





INTRODUCTION

end of the 1990s. Today, out of some 40 diamond hard rock mines, approximately half 1 illustrates the production to date from Ekati underground and open pit mines. are underground and a number of others have underground plans or the potential to mine underground.

CANADIAN UNDERGROUND DIAMOND MINES OVERVIEW

The largest growth of diamond underground mining in the world was experienced in Canada. To date, underground mining was used with five kimberlite pipes and one kimberlite sill. These are Panda, Koala and Koala North at the Ekati Mine; A418, A514N and A514S at the Diavik Mine and at Snap Lake. The focus of this paper is to document experiences with underground mining of kimberlite pipes at Ekati (Fig. 2) and Diavik Mines

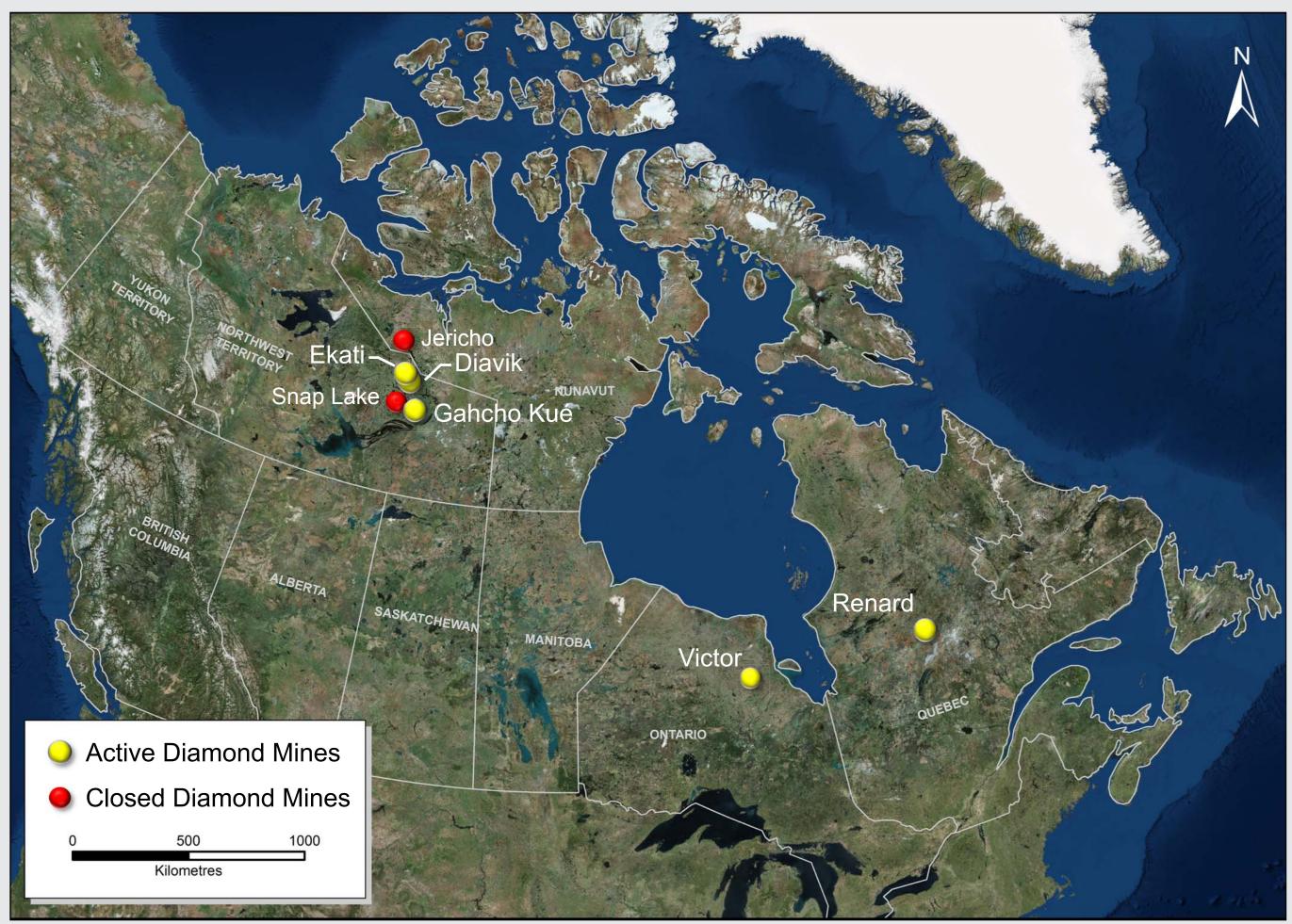


Figure 1: Location of Diamond Mines in Canada.

The Ekati Diamond Mine was the first diamond mine to be developed near Lac de Gras in the Northwest Territories of Canada. Mining commenced with an open pit operation first at Panda, followed by an open pit at Koala then Koala North. Project feasibility analysis was then implemented for the purposes of identifying suitable methods for extracting underground resources beneath the Panda and Koala open pits.

The Koala North pipe had been selected as a trial underground mine location for the purposes of testing mining methods and to provide access to the lower elevations of the Panda and Koala pipes. The upper 40m of the Koala North pipe was mined in late 2000 as an open pit which provided grade and geotechnical information and a prepared sur- Figure 3: Aerial view of Diavik Diamond Mines. face for the transition to underground mining.



Figure 2: Aerial view of the Ekati Mine.

Primary diamond deposits have been mined on an industrial scale only within the past In 2002, Koala North underground was formally opened and it became North America's 150 years, mainly as open pit operations. Underground mining of these deposits was first underground diamond mine. Koala North pipe has been successfully mined as implemented only within the second half of the 20th century in South Africa and over the mechanized open-benching down to 2115 level and proved that sub-level retreat (SLR) last 50 years, a relatively large number of underground mining methods were tested is technically feasible and an economically viable mining method for exploiting kimberand implemented. In the mid 1990's, Alrosa started the development of the first under- lite pipes in the Arctic. Since then, Panda and Koala pipes were also mined as underground diamond mine in Russia, Internationalnaya. Since then, underground mining ground mines after open pits were completed and several other pipes are being investiwas implemented on several mines in Yakutia including Aikhal, Mir, and Udachny. China gated for underground mining. At Ekati, three principal underground mining methods had also experimented with underground mining at Nhangma 701 Diamond Mine at the were utilized including SLR, sub-level caving (SLC) and incline cave (IC) mining. Table

Mining Method	Pipe	Mining Method	Production Rate (Mwmt/annum)	Tons Produced (Mdmt)
Open Pit	Panda	Open Pit	2.8	14.2
	Koala	Open Pit	3.5	10.6
	Beartooth	Open Pit	0.4	1.8
				8.7
	Misery	Open Pit	1.4	(includes inferred
				satellites)
	Fox	Open Pit	3.1	24.3
Underground	Panda	SLR	1.2	4.7
	Koala	SLC, IC	1	IC still operating
	Koala North	SLR	0.3	1.8

Table 1: Ekati underground and open pit mines production to date.

Diavik Diamond Mine started open pit production in 2003. By 2005, underground development had commenced with initial plans to mine the A154 and A418 pipes using backfill methods. As geotechnical knowledge was gained, the mining methods were re-evaluated and the SLR method was chosen for the A154S and A418 pipes, however blasthole stoping (BHS) with cemented rockfill was chosen for the A154N pipe.



In 2012, the open pits reached their ultimate depths and Diavik became a fully underground operation. The current life of mine is planned to 2024. A mining summary to date is illustrated in Table 2.

Mining Method	Pipe	Mining Method	Production Rate (Mt/annum)	Tons Produced (Mt)
Open Pit (2003-2010)	A154S & A154N	Open Pit	1.61 (avg)	12.9
Open Pit (2008-2012)	A418	Open Pit	1.10 (avg)	5.5
Underground (2010 start)	A154N	BHS	0.57 (avg), 0.75 (current)	4
Underground (2010 start)	A154S & A154N	SLR	0.40 (avg), 0.49 (current)	2.8
Underground (2011 start)	A418	SLR	0.58 (avg), 1.10 (current)	3.5

Table 2: Diavik underground and open pit mines production to date.

11th International Kimberlite Conference, Botswana, 2017 **Underground Mining at Ekati and Diavik Diamond Mines**

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UNDERGROUND MINING METHODS

While the BHS method with cemented rockfill used at Diavik, and the SLC method used at Ekati are commonly used in Canadian underground operations, the SLR method was newly introduced to Canada; hence, this poster will focus on the SLR mining method. The decision to select the SLR method was made as a result of technical, economical and safety risk considerations. Competent country rocks, favourable geometry, relatively competent kimberlite, and the Arctic context of the projects played an important role in the mining method selection process at both Ekati and Diavik Mines. The schematic section illustrating the SLR method is shown in Figure 4.

To date, the SLR method has been successfully implemented at both Ekati (Fig. 5) and Diavik (Fig. 6) diamond mines.

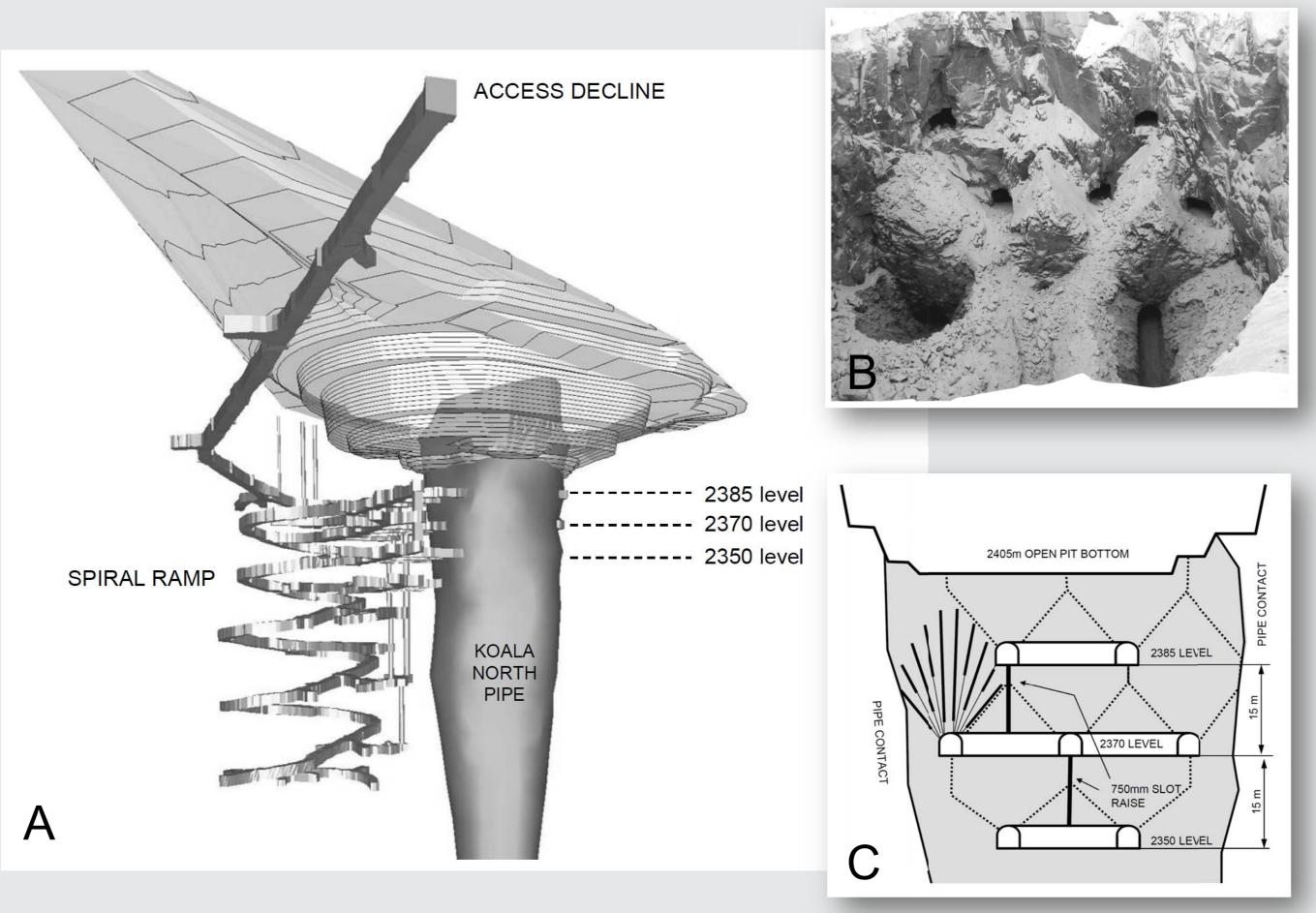


Figure 4: Isometric view of Koala North underground mine (A), SLR stopes (B) and a schematic section through an SLR mine (C).

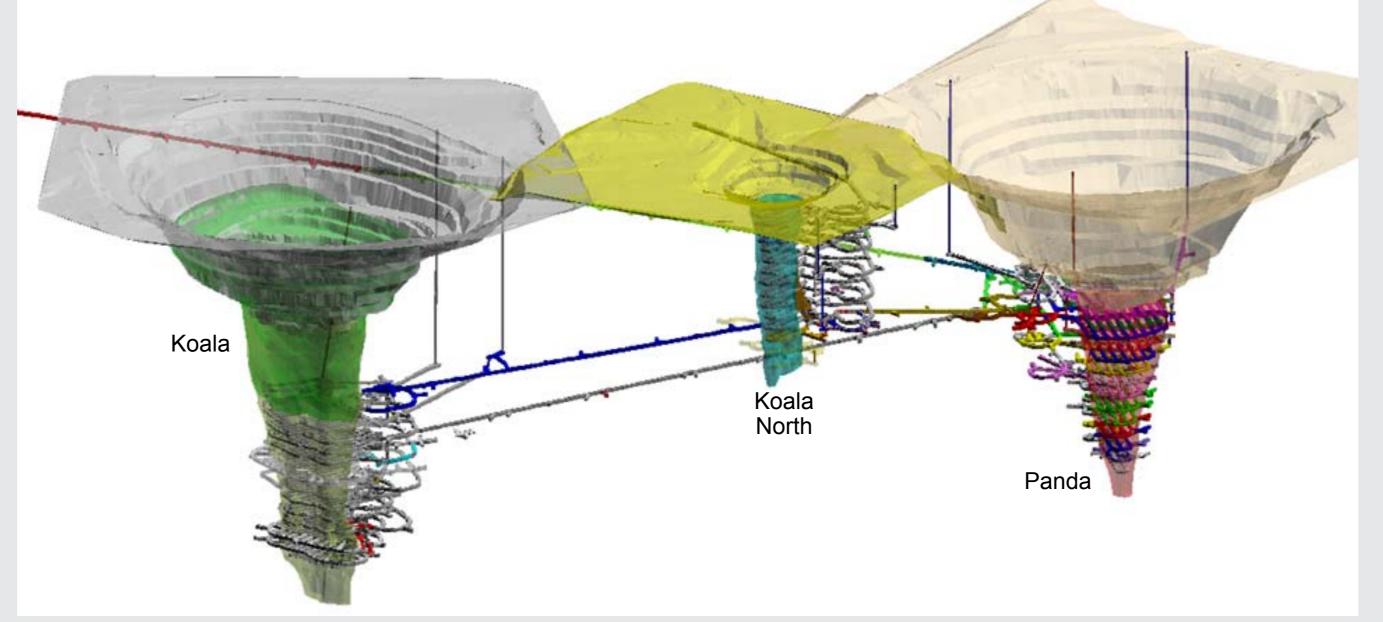


Figure 5: Ekati's underground mine complex.

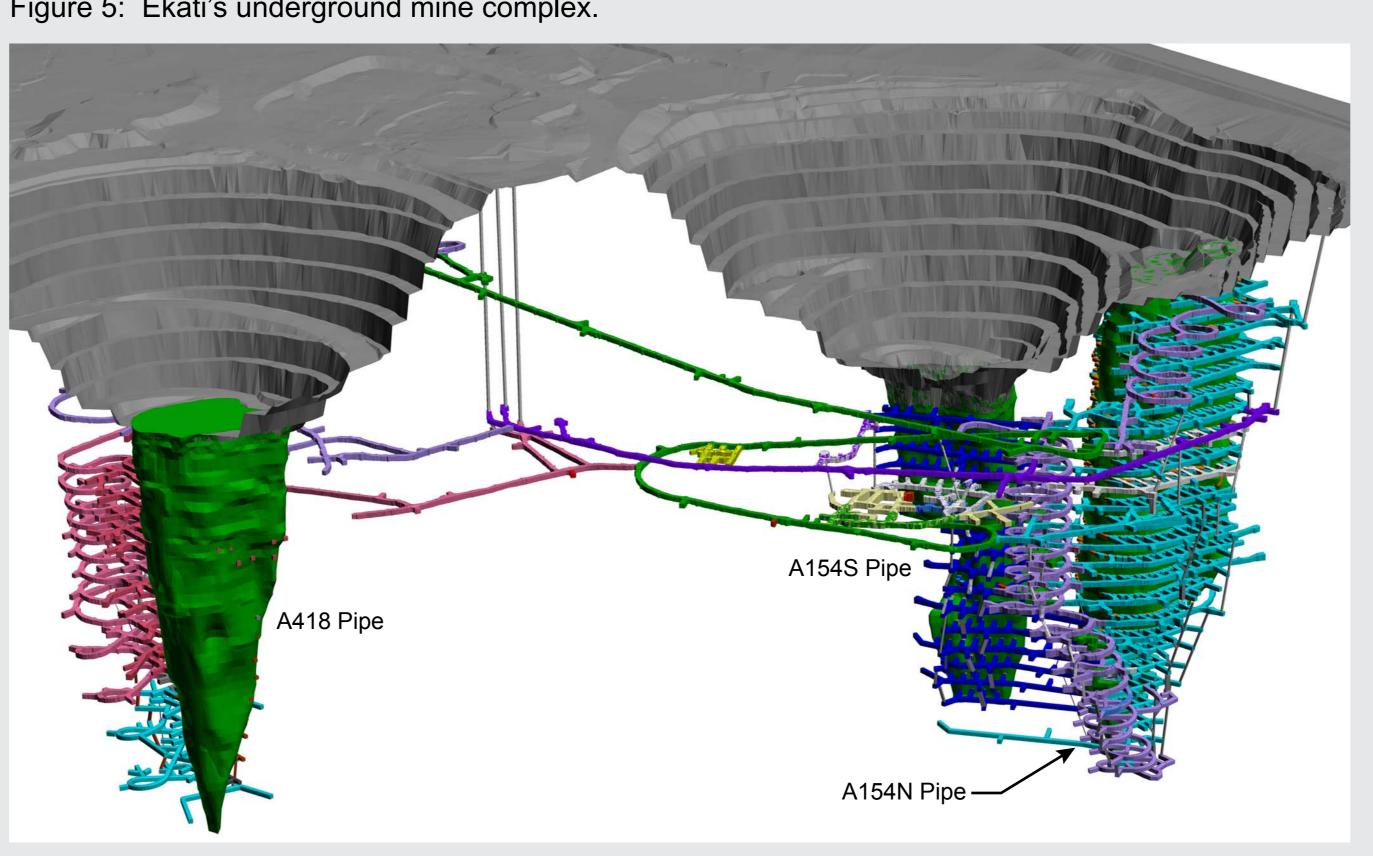


Figure 6: Diavik's underground mine complex.

OPERATIONAL CHALLENGES IN AN ARCTIC CONTEXT

Operating an SLR underground mine in winter poses a number of significant challenges. Specifically, a freezing muckpile, the stability of the country rock contacts, development in permafrost, ventilation, application of shotcrete and production drilling.

Freezing Muckpile - During the winter months the broken muckpile in the stope after the production blast will freeze up if not removed. The key to successful ore recovery is removal of the freshly blasted muckpile as soon as possible and prevention of water access to the stope.

Wallrock Stability - During the winter, granite wallrock contacts are stable (Fig. 7), but during the freshet, wall stability issues have been experienced. Contact wall failures are variable in size, some exceeding 100K tonnes. To manage safety at the SLR drawpoints, drawpoints are left choked.



Figure 7: SLR drawpoint at Koala North.

Ventilation and Fogging – Initially both mines experienced fogging challenges. At Diavik, when drawpoints were cracked open, cold outside air was drawn underground. When this occurs, individual drawpoints are overcome with fog to the point of nearly zero visibility, ice begins to form on the sill, and service water pipes freeze. For this reason, ventilation doors are installed at the entrance of each level with secondary fans mounted in the door frame. This increases the relative pressure on the level, ensuring air is exhausted out of cracked drawpoints.

Shotcrete mix for cold climate - At Ekati, current shotcrete mix used underground comprises 480kg ready mixed shotcrete and 1120kg aggregate. In the winter, 27.5kg of CaCl is added to prevent freezing.

At Diavik, wet mix shotcrete is utilized. It is batched in a surface batch plant and delivered

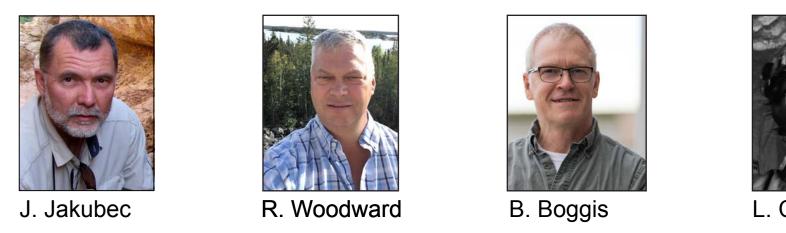


Figure 8: Solo production drill at Koala Mine.

underground using Normet mixers. The current mix design is 585kg Type 10 cement; 1508kg 10mm minus aggregate; 215 liters of water, plus admixtures. The aggregate is crushed on site and kept heated in the winter months using steam.

Development and Production drilling -Due to the susceptibility of kimberlite to weathering, the production drillholes at Ekati had to be drilled dry (Fig. 8). This proved to be very successful and the only problem that had to be addressed was the need to re-drill due to the icing up of the drillholes. Development in the permafrost granite required drilling with brine.

At Diavik, production drilling (Fig. 9) is generally carried out using conventional water flushing with few issues. When weak kimberlite is encountered, the air/water mist feature on the drill is used and successfully prevents hole washout.







CONCLUSIONS

Both mining operations at Ekati and Diavik proved that not only open pit mining but also concurrent development and implementation of underground mines in an extremely challenging environment is technically feasible and economically viable.



Figure 9: Underground driling at Diavik Diamond Mine.

Both mines had to overcome extreme logistical and technical challenges. This would not be possible without the commitment and dedication of all members of the team and without innovative mining solutions. To date, the SLR method has been completed at Panda (Fig. 10) and at Koala North. The SLR method continues to be used as a primary underground mining method at Diavik mine.



Figure 10: SLR crater at the bottom of Panda open pit

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BIBLIOGRAPHY

- 1. Jakubec, J., Long, L., Nowicki, T., Dyck D., "Underground Geotechnical and Geological Investigation at Ekati Di-amond Mine Koala North Case Study", 8th International Kimberlite Conference, Victoria, 2002, Lithos, v. 76, iss. 1-4 [SPECIAL ISSUE], p. 337-345, 2004
- 2. Jakubec, J., Page C., Harvey, P., "Mining Method Selection for Diamond Mines Challenges in the Arctic", MASSMIN 2004, Santiago, Chile, Aug. 2004
- 3. Jakubec, J., Long, L., "Open Benching at Ekati Mine Koala North Case Study", MASSMIN 2004, Santiago, Chile, Aug. 2004