Mining for diamonds – history and present

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Abstract

Mining for diamonds most likely started in India centuries ago. Until discoveries of diamond deposits in Brazil in the early 18th century, alluvial mining in India was the only source of diamonds in the world. Mining of primary kimberlite diamond deposits on an industrial scale had only emerged with diamond discoveries in South Africa within the second half of the 19th century. Initially, kimberlite deposits were mined as open cast mines but as soon as open cast mining reached technical and economic limits, underground mining was implemented in the 1890s. To date, primary diamond deposits mined by surface or underground mining methods on an industrial scale are mainly volcanic pipes, steeply dipping dykes or shallow dipping sills. The recent discovery of tube-like shallow dipping bodies will no doubt justify consideration of different underground mining approaches. Underground mining only became practical after the development of the chambering method in the 1890s which remained in use until the 1950s, when the block caving mining method was implemented. Since then, more than 18 mining methods have been introduced and developed in diamond mines. Another major development in diamond mining is offshore mining along the coast of Namibia. Open pit mining today accounts for the majority of carats produced but underground mining is playing an increasing role. Excluding alluvial and offshore diamond mines, approximately 15 of 50 primary diamond deposits are operated as underground mines and another 15 or so have underground plans or hold the potential for underground mine development. The objective of this paper is to provide an overview of historical and modern mining methods implemented in diamond mines worldwide with the focus on primary diamond deposits.

1 Introduction

Mining for diamonds most likely started in India centuries ago. Until discoveries of diamond deposits in Brazil in 1726, alluvial mining at the Krishna River in India was the only source of diamonds in the world. Mining of primary kimberlite diamond deposits on an industrial scale had only emerged with diamond discoveries in South Africa in the second half of the 19th century. There is inconsistency in when and where exactly diamonds were associated with igneous rocks, but by the 1870s it was obvious that diamonds were sourced from deposits other than alluvial deposits. Soon after these discoveries, the igneous rocks associated with diamonds were named "kimberlite" after the diamond rush town of Kimberley. Initially, kimberlite deposits were mined as open cast mines but once open cast mining reached technical and economic limits, underground mining was implemented in the 1890s – see Figure 1. To date, primary diamond deposits mined by surface or underground mining methods on an industrial scale are mainly volcanic pipes, steeply dipping dykes or shallow dipping sills. Recently, another type of kimberlite body was discovered in Canada and these tube-like shallow dipping bodies will no doubt justify consideration of different underground mining approaches. According to Owen & Guest (1994), underground mining was first introduced in 1884 but only became practical after the development of the chambering method by Williams in the 1890s (1902). This method was the primary underground mining method used until the 1950s when the block caving mining method was tested and implemented at Bultfontein mine. Several other underground mining methods such as Sub-Level Caving (SLC), Vertical Crater Retreat (VCR), Open Benching and Sub-Level Retreat (SLR) were developed and introduced in South African diamond mines since then. Although a variety of underground methods were implemented with variable success, block caving remains the most productive underground mining method used on primary kimberlite and lamproite diamond deposits to date. Another major development in diamond mining is offshore mining along the coast of Namibia. Recent development of underwater mining technologies has enabled economic exploitation of secondary diamond deposits at water depths of 100 m or more.

The discovery and mining of diamond deposits in Siberia in the 1950s and in Canada in the 1990s represents a significant development in diamond mining in extreme climatic conditions where winter temperatures plummet to –50°C or colder.

Large diamond pipes were discovered in Botswana in the late 1960s. Today, 50 years later, Botswana continues to be a top diamond producer globally with Jwaneng mine being arguably the most valuable diamond mine in the world. Jwaneng is estimated to independently produce 15% of the world's diamonds in value. The Karowe mine in Botswana recently produced a series of large, high-value gem diamonds, of which the 1,109 carat Lesedi La Rona is the fourth largest rough diamond ever produced.

Open pit mining accounts today for the majority of carats produced but underground mining is playing an increasing role. However, underground mining also introduces increased complexity and the cost typically exceeds many times the cost of open pit mining while production rates are significantly lower. Excluding alluvial and offshore diamond mines, approximately 15 of 50 primary diamond deposits (kimberlites or lamproites) are operated as underground mines and another 15 or so have underground plans or hold the potential for underground mine development. The objective of this paper is to provide an overview of historical and modern mining methods implemented in diamond mines worldwide with the focus on primary diamond deposits.

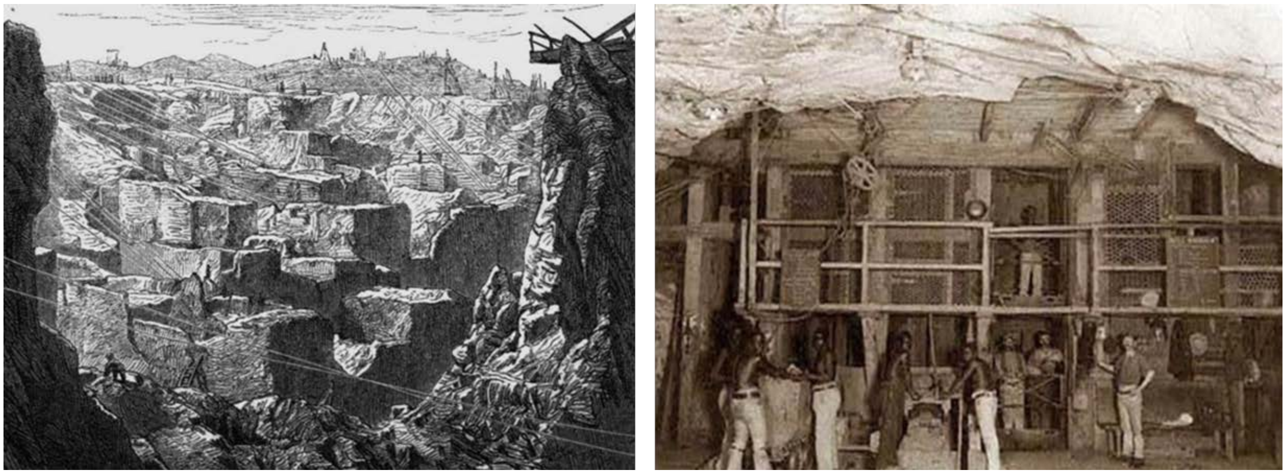

Figure 1 Historical open cast diamond mining in Kimberley mine illustrated by E. Holub in 1871 (left) and picture of Kimberley underground mine from early 19th century (right)

2 Diamond mining around the world

Diamond mining is currently being conducted in some 23 countries on six continents. Significant industrial exploitation of primary and secondary diamond deposits occurs in Botswana, South Africa, Angola, Namibia, Zimbabwe, Tanzania, Lesotho, Sierra Leone, Russia, Australia, Brazil, India and Canada – see Figure 2. In addition to industrial scale diamond mining of placer deposits, artisanal mining occurs in Angola, Sierra Leone, Democratic Republic of Congo, Central African Republic, Cote d'Ivoire, Guinea, Ghana, Liberia, Tanzania, Togo, Brazil, Venezuela, Guyana and South Africa. Excellent overview of the diamond resources in Africa is presented in M. de Wit et al. (2016)

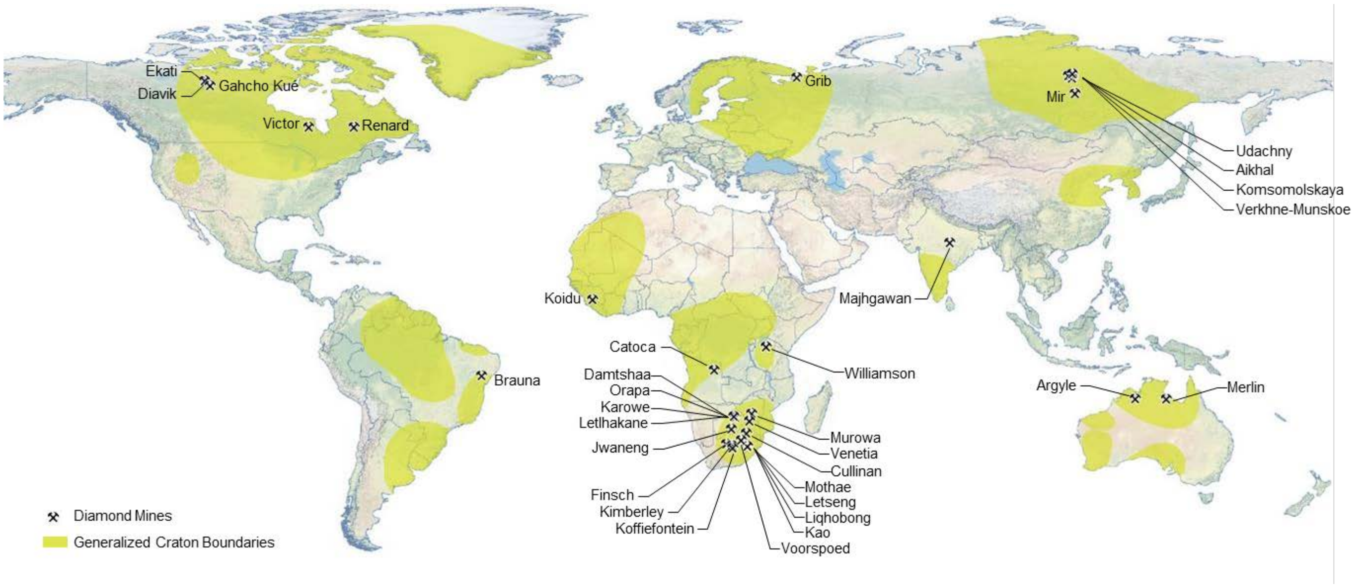

Figure 2 Major diamond mines and kimberlite clusters around the world

Zimnisky (2017) estimated global diamond production in 2017 to be 142.3 million carats worth USD 15.6 billion. Russia is the largest producer by value, followed by Botswana, Canada, Angola and South Africa respectively – see Figure 3.

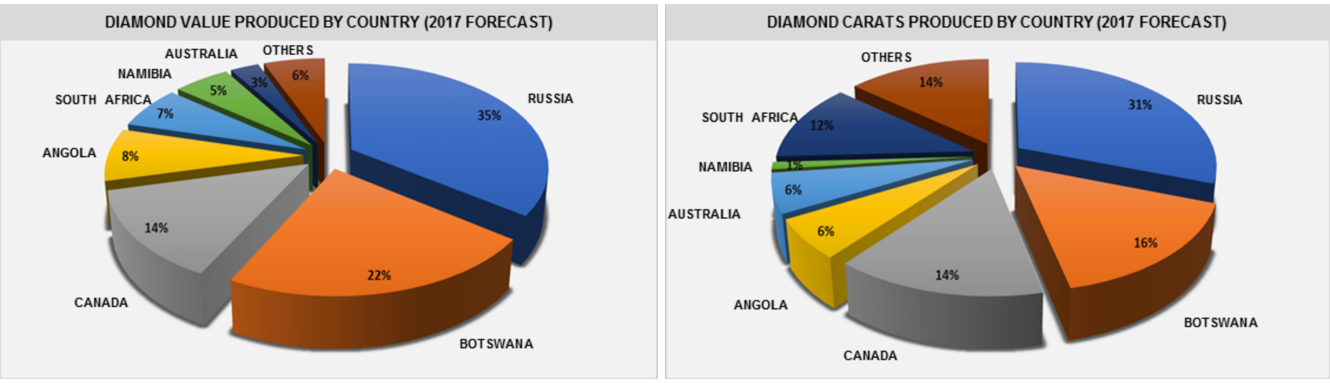

Figure 3 Diamond values (left) and carats (right) produced by countries

3 Diamond mining methods – milestones

Although mining of secondary (alluvial) diamond deposits has been practiced for millennia, hard rock mining of primary deposits over the past 150 years has resulted in development of several open pit mining methods and more than 18 methods for underground mining of kimberlite pipes, dykes and sills. The following are the main milestones in the evolution of diamond mining techniques:

- Alluvial Mining – 4,000 years ago; it is believed that diamonds were first mined in India from secondary (alluvial) deposits
- Hard Rock Surface Mining – Late 19th century in South Africa
- Hard Rock Underground Mining – Late 19th century in South Africa
- Mining in the Arctic – Mid 20th century in Russia

- Deep Sea Mining – End of 20th century off the coast of Namibia
- Mine Dumps Re-treatment – End of 20th century in South Africa
- Mining Under Lakes – Early 21st century in Canada

In the past 20 or so years, mining technology has advanced significantly and enabled increased productivity, recovery, safety and efficiency of mining processes, and ultimately enabled economic exploitation of deposits that were previously out of reach. Salient characteristics of these advances are:

- Open Pit Mining – Pit depths exceeding 800 m, single blasts exceeding 100,000 tonnes, in-pit crushing, haul trucks capacity exceeding 300 tonnes, automation and electrification of equipment, radar pit slope monitoring and use of single shot electronic detonators which can significantly improve blasting efficiency and reduce diamond breakage.
- Mass Underground Mining – Production rates exceeding 10,000 tonnes per day, mining at depths exceeding 1,000 m, introduction of tele-remote mining and automated haulage systems, and introduction of new mining methods such as SLR.
- Mining in the Arctic – New technology and logistical processes enable mining in remote places and at extremely low temperatures as well as mining in permafrost and under lakes.

Figure 4 illustrates the proportion of the different mining methods as of 2017.

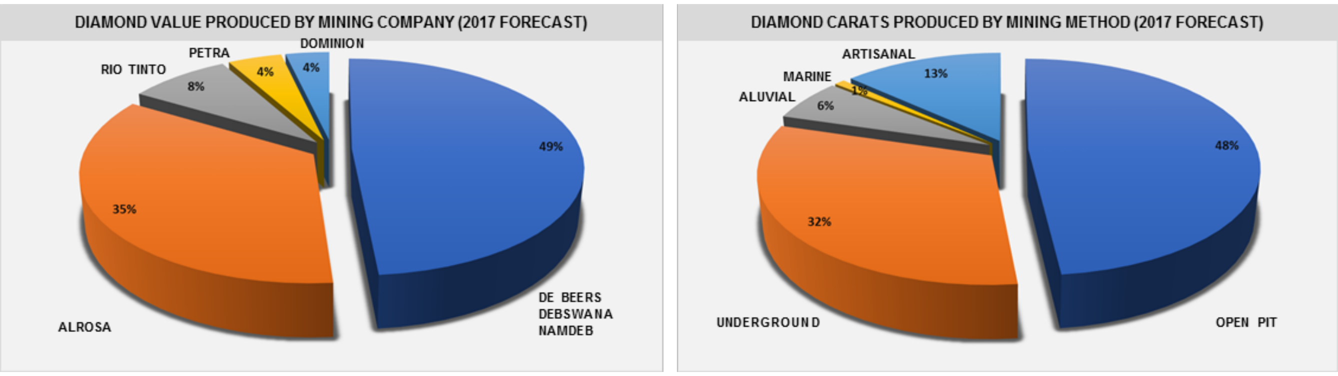

Figure 4 Diamonds produced by major mining companies (left) and by mining method (right)

4 Mining methods selection criteria

Both primary and secondary diamond deposits have been mined by more than 18 different mining methods including open pit and underground mining. Figure 5 illustrates the combination of various mining methods for different diamond deposits. In general, the choice of mining method depends on the following:

- Geological setting (diamond deposit internal and external geology)
- Orebody size and geometry
- Ore value per ton or m^3 (often represented by NSR – Net Smelter Return value)
- Grade distribution and dilution
- Rock mass competency and susceptibility to weathering
- Disturbances (in-situ stress, surface and ground water)
- External constraints (corporate, market, social economic, environmental, etc.)

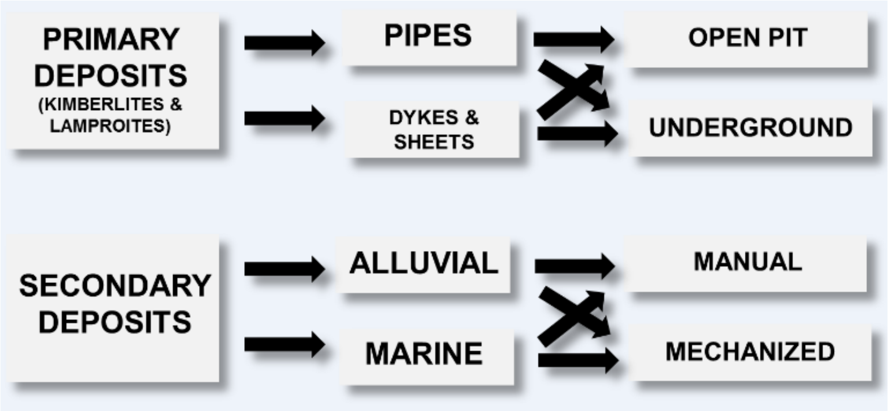

Figure 5 Mining methods for primary and secondary diamond deposits

4.1 Geological settings

Country rock geology has a significant impact on kimberlite and lamproite emplacement processes and hence deposit geometry. The processes leading to the formation of primary diamond deposits are complex and the subject of ongoing research and debate. The geological setting for emplacement includes lithostratigraphy of country rocks, structural geology, in-situ stress regime and hydrogeological conditions. In the context of selecting a viable mining method, characterization of the country rock plays an equally important role as the geology of the primary diamond deposit. Weak, poorly consolidated and saturated sedimentary units of the country rocks (e.g. Fort a la Corne) will dictate a different approach to mining than competent and strong country rock (e.g. granites of the Slave Province). The presence or absence of wall rock breccias and external contact zones will have a direct impact on wall rock dilution and pit wall stability. The presence or absence of permafrost must also be defined in cold climate locations.

Internal orebody geology is largely dictated by the emplacement processes involved, including the style and extent of volcanic processes, and the level of erosion. Geomechanical properties are influenced by the kimberlite type and the degree and style of alteration. Volcaniclastic kimberlites tend to be weaker and may be clay-rich while coherent kimberlites are generally more competent and stronger. A range of different kimberlite types may be present in a single pipe. Alteration due to water migration on the pipe perimeter could have created weak internal contact zones.

4.2 Orebody size and geometry

Emplacement processes and the level of erosion have a direct impact on the orebody geometry. Based on the geometry, the following orebody types can be recognized among primary deposits:

- Steeply dipping volcanic pipes,
- Steeply dipping dykes,
- Shallow dipping sheets, and
- Shallow dipping tube-like bodies recently described from Canada.

Complex orebody geometry such as the 5034 pipe at Gahcho Kue mine, the Misery pipe at Ekati mine and kimberlite pipes at Venetia mine will require a different mining approach than regularly shaped pipes. An attempt was made to characterize the pipe shape complexity using cross-sectional area and perimeter into three basic categories of regular, irregular and complex shape pipes (Jakubec 2008). The size of the pipe will also dictate the mining method approach. For example, a small diameter pipe may not have enough cross-sectional area to implement cave mining and thus blasting of ore may be necessary.

The size of the resource will dictate the economic viability and mine life. Small orebodies, albeit rich, may not have enough value to justify all the capital development. Today, the capital expenditure for diamond mining projects will range from hundreds of millions to billions of dollars.

4.3 Ore value

Aside from the size of the resource, the recoverable grade, diamond value and operating cost will ultimately drive the project economics. Net smelter return value is typically used for mining method selection and evaluation. The challenge with evaluating diamond deposits lies not only with low-grade deposits and determination of diamond value, but also with estimating the impact of diamond damage, especially in the case of large stone producers. Diamond breakage can significantly erode the value per carat and hence the economics of the project. Besides the processing plant design, the mining method can also influence diamond breakage – e.g. blasting vs. naturally caving mining methods. Several technologies have been tested (see Figure 6) to reduce diamond breakage during the mining process but thus far without significant results.

Figure 6 Wirtgen cutter tested by Ekati mine at Fox pit (left) and bucket wheel excavators used for trial mining at Udachnaya mine in Siberia (right), both implemented to reduce diamond breakage

4.4 Grade distribution and dilution

Another critical aspect of the mining method selection is the value distribution in the resource. This is primarily driven by internal orebody geology and by dilution. Complex internal geology creates great challenges with sampling and estimation as well as reconciliation of the resource. Ore dilution by barren or low-grade material also creates a potential problem with the mining method. For example, large granite xenoliths may require excessive secondary blasting in the case of the caving method. Waste- or ore-sorting circuits may increase the operating cost by re-handling of mined material, slower throughput and excess wear in the processing plant.

4.5 Rock mass competency and susceptibility to weathering

Geomechanical characterization of the orebody and host rocks is one of the key aspects of the mining method selection and design. Comprehensive geomechanical characterization of the host rocks and contact zone will also be critical to the pit slope geometry, infrastructure location and capital development. Characterization of overburden will impact directly on mining risks such as mudrush and dilution.

Geomechanical characterization of kimberlite should include not only strength and rock mass competency but also weathering susceptibility and clay content. This will have an impact on the mining method as well as on operating costs and risks.

4.6 Disturbances (in-situ stress, surface and ground water)

With mining progressing to greater depths, in-situ stress is becoming a major player in the mining method selection. Stress acting on weak rock mass will cause excessive dilation of the rock mass resulting in deformation and collapse of tunnels and other excavations. In stronger kimberlite, stress could accumulate and a sudden release of energy could result in rockbursts and seismicity. Mitigation of adverse stress conditions requires an appropriate mining sequence to be followed. In mining methods with subsidence (BC, SLC, or SLR), both surface and groundwater could, and often do, play a key role in mudrushes. All effort should be made to divert all the water sources from entering the mining areas.

4.7 External constraints

Environmental and socio-economic aspects of mining projects are becoming increasingly important in various mining jurisdictions around the world. In most countries it is not possible to permit a mining project without comprehensive environmental impact studies, engagement of the local communities and a detailed closure plan. Closure costs have increased markedly in the past decade and responsible mining is becoming the norm rather than optional.

4.8 Mining in the Arctic

The Arctic imposes another layer of complexity when considering mining method selection (Jakubec et al 2004). The main issues are associated with the logistics to operate at extreme cold temperatures and weather conditions and permafrost which can extend over 400 m below surface. The issues that may arise include:

- Snow could accumulate in open drawpoints during storms
- Freezing muckpile – broken rock (ore or waste) can freeze after blasting and may require re-blasting
- Icing-up of blast holes: ice build-up in the drillholes was experienced at Koala North (Ekati mine) during the freshet and freeze up season that required re-drill
- Stabilizing effect of frozen pipe walls – during the winter months exposed pipe walls will be frozen and very stable
- De-stabilizing effect of ice jacking – freezing of water in the open joints will cause volumetric expansion and movement of the loose blocks. Subsequent melting could destabilize the blocks resulting in a rockfall
- Fogging – effect of very cold air coming into contact with warmer and moist underground conditions, especially in drawpoints or declines. This could have a significant impact on haulage, people and material movement
- Trafficability – build-up of ice on roadways, especially at the portals to declines and in the open drawpoints, requires special and continual attention to prevent slippery conditions (also, extensive ice build-up at exhaust shafts could constrict the opening and flow of air)
- Effect of underground cold on productivity – the effectiveness of both personnel and/or equipment can be affected if air must be kept below freezing to preserve the strengthening effect of the permafrost

- Shotcrete mix for cold climate – special additives are often required to ensure that shotcrete will set. Constituents have to be stored above freezing before use and heated water or heated aggregates and brine is necessary. Similar considerations are required for grouting of rock reinforcement
- Brine drilling – if rapid weathering rocks are not present and dry drilling is not possible then brine is necessary to combat freezing-in of drill rods.

5 Underground mining methods

Over the past 150 years, numerous mining methods have been developed, tested and implemented. They include the following:

- Chambering (CH)
- Gravity (Slusher or Scraper) Block Caving (BC)
- Mechanized Block caving (MBC)
- Panel Caving (PC)
- Front Caving (FC)
- Incline Caving (IC)
- Sub-Level Caving (SLC)
- VCR Assisted Caving
- Open Benching (OB)
- Sub-Level Retreat (SLR)
- Open Stoping (OS)
- Blast Hole Open Stoping (BHOS) with and without backfill
- Blast Hole Shrink Stoping
- Room and Pillar (R&P)
- Cut & Fill (C&F)
- Drift & Fill (D&F)
- Underhand Stoping (US)
- Overhand Shrinkage (OS)

Chambering – The first industrial underground mining method invented by G. Williams was introduced in the 1890s in the Kimberley diamond mine and was successfully used until the 1950s; Wesselton mine still used chambering until the late 1960s. Chamber levels were developed from the sub-vertical shaft at 12 m vertical intervals. Successive 8 m wide cuts were mined across the pipe extending vertically to the level above, leaving a 3.5 m wide pillar. The chamber was then mined by overhand shrinkage stoping and the pillar above was undercut and collapsed into the chamber. The method is described in Peele (1941).

Gravity Block Caving – Jagersfontein was the first diamond mine fully converted to block caving in 1958, followed by Du Toits Pan, Bultfontein, Wesselton and Premier mines. The last operating diamond mine still using gravity block caving is Wesselton mine. The scraped drifts were developed across the pipe at 14 m intervals and fully concrete lined. Staggered drawpoint openings are spaced at approximately 3.5 m and raises are developed to the footwall of the undercut level above and slashed into drawbells. The whole cross section of the pipe is undercut and broken kimberlite flows to the scraper drift by gravity. Mechanical scrapers then scrape the broken ore into trucks on the main haulage level. Detailed descriptions of the first use of a gravity cave on a diamond mine are in Gallagher & Loftus (1960) and Owen (1981).

Sub-Level Caving – As pipes were getting narrower and caveability of the kimberlite became problematic, the SLC method was established in Kimberley mines in 1979. Sub-levels were developed at 15 m vertical intervals and parallel crosscut tunnels were developed at 11 m spacing across the pipe. Slots were established at the end of the crosscuts and individual rings were blasted in each crosscut. Several levels with staggered crosscuts were operated at the same time. Some discussion of SLC design is documented in Hartley (1981). The SLC method was used between 1979 and 1989 when it was replaced by VCR assisted caving. The most recent SLC has been successfully completed at Koala at Ekati mine (Jakubec et al. 2017). In Africa, Gem Diamonds developed Ghaghoo mine as a SLC but it was put on care and maintenance in 2017. SLC is also being used by Petra Diamonds at Koffiefontein, Cullinan, and below Block 4 at Finsch mine.

VCR Assisted Caving – This method was first introduced at De Beers and Bultfontein mines to mitigate the lack of caveability of the narrow kimberlite pipes and to mitigate mudrush risks. The method had mixed success and it is described in detail in Granger (1992).

Open Stoping – Large open stopes were designed at Premier mine under the Gabbro sill. The stopes were planned to be 80 m wide, up to 80 m high and 125 m long with pillars 40 m wide between. The production started in 1983 but shortly after the roof started to collapse and the mining method was abandoned. Detailed analysis of the performance is described in Esterhuizen (1987).

Open Benching – This method was developed and first implemented by De Beers in 1948 at Premier mine. It was also called “slot mining” and evolved into a better design at Finsch and Koffiefontein mines as a transition between open pit and underground operations. At Premier, the mining levels were initially established at 15 m vertical spacing. From the central tunnel vertical, a 14 m wide slot was blasted. On each level, drilling crosscuts were developed at 28 m spacing. On the level below, a series of draw cones were developed on 14 m centres leading to grizzlies and ore was fed by gravity via ore pass to the main haulage below. In the late 1980s, mechanized open benching was designed for Finsch and Koffiefontein mines. The drilling levels were at 36 m centres and 60 m above the loading levels with 80 degrees inclination of upper holes and 50 degrees inclination of down holes. The compound ring variation was implemented in 1991 and a year later it was introduced to Koffiefontein. Detailed description of the open benching, compound ring design and performance was published by Guest (1989) and Silverton & Smart (1992).

In 1999, an open benching design was introduced to Ekati mine by C. Page and J. Jakubec. The Koala North pipe was selected for an initial trial and in 2002 became the first North American underground diamond mine to operate an open bench. The initial design included sub-levels at 15 m horizontal spacing and crosscuts at 15 m. The sub-level spacing was subsequently increased to 20 m and after a successful trial the method was implemented at Panda pipe. The open benching was converted to sub-level retreat – a variation of open benching with a protective cover of broken muckpile left on the extraction levels to increase safety. Mining at Panda was successfully completed in 2015 and the method was also introduced at Diavik A154S and A418 pipes. This mining method is illustrated and described in Jakubec & Long (2004) and Jakubec et al. (2017).

Front Caving – This mining method involves establishment of semi-permanent drawpoints on two or three sub-levels and retreat from the central slot to the pipe perimeter. The front caving method was used at Koffiefontein between 1997 and 2003 when failure of the front cave halted the production. Various aspects of the front cave were described by Hannweg & Van Hout (2001) and Hannweg et al. (2004).

Mechanized Block and Panel Caving – This is the current mining method at Cullinan (formerly Premier) and Finsch mines in South Africa, and at Argyle mine in Australia. The mechanized block cave utilizes load-haul-dump

(LHD) equipment instead of scrapers and was introduced to Premier mine in 1990 in Block BA5 and in 1996 in Block BB1E. Mechanized caving involves the development of undercut, production, ventilation and haulage levels. The drawpoint spacing was 15 m x 15 m in BA5 and 15 m x 18 m in BB1E. There are numerous variations of block cave undercutting and sequencing, with outcomes from Premier mine published in Bartlett (1992) and Bartlett & Croll (2000). In 2004, Finsch mine also introduced mechanized block caving for Block 4 after open benching was completed; the mine is currently transitioning to SLC. Argyle mine also recently implemented a panel caving method.

Incline Caving – The mining configuration for incline caves involves rows of drawpoints that are offset vertically and follow an incline plane. In the incline plane, the individual drawpoints (drawbells) in the row and between individual sub-levels are spaced so that they allow full interaction, more or less the same way as in a horizontal layout. In the incline layout, this interactive draw is fundamentally different from SLC where there is no or limited interaction between individual drawpoints, although the layout of sub-levels appears to be similar. Incline cave was studied to pre-feasibility level at Finsch for Block 5 (Paucar & Mthombeni, 2004) but was not implemented. The first incline cave was implemented in 2014 at Koala pipe, Ekati mine. The design included three levels of double-sided incline cave with approximately 47 drawpoints at 15 m spacing following approximately the pipe geometry. The incline cave performed well and enabled extraction of low-grade material that would otherwise be uneconomical for the SLC method.

Blast Hole Open Stoping (BHOS) with Backfill – Underground mine development commenced at Diavik in 2005 and BHOS was implemented at A154N pipe. The main reason for selecting this method was to limit surface subsidence given the proximity of the pipe to the pit wall and dykes.

Cut & Fill and Drift & Fill – These fill methods were recently implemented in Russian diamond mines to limit the potential impact of subsidence and to mitigate mudrush risks. Internatsionalnaya was the first Russian diamond mine to develop underground in the 1990s. Since 2005, Aikhal, Mir and Udachny mines also developed underground mining using backfill methods.

Blast Hole Shrink Stoping (BHSS) – This unique underground mining method in several variations has been adopted by Renard mine at their Renard 2, 3 and 4 kimberlite pipes. The infrastructure for underground mining is currently being developed. For details refer to Stornoway (2016).

A list of underground diamond mines on kimberlite and lamproite pipes is shown in Table 1 and a list of underground diamond mines on dykes and sheets is presented in Table 2.

Table 1 List of main mining methods for active (A) and closed (C) underground diamond mines on kimberlite pipes and lamproite pipes

Country	Underground Diamond Mines – Pipes	Status	Open Pit	Chambering	Gravity Block Cave	Mechanized Block Cave	Front/incline Cave	VCR Assisted Cave	Sub-level Cave	Sub-level Retreat	Backfill methods	Open stopes
South Africa	De Beers	C	X	X	X			X	X			
	Bultfontein	A	X	X	X			X	X			
	Du Toits Pan	A	X	X	X							
	Wesselton	A	X	X	X				X			
	Jagersfontein	C	X	X	X							
	Koffiefontein	A	X				X			X		
	Cullinan (Premier)	A	X		X	X				X		X
	Finsch	A	X			X				X		
	Venetia	D	X						X			X
	Lace	A	X			X						X
Canada	Koala North	C	X							X		
	Koala	A	X				X		X			
	Panda	C	X							X		
	Misery	D	X							X		
	A154S	A	X							X		
	A154N	A	X								X	
	A418	A	X							X		
	Renard	D	X									X
	Snap Lake	C	-								X	X
Russia	Udachnaya	A	X								X	
	Mir	A	X								X	
	Aichal	A	X								X	
	Internationalnaya	A	X								X	
Australia	Argyle	A	X			X						
China	Nchangma 701	C	X							X		
Sierra Leone	Koidu	A	X							X		
Botswana	Ghaghoo	C	-						X			

Table 2 List of active (A) and closed (C) underground diamond mines on kimberlite dykes

Country	Mine	status	steep	shallow	blows	open pit	underground
Canada	Snap Lake	C		**X**			**X**
South Africa	Frank Smith	C	**X**		**X**		**X**
	Newlands	C	**X**		**X**		**X**
	New Elands	C	**X**		**X**	**X**	**X**
	Kaalvallei	C	**X**				**X**
	Roberts Victor	C	**X**		**X**	**X**	**X**
	Doornkloof-Sover	C	**X**		**X**		**X**
	Marsfontain	C	**X**		**X**	**X**	
	Klipspringer	C	**X**		**X**		**X**
	Star Mine	C	**X**		**X**		**X**
	Theunissen group (Saital Mine)	C	**X**		**X**		**X**
	Loxtondal (Don)	C	**X**		**X**	**X**	**X**
	Bellsbank	C	**X**				**X**
	Swartruggens (Helam)	A	**X**				**X**
Zimbabwe	Wessels Mine	C	**X**	**X**			**X**
Sierra Leone	Tonguma	C	**X**		**X**	**X**	
	Koidu Dykes	A	**X**		**X**	**X**	

6 Conclusions

In the past 150 years, diamond mining of primary diamond deposits has experienced major technological and logistical advances. This has enabled safe and economical mining of diamonds on a bigger scale than ever before with open pits reaching more than 800 m, underground mining at depths exceeding 1,000 m, mining under the ocean in waters more than 100 m deep, and mining in extreme climates with frigid temperatures. Discovering new kimberlite orebodies such as those at Kennady North in Canada will no doubt bring new mining techniques. Automation and increased implementation of mass mining techniques such as block caving will enable economic exploitation of larger but lower grade deposits. However, diamond mining is not without failure. Several diamond mines have closed prematurely or failed to deliver on what was promised. New technologies such as continuous miners and cutters for surface deposits and tele-remote miners for undersea deposits (see Figure 7) are playing an increasingly important role in diamond mining. The understanding of geological context will remain a crucial part of successful mining ventures.

Figure 7 Bauer trench cutter (left) and new continuous miner for undersea mining (right)

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