Open Benching at EKATI diamond mine – Koala North: Case Study

Jaroslav Jakubec, SRK Consulting, Canada, Larry Long, BHP Billiton Diamonds Inc

Abstract

EKATI Diamond Mine was the first diamond mine to be developed near Lac de Gras in the Northwest Territories of Canada. The first production came from the Panda open pit in 1998. Current operations are based on mining multiple pipes by the open pit method, and Koala North pipe has been developed and mined underground. Koala North underground project was undertaken to test the underground mining method and to provide access to the lower elevations of the Panda and Koala pipes, which will also be mined from underground once the open pit operations are completed.. The Koala North underground mine, North America's first underground diamond mine, formally opened in November 2002. It is being developed as an open-benching, mechanized, trackless operation. This paper documents the experience from the first two years of open benching mining method applied to kimberlites in Arctic conditions.

1 INTRODUCTION

The EKATI Diamond Mine, operated, and 80% owned by BHP Billiton Diamonds Inc. (BHPB), 10% owned by Stewart Blussom, and 10% owned by Chuck Fipke, is Canada's first diamond mine. The EKATI Diamond Mine is located in the heart of Arctic in Northwest Territories of Canada, approximately 300 km northeast of Yellowknife and 200 km south of Arctic Circle – see Figure 1. The mine lease area is entirely covered by treeless tundra and approximately one third of the surface is covered by lakes.

Figure 1: Geographical location of EKATI Diamond Mine.

Since its opening in 1998, the EKATI Diamond Mine has produced more than 15 million carats. Its annual output contributes to approximately 6% of world diamond production by value. As of 2002 more then 150 kimberlite occurrences had been found at EKATI claims that cover more than 3,400 km^2. Currently six kimberlite pipes are included in the mining plan and nearly all of the diamond production has been from open pit mining of multiple pipes.

However, as some pits deepened the decision was made to convert some of them into underground mines.

The upper 40 meters of the Koala North pipe was mined in late 2000 as a small open pit to provide grade and geotechnical information and a prepared surface for the transition to underground mining.

The Koala North pipe has been selected as a trial underground mine for the purposes of testing mining methods and to provide access to the lower elevations of the Panda and Koala pipes which will be also developed as underground operations once the open pit mining is completed. The trial mining decision was made primarily because of uncertainty in the several aspects of open benching and mass underground mining at large in the northern Arctic environment. Although this mining method was successfully used on several De Beers diamond operations in South Africa, it has not been tested in this setting.

2 GENERAL GEOLOGY

Koala North kimberlite pipe intruded into Archean granitoids within central Slave Structural Province in the Northwest Territories. It belongs to Lac de Gras group of kimberlites and it is located between Koala and Panda kimberlite bodies along the North-East trending structure (Figure 2).

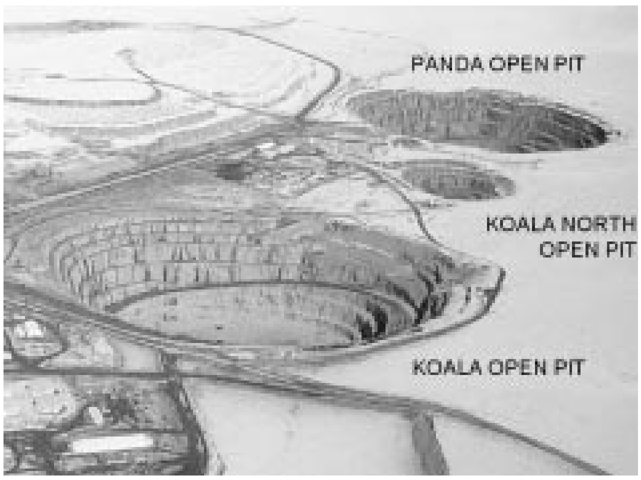

Figure 2: Aerial view (looking approximately north) across the central development area at EKATI Diamond Mine.

3 KOALA NORTH PIPE GEOLOGY

The Koala North body forms steep-sided pipe with inverted cone morphology typical of most kimberlites in the Lac de Gras area (Figure 3). It was covered with 15 to 20 m of boulder - and gravel-dominated glacial till overburden and it was located in a depression formerly occupied by the Koala Lake. Immediate country rocks are formed by competent, granodiorite of the Koala Batholith.

In general the kimberlite outline is roughly circular with wall rock contacts dipping steeply inward at angle of approximately 86°. The pipe has irregular geometry in the upper part where the eastern margin of the pipe flattens out considerably. It was suggested that the irregular morphology of the upper portion of the pipe is possibly controlled by a fault that predates kimberlite emplacement.

The dominant infill lithology at Koala North is crudely bedded to massive, relatively mud-rich volcaniclastic kimberlite. This includes fine- to medium-grained crater sediments, ash/mud-rich to olivine-rich resedimented volcaniclastic kimberlite (RKV) and primary volcaniclastic or pyroclastic kimberlite (PVK).

Current drilling at Koala North has intersected kimberlite down to the 155 m elevation (~ 270 m below the top of the pipe) and indicates that it is comprised exclusively of volcaniclastic kimberlite material to this depth.

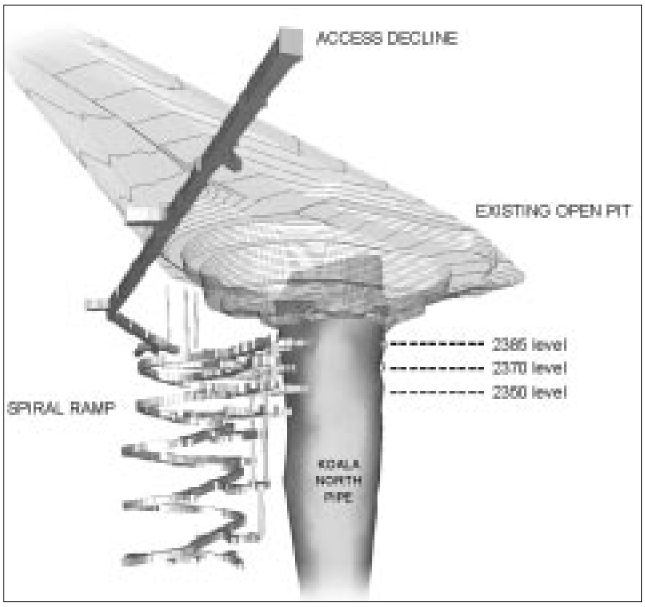

Figure 3: An isometric view of the Koala North pipe and underground development (after Jakubec et al 2003).

4 GEOTECHNICAL CHARACTERIZATION

The initial geotechnical information was obtained from the exploration drillholes using Laubscher's rock mass rating (RMR) classification system (Laubscher, 1990) for both kimberlite and country rock masses. This was later updated with data obtained from the open pit and it is continuously updated with ongoing geotechnical mapping using updated Laubscher's classification system (Laubscher and Jakubec, 2001).

In comparison with other known pipes in the vicinity of the Koala North it was very clear that majority of the kimberlite rocks are relatively competent. The exceptions are clay rich intervals within the RVK units that are relatively weak and show low rock mass competency. Such clay units form irregular bodies and are also highly susceptible to degradation and weathering when exposed to moisture.

The rock mass weathering susceptibility in the mining context is the strength deterioration within the life of excavation due to the exposure to moisture. The degree of weathering is influenced mainly by the clay minerals within the kimberlite rock types. Weathering of the kimberlite can adversely impact on ground support performance, production blasting and trafficability. Weathering can also promote the generation of mud as experienced in South African operations and it is an important issue that needs to be addressed in any kimberlite mining. An accelerated weathering tests performed on the core revealed that the majority of the Koala North kimberlite has low weathering susceptibility except above mentioned clay-rich kimberlite and mudstone, which form only 5-10% of the rock mass.

It is often found that poor quality rock mass is present adjacent to the kimberlite body contacts. This could create mining difficulties in both open pit and underground operations. From the geotechnical point of view, two types of contact zone are usually recognized: the internal contact zone within the kimberlite body and the external contact zone developed in the country rocks. In case of Koala North the external contact zones are variable both in the geometry and competency. Typically, as the development in the country rock approaches the kimberlite pipe contact, there is a zone of granodiorite approximately 1m to 5m in width with increased joint frequency and in some areas there is also a narrow (approximately 1m to 2 m wide) transition zone at the pipe contact in which kimberlite stringers occupy joints within the granodiorite. Although the contact zones are not equally developed around the entire perimeter of the pipe, their presence negatively impact on the dilution.

Based on the physical properties of the individual rock types and geological zones, a geotechnical domain model was developed subdividing the rock mass in the mining area into eight geotechnical domains. The rock mass parameters for individual domains are illustrated in Table 1.

5 MINING METHOD

The selected mining method for Koala North is open benching. The decision was made as a result of technical, economical and safety risk assessments. Competent country rocks, favorable geometry, relatively competent kimberlite, and most importantly, the arctic context of the projects played an important role in the mining method decision making process.

Table 1: Rock mass rating values for individual geotechnical domains

Geotechnical Domain	RMR
Overburden	---------
Near-surface Granodiorite	35 - 55
Granodiorite	60 - 75
External contact zone	40 - 55
Internal contact zone	18 - 30
Upper RVK	20 - 40
Lower RVK	45 -65
Clay-rich RVK	15 - 30

The natural caving option was rejected because the size of the pipe in terms of the Hydraulic Radius (plan area/perimeter) varies from HR=18m at the surface to HR=10m at the base of the current study zone. These are small values in terms of caving and would require very weak material for an assured cave.

The open benching is a top-down retreat mining method, similar to sublevel caving but without the caved waste behind the drawn ore.

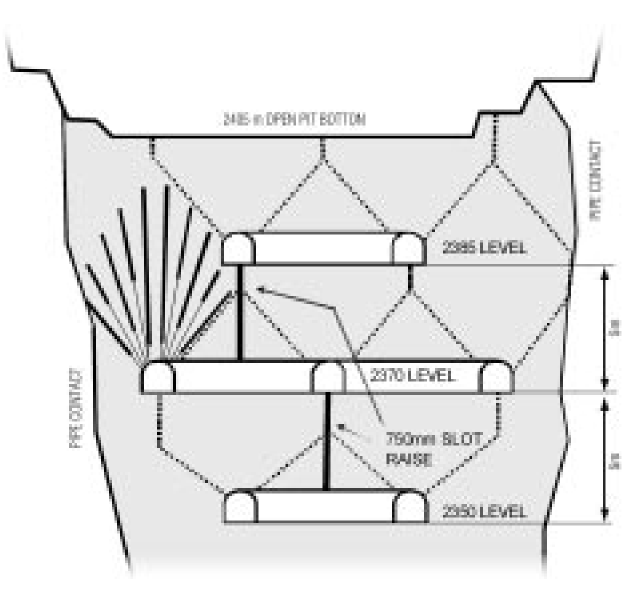

Figure 4: Schematic vertical section of open benching with individual production level geometries (after Jakubec et al 2003).

An access ramp to the underground workings was developed from the surface down to the first production level at 2385. The ramp has an arched profile of 5.5 x 5.5 m and all the development drilling was conducted using brine solution due to the presence of permafrost and cold air temperatures.

Accesses to the individual production levels are developed from the main ramp at regular intervals. These drives provide access for stope production, exploratory diamond drilling and installation of the mining infrastructure such as sumps, electrical installations and refuge bays. All the level accesses have flat back square profiles of 5 x 5 m.

Production crosscuts were developed into and across the kimberlite pipe for slot access, stope drilling and production mucking. These cross-cuts are designed in an arched profile of 4.0 m wide x 4.0 m high. Due to the susceptibility of kimberlite to weathering, all the development and production blast-hole drilling has been completed dry.

Figure 5: Production stope after the mucking is completed. Note that frozen muck on top of apex pillar is standing up in very steep angles.

When the crosscuts are fully developed, the slot drifts connect individual tunnels and the level is ready for the slot development and production blast. Production stope with apex pillars is shown in Figure 5.

Individual production levels have been developed at 15 m spacing. The mining front maintained 3 levels in production, maintaining approximately a 45° slope for stability purposes. In the plan view, the front maintained a concave shape with the boundary drawpoints lagging behind the central drawpoint.

6 ACHIEVEMENTS IN ARCTIC CONTEXT

6.1 Production rates and Dilution

The production rates 1,500 wtpd achieved as planned.

Koala North underground operation experiences more dilution than the open pits during normal mining operations. The current average dilution rate is approximately 17%. Half of the dilution is eliminated underground at the draw points, and half is sorted on surface. It has to be noted that approximately 75 % of the dilution is from upper 2385 level, compared to 25 % from 2370 level. This is due to several factors including pit bottom blasting damage, relaxation of the rock mass at the upper edge of the pipe contacts and also due to the underground production blast design for the upper level. Once the rock mass is damaged and "loosen up" then the effect of thaw and freeze up - ice jacking can create small scale rock falls resulting in dilution.

6.2 Operational Issues

Freezing muck pile

During the winter months the broken muck pile in the stope after the production blast will freeze up if not removed. The level of freezing depends on water content. This can potentially result in operational problems if measures to mitigate the impact would not be implemented. The key to the successful ore recovery is removal of freshly blasted muckpile as soon as possible and prevention of water access to the stope.

Any muck that left behind was primarily on the apexes between the drawpoints was recovered on the next level below when it was blasted. Although sometimes experienced, the truck "carry back" of the ore due to freezing has never been a serious problem.

Stabilizing effect of frozen pipe walls and the destabilizing effect of ice jacking

When the Koala North open pit walls and the "glory hole" walls are completely frozen from October to May no stability problem as observed on exposed pipe walls. In late May with the walls warming up due to the longer exposure to sun and warmer temperatures followed by freezing during the short night small scale rock falls were experienced. This is mainly due to the "ice jacking" effect on open joints – see figure 6.

Trafficability and Ice build up

When the Panda Ramp had advanced to the point that it was developed below the permafrost water began to seep through the joints in the rock mass. Ice began to build up on the haulage road and it quickly became a problem with equipment moving on the ramp. After evaluating of the alternatives the decision was made to install heaters on the fresh air intake raise and within a few days of commissioning the system the roads were free of ice.

During the winter there is also ice build up on the escape ladder way and cleaning procedures were developed to combat the problem.

Fogging - cold and heated air

After the heaters were installed on Panda fresh air intake raise a pocket of fog would develop where the unheated air

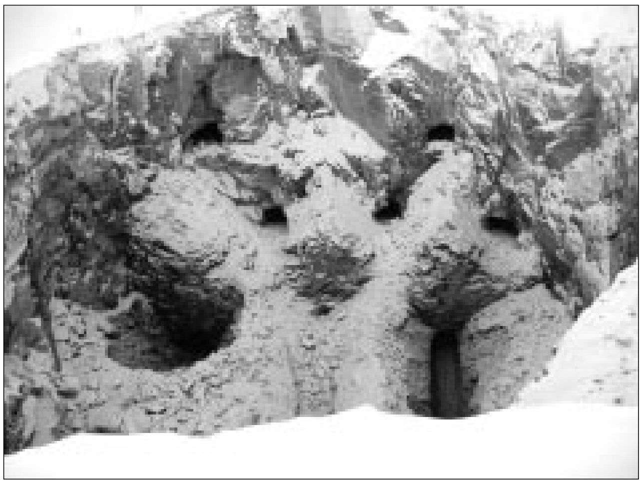

Figure 6: View into the open stope from the open pit. Note well developed apex pillars and stable blasting face. The main source of wallrock dilution came from the upper levels, combination of poor blasting, pit bottom relaxation and ice jacking.

from Koala North mixed with the heated air. A "fog zone" was created between 2245 Level and 2205 Level of the Koala North Ramp. The fog would begin to dissipate once temperatures rose above –30°C. Procedures were developed that allowed traffic to move safely through this zone and prohibited pedestrians.

Impact of cold on productivity, men and equipment

Temperatures in the underground workings follow the temperature outside with a significant delay of approximately 1 month. Long development headings were still +4.50°C after 3 weeks of –10°C to -15°C outside. The main reason is heat generated by the working equipment at the headings and as well as low airflow due to leakage in the vent ducting. Before the heaters were installed, some of the mine areas could became very cold in the winter months. The open drawpoints in the kimberlite could easily reach -50°C with the wind chill factor.

The underground crews work an 11-hour shift but their effective time at the face is 8.5 hours. Based on the assessment of the performance of the underground crews in the winter months, the rotation of the underground personnel was changed from 6 weeks in and 3 weeks out to 4 weeks in and 2 week out. The main reason for this was the impact of the severely cold temperatures. It was felt that six weeks proved to be too long to be exposed to that work environment.

The primary impact the cold had on the equipment was on the hydraulic systems. This was especially true at the beginning of the project when ruptured hydraulic hoses were a common occurrence. This was because the equipment was more frequently exposed to the low temperatures on the surface outside the mine. Indirectly, there was also increased damage to the equipment due to the use of brine for drilling. This issue is discussed below separately.

Shotcrete mix for cold climate

Current shotcrete mix used underground comprises of 480 kg ready mixed shotcrete (Type 30 include silica fume) and 1120 kg of aggregate. In the winter 27.5 kg of CaCl is added to prevent freezing.

In order to achieve good quality product it was important to introduce the QA/QC program that covers entire process from batching to application. Daily inspections by the geology/geotechnical staff are the best tool to inspect shotcrete performance.

The overall volume of shotcrete used per meter of kimberlite development is 1.4 m3. It was found during the testing that the shotcrete set up poorly at -18°C, and never attained full strength, but from –5°C to 20°C, the compressive strength averages 38 MPa which is acceptable for Koala North application.

Development and Production drilling

Two issues have to be considered: development drilling in permafrost and production long hole drilling in the kimberlite.

Due to the susceptibility of kimberlite to weathering, the production drillholes had to be drilled dry. This proved to be very successful and the only problem that has to be combated in the context of the cold climate is re-drill due to the icing up of the drillholes. Although this problem could have a significant impact, it is experienced only during the spring snow melt and freeze-up period, while in the remainder of the year there were virtually no issues with re-drilling.

The development in the permafrost granite required drilling with brine. Some increased corrosion problems were experienced on underground equipment. It was also found that high quality two-stage settling of solids out of re-circulated brine is essential.

Roadways construction

The key to the successful roadway maintenance system in any underground mine is to keep water out of the running surface.

In diamond mines this rule even more important due to the weathering susceptibility of the kimberlite. Harsh winter condition can add another level of difficulties to the roadway maintenance especially during the spring time of the year.

In Koala North all the drawpoints were driven at +4% grade to allow water to drain quickly and for ease of equipment recovery. Three roadway designs were tested on 2355 mining level; 150mm granite crush, graded kimberlite, and "geogrid" beneath 100mm crush. The 100mm granite crush as required on kimberlite floor provided the optimal acceptable running surface. Kimberlite roadways when frozen from November to June - provide excellent pavement surface.

6.3 Stress Release

In order to accelerate the development of an access to Koala and Panda pipes it was decided to temporarily suspend the mining of Koala North. The production levels that were already developed were retreated all the way to the granite contacts but no slot was excavated on level 2340 below.

While the level 2355 was approximately half way mined out, some shotcrete cracking occurred in the tunnels and on level 2340 below. The intensity of cracking on level 2340 increased towards the slot end of the pipe. Stress measurements in the vicinity of the pipe were conducted by CANMET and numerical modeling using FLAC3D was undertaken by ITASCA. The model was calibrated to the mining sequence and the level of cracking was reproduced. The results from the Koala North modeling are used to evaluate the geometry, support and mining strategy for other underground projects.

7 CONCLUSIONS

The successful introduction of open benching at Koala North kimberlite pipe is very encouraging. Although this mining method was successful on several De Beers diamond operations in South Africa, it has not been tested in the harsh arctic environment prior to commissioning the Koala North underground operation.

The long term data are not available yet and initial experiences are influenced by the learning process. For example the 2003 spring snowmelt in comparison with previous year had only relatively minor production impact and in total only three shifts were lost due to water issues, and approx. one additional week of 25% reduced production.

While it is probably too early to properly assess all the aspects of the operation very valuable lessons were learned. The knowledge gained at Koala North will contribute to the planning processes for the other underground mining projects

ACKNOWLEDGEMENTS

The authors would like to thank BHP Billiton Diamonds for permission to publish this paper. Also, the help of Tyla Hay of SRK in making this paper a reality is greatly appreciated.

REFERENCES

- Jakubec, J., Long, L., Nowicki, T., Dyck D., 2003. Underground Geotechnical and Geological Investigations at EKATI Mine – Koala North: Case Study. 8th International Kimberlite Conference Abstracts. Victoria, Canada
- Laubscher, D.H, Jakubec, J., 2001. The MRMR Rock Mass Classification for Jointed Rock Masses. Underground Mining Methods, Society for Mining, Mettalurgy, and Exploration, Inc. (SME). Littleton, Colorado, pp. 475 – 483.
- Laubscher, D.H., 1990. A geomechanics classification system for the rating of rock mass in mine design. J.S. Afr. Inst. Min. Metall. vol. 90. no. 10. South Africa, pp.257 - 273.