant have made it possible to recover diamonds more efficiently. Collectively these applications and the use of technology as summarised in Table 1 allows low and ultra-low grade deposits to be mined economically. Overall, the success of the modern entrepreneurial alluvial miner is a reflection of their ingenuity, adaptability, 'home-grown' expertise, and ability to move and start up a new operation in a very short space of time (typically less than 6 weeks).

Carboniferous Dwyka glacier impacts - Work by the authors on the transport (regional and local) and concentration mechanisms in the alluvial systems and precursor Dwyka sequences have played a key role in the successful delineation and mining of these deposits. Likewise other recent studies on the evolution, transport and diamond distribution of the lower Orange River system by Van der Westhuizen (2012) and others, have led to a revised diamond-dispersal model operated in the lower Orange River system, which included the effects of: (1) pre-Karoo drainages; (2) Dwyka ice sheets and glaciers, and (3) post-Karoo drainages, of which the Orange-Vaal system has been the most important for at least the last 100 Ma (Jacob, 2005).

Although it has been proposed that South Africa's deeply weathered Cretaceous (66 – 145 my) kimberlites were the main source of the inland and West Coast alluvial Diamonds (De Wit, 1993, 1999), clusters of older diamondiferous pipes have also shed diamonds which ended up on the west coast, including some large stones. Important diamondiferous kimberlite clusters, including much older Premier (~1 200 my) and Venetia (~ 550 my) deposits, predate Karoo sedimentation, which took place between 300 and 190 Ma ago. These older kimberlites would have been subjected to rock-mass destruction and transport by Carboniferous Dwyka glaciers and their associated drainage systems. Pre-Karoo weathering and erosion with weathered material and detritus moving within pre-Karoo drainages would have also contributed additional diamonds.

Mineral policy and Red-tape - Small and Junior diamond miners were once numerous in South Africa's alluvial and small kimberlite (dykes, small pipes, and 'blows') sector. Their numbers have been decimated by adverse minerals policy and regulations, 'one-size-fits-all' mine health and safety policy challenges, and unnecessary red-tape. Prior to 2004 there were more than 2 000 small diamond operators in the country, whereas a recent study (Dlakavu, 2021) reported about 220 small and Junior diamond operators left in RSA. Lengthy delays in securing mining permits and water licences, lack of funding for entrepreneurs, and the policy and regulatory challenges noted above represent some of the key challenges that confront start-up and existing alluvial diamond miners.

The experience, skills, technology, and markets exist to ensure the successful recovery, exploitation, and marketing of the exceptional diamonds that are recovered from these deposits, and millions of tonnes of low- and ultra-low grade gravels are still to be found in the Northern Cape (and West Coast) and North West Provinces. An enabling minerals and mining policy environment and less red-tape are required to rebuild this important sector and create economic growth and employment.

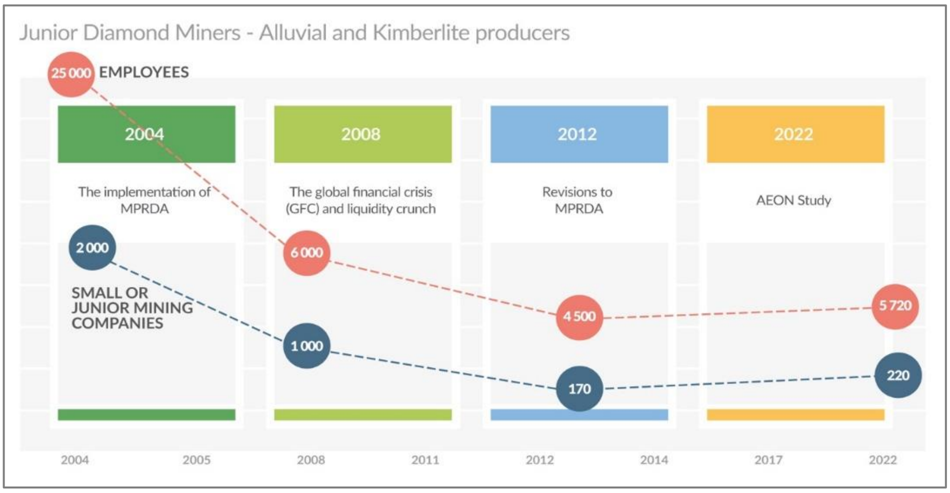

Figure 3: Summary of Junior diamond mining companies and employee numbers
(Sinazo Dlakavu (AEON-NMU, 2020), Farrell (2012), SADPO, GDN)

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Lyndon De Meillon - *Lyndon has 30 years of experience in diamonds. He has an MSc degree in Geology/Oceanography, and started his career at De Beers as an Exploration Geologist. During the next 15 years he was operations Manager or COO of various public and private companies mining alluvial diamonds, mainly along the Middle Orange River. About 10 years ago he started-up his own*

alluvial mining venture and is currently co-owner and CEO of 3 private diamond mining operations on the Lower Vaal and Middle Orange Rivers.

Dr John W Bristow *– BSc Hons, MSc Geology (Natal), PhD Geochemistry (UCT), Post-doc Univ New Mexico, Tourism Diploma (UNISA). John has forty years in geological research, mineral's exploration, project development, mining, manufacturing, and marketing (primarily in the diamond sector), with extensive local, African, and international experience. He has successfully created and operated private and listed Junior exploration and mining ventures, with related executive and directorship roles.*

Sinazo Dlakavu *– Sinazo completed a BSC geology at Rhodes University and an MSc at the Nelson Mandela University African Earth Observatory Network (AEON) Institute studying ground water samples extracted from boreholes in the southern Karoo as part of a regional shale-gas research program. She undertook and completed a detailed field investigation and comprehensive report (NMU AEON Report Series #7) on the of the small and Junior diamond sector from late 2018 to early 2021.*

Artisanal mining of Rooikoppie gravels in 'makondos' on Brakfontein Terraces, MOR (1998)

Rotary pan and sorting table for processing and recovering diamonds, Brakfontein, MOR (1998)

ALLUVIAL DIAMOND DEPOSITS IN AFRICA

Dr Tania R Marshall, Dr John Ward^, Dr Mike C J de Wit"*
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Africa is by far the most productive continent with respect to diamonds. While this refers primarily to kimberlite deposits, it is also true of alluvials. It is true that volumetrically, alluvial diamond production is insignificant, however, the gem-quality diamonds produced by the alluvial deposits is an important contributor to the economies of many countries, especially by way of small-scale and artisanal mining.

In Africa, we find alluvial deposits at all ages in the geological calendar – from the Archaean all the way to still developing today. However, by far the majority of the deposits are in the Mesozoic and Cenozoic. In addition, the deposits are also found in a number of different depositional environments, from proximal to source, all the way to the sea, and pretty much everything in between. Many of these alluvial deposits are obviously related to known primary kimberlitic sources. But, for others, the source is far more enigmatic – undiscovered kimberlites (or other possible diamond sources), multiple cycles of erosion are all possibilities.

An investigation of African alluvial diamond deposits demonstrates how levels of erosion, local and continental geomorphology and landscape evolution affect the type of deposit formed as well as influence its economic potential.

Dr Tania R Marshall *has a PhD from the University of the Witwatersrand (1990). In 1996, Dr Marshall founded Explorations Unlimited and has been actively involved in the alluvial diamond and gemstone exploration/mining industry, locally and internationally. Dr Marshall is a Fellow of the Geological Society of South Africa, a Member of the Southern African Institute of Mining & Metallurgy, a life member of the Geological Society of Africa and is registered with the South African Council for Natural Scientific Professions. In addition, she is the current President of the GSSA. She is the immediate past Chairperson of the SAMCODE Standards Committee and the Chair of the Diamonds/Gemstones Working Group. She is also an Adjunct Visiting Professor at the Department of Mining Engineering at the University of the Witwatersrand, where she lectures in professional ethics as well as Compliance and Reporting in the Minerals Industry.*

THE DIAMOND COAST: A HISTORY OF PEOPLE, WILD IDEAS, INNOVATION, AND LEARNING

Ian Corbet
(Consultant)

For the prospector, nothing is more compelling than making the find of one's life! For explorationists seeking to make their name, there is nothing worse than missing an opportunity.

Few experience the first. Rather more enter the somewhat less exclusive club linked to the second. The only certainty is that the adrenalin rush of the next find will, as it has for centuries before, continue to drive people to venture to extraordinary places to do extraordinary things!

History abounds with examples of fabulous riches hidden in remarkable landscapes. The Diamond Coast on the southwestern margin of Africa does not disappoint. It too has earned its place in "placer" history.

At first glance, the setting in which this story unfolded differs markedly from where people had ventured before. Perhaps, that is why it apparently went unnoticed by those passing through earlier – we shall never know.

In Namibia, as in the Yukon before, initial discovery ultimately fell to a local man, Zacharias Lewala, a railway worker who discovered the first diamond at Kolmanskop would from then on be immortalised in history. So began a story that, 114 years later, as you will see, is still evolving today.

Like all great stories, controversies abound, both in terms of who was responsible for various discoveries along this vast tract of land as well as when and how the diamond deposits came to be.

Following their initial discovery in 1908, innovation led rapidly to some of the most advanced (and audacious) placer mining operations in the world being established in the hostile Namib desert. Gradually, as knowledge of the deposits grew, many concepts as to the origin of the diamonds emerged. The names of those involved reads like a geological "hall of fame".

As with the other great placer fields of the world, the majestic scale is one of the most dramatic aspects of the Diamond Coast deposits – the other perhaps unique element is the range of different sedimentary environments in which the deposits occur. Multiple cycles of innovation were required to discover and access the full spectrum of the onshore Mineral Resources. Ultimately one such cycle of innovation brought Sammy Collins to the coast, whereupon he is famously supposed to have asked "If the diamonds are here right on the coast, why don't they continue out there?" As is so often the case in hindsight, obvious questions are often the hardest to ask.

Putting Collins' theory to the test would prove to be quite another thing altogether. Initially, larger than life figures launched forth and fortunes were won and lost. The journey would prove to be a challenging one, in which the ability to take the long view, a hallmark of De Beers, would win through. But this brings with it the challenge to learn with the long view in mind, avoid pitfalls created by forgetting what has gone before, and keep operations improving continuously. A challenging task as the baton passes from one generation to the next, and the advance of technology marches on.

Beach mining for diamonds on the south-west Namibian coast, Atlantic seaboard

Dr Ian Corbet (*BA Geology Hons Dunelm; MSc Applied Sedimentology, Reading; PhD Geology & Mineralogy UCT; Advanced Management Pgm Oxon). Ian has extensive research and field experience in major diamond, gold and platinum placer provinces of the world. He worked as the Consulting Geologist Placers and Intellectual Capital Manager for De Beers Exploration & Operations Division prior to establishing an international consultancy in Knowledge Management. Now retired, he has a continuing interest in West Coast sedimentology.*

ORIGIN AND DEVELOPMENT OF THE WEST COAST MARINE DIAMOND PLACERS OF SOUTHERN AFRICA: THE NAMAQUALAND (RSA) PLACER AND SPERRGEBIET (NAMIBIA) MEGA-PLACER (THE WORLD'S RICHEST GEM DIAMOND DEPOSIT)

John Ward and Mike De Wit^*
*(*Namakwa Diamonds, ^University Stellenbosch)*

The West Coast of southern Africa hosts two major, gem quality diamond terminal placers developed in predominantly marine deposits with subordinate fluvial and more rarely, aeolian, deposits: (i) Namaqualand Placer of South Africa and (ii) Sperrgebiet Placer of Namibia. Both these major placers are the end member of a classic "source to sink" geological model involving proximal reach placers on the Kaapvaal craton, mid reach placers through the marginal orogenic belts to terminal placers on the littoral tract along the Atlantic coast of southern Africa. These two terminal placers have seen the maximum concentration of gem quality diamonds in mainly marine deposits along the West Coast of southern Africa emplaced by two separate but evolving drainage systems since the break-up of West Gondwana:

1. ***Namaqualand Diamond Placer:*** Older, but smaller, terminal placer along the Namaqualand coast of South Africa was emplaced during the upper-part of the Mesozoic but reworked and upgraded during the Cenozoic. The Namaqualand Placer diamonds were sourced predominantly off the Kaapvaal craton from primary sources older than the main Cretaceous kimberlite emplacement phases and from Phanerozoic and older sedimentary deposits via the Karoo River. The subsequent dispersion along the Namaqualand coast was by the virtual total reworking of the Cretaceous marine deposits by Cenozoic sea level high stands and their subsequent erosion by short-reach fluvial systems across the coastal plain to younger, lower-lying marine deposits.

   In general, the diamond size is smaller and the overall diamond content less in the Namaqualand placer compared to the Sperrgebiet Placer – a consequence of not tapping the widespread Cretaceous kimberlite sources and a less incised, lower gradient fluvial system transporting from the Kaapvaal craton to the Atlantic sink at that time. Therefore, although running at 95% gem quality, the Namaqualand Placer – having yielded about 50 million carats to date and not that amount again in the remaining deposits - does not meet the minimum 100 million carat requirement of a diamond mega-placer.

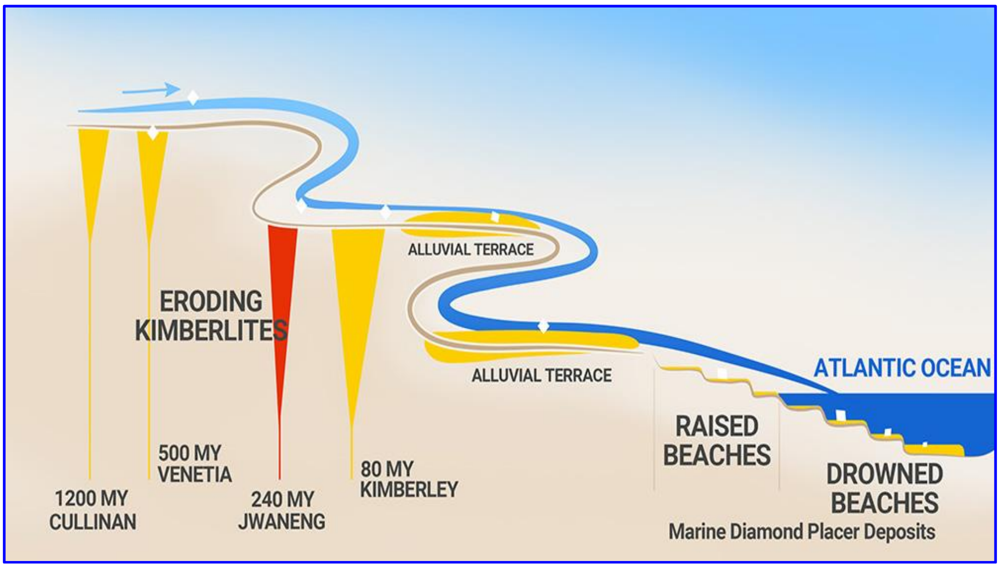
2. ***Sperrgebiet Diamond Place:*** Younger, but considerably larger, terminal placer emplaced and reworked during the late Cretaceous to Cenozoic that conforms to the mega-placer definition of >100 million carats at 95% gem quality diamonds. The input of diamonds from the interior sources, included diamonds from the Cretaceous kimberlite phases on the Kaapvaal craton, to the Sperrgebiet placer occurred as noted above took place through the Cenozoic. The overall diamond size and grades were small and low grade in the early Cenozoic, followed by increasing size with maximum grade in the mid Cenozoic, and then maximum size but minimum grade in the Late Cenozoic.

   The Sperrgebiet Placer demonstrates a northward-diminishing diamond size away from the outfall of the Orange River which has been the long-lived fluvial conduit to the Sperrgebiet Placer. From this outfall northwards, the marine deposits hosting the bulk of the diamonds in this mega-placer transition from barrier beach through linear beach to pocket beach marine deposits with a corresponding decrease in average diamond size from 1-2 carats/stone to 0.1 carats/stone along this natural sedimentary sorting path over an initial 300 km. Within the pocket beach reach of the Sperrgebiet placer, unusual localised sedimentary processes have reworked and concentrated older marine deposits into a series of deflation and aeolian diamond-bearing deposits that were incredibly rich, adding to the unique character of the Sperrgebiet Placer.

The origin and development of the Sperrgebiet Placer has provided the background for a generalised "Source to Sink' geological model for diamond placers as well as defining the top end of a diamond mega-placer as a deposit with at least 100 million carats of 95% gem quality diamonds.

John Ward *- John holds a Doctorate in Geology (PhD from the now UKZN) and has worked in about 26 countries, 20 of which were in Africa, mainly on alluvial and kimberlite diamond projects ranging from greenfields exploration through to large-scale mine production operations. Apart from his current consulting, John has also worked for a major, and two junior diamond companies and is the recipient of two medals (Oliver Davies medal and Henno Martin medal) for his contribution to academic and economic geology in southern Africa. He is a Life Fellow of the Geological Society of South Africa, a Life Member of the Geological Society of Namibia and SASQUA respectively, and a SAMREC Competent Person in primary and secondary diamond deposits.*

Michiel ('Mike') C. J. de Wit *– Mike holds MSc degrees in geophysics and sedimentology from the Universities of Pretoria and Reading (UK) respectively, and a PhD degree from the University of Cape Town. He has some 40 years of exploration experience primarily in the diamond industry, having begun his career as an exploration geologist for the Geological Survey in South Africa prior to joining De Beers, where he worked for 29 years. He managed various exploration programs for De Beers in Africa which led to a number of kimberlite discoveries, and assumed responsibility for all De Beers programs in Africa, including general manager for De Beers in the DRC. Since leaving De Beers, Dr de Wit has worked on a number of diamond and base metal projects in Africa including Botswana.*



Schematic diagram highlighting the concept of "source to sink" diamond placer development

AN OVERVIEW OF SOUTHERN AFRICAN MARINE DIAMONDS

Urban Burger
(De Beers Marine)

Diamonds have been recovered from the sea on the west coast of southern Africa for over 60 years from De Punt in the south, to Hottentots Bay in the north, along a stretch of coastline spanning 700 kilometres. Marine diamond deposits can roughly be divided into shallow-, mid- and deep-water deposits. The recovery of diamonds from the shallow-water deposits has traditionally been the domain of small-scale diver operations working to depths of no more than 30m. The mid-water (between 30 to 70m) has been the domain of mid-tier companies of which many have come and gone over the years, whilst the deep-water deposits, situated between 120 and 140m below sea level, have been exploited with great success by sister companies De Beers Marine Namibia and De Beers Marine South Africa, since 1990.

The diamonds found in the offshore placer deposits along the west coast of southern Africa have been transported to the coast by rivers from the richly endowed kimberlite provinces found on the Kaapvaal Craton. Several episodes of regional uplift, starting in the late Cretaceous, caused severe erosion and subsequent denudation of the interior. This resulted in the deposition of large quantities of sediment and diamonds onto the continental shelf. The offshore sedimentary sequence is capped by a diamondiferous gravel lag that formed in response to several episodes of deposition, uplift and erosion. The west coast is a high energy environment where sand and gravel are carried northwards by a powerful longshore drift under prevailing strong southerly winds. Deep-water deposits are present in South Africa along the Namaqualand coast and have been exploited with mixed success in the past. The Atlantic 1 deposit, situated offshore, just to the north of the Orange River mouth, has been by far the most economically significant marine diamond deposit.

The deposition of diamondiferous gravels onto the Atlantic 1 shelf occurred during sea level low stand events since the Eocene. Repeated reworking and winnowing of the deposits, especially during marine transgressions and regressions driven by Plio-Pleistocene glaciations resulted in a very variable and complex deposit. The footwall, on which the gravel lag rests, consists of clays, sands, sandstones and conglomerate. The shelf is relatively flat, but the varying hardness of the sedimentary units and their subsequent response to erosion, resulted in subtle changes in footwall topography. This topography, in combination with the texture of the gravel, have a big influence on diamond concentration, which is highly variable.

In order to successfully recover diamonds from the deposit, De Beers Marine Namibia first conducts detailed geosurvey and sampling operations. High resolution geophysical surveys using autonomous underwater vehicles gather detailed information of the seafloor and orebody. This is followed by sampling using a dedicated sampling vessel. These in-depth survey and sampling activities are used to construct geological models and generate a resource inventory.

Diamonds are recovered from this resource by a fleet of 7 production vessels that utilise highly advanced technology, supported by sophisticated tracking, positioning and surveying equipment. Two diamond recovery techniques are utilised to suit different ground conditions. Airlift-drill technology is deployed off 5 vessels and utilises a 6.8m diameter drill bit working in overlapping circles on the seafloor, whilst crawler systems are deployed off 2 vessels and uses a 280 tonne, track-mounted crawler dredging on the sea floor. Once the dredged gravel reaches the vessel, it is washed, screened and concentrated using x-ray technology to recover diamonds, and all of the 'reject' materials, are returned to the seafloor.

The rehabilitation of the marine environment occurs naturally and recolonisation and recovery takes place once operations have ceased in a particular area. Comprehensive environmental studies have been ongoing since the beginning of production in 1990 to understand the consequences of diamond recovery and to monitor changes over time. Ongoing monitoring surveys are conducted by independent scientists and peer reviewed results are published annually.

De Beers Marine Namibia has produced more than a million carats annually since 2006 and aims to maintain this level of production for the foreseeable future. With 95% of production being of gem quality, they are the sixth largest diamond producer by value. De Beers Marine South Africa operated a crawler vessel in the deep-water deposits off the Namaqualand coast between 2007 and 2010.

Debmarine Namibia's latest diamond recovery vessel, the Benguela Gem

Debmarine prospecting vessel construction
https://www.youtube.com/watch?v=6y6B14NND8A

Benguela Gem
https://www.youtube.com/watch?v=JmX74Nn6PJg

Urban Burger – *Urban has a BSc Honours degree in Geology from the University of Stellenbosch and an MSc in Earth Science Practice and Management from the University of Pretoria. He has some 25 years' experience in the profession, most of it gained in the diamond industry, but has also worked on placer gold deposits. He has worked on kimberlite (primary), fluvial, marine and aeolian diamond deposits, with extensive related experience in production geology, exploration, various types of drilling, sampling and sample treatment, geological modelling, resource estimation, mineral resource management and mine planning. He is a member of the Geological Society of South Africa, and a registered Geological Scientist with the South African Council for Natural Scientific Professions.*

THE RESURRECTION OF THE HELAM FISSURE DIAMOND MINE: SWARTRUGGENS, NORTH WEST PROVINCE, SOUTH AFRICA

Jim Davidson
(Helam Mining)

By and large, fissure (or kimberlite dyke) Diamond Mining has only been practiced successfully and sustainably in South Africa. The fundamental reason for this being the abundance of relatively inexpensive labour for labour-intensive operations, interwoven with the abundance of entrepreneurial mining individuals (and South Africa had many), who prospected for and found these deposits. These occurrences were always found at surface and were always initiated on a “shoestring” budget (except Klipspringer) and opened-up by entrepreneurial development.

There are many fissure deposits in South Africa, however, only a handful of them, namely Helam, Bobbejaan, Star, Bellsbank, Ardo/Duplessis, and Klipspringer, have been mined successfully to any great depth (named from deepest at 750m to shallowest at 200m approximately). Usually, with the exception of Klipspringer, these deposits were found, started and mined successfully by individuals who then on sold them to larger companies. Because of the way these mines were started, these operations were always “capital starved”, until “recapitalized” by the purchaser, who in many cases was ill-advised by the myriad of “specialists” that abound in abundance in the mining field.

All these fissure mines have in the past been plagued, firstly, with an ore-dilution problem that emanates from their intrusion where all (in southern Africa) have a well-developed parallel fracture cleavage that comes away with mining to a greater or lesser degree. This is also dependant to some extent on the host rock intruded into. This parallel fracture cleavage is actually a benefit if handled correctly (by wizened old specialists in the blasting of fissures), or it becomes a dilution nightmare if done by a young miner (who usually had his training in hard rock gold or platinum mines). Today, the latter represent the majority source of available miners, so a lot of mentoring is required before these young inexperienced miners are let loose in the stopes so that one is not overwhelmed by waste-diluted ore.

Secondly, the waste dilution is the result of the mining method chosen. Fissure mines, fundamentally, operate on one of two mining methods - underhand or overhand stoping. There is a dramatic effect on the grade between the two methods. The recovered grades of Star vs Bobbejaan can be used as an example.

Fissure mines have historically been run as labour intensive operations, and circumstances have changed dramatically in recent decades, such that if the operators did not adapt rapidly, they soon became overwhelmed with costs due to numerous interrelated circumstances and challenges. Amongst others, these include winder duty cycles, ventilation, and dewatering. Typically, there will be issues with the duty cycle of the winder as the operation gets deeper. These are initially countered by numerous methods to combat the decreasing duty cycle with depth, but over time this overtakes the effort to combat the loss of duty cycle. Ventilation never receives the attention it deserved and as depth increases, this became a serious factor. Likewise ensuring that small and medium sized fissure mines are continuously dewatered also becomes an increasing factor as mining depth increases.

The above are just a few of the myriad of issues that are ever- present and have to be planned for in any fissure operation.

Finally, a key aspect given insufficient attention in the early stages of planning of a fissure mining operation, is the sale of the mined goods. It is essential that there are robust arrangements in place from the outset and that cash flow is not interrupted. If this is not in place the operation will be at the mercy of the many issues that will be encountered in disposing of the goods, including tender schedules, the South African Government's Diamond Valuator (GDV) and State Diamond Trader (SDT), and the South African diamantaires, amongst other challenges. It is also important to bear in mind that if you wished to export rough goods to (say) Dubai or Antwerp, there will be a 6% export levy and then a wait of possibly 6 weeks before the cash flow occurs. So, either have a very strong treasury or a well worked out (and solid) sales mechanism.

In the resurrection of Helam mine, all the above mentioned have been given considerable attention from the outset. A workforce of 600 used to slog to produce 400 tons of run of mine (ROM) ore in a day. The redevelopment of the mine is catering to produce the same number of tons with approximately 175 personnel. Mechanization is being practised wherever practicable, costs are being cut dramatically in most departments, and the ore processing plant has been modified to reef picking (as opposed to waste sorting). A new plant is also under construction which will utilise Autogenous Griding (AG) or milling and reef picking, and thereby do away with all crushers to improve comminution efficiencies and reduce diamond breakage. Historically (since 1990) the plant received no more than 23% kimberlite (due to dilution) and achieved a grade of 65 cpht (carats per hundred tonnes) as a result of the mining method (and what it allowed people to do). A modified mining method (on-level retreat mining), which is basically the same as a front-cave method, will be introduced. This new approach is a consequence of technology advances and the availability of narrow-vein TMM equipment, which Helam is adapting to. This new mining method should reduce the waste dilution and (in a worst-case scenario allowing for a 2m wide stope) increase the kimberlite content to 30%, and lift the grade to 85 cpht.

Since taking ownership three years ago, the mine has been dewatered (a billion litres of water), and all licences and permits have been put into place. Since May of 2021, when access was gained to long abandoned stopes on 22-level and subsequently 23-level, the mine has produced in excess of 9 000 carats at an approximate grade of 25 cpht, all from old stopes, done as reclamation mining and delivering approximately 8% kimberlite into the plant. In the three months of December 2021 to February (2022), 3 659 carats have been produced that have sold at an average price of $156 per carat

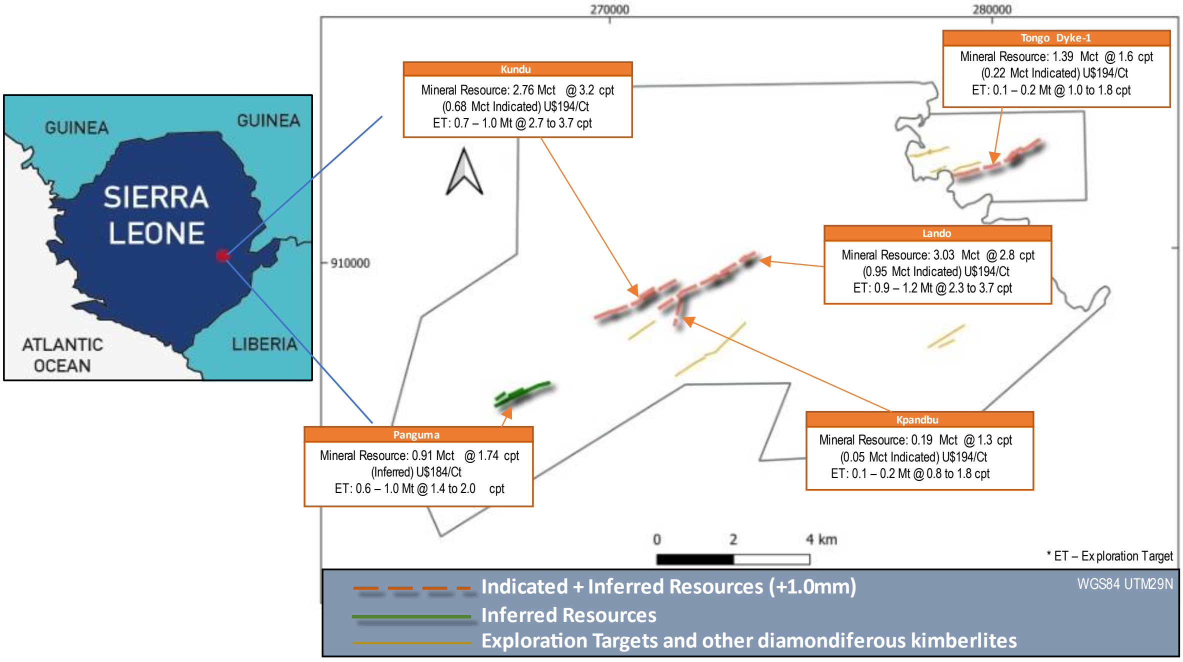
Now that the mine has been dewatered, we are busy re-supporting 24 level so as to get access to new ore. In approximately 4 months' time (August 2022) when the level will again be operational, the tonnage build-up of fresh ore will begin.

Jim Davidson *– BSc (Hons) Rhodes University, 1971. During his 51-year career in minerals exploration and mining, Jim has gained experience in diamonds, base and precious metals, coal, semi-precious stones, and uranium, with a major part of this time spent in the diamond sector. He has had exposure to all the facets of the diamond industry, and since 1991 has been intimately involved in mining, processing and recovery activities. He was the technical director for companies operating the Star, Bobbejaan and Helam fissure mines, and served as the technical director of Petra Diamonds for a period of 13 years, where he was also responsible for the discovery of KX-36 kimberlite pipe in the extensively sand covered area the Central Kalahari region of Botswana. After his retirement from Petra in 2018, he orchestrated the buy-out of the Helam mine with a BBEEE consortium and has spent the last three and a half years successfully rehabilitating and modernising this fissure mine.*

HISTORY, GEOLOGY AND DEVELOPMENT OF THE TONGO KIMBERLITE DYKES IN SIERRA LEONE, WEST AFRICA

Mike Lynn
(Newfield Resources Ltd)

Discovered in the 1950s, the Tongo dykes (Figure 1) are the eroded remnants of kimberlites emplaced into the West Africa (Man) Craton subsequent to Jurassic rifting of West Africa from South America. Erosion of the kimberlites following uplift of the rift shoulder, and at least three subsequent erosion events, liberated several million (probably tens of millions) of carats into the secondary environment. Mining of the eluvial and proximal alluvial deposits associated with the kimberlites commenced in 1956. Reliable records of the quantum of diamonds mined from the Tongo fields to the present day are not available, but at least 1.6Mct were mined up to the end of 1966 (approximately 160,000ct per annum) and large-scale production continued into the 1990s. Artisanal mining continues to the present day.



The dykes are near vertical to steeply-dipping intrusions of coherent kimberlite which show local variations in thickness from a few centimetres to over 1 m. The dykes show an apparent en echelon arrangement which is typical for kimberlite dykes, with individual lenses of kimberlite ranging from 100 to 200 m in length, marked by relatively thick centres which thin towards the ends, in some cases creating horsetail apophyses into the country rock. Small offsets of <2 m occur along strike, while the distance between en echelon dyke segments can be > 5 m. The dykes occur as one or more sheets or stringers in anastomosing networks, in some cases separated by >0.5 m of intervening country rock, and collectively define dyke "zones". The kimberlite comprises abundant (35-60 %), coarse (up to 25 mm in size), and variably serpentine-altered olivine grains, set in a groundmass comprising carbonate, serpentine, phlogopite, spinel, perovskite and minor apatite. The variation of olivine concentrations possibly reflects flow sorting during emplacement. A single blow (Kpandebu Blow) is known in the cluster. The country rocks comprise a dominant granodiorite and granite gneiss, with minor amounts of hornblende-facies amphibolite (<10 % of drill intercepts in country rock) and dolerite dykes (<2 %).

Kimberlite evaluation is achieved by extensive core drilling (over 75 km of drilling to date) to determine kimberlite geometry, to estimate bulk densities, to recover microdiamond samples (4.15t of microdiamond sample to date) and to map dyke zone thickness, waste/kimberlite thickness within the dyke zones, and olivine size and abundance ('macrocrystocity'). Based on initial production data, the size and abundance of olivine in the dykes appears to correlate quite well with grade and maximum stone size, but this has not yet been quantified. The drilling has been complemented by surface bulk sampling (~2,600 dry kimberlite tonnes to date) to confirm macro-diamond grade, size-frequency distribution of the diamonds, and to determine average diamond value.

Average grades of the (undiluted) kimberlite within the first two dykes being developed (Kundu and Lando) are 2.9 cpt and 2.5 cpt respectively (+1.18mm cut-off), whilst the total Diamond Resource (Indicated plus Inferred Resources) for the Tongo Project stands at 8.3 Mct (+1.0mm cut-off).

The diamonds are of generally high quality with only approximately 23% of rejections and boart. The Gem to Near Gem to Industrial ratios are very high for kimberlites and are similar to some of the higher value kimberlites known. In fact, they are closer to the ratios for most alluvial deposits. 38% of gem and near gem diamonds are sawables, and 31% makeables.

The level of top colour or collection goods is very high (40% to 50%). A small number of fancy yellows have been identified, as well as a single pink stone from the bulk sampling.

Only five (of 11 known) dykes have so far been evaluated to the Resource status, although all of the known dykes are diamondiferous. In addition, the dykes have only been evaluated to 100m or 200m depth. There therefore exists a longer-term pipeline of resource development which has the potential to make the Tongo Mine a generational asset. Small production from development tunnels has commenced and will continue to grow when stoping commences in mid-2022.

Mike Lynn *– BSc Hons (Portsmouth) MSc Exploration Geology (Rhodes). Mike has 37 years in the mineral exploration and mining industry, including 23 years with Anglo American/De Beers, six years consulting with The MSA Group, and seven years as an Executive Director with Newfield Resources Ltd (ASX: NWF). He has worked in many African countries as well as India, Brazil and Canada, in several commodities, including gold, coal, REEs, lithium, copper, cobalt, graphite and tin-tungsten-coltan. However, his passion remains diamonds, and he is a co-author of the standard references for diamonds in South Africa for the Council for Geoscience.*

DIAMOND MINING METHODS APPLIED TO KIMBERLITES AND LAMPROITES

Patrick John Bartlett
(Consultant Geologist)

The first diamond pipes in South Africa were found in 1869 and by 1891 all the major kimberlites in the Kimberley region and surrounds had been discovered and were being exploited by open pit "glory holes". Near surface mining of individual claims measuring 31 feet by 31 feet in the weathered "yellow ground" was done by pick and shovel. At increasing depths mining moved into the more competent blue ground and drilling and blasting were commonly used. Consolidation of individual claims was widespread. The "glory holes" ranged in depth from 70 metres (Bultfontein) to a depth of 240 metres (Kimberley Mine "Big Hole").

As mining continued to greater depths, all the major mines moved underground, using "chambering" – a mining method analogous in concept to sub-level caving - as their underground mining method. In the early 1950's the Kimberley mines, based on the experience of block caves in the iron-ore mines of the United States, moved to block caving using scrapers. Sub-level caving was used in some areas of competent kimberlite. Vertical Crater Retreat mining was also attempted.

Additional kimberlite mines, including Cullinan, Voorspoed, Finsch, The Oaks and Venetia, were subsequently found in South Africa. Cullinan, using drilling and blasting methods including open stoping and, after 1972 block caving, was operated as a "glory hole" to a depth of 280 metres. Finsch, operated as a benched pit, transitioned to underground using blast hole open stoping and then block caving. The Venetia kimberlite pipes were mined as a benched open pit and the mine is in the process of transitioning to underground mining using sub-level caving.

In total De Beers operated 7 "glory holes" 4 benched open pits, 23 individual block caves and 4 sub-level caves in South Africa.

Under the ownership of Petra Diamonds, block caving, sub-level caving and rim loading was used where deemed appropriate in the Cullinan, Finsch, Koffiefontein and Kimberley underground mines.
In South Africa, using current (2021) diamond prices, 10 mines have contributed in excess of $72 billion to the country.

In the early 1950's the Russian government undertook extensive prospecting for kimberlite pipes and by 1955 had discovered several kimberlite clusters in the vicinity of the towns now known as Mirny, Aikhal and Udachny. The high grade Aikhal, Mirny and International pipes were soon brought into production as open pits. All eventually transitioned to underground mining using cut and fill mining methods. The Udachny mine, using caving methods, moved to underground mining starting in 2004. Numerous other, generally lower grade, kimberlite pipes in Yakutia, some found many years ago and some more recently, have been brought into production as open pits as have the Arkangel and Grib pipes, located outside the Yakutia province.

The contribution of diamond mines to the remote Yakutsk area of Russia has been immense. More than 60 000 people, whose livelihoods depend almost entirely on diamond mining live in the towns of Mirny, Aikhal and Udachny.

In Botswana, the major diamond-bearing pipes of Orapa, Lethlakane and Jwaneng as well as other smaller pipes were found during the period 1965 to 1975 by De Beers geologists. All the mines have and are using benched open pits as their mining method. Jwaneng is in the process of planning an underground mine after 40 years of open pitting. The 2.4 million people who live in Botswana have derived large benefits from diamond mining. In 2018 diamond mining contributed 25% percent of GDP, 85% of export earnings and 33% of government revenues.

Numerous kimberlite pipes have been found in Angola but to date only Catoca has been brought into production as a major open pit operated by mining consortium that includes Endiama (State Mining Company) and Alrosa (Russian). Currently a new mine is being developed about 20kms north of Catoca at Luaxe by the same partners.

The Williamson Mine in Tanzania owned and operated by Petra Diamonds, is a major open pit. It is a large, low-grade resource. The recently closed, high-grade, low-diamond-value Argyle lamproite owned by Rio Tinto has been a major diamond producer since 1985 first as an open pit and then as an underground mine using block caving.

Numerous diamond bearing kimberlites have been found in Canada. The Diavik, Ekati and Gacho Kue mines used open pits to exploit small pipes in kimberlite clusters. Several of the pipes have moved to underground mining using sub-level crater retreat mining methods. Snap Lake was mined using underground methods and Victor was mined as a benched pit.

Geological, geotechnical and financial models are usually developed for any resource that is to be mined. Based on the geological and geotechnical models, a mining method must be selected to exploit to resource. The NPV of the resource for the Life-of-Mine needs to be calculated. The capital and operating cost of each phase of mining then needs to be determined. All pipes that transition from open pits to underground mining face similar financial and technical challenges. The cost, time and technical complexity required to go underground for a major diamond mine requires a major financial commitment and requires considerable technical skill. Any such enterprise incurs considerable financial and technical risk.

Examples of the mining of kimberlite pipe mines that range from a depleted mine (Bultfontein), a mature mine (Cullinan), a mine that is in the final phases of transitioning to underground (Venetia) and a mine that is planning to go underground (Jwaneng) are considered in detail.

The major operational, financial, and political risks that kimberlite pipe mines face, are considered.

Dr. Patrick John Bartlett *– BSc Hons (Rhodes), MSc (London University), D.I.C. (Imperial College London), BA (Economics and Communications UNISA), PhD (Mining Engineering Pretoria University), Management Development Programme (UNISA), USB- Ashridge International Executive Programme (Stellenbosch). Patrick started his diamond career in 1965 prospecting for De Beers Namaqualand Ventures in the Koingnaas area, worked for ASAM minerals along the lower Orange River, and after graduating worked for De Beers Consolidated Mines at Orangemund on the marine terraces and Orange River alluvials. He was involved in delineation and evaluation of Jwaneng, mine geologist in the Kimberley Mines Division with responsibility for Bultfontein, Wesselton, De Beers, Du Toit's Pan, Finsch, Koffiefontein and Letseng, and subsequently became the mine geologist at Cullinan (Premier) with responsibility for geotechnical services. He worked as a geotechnical engineer for Anglo American in the project that took Palaborwa underground, and retired as Chief Geologist for De Beers with responsibility for all kimberlite mines in South Africa and Botswana. He subsequently joined the Board of Rockwell Diamonds who mined alluvial deposits along the proto-Vaal and Middle Orange River and, later, the Board of LSE-listed Petra Diamonds who were operating the Cullinan, Finsch, Koffiefontein, Mwadui and the Kimberley mines as non-executive director. Since retirement he has worked on various projects and reviews for De Beers, Anglo American, Rio Tinto, BHP and Alrosa. He is currently involved with the project taking De Beers Venetia mine underground, and with Petra Diamonds.*

MODERN DIAMOND PROCESSING TECHNOLOGY WITH REGARD TO LARGE SCALE KIMBERLITE PROCESSING

Derek Lahee
(Consulmet)

Consulmet has recently been involved in the design of 2-off large Kimberlite Processing Plants, with diametrically opposed ores. The primary aim of this presentation is to share our recent experiences regarding the design of these plants.

This presentation and discussion will highlight the:

(i) Process Flows Diagrams of each design

(ii) Layout considerations of each design

(iii) Key Equipment Selection and Technology

(iv) Potential Future Technology

Consulmet began life as a reagent dosing company and in 2004 Derek Lahee converted it into a Process Engineering company, with a primary focus on the design, supply and installation of Modular Diamond Recovery Plants.

From 2004 to 2022 Consulmet developed from a single company to a group of companies, each with their own unique specialisations in mineral processing, metals recovery and engineering consulting.

Africa remains the primary focus area, but Consulmet has expanded and now has a Global presence. Consulmet specialises in fast-track design and construction of minerals and metals processing plants primarily on a fixed-price basis.

With regard to Diamond Processing Plants, Consulmet has been involved with well over 100 diamond projects over the last 18 years, and is constantly striving to bring new technologies into the Diamond Processing Flowsheet, as well as improve on Project Management Systems and Design Software.

Derek Lahee *– Derek completed a National Higher Diploma in Extraction Metallurgy at the Technikon Witwatersrand School of Mines, is a member of the SAIMM (South African Institute of Mining and Metallurgy), and is the Managing Director of Consulmet (Pty) Ltd.*

AUTOGENOUS MILLING, AND SETTLING TEST PARAMETERS FOR A MAJOR KIMBERLITE PROJECT

Nico van Vuuren
(Consulmet)

Considering Consulmet's long standing experience with kimberlitic ore processing, a radical approach was taken in terms of the thickener design for the LUAXE diamond project in Angola. A dedicated sedimentation test work program was developed to fingerprint the various ore types in terms of flocculant type, settling flux, mud bed residence time, achievable underflow solids concentration and mud bed rheology. The slurry sample was pre-milled on site to -xxx micron. Once received in Gauteng, South Africa, the samples were further milled to generate a worst-case particle size distribution.

The Consulmet design team fully understood the challenge with regards to the project timeline. The challenge was the time taken from sample collection on-site in Angola until sedimentation results presentation. This time period would severely impact the project schedule in a negative manner.

Considering the time frame challenge, the decision was taken to design/specify and procure the tailings thickener based on the Consulmet's vast experience with kimberlite processing. The following design considerations were chosen as key parameters for the tailings thickener:

- Settling Flux
  - A solids settling flux of 0.20 t/h/m^2 was chosen, as this was considered to be a worst-case value taking into account previous thickener test work performed on site (by others) as well as historical data from Consulmet's data base. In terms of high-rate thickener settling flux capacity, this value is well within the design limit for a high-rate thickener
- Drive Type & "K" factor
  - Typically, thickened kimberlite slimes exhibit thixotropic behaviour and as such yield stress. Considering that the thickener underflow pumping system is a traditional centrifugal type, a maximum yield stress of 100 pascals was used as the drive design. Thickener drive design theory indicates that 1 pa = 1 Imperial K factor unit. The K factor unit considers the thickener diameter and is used to specify the thickener drive maximum operating torque. For the sake of longevity and installed torque, a ring gear type drive unit with multiple drive pods was chosen.
- Tank Geometry
  - Apart from the thickener diameter two (2) main factors were considered here, the thickener floor slope and side wall height. The use of a concrete floor allows for a dual floor slope. The inner 1/3rd of the diameter will be steeper in relation to the rest of the diameter (outer 2/3$^{rd's}$). This design will help contain any coarse/grit type material to the centre section and prevent sanding due to the steeper floor angle. The side wall hight was increased to allow for a high clarification zone. This will reduce flocculant consumption and increase the clarity level of the overflow produced.

Nico Van Vuuren – *Nico is a minerals processing engineer with 22 years' experience in the design, commissioning, operation and maintenance of materials handling and physical separation plants. His areas of expertise include Metallurgical studies (specialising in physical separation techniques), PFD and P&ID development, Equipment sizing, Plant layout development, Process automation and functional specification development, Plant commissioning, Operator training, Problem identification and systematic problem solving, Process optimisation and de-bottlenecking, Maintenance planning and Spares logistics. He has a successful track record of designing and commissioning materials handling and physical separations plants used for the beneficiation of precious metals, industrial minerals, base metals, and diamonds.*

MARKETING AND VALUATION OF ROUGH AND POLISHED DIAMONDS: INSIGHT INTO A MODERN DIAMOND TENDER HOUSE

Grant Ziegler, John Bristow^, and Daniel Nathan**
*(*Alexander Bay Diamond Company)*
(^Global Diamond Network)

No two rough diamonds are the same and equally are not fungible. Notably there is no daily publicly available rough diamond price available on the internet or from accredited international minerals trading houses as for example the many on-line marketing and trading platforms (eg. *London Metals Exchange*) which publish daily prices for iron ore, copper, silver, base metals and many other minerals. In the broader scheme of diamond 'valuation', the ultimate pricing of diamonds, particularly for large and exceptional high-quality stones, relies to a large part on a 'willing buyer, willing seller' principle.

Diamonds are not as standard as most other commodities. In addition to the 4Cs (carat weight, colour, clarity, cut) which are commonly known to consumers and investors alike, rough diamonds have many other attributes and subtleties that impact on their 'value' or 'price'. These include the quality of polishing, symmetry, fluorescence, location of inclusions, colour, and many collective irregularities, each of which helps determine the value of a polished natural diamond. As a consequence of these subtleties, comments on grading certificates of polished goods such as a GIA (*Gemmological Institute of America*) certificate can contribute to significant differences in prices between polished diamonds of the same size and 4C characteristics. Diamonds can only truly become a commodity if buyers understand the importance of these characteristics, and their role in the final price.

Run of Mine (ROM) rough diamonds - When diamond miners produce ore, the extracted rough goods include a complete spectrum of unsorted and uncategorised stones that typically range from poor quality cheap-goods (ie. industrial diamonds, boart) to high quality gemstones. Every single rough diamond with its own set of characteristics will yield a unique polished diamond which is measured by the criteria of the 4Cs combined with its irregularities.

In the trade, this spectrum of rough diamonds is called run-of-mine (ROM), comprising millions of different combinations of diamond size, colour, shape, clarity and thousands of other characteristics. ROM from primary kimberlite and lamproite production shows the greatest variability, whereas alluvial (secondary) ROM shows far greater consistency, generally larger well sorted sizes, a higher abundance of gem quality goods, and values which may be orders of magnitude higher than primary kimberlite ROM rough values.

Through decades of documenting and analysing the prices of rough diamonds, combined with up-to-the-minute data of supply and demand trends, most diamantaires have developed their own unique and innovative methodology which objectively prices the complete spectrum of ROM) goods. Nevertheless, the modern industry continues to strive for transparent, robust, market-related valuations and 'pricing', with technology playing an increasing role in valuation of diamonds.

Reverse Engineering - To determine the accurate price of rough diamonds requires both an in-depth technical knowledge of rough and polished diamonds, and a thorough and current knowledge and mastery of the international diamond markets at any given moment. Before rough diamonds are valued (priced) they are cleaned and sorted with precision. Thereafter experienced diamantaires (valuers) determine the price of a rough diamond using what is effectively a **reverse engineering process**. In the past this valuation process was driven by personal inspection of the rough goods available for sale/purchase, thereby involving often extensive travel by buyers (many from countries such as India, Belgium (Antwerp), Israel, and the USA (New York).

They estimate the yield of the polished outcome of the rough diamond and the resulting value of the diamond when polished, and then work back from current polished prices to determine the price of the rough diamond. An accurate valuation relies on the experience and market knowledge of the valuer, and the most accepted standard for common qualities of polished prices is the Rapaport price list published weekly out of NY.

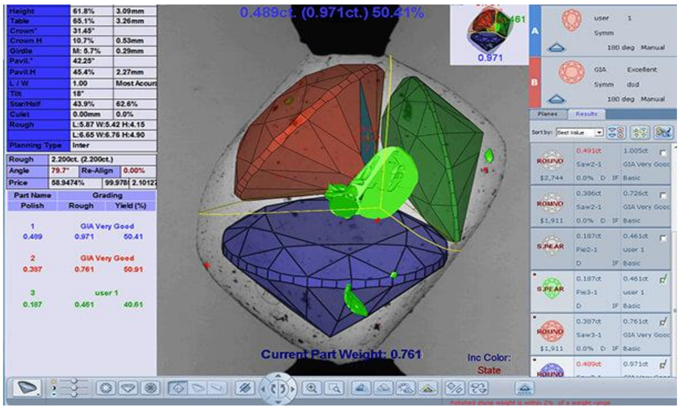
Technology developments - Automated sorting and colour-grading, image-analysis and software evaluation programs (eg. **Sarine** and **Galaxy**), and linked automatic laser-cutting systems for rough goods, are benefiting rough diamond valuations and pricing. The more Swiss **Synova** laser system utilises a water-based laser that reduces diamond damage and wastage, yielding high quality finished surfaces requiring much less final polishing than conventional laser cutting systems.

Equally, Sarine, Galaxy, and Synova have revolutionised manufacturing and 'recoveries' of polished-product from rough diamonds, leading to reduced 'mine to market' timelines, lower financing costs across the diamond-pipeline, and improved profit margins. These technologies, and IT platforms are driving on-line marketing, tenders or auctions, and trade of rough and polished goods, reducing the time, travel, and costs for buyers who traditionally physically inspected rough goods before making bids. Okavango Diamonds (Botswana Government), which sells up to 25% of the country's rough production, is a good example of an online rough diamond marketing platform.

Covid-lockdowns and travel restrictions (through 2020 and 2021) which initially harshly impacted the international diamond market, particularly so during 2020/early-2021, have helped fast-track new developments in the marketing and sales of rough, and polished, sectors.

Typical <u>kimberlite diamond mine</u> rough diamond layout prepared for valuation of sorted and sized parcels. Note the variability of qualities and sizes of the rough goods (Kimberley, RSA)

Layout of rough diamonds recovered from <u>marine alluvial deposits</u> on the West Coast (Namaqualand) of RSA



Sarine diamond image analysis technology ('CAT-scan') and Galaxy system, optimises the number of diamonds cut, polished, and sold from rough stones

Laser sawing at Kiran Gems

Laser cutting of diamonds for further polishing and finishing in India

Grant Ziegler *– Grant began his career in the diamond industry as a small-scale alluvial diamond miner in the Northern Cape Province (RSA), and pursued small kimberlite and tailings retreatment operations. His experience of producing, handling, valuing, and selling rough diamonds, led to his subsequent involvement in the specialist cleaning, sorting, valuation, marketing, and sales of rough diamonds via competitive sealed-tenders or 'auctions'. He has a collective 28 years in the diamond sector, including 12 years as a specialist in the marketing and sales of rough, including rare and exceptional stones.*

Dr John W Bristow *– John completed BSc Hons, MSc Geology (Natal), PhD Geochemistry (UCT), and Post-Doc studies at the University of New Mexico (USA), and Tourism Diploma from UNISA (RSA). He has forty years of experience in geological research, mineral's exploration, project development, mining, manufacturing, and marketing, primarily in the diamond sector, with extensive local, African, and international experience. He has successfully created and operated private and listed Junior exploration and mining ventures, with executive and directorship roles in these and entities.*

Daniel Nathan *– has over 30 years in the diamond industry Daniel and is an expert in diamond valuation and marketing. His Johannesburg based company specialises in the trading and polishing of rough diamonds, and provides a range of services that includes the selling and exporting of the finished products to major outlets, both locally and internationally.*

Sarine diamond system YouTube link - *https://youtu.be/8YaBiJsClJc*

Rapaport - The Man Trying to 'Democratize' Diamond Cutting (Interview with Bernold Richerzhagen, founder and CEO of Swiss technology company Synova) - May 2, 2022
https://www.diamonds.net/News/NewsItem.aspx?ArticleID=68639&ArticleTitle=The%2bMan%2bTrying%2bto%2b%25e2%2580%2598Democratize%25e2%2580%2599%2bDiamond%2bCutting

EVALUATION OF DIAMOND DEPOSITS ACCORDING TO THE SAMREC CODE

Dr Tania R Marshall
(SAMREC Diamond Working Group)

Diamond deposits are, in many ways, different from typical metalliferous and coal deposits. Some of the more significant differences include:

- The widely differing nature of diamondiferous deposits and their associated forms of mineralisation and the estimation relevant to these. Diamond deposits can be subdivided into (i) igneous-hosted deposits (ii) marine and alluvial placers (iii) tailings and stockpiles.
- The low diamond content of primary and placer diamond deposits and their variability
- The particulate nature of diamonds and individual physical characteristics, which have a significant impact on diamond value. These characteristics are size and assortment, the latter being comprised of model (shape or morphology), quality and colour.
- For diamond exploration programmes, Exploration Targets, Mineralisation, Resources and Reserves, the term 'quality' cannot be used as a substitute for 'grade'.
- The specialised field of diamond valuation.
- The relationship between average diamond value and the underlying diamond size distribution.

As a result of the above characteristics, the SAMREC Code contains a diamond/gemstone specific section (Clauses 60-72) and also a companion "Guideline Document for the Reporting of Diamond Exploration Results, Diamond Resources and Diamond Reserves (and other Gemstones, where Relevant)", known as the Diamond Guidelines. This document provides the methodologies and definitions of the relevant terms that must be considered in the preparation of reports on Diamond Exploration Targets, Diamond Resources and Diamond Reserves. It is not a stand-alone document and must be read in conjunction with the SAMREC Code and Table 1. While it was primarily written for the evaluation/reporting of diamond deposits (primary and secondary), many of the principles are applicable to single and multi-commodity gemstone deposits as well.

The diamond guidelines acknowledge the difficulties associated with evaluation and valuation of alluvial diamond/gemstone deposits. These are widely known but, regrettably, often not widely understood – leading to several misconceptions over what can and cannot be expected from such deposits. Fortunately, there is a reasonably well-established body of knowledge on alluvial diamonds that has resulted in accepted industry-standard practices of how to evaluate these deposits. The Diamond Guidelines includes several sections specific to the requirements of secondary diamond and gemstone deposits, both alluvial and marine. Consequently, it is possible to define all Diamond/Gemstone Resources in accordance with the major international Committee for Mineral Reserves International Reporting Standards (CRIRSCO) type codes.

The Diamond Guidelines, further, highlight the similarities and differences between the nature of the reporting required for diamond deposits and other mineral/metal commodities. For example,

- The fact that in place of quantity and grade being the deciding factors for metal deposits, the reporting of diamond (and gemstone) deposits, quantity, grade AND quality (value/price) need to be estimated.
- How microdiamonds can be incredibly useful indicators in grade estimation in primary deposits but need to be paired with macrodiamonds before estimations of value can be made.

- The fact that mine grades, particularly, are not reflective of in-situ values, but are entirely dependent on the recovery plant used.
- That diamond deposits rarely achieve Measured Resource status, which impacts significantly upon the classification of Proved Reserves. The sampling and estimation of marine placer deposits is particularly difficult and expensive and thus even the assignment of Indicated status may prove difficult.
- The valuation of diamonds requires, in most cases, a significant size of run-of-mine parcel for modelling and/or sale. Diamond value is deposit specific. The parcel size for diamond valuation at each resource category confidence level is also deposit specific. The planning of the recovery of diamonds for valuation purposes is an important activity that should attempt to predict the parcel size ahead of sampling in order that the level of confidence in this factor may not fall short of expectations for the stage of project progress. Under certain circumstances, the number of stones/carats required to estimate the diamond value to a low, reasonable or high confidence may need to be significantly different from the numbers and thresholds given below for guidance. The SFD and assortment under study should be the determining factor for the specific numbers and threshold.

Dr Tania R Marshall *has a PhD from the University of the Witwatersrand (1990). In 1996, Dr Marshall founded Explorations Unlimited and has been actively involved in the alluvial diamond and gemstone exploration/mining industry, locally and internationally. Dr Marshall is a Fellow of the Geological Society of South Africa, a Member of the Southern African Institute of Mining & Metallurgy, a life member of the Geological Society of Africa and is registered with the South African Council for Natural Scientific Professions. In addition, she is the current President of the GSSA. She is the immediate past Chairperson of the SAMCODE Standards Committee and the Chair of the Diamonds/Gemstones Working Group. She is also an Adjunct Visiting Professor at the Department of Mining Engineering at the University of the Witwatersrand, where she lectures in professional ethics as well as Compliance and Reporting in the Minerals Industry.*

DIAMOND EXPLORATION AND MINING: PAST, PRESENT AND FUTURE TRENDS

Bill McKechnie
(Consultant Geologist)

More than 150 years after the first diamond find in South Africa, the diamond industry remains solidly in place, despite various ups and downs of varying intensity, and occasional predictions of its demise. Many new diamond producing areas have come on stream in the last 100 years, making the diamond business truly global.

Notwithstanding the impact of the newcomers, according to statistics published by the Kimberley Process, in 2020, mines on the combined southern African Kaapvaal and Zimbabwe cratons produced 50% of the world's diamonds by value and 28% by weight. Approximately 5% of South African production and 2.5% of global production by value still comes from mines that are more than a hundred years old.

The youngest southern African producers, Jwaneng and Venetia, came into production between 30 and 40 years ago, and the Canadian Slave craton mines are also almost 20 years old. Since of those discoveries, the only significant new discovery is the Luaxe deposit in Angola on the Angola/Kasai craton, a joint venture between Endiama and Alrosa.

In the last 50 years, the results of intense diamond exploration and improvements in our knowledge and understanding of the geological factors that influence the distribution of diamond deposits suggest that the most prospective parts of the world have been well explored.

This contribution will comment on the factors that are likely to influence diamond exploration going forward, what this might mean in terms of the strategies applied, and the likelihood of success.

Bill McKechnie - *B.Sc. Hons (Geology), Aberdeen University, UK, Pri. Sci. Nat., Fellow of the GSSA, and Member of the SAIMM. Bill is a highly experienced exploration and project development geologist with more than 45 years in the international mining and metals industry at the executive, strategic and operational level. He has a demonstrated history of success and is an expert in diamond project exploration and evaluation. He was head of De Beers global exploration and evaluation projects for 7 years which included responsibility for De Beers' laboratory and technical support services, and research and development. He continues to operate in the minerals sector as an independent consultant.*

TECHNOLOGY INNOVATION DRIVING CHANGE AND TRENDS IN THE DIAMOND INDUSTRY

Dr John Bristow
(Global Diamond Network)

The last half century has seen a massive shift in geological thinking and technological innovation and developments all facets of diamond exploration, mining, processing, recovery, manufacturing, marketing and sales. Recently synthetic gemstone diamonds have taken a place alongside natural gemstone-diamonds and jewellery, offering branded diamond jewellery ranges.

New technologies for exploration and evaluation of kimberlites and lamproites include rapid 'high-resolution' airborne geophysical surveys, **drones** to delineate lineaments and trap-sites in land-based alluvials, and enhanced side-scan sonar and bed-rock profiling methods for mapping and delineating marine alluvial deposits.

There have been advances in the use of **indicator-mineral** sampling and treatment, recovery, analytics, and interpretation, particularly for mantle derived eclogitic and peridotitic garnets, pyroxenes, olivines, chromites, and ilmenite. Use of peridotitic-garnets to target and rank diamondiferous-pipes has made significant strides, likewise the application of **micro-diamond studies** in the evaluation and pre-mining assessment of diamond projects.

Progress in fragmentation (blasting) and comminution of primary diamond bearing ores, including high-pressure grinding rolls (**HPGR**) and autogenous grinding (AG), have enhanced efficiencies and liberation, with concomitant reduction in diamond breakage. This technology was particularly advantageous to the processing of high-grade Argyle lamproite ore containing predominantly poor-quality diamonds, ensuring less breakage and improved revenues. The use of **high frequency sand-screens** has reduced fines and sand reporting to rotary-pans and dense media circuits, reducing the volume of water required for ore processing, and decreasing the size and costs of slimes dams.

The recovery of diamonds has benefited from significant advances in X-Ray systems for small and large operations, eg. Bourevestnik (BV) and X-Ray Tomography **(XRT**) systems, and ensured more efficient (less breakage) and far greater numbers of large high-value Type-2a diamond recoveries. Tomra have been a key player, and more recently XRT units constructed by De Beers and installed at the Jwaneng diamond mine in southern Botswana have effectively provided a 'single-particle sorter' facility for medium and large diamond sizes.

Automated sorting and colour-grading, image-analysis and software evaluation programs such as the Israeli developed **Sarine** and **Galaxy** systems, and linked automatic laser-cutting systems for rough goods, are revolutionising manufacturing, and 'recoveries' of polished-product from rough diamonds. The more recently introduced Swiss **Synova** laser-cutting system utilises a water-based laser system that reduces diamond damage and wastage, and produces high quality finished surfaces requiring much less final polishing than conventional laser cutting systems.

The use of **Blockchain** technology to track diamonds from '*source to sales point'*, ensure transparency, and ultimately attract a 'premium' on pricing is making strides in the business. According to De Beers their **Tracr™** system first launched in a research and development mode in 2018, is the world's only distributed diamond blockchain that starts at the source, and was named by Forbes as one of the 50 leading blockchain solutions in both 2020 and 2022. It is said to provide tamper-proof source assurance at scale, ensuring rough-diamond '*Sightholders*' with an immutable record of a diamond's provenance and point.

The Tracr™ platform combines a range of leading technologies, including blockchain, artificial intelligence, the 'Internet of Things', and advanced security and privacy technologies, to track a diamond's journey through the value chain.

Overall, the industry is experiencing enhanced transparency, reduced 'mine to market' timelines, lower financing costs across the diamond-pipeline, and improved profit margins. These technologies, and IT platforms are driving on-line marketing, auctions, and trade of rough goods, reducing the time, travel, and costs for rough-buyers who traditionally physically inspected goods before making bids.

Okavango Diamonds (Botswana Government), which sells up to 25% of the country's rough production, is a good example. Covid-lockdowns and travel restrictions since early-2020 have fast-tracked these new developments in the rough diamond, and strongly so in the polished, sectors.

However, in spite of the above technology driven progress, the diamond sector has not seen a new world-class (Tier-1) diamond mine discovery since 1991. Existing mines have mostly transitioned to underground operations with concomitant reduction of mined product. The famous pink-diamond producer Argyle Diamonds closed in November 2022, and several other small operations and projects in Botswana, Canada, and Lesotho, have shut.

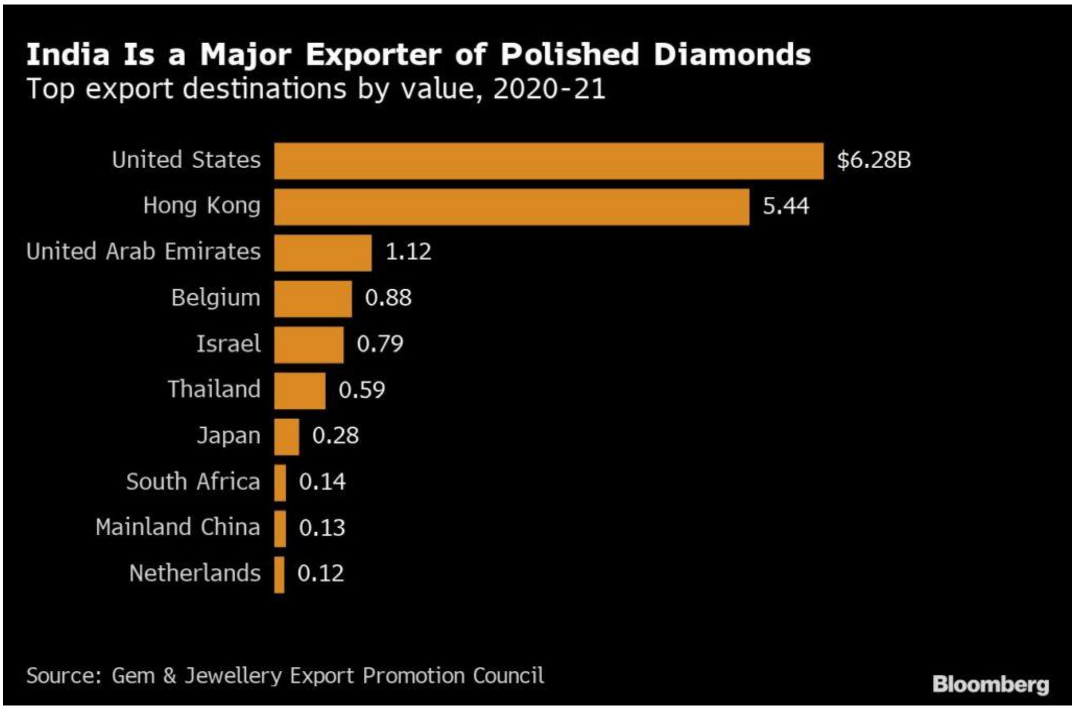
World natural rough diamond production has dropped by about 30% since 2017 (152 m to 107m carats in 2021), paving the way for the growth of synthetic or laboratory growing diamonds.

The shortage of rough diamond supply that the international diamond market currently faces and the uncertainty being created by the Russian/Ukraine war and sanctions on Russian miner ALROSA, which produces about 30% of the world's rough diamonds, are starting to impact the international market. Particularly so the Indian manufacturing sector which purchases and manufactures about 95% of world rough production, and then resells polished goods into key retail and diamond jewellery markets.

The world shortage of rough supply, and challenges and uncertainties faced by the international diamond business should be a positive development for South African diamond producers. Particularly so the numerous small land and marine-based alluvial, and small kimberlite diamond producers, in the North West and Northern Cape Provinces, including the West Coast. These alluvial diamond producers consistently produce the world's highest run of mine (ROM) value gemstone diamonds. However, the challenges of obtaining prospecting and mining, and water use licences, due to the dysfunctionality of the Department of Minerals Resources (DMRE), 'one-size fits-all' mine health and safety regulations, and excessive red-tape, are stifling the productivity and survival of this Small and Junior diamond mining sector.

The presentations given during the June 2022 *Online Diamond Short Course*, and July 2022 mine and field trips, will address the range of technology driven interventions driving modernisation of this fascinating 2 000 year old industry. Equally they will highlight the challenges of diamond exploration, declining rough diamond supply, and lack of new diamond mines (kimberlite or lamproite) discoveries in some detail, and highlight likely future trends for the business.

Dr John W Bristow *– BSc Hons, MSc Geology (University of Natal), PhD Geochemistry (UCT), Post-doc Univ New Mexico, Tourism Diploma (UNISA). John has forty years in geological research, mineral's exploration, project development, mining, manufacturing, and marketing (primarily in the diamond sector, with extensive local, African, and international experience. He has successfully created and operated private and listed Junior exploration and mining ventures, with executive and directorship roles in these and other listed entities.*



Udachny, ALROSA's largest diamond mine near the city of Udachny, Yakutia, Russia. Photo by Alrosa.

A Wake-up Call from Russia – Avi Kravitz (Rapaport, 10 May 2022)
https://www.diamonds.net/News/NewsItem.aspx?ArticleID=68655&ArticleTitle=A%2bWake-Up%2bCall%2bfrom%2bRussia

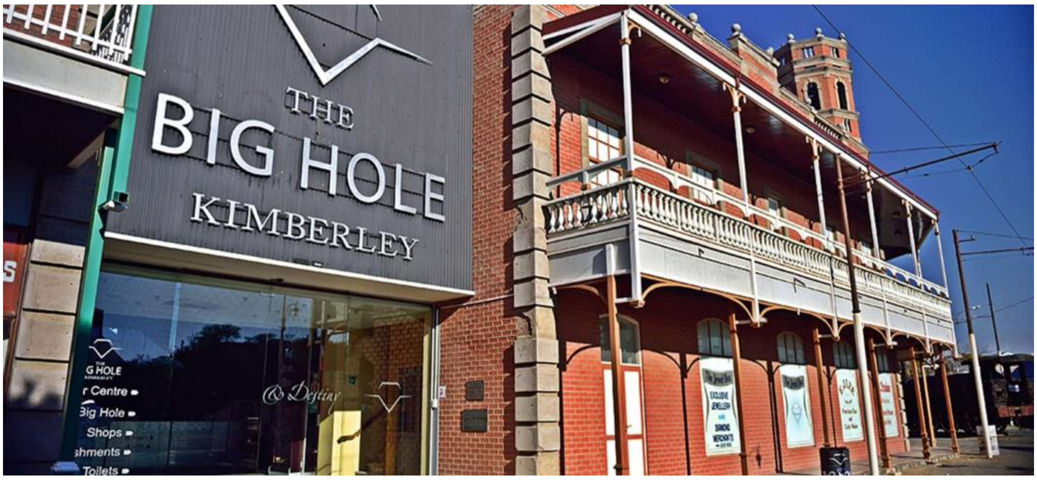
Global diamond trade fractures under the weight of Russia sanctions. Bloomberg, May 12, 2022
https://www.mining.com/web/global-diamond-trade-fractures-under-the-weight-of-russia-sanctions/

KIMBERLITE MINE & AND ALLUVIAL DIAMOND DEPOSIT EXCURSIONS

1. *Kimberley Big Hole Mine Museum (Thursday, 14 July 2022, 13.00am)*
2. *Wouterspan Middle Orange River Alluvial Operation (Friday, 15 July 2022)*
3. *Kimberley Nodule Dumps (Saturday 16 July 2022, 8.00am)*
4. *Blue Rock Kimberlite Diamond Mine (Saturday, 16 July 2022)*

5. Cullinan Diamond Mine *(Wednesday, 20 July 2022, 8.00am)*
6. *Helam Fissure Diamond Mine (Thursday, 21 July 2022, 10.00am)*

7. *Rough Diamond Sales Tender House (Johannesburg) (July, August 2022)*



Garnet peridotite from the Kimberley (Bultfontein) Dumps cut in half and polished (Donor- Richard Molyneux)

ALLUVIAL DIAMOND DEPOSITS OF THE MIDDLE ORANGE RIVER (MOR) THE WOUTERSPAN GRAVEL DEPOSIT

Lyndon de Meillon and John Bristow^*
*(*Hardcore Mining, ^Global Diamond Network)*

Introduction – The Orange River was the site of the first diamond discovery in South Africa in 1867 (155 years ago) on the farm De Kalk on the left-bank of this river approximately 30 km upstream from the confluence with the Vaal River, immediately downstream of Douglas. To this day this remarkable drainage system, which originates in the highlands of Lesotho, remains a key contributor to South Africa's diamond production due to regular production of exceptionally high value gemstone diamonds (included large and colored stones).

The Orange River is joined by the Vaal River system at the confluence, approximately 12 kms downstream (west) of Douglas. This second major river system (the Vaal), whose source is in the eastern part of Mpumalanga, along with a series of other tributaries such as the Riet, Harts, and others, add further high-quality goods to the population encountered down-stream of the confluence.

Mining of the alluvial deposits initially identified on the Orange River, and then the Vaal River at Klipdrift (today's Barkly West) in 1869, created a once thriving industry of small and Junior entrepreneurial alluvial diamond miners who successfully developed the skills and technology to exploit low grade, and now days ultra-low grade deposits. Production from these deposits is exceptional, and goods recovered from the Middle Orange River (MOR) are consistently amongst the world's highest-value (USDollar per carat) Run of Mine (ROM) rough goods.

Regional Setting - The MOR is defined as the section of the river downstream of the Vanderkloof dam and Prieska (Figure 1), and has become synonymous with the recovery of large high value diamonds (see Figures 2, 5 and 7). Key small and medium towns in the area are Hopetown, Douglas and Prieska, with local economies supported by agricultural activities of which irrigation farming is the largest. Over the last 20 years, alluvial diamond mining has provided increasing role support to these economies and creating much needed jobs, as farming has become increasingly mechanized. Through modernization of alluvial mining and technology advances, these mining activities have to a large degree absorbed the labour shed by the agricultural sector. None the less, unemployment in the area is still a major challenge for the Northern Cape Province and its small and medium towns.

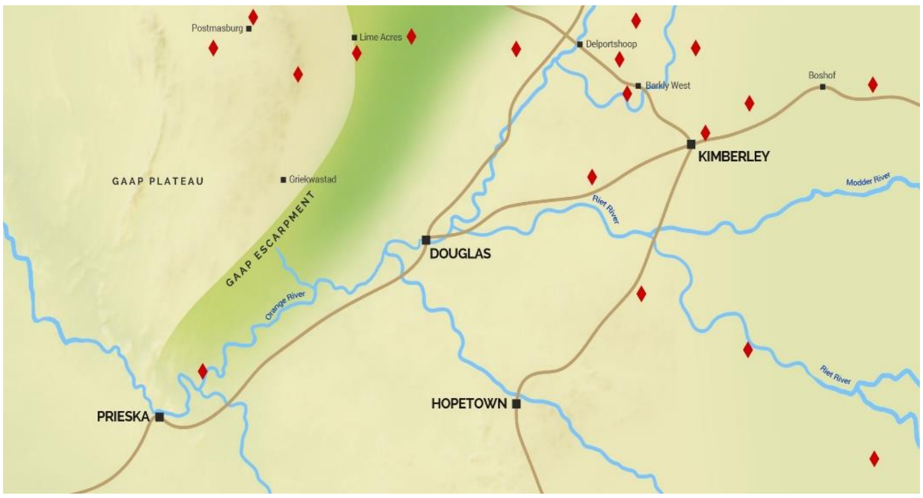


Figure 1: Map of the Orange, Vaal and Riet Rivers in the Northern Cape Province. The main kimberlites and kimberlite clusters in the area are shown as red diamonds.

As noted above, these three major rivers in the area are the Orange, Vaal and Riet Rivers, all of which contain diamond bearing gravel terraces formed by older-proto rivers. Although all three rivers confluence within a 30 km radius, the latest research has shown that they each contain a unique diamond population.

Initially (1900 – 1930), the Rooikoppie or ***deflated*** gravels were targeted as they were unconsolidated and easy to mine. As larger machinery was developed, capable of breaking the hard calcrete capping and processing the large boulders, the underlying gavels were worked. Today, only a handful of small to medium sized operations are left, mainly targeting the calcretised basal gravels that have historically been difficult to mine.

Most of these remaining deposits require drilling and blasting and very large earthmoving machines to achieve the liberation and economies of scale required to mine these deposits efficiently and economically. Ages of the deposits vary between Miocene and Recent.

Figure 2: Run of mine (ROM) production from the farm Marksdrift, upstream of the confluence on the Orange River. Stones like the large 44ct intense yellow (centre-left) and large D-colour Type II diamond below it, are the reason for the high average value from this area.

The Orange River between Hopetown and Douglas **-** Recent studies have shown that the source of the diamonds in the section between Hopetown and Douglas, upstream of the confluence, are most likely the kimberlites in Lesotho. This is borne out by a number of factors, including the high proportion of exceptional D-colour Type-II diamonds, with average USDollar per carat values in excess of US$7000 per carat in today's market (see Figure 2 above), and rare blue stones which are characteristic of the Lesotho diamond mines, particularly the Kao kimberlite.

The grade (carats per hundred tonnes) in this area can only be described as ultra-low and varies between 0,1 and 0,2 cpht. The location of the deposits along this stretch of the river is strictly controlled by a series of gorge and splay features and the availability of Carboniferous Dwyka diamictite clasts.

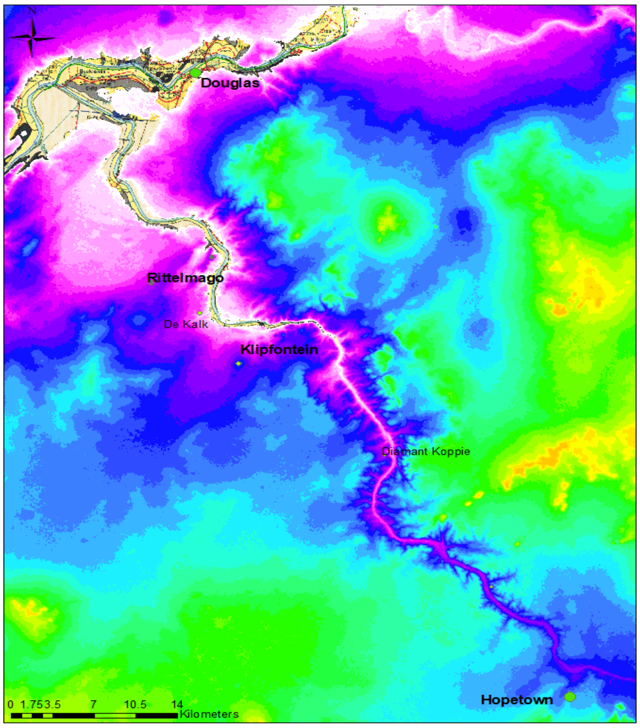


Figure 3: Digital Elevation Model showing the surface topography along the Orange River between Hopetown and Douglas. Note the gorge that the river is trapped in until it exits close to the farm Klipfontein.

Figure 3 above shows a digital elevation model (DEM) of the area on which the gorge immediately downstream of Hopetown is clearly visible. Larger scale alluvial gravel deposits only start to form after the river exits the gorge where the river gradient becomes flatter. The gorge was a previous glacial pathway as shown by the many glacial striations along the riverbed. The glacial debris that filled the gorge was the major source of the gravel clasts. Most of the deposits occur at an elevation of 40 m above the current river or less, with the exception of the 70m terrace on the farm Klipfontein.

The Orange River between the Confluence (Douglas) and Prieska – Following the discovery of a diamond at De Kalk downstream of Hopetown, prospectors subsequently turned their attention to downstream parts of the Orange, and encountered interesting gravels on the farm Brakfontein (left bank) between Douglas and Prieska. In 1925 an area of about 10 ha was proclaimed as State Diggings, and soon a town of mud and zink dwellings known as Higgshope, 70km west of Douglas, sprung up on a Terrace about 100 metres above the present-day river. Also known as Die Bult (Hillock), this locality flanked the farm Zaxendrift (now Saxendrift). The first diamond staking 'Rush' took place on Brakfontein in 1925, and this locality and small 'Town', which had a population of about 9 000 people according to 1928 census, existed until about 1954, though experienced Digger John Fincham remained until April 1992 (Historical Account of the Higgs Hope Diggings, 1997).

Subsequently, this part of the MOR river saw a revival of interest in the late 1970's when geologist Robert Cooke, engaged Professor Terrence McCarthy of the University of the Witwatersrand to map the alluvial gravels between Prieska and Douglas. Notably in the in the early 1990's Eddie and Vic Pienaar, two very creative Diggers, introduced the use of very large 90tonne Fiat Allis bulldozers on Saxendrift to rip (break) and remove the extensive, often thick, extremely hard *calcrete-cappings* on the MOR terraces, and *'rip and trap'* (disaggregate) the underlying gravels to liberate the diamond population, particularly larger stones.

The authors of this document undertook an in-depth on the ground study of these gravel terraces in the latter part of 1997, facilitated the successful Pienaar mining operations in early 1998 to create the successful *Gem Diamond Mining Corporation* (Gem) in 1998 with backing from Brett Kebble and the Corner House with assistance from Dennis Tucker and Theo Botoulas. Tokyo Sexwale and the *Trans Hex Group* (THG) took over Gem in 2000.

In 2008 the Saxendrift property was bought by the then *Rockwell Diamonds Inc* (Rockwell) who were already mining on Wouterspan (across the river from Saxendrift), and on the Holpan/Klipdam alluvial properties north-east of Barkly West. Subsequent to the liquidation of Rockwell in 2017, the key MOR alluvial diamond properties, notably Wouterspan and Saxendrift, have ended up in the ownership of *Hardcore Mining* in which Lyndon De Meillon is a director and chief geologist.

Gravel Deposits and Mining of the Douglas – Prieska MOR section - The gradient of the river between Douglas and Prieska is generally less than that between Hopetown and Douglas, and this section is characterized by large meanders with the average amplitude of the meanders about 6 km with a wavelength of 13 km (Gresse, 2003).

Approximately 33 km downstream of the confluence, a large drainage, which according to McCarthy (1983) was a previous major river system, introduced large volumes of banded ironstone into the Orange River deposits (Figure 4). The added mass and high SG of the banded ironstone to the bedload increased the ability of the system to trap and retain diamonds. Several terraces have been preserved along this stretch of the river.

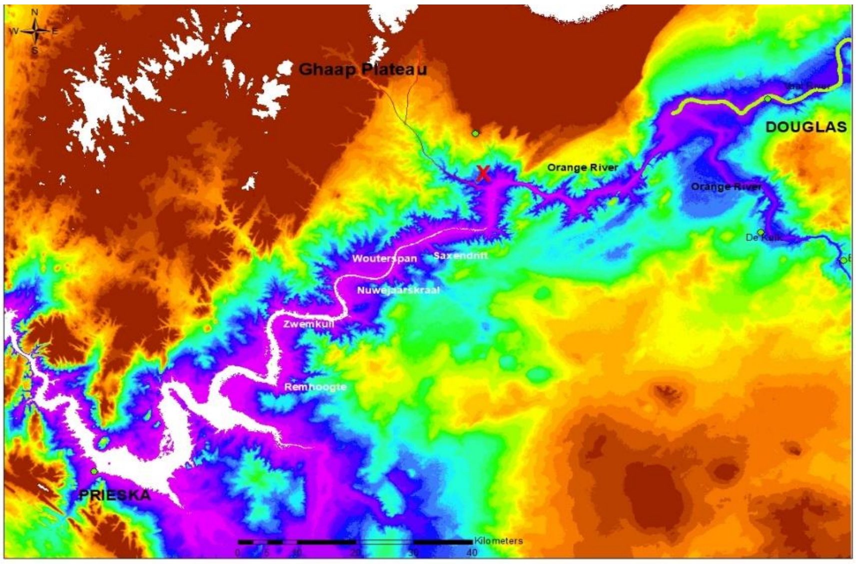


Figure 4: DEM of the Orange River valley downstream of Douglas. X marks the entry point of the BIF into the system. Note the relatively large meanders.

The highest terrace is situated on the farm Waaihoek, on the edge of the Ghaap Plateau at an elevation of +200m above the current river. Terraces at +110m, + 70 m and +20 m are also present. Differences in the composition of the sediments in these terraces reflect their provenance and has a direct correlation with grade (Gresse, 2003).

Grades in the area value between 0,2 and 1 cpht, depending on elevation and trap-sites present. Diamond values vary between about US$1800 and +US$3000, depending on the terrace elevation and whether the Vaal or Orange River was the dominant diamond source system at the time. Figure 5 shows a photograph of 2 of the larger stones from this area.

Figure 5: A 154ct D colour stone and a 196ct off-white stone recovered from the MOR.

Wouterspan Alluvial Gravel Deposit **-**_The Wouterspan deposit is situated approximately 50 km downstream from the confluence. This deposit has been mined by various operators in the past, but the bulk of the deposit is still intact. On Wouterspan a +20m as well as a +40m terrace is present. The +20 m terrace contains a well-defined channel feature and has in excess of 20 million tonnes of resource left (Figure 6).

These large terrace areas are overlain by surface Rooikoppie deflation deposits consisting of abundant banded ironstone, followed by very hard calcrete layers (2 – 3 metres), typically followed by a rather sandy finer gravel, underlain by thick basal gravels. The +40 m terrace consist only of Rooikoppie or **d*eflated*** gravels that has spread over a wide area. The extensive +20m terrace varies from about 10 to 15 metres thickness in total.

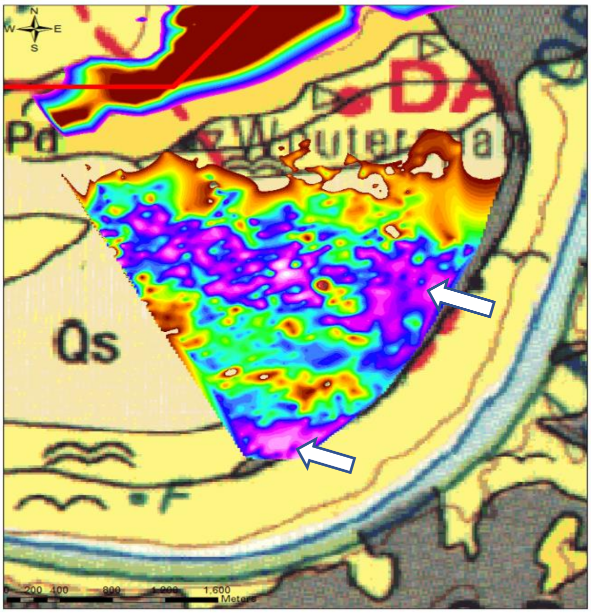


Figure 6: Bedrock elevation model of the +20 m terrace on Wouterspan. Note the 2 well defined channel features.

The mining operation on Wouterspan is owned and operated by Hardcore Mining. Approximately 150 000 tonnes of gravel (with a strip ratio of about 1:1) is mined and processed per month with a large earth moving fleet and customized gravel screening, processing, and X-ray final recovery plant, as summarized in Table 1.

Location	Middle Orange River (right-bank) between Douglas and Prieska, Northern Cape Province
Mining fleet	8 x 90 tonne Rigid Trucks, 4 x 40 tonne ADTs, 110 Tonne Dozer, 7 x Hydraulic Excavators, 6 x Front End Loaders, and ancillary vehicles
Screening plant	2 Finlay mobile screens to remove oversize and fines
Desanding Screens	2 x Dabmar desanding screens (bottom cut-off 6 mm)
Processing plant	4 x 19ft Rotary pans (with magnetic separators to reduce BIF)
Final recovery plant	4 in-line Bourevestnik X-Ray units (double pass)

Table 1: Summary of the Wouterspan diamond mining, processing and recovery plant

Conclusions – alluvial diamonds are amongst the most challenging, and highest financial risk commodity to mine. Detailed geological work, on-going prospecting, and use of modern technology are the key to a successful future mining operation on these ultra-low grade deposits. After some 60 years of collective experience, hard-paid 'school fees', and success in the alluvial diamond sector, assisted by extensive interaction with colleagues and successful private operators, the authors of this document have been fortunate to gather considerable information and practical experience in the alluvial diamond sector across southern Africa.

Notable developments in the alluvial diamond sector over the past thirty years have been the importance of hands-on management, quality geological observations, documenting and size-frequency studies of diamond populations, leveraging the 'value' and revenue of the exceptional alluvial diamonds recovered, understanding of the macro and micro-detail of each and every deposit and their economics. Likewise understanding the key drivers of diamond transport and concentration from a macro to micro perspective, and use of appropriate modern technologies that can be applied to different types, sizes, and scales of deposits and their exploitation, are key.

The above developments, aided satellite and Google imagery, drone-surveys, have provided some of the most elucidating and important developments, and have led to the location of deposits in least expected places. Equally this work has brought into questions some of the old and established prescripts in respect of rock-mass disaggregation, transport, and local critical concentration by the boulders and cobble 'standing-proud' in Carboniferous Dwyka bed-rock.

Much has been written about the role of the diamond transport by Carboniferous glaciers from the earliest publication by Alex DuToit, who in in 2010 wrote a remarkable paper highlighting his observation that the Dry Harts River Valle (North West Province) was an exhumed Karoo drainage line. Likewise work by Moore and Moore (2004, 2006) has added value to the process, and more recent work by Van Der Westhuizen (2012), DeJager (2022), and the authors of this Field Guide have demonstrated the unequivocal role and contribution to South Africa's exceptional alluvial diamond deposits by the Dwyka glaciers, and their weathered bedrock residues.

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Lyndon De Meillon - *Lyndon has a MSc degree in Geology/Oceanography from NMU, and 30 years of experience in diamonds. He started his career at De Beers as an Exploration Geologist. During the next 15 years he was operations Manager or COO of various public and private companies mining alluvial diamonds, mainly along the Middle Orange River. Approximately 10 years ago he started up his own alluvial diamond mining venture and is currently co-owner and CEO of three private companies mining alluvial diamonds along the Lower Vaal and Middle Orange Rivers.*

Dr John W Bristow *– BSc Hons, MSc Geology (University of Natal), PhD Geochemistry (UCT), Post-doc University of New Mexico, Tourism Diploma (UNISA). John has forty years of experience in geological research, mineral's exploration, project development, mining, and marketing (primarily in the diamond sector), with extensive local, African, and international experience. He has successfully created and operated private and listed Junior exploration and mining ventures, with executive and directorship roles in these and other listed entities.*

KIMBERLEY – ITS KIMBERLITES AND MANTLE NODULES

Following the discovery of diamonds in river deposits in central South Africa in the mid nineteenth century, it was at Kimberley where the volcanic origin of diamonds was first recognized. These volcanic rocks, named "kimberlite", were to become the corner stone of the economic and industrial development of southern Africa. Following the discoveries at Kimberley, even more valuable deposits were discovered in South Africa and Botswana in particular, and in Lesotho, Swaziland and Zimbabwe.

A century of study of kimberlites, and the diamonds and other mantle-derived rocks they contain, has furthered the understanding of the processes that occurred within the sub-continental lithosphere and in particular the formation of diamonds. The formation of kimberlite-hosted diamond deposits is a long-lived and complex series of processes that first involved the growth of diamonds in the mantle, and later their removal and transport to the earth's surface by kimberlite magmas. Dating of inclusions in diamonds showed that diamond growth occurred several times over geological time.

Many diamonds are of Archaean age and many of these are peridotitic in character, but suites of younger Proterozoic diamonds have also been recognized in various southern African mines. These younger ages correspond with ages of major tectonothermal events that are recognized in crustal rocks of the sub-continent. Most of these diamonds had eclogitic, websteritic or lherzolitic protoliths. In southern Africa, kimberlite eruptions occurred as discrete events several times during the geological record, including the Early and Middle Proterozoic, Cambrian, Permian, Jurassic and the Cretaceous.

Apart from the Early Proterozoic (Kuruman) kimberlites, all of the other events have produced deposits that have been mined. It should however be noted that only about 1% of the kimberlites that have been discovered have been successfully exploited. In this paper, 34 kimberlite mines are reviewed with regard to their geology, mantle xenolith, xenocryst and diamond characteristics and production statistics. These mines vary greatly in size, grade and diamond-value, as well as in the proportions and types of mantle mineral suites that they contain.

They include some of the world's richest mines, such as Jwaneng in Botswana, to mines that are both small and marginal, such as the Frank Smith Mine in South Africa. They include large diatremes such as Orapa and small dykes such as those mined at Bellsbank, Swartruggens and near Theunissen. These mines are all located on the Archaean Kalahari Craton, and it is apparent that the craton and its associated sub-continental lithosphere played an important role in providing the right environment for diamond growth and the formation of the kimberlite magmas that transported them to the surface.

Aside from the locality at which diamond bearing kimberlite intrusions were first recognised, the voluminous old Kimberley mine tailings and waste dumps going back to 1869, have provided a unique treasure trove of deep-seated mantle nodules, including periodotites, eclogites, dunites, and just about every other possible type of deep-seated lower-crust and mantle nodule type that has been documented. This was due to the early years of extraction and processing of diamond-bearing ore from the Kimberley mines not being subject to crushing, with a process of 'flooring' being used instead.

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Accounts and publications of Steve Haggerty, Jock Robey, and numerous other mantle petrologists wh.

BLUEROCK DIAMONDS: KAREEVLEI KIMBERLITE MINE VISIT, NORTHERN CAPE PROVINCE, RSA

Jock Robey
(Rockwise Consulting CC)

BlueRock Diamonds, a company incorporated in England and Wales, was established in October 2012, and admitted to trading on the Alternative Investment Market (AIM) of the LSE in September 2013. BlueRock holds a mining right to mine and operate on the Kareevlei Tenement which covers 3 000ha.

The Kareevlei kimberlite cluster, situated about 130km north-west of Kimberley (Northern Cape Province), comprises 5 pipes of variable size, with intrusive ages of approximately 120 million years. K1 and K2 are roughly 1.2ha each and are so close to each other that they are now mined in one single open cast pit. K3 is the largest at some 5.5ha in size and has as yet not been mined. K4 and K5 are small at ~0.3ha each.

The Kareevlei cluster was discovered by De Beers during an airborne magnetic survey of the Ghaap plateau in 1991. The project was abandoned because mineral chemistry, microdiamonds and petrography indicated a low grade. AfriOre conducted further exploration in 1993, and in 2002 Tawana Resources conducted an extensive percussion and LDD drilling program that proved kimberlite down to a depth of 100m. Tawana eventually abandoned the project and it was acquired by BlueRock.

The Kareevlei kimberlites are classified as phlogopite rich Group2 types similar to the nearby Finsch and Bellsbank mines. However, it was realised early on by De Beers' petrographers that these kimberlites are full of groundmass leucite and more recent studies have also shown the presence of K-richterite amphibole. These minerals are typically found in lamproites and Kareevlei has therefore been reclassified as an olivine lamproite – Kaapvaal style as suggested by Barbara Scott Smith.

The pipes are intruded into dolomites of the Transvaal Group and also have large blocks of down-rafted Karoo shales. Other crustal xenoliths observed are dolerites, Karoo basalt, and ironstones.

Kareevlei is characterised by the following mantle minerals: peridotitic garnets, abundant eclogitic garnets, abundant chromite, common ilmenite, rarer Cr diopside and rare corundum. Small harzburgite and lherzolite xenoliths as well as eclogites are present.

Current mining in the K1 and K2 pipes is at a rate of some 40 000 tons a month. Grades are low at ~5cpht but the diamond quality is very good for a primary kimberlite mine. Average run of mine (ROM) rough diamond prices received on tender are typically >USD500 per carat.

Jock Robey *– BSc Hons, MSc Geology (Rhodes), PhD Geochemistry (UCT). Jock worked for De Beers Exploration for 25 years specializing in kimberlite and mantle petrology. Since 2009 he has worked as a consultant for De Beers, Petra, Gem, MSA, and now Kareevlei (jjrobey@telkomsa.net).*

CULLINAN DIAMOND MINE – GAUTENG, RSA

Anton Wolmarans
(Petra Diamonds)

The Cullinan kimberlite mine (previously known as Premier mine) is renowned as a source of large, high-quality gem diamonds, including Type-II stones, as well as being the world's most important source of very rare blue diamonds. The mine earned its place in history with the discovery of the Cullinan diamond in 1905 which was cut to form the two most important diamonds in the British Crown Jewels.

The **Cullinan Diamond** is the largest gem-quality rough diamond ever found,https://en.wikipedia.org/wiki/Cullinan_Diamond_-_cite_note-centennial-2 weighing 3,106.75 carats (621.35gms; 21.9ounces; 1.37pounds) discovered at the Premier No.2 mine in Cullinan, South Africa, on 26 January 1905. It was named after Thomas Cullinan, the mine's chairman. Many of the world's most famous diamonds herald from Cullinan mine, and it continues to produce world-class diamonds under Petra's stewardship.

The original surface area of the kimberlite pipe was 32ha, which decreases to about 21ha at 500m below surface. The pipe comprises a Type-1 ilmenite bearing kimberlite, with multiple intrusions, generally referred to as the 'brown', 'grey', 'black' and 'piebald' kimberlites, and is cut by a series of late-stage 'carbonatized kimberlite' dykes and veins.

U-Pb dating by in-situ secondary ion mass spectrometry and laser ablation multi-collector inductively coupled plasma mass spectrometry of perovskites from the Cullinan (Premier) kimberlite yielded emplacement ages of 1 150±16, 1 151±9, and 1 156±12Ma for the brown, black, and grey kimberlites, respectively, demonstrating that the different phases of the kimberlite were emplaced contemporaneously at ~1 150Ma. As such Cullinan is the world's oldest producing diamondiferous kimberlite.

Cullinan contains a world-class gross diamond resource of 149.82 Mcts as of 30 June 2021, which suggests its mine life could be significantly longer than the current mine plan to 2030.

The Company's on-going development and optimisation plan has led to underground run of mine (ROM) throughput increasing from 3.7 Mt in FY 2018 to 4.6 Mt in FY 2021, which delivered 1.8 Mcts ROM and 182 Kcts from surface tailings production. The C-Cut block cave reached full production capacity, producing 4.4 Mt during FY 2021 with the old B-block areas now depleted and closed. In November 2021 the mine received board approval to commence with the expansion capital project to establish the new CC1E sub-level cave mining block. With production ramping up from FY 2024, the 3-level SLC will produce roughly 1.6 Mtpa between FY 2026 and FY 2031.

Plant optimisation at Cullinan is ongoing, with the recovered ROM grade improving from 35.9 cpht in FY 2018 to 38.2 cpht in FY 2021.

The Company is on an ongoing basis investigating the optimal plan to utilise the full extent of the large Cullinan orebody, which is about 16 hectares at current production depths, making this the world's largest producing underground diamond mine.

Long-hole drilling rig aligned for ring drilling to develop a draw bell at C-Cut 839L

Location	Cullinan, Gauteng Province, South Africa
Petra Diamonds acquisition date	July 2008
Acquisition cost	ZAR1 billion
Current ownership	Petra Diamonds Limited: 74% Kago Diamonds (Pty) Ltd: 14% Itumeleng Petra Diamonds Employee Trust: 12%
Start of mining date	1903
Size of kimberlite at surface	32ha
Approximate size at current mining depth	Approximately 16ha
Type	Type-1 ilmenite-rich kimberlite
Age	~1 150 Ma
Total diamond resources	152.50 Mcts
Current depth of resources	1,073m
Average grade	~39cpht
Mining method	Block Cave
Depth of current mining	~880 m
Mine plan	To 2030
Potential life of mine (LOM)	+50 years
Processing plant configuration	2 X 9m Autogenous Grinding Mills; DMS for processing smaller fractions (high ilmenite content)
Final recovery technology	Bourevestnik X-ray sorters
Average diamond price	H1-2021 ~ US$120 per carat H2-2022~ US$190 per carat#
	#- *Highlights strong 'post-covid' market situation and impact of number of special stone sales.*

An exceptional 20.08 Type IIb blue diamond, September 2019

424.89 carat and 209.2 carat D-Colour Type II diamonds, March and April 2019

North-westerly aerial view from the Cullinan mine 'open-pit', across the headgear and processing plant, to the slimes dam behind.

Sources of Information*:* https://www.petradiamonds.com/our-operations/our-mines/cullinan/ and Petra Diamonds Annual Reports

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Anton Wolmarans – *Anton has a BSc Exploration Geophysics from the University of Pretoria, spent 13 years with De Beers where he held positions as a principal geophysicist and resource development manager, prior to moving to Petra Diamonds in August 2014. He has been with Petra diamonds for nearly 8 years, where he has played a key role in the modernisation of the Cullinan diamond mine. He currently holds the position Technical Services & Assurance Manager at Cullinan.*

HELAM KIMBERLITE FISSURE DIAMOND MINE, SWARTRUGGENS, NORTH WEST PROVINCE, RSA

Jim Davidson
(Helam Mining)

Secrets of Fissure diamond mining by Jim Davidson - YouTube
https://www.youtube.com/watch?v=ByJiUzQetyY

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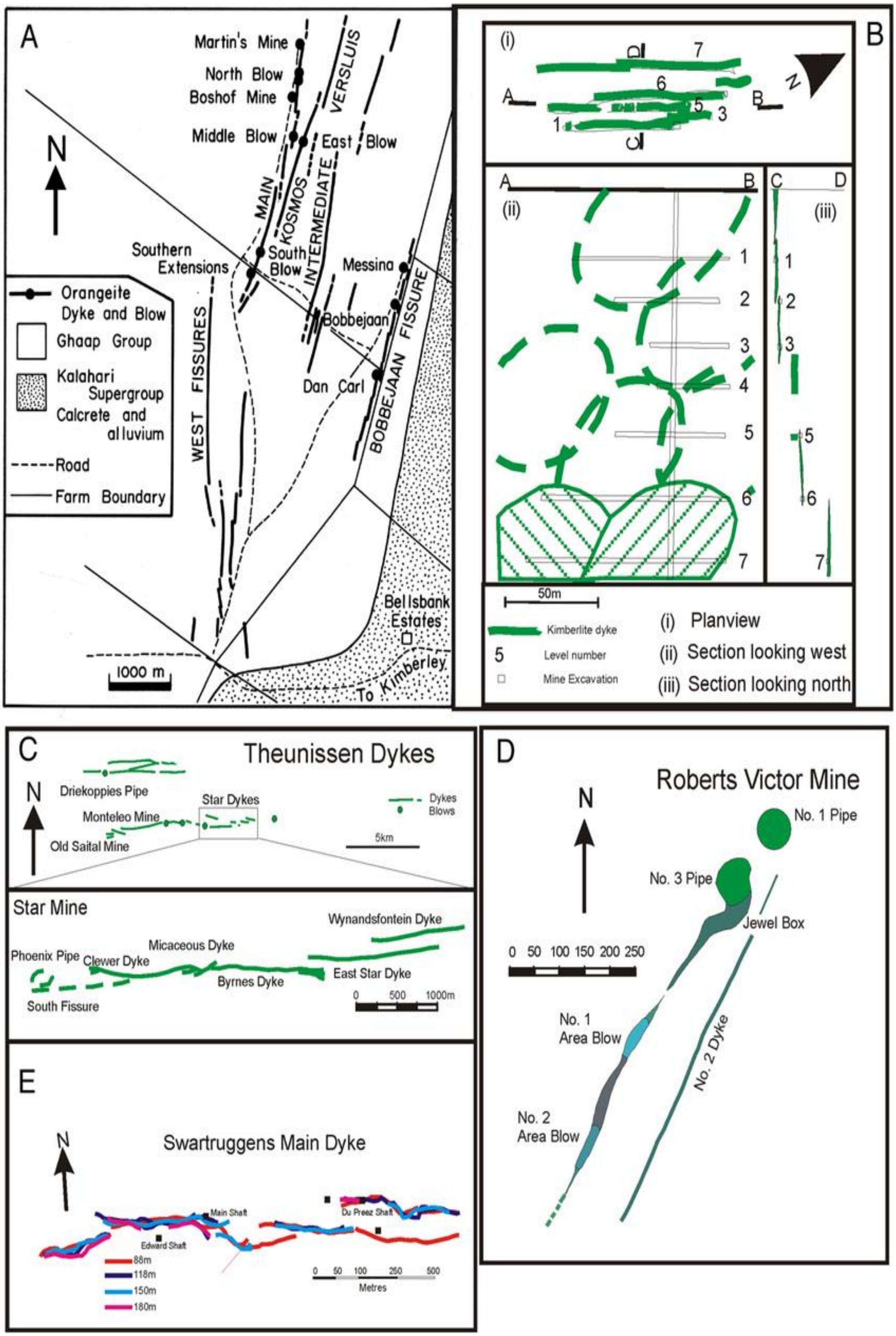
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East Blow
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ALEXANDER BAY DIAMOND COMPANY (ABDC) - ROUGH DIAMOND SALES TENDER HOUSE, HOUGHTON ESTATE, JOHANNESBURG

Visits to ABDC will be undertaken in the later part of July or in August 2022 at dates which coincide with the sale of rough goods by ABDC from predominantly alluvial diamond producers in RSA. Details will be provided by the organisers, and the visits to this facility will be coordinated by Grant Ziegler (082 448 4859) and John Bristow (082 571 3004). This facility is located at 1 River Street, Houghton Estate, immediately below (north) of the Killarney Mall in Johannesburg.

The company was established in 2014 by current CEO Daniel Nathan, who has over 30 years of experience in the diamond marketing industry and consists of a small highly skilled team with extensive experience in the diamond trade. It specialises in marketing, trading and polishing rough diamonds for major outlets both locally and globally, and is housed in a state-of-the-art facility conveniently situated in Johannesburg. The premises were previously used as an American Embassy, hence are monitored 24/7 by sophisticated CCTV camera systems, and a world-class security team.

The facility enables ABDC to provide a safe and protected environment to conduct diamond valuations in private viewing rooms that are fully equipped with the latest technology and equipment for rough diamond inspection and valuation, allowing buyers to make informed decisions in an efficient manner.

The Company has acquired a substantial network of over 250 local and international South African licensed buyers, all in accordance with RSA diamond trading laws. The company also utilizes the latest technology and methods to carefully clean, sort, and meticulously curate, photograph all rough diamonds made available for marketing and sales. This procedure is followed for each tender sale (generally ten per annum), with the data for the sorted, categorised, and numbered parcels of prepared rough diamonds made available on an online bidding sales platform, on the company's website. The LIVE bidding system is user-friendly, allowing Buyers to sign-up, become registered rough diamond buyers, and visit the facility to view the available diamonds. Once the auction goes LIVE, the tender closes on a specified date and buyers are notified within a few hours if their bids are successful.

The ABDC marketing team closely track rough and polished diamond sales, and marketing trends worldwide, utilising this data and their experience to market and sell clients rough diamonds as efficiently and quickly as possible. Importantly, ABDC is not itself a producer or buyer, but an unrelated independent facilitator of rough sales for which it receives a market-related fee. Thereby upholding its mission to provide a convenient, safe, transparent and honest marketing service.

https://youtu.be/i3nv-9lIO-g

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