UNDERGROUND GEOTECHNICAL AND GEOLOGICAL INVESTIGATION AT EKATI MINE – KOALA NORTH CASE STUDY

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PROJECT BACKGROUND

Since its opening in 1998, the Ekati Diamond Mine™ has produced more than 10 million carats. Nearly all of the diamond production has been from open pit mining of multiple pipes. However, as some pits deepen it is planned to convert 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. The upper 40 meters of the Koala North pipe was mined in late 2000 as a small open pit to provide grade information and a prepared surface for the transition to underground mining. The Koala North underground mine, North America's first underground diamond mine, formally opened in November 2002.

GENERAL GEOLOGY

Koala North forms part of the Lac de Gras kimberlite field that occurs within the central Slave Structural Province in the Northwest Territories of Canada. The Lac de Gras kimberlites range in age from ~ 45 to 75 Ma and intrude Archean granitoids as well as metamorphosed supracrustals (primarily metagreywackes) of the Yellowknife Supergroup. Multiple Proterozoic diabase dike swarms with ages varying from 2.4 -1.27 Ga intrude the Archean rocks. Kimberlites are the only Phanerozoic rocks known in the Lac de Gras region, although fossil-bearing mudstone xenoliths within the kimberlites indicate that sediments must have formed a thin veneer over the older rocks at the time of kimberlite emplacement. A model Rb-Sr age of 53.1 ± 0.3 Ma (Geospec, 2002) has been determined for the Koala North kimberlite.

The kimberlites in the Lac de Gras province generally form steep-sided, diatreme-shaped pipes. They are relatively small features with surface areas ranging from approximately 0.1 to 16 hectares in size. With few exceptions, they are made up almost exclusively of volcaniclastic kimberlite material. 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).

KOALA NORTH PIPE GEOLOGY

The Koala North kimberlite is a very small body (0.4 ha at surface) situated between the Panda and Koala pipes in the central portion of the Ekati property (Figure 1).

The pipe lies within a depression formerly occupied by the Koala Lake and was originally covered by 8 m of water and 15 to 20 m of boulder- and gravel-dominated glacial till overburden. Koala North intrudes competent, syn-tectonic biotite granodiorite of the Koala Batholith. Modelling of the Koala North body, based on mapping of the kimberlite / granodiorite contact in the test pit and on interpretation of kimberlite drill intersections, suggests that the lower portion of the pipe has an overall steep-sided cone morphology typical of most kimberlites in the Lac de Gras area (Figure 2).

Figure 1. Oblique view looking south across the central development area at Ekati. The Panda open pit is in the foreground, the Koala North underground project is located beneath the existing test pit mid-frame, and the Koala pit and Ekati plant site are in the background. Photo taken in mid-2002.

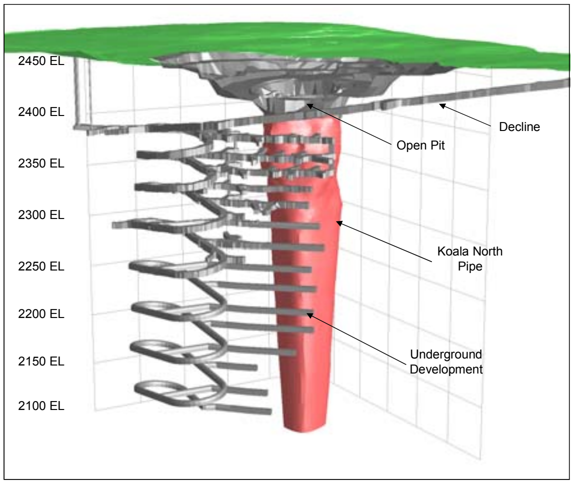

Figure 2. An isometric south-west looking view of the Koala North underground mine model. Each grid cell is 50 m x 50 m for scale.

In plan view, the kimberlite outline is roughly circular with no consistent elongation evident. Drilling data suggest that, below the 370 m elevation, wall rock contacts typically dip inwards at a regular angle of approximately 86^{o}. Above this elevation, however, the eastern margin of the pipe flattens out considerably. It is likely the irregular morphology of the upper portion of the pipe is controlled to a large extent by fault / joint zones that predate kimberlite emplacement.

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.

The dominant infill lithology at Koala North is crudely bedded to massive, relatively mud-rich volcaniclastic kimberlite with varying, but generally moderate to high olivine contents. These appear to represent a "package" of resedimented volcaniclastic kimberlite. The RVK is generally dark grey and typically contains between 10 and 20 % glassy pale green, partially serpentinized olivine grains. However, olivine contents vary locally with minor intervals of both mud-rich (< 10 % coarse olivine) and significantly more olivine-rich (30 to 60 % coarse olivine) material evident in most drill intersections. Olivine grains range in size from < 0.3 to ~ 5 mm in diameter, but commonly exceed 1 mm. In addition to olivine, a minor amount of quartz (generally less than 0.5 mm in size) is evident. The olivine and quartz occur in a matrix consisting primarily of grey to black very fine grained material comprising serpentine-group minerals and relatively abundant probable disaggregated mud (65-80% of the rock). The RVK is typically xenolith poor with small (generally < 3 cm) angular to rounded fragments of biotite granodiorite and black to brown mudstone usually constituting less than 10 % of the rock. Rare zones with increased xenolith content (up to ~ 20 %) are present in places. Centimetre-scale bedding is moderately developed in places, but in general the RVK has a massive appearance.

Dark brown to black fine-grained sedimentary material occurs as rare blocks / bands ranging in width from tens of centimetres up to 5 m. The morphology and lateral continuity of these intervals is not constrained by the current drilling. However, exposure of the kimberlite in underground workings indicates that mudstone occurs both as xenolithic blocks and *in situ* lenses / bands of fine-grained sediment. This material is indurated, laminated and fissile. It generally lacks olivine (<1%) and other obvious kimberlite components.

While the RVK material shows variations in coarse-olivine and, to a lesser extent, xenolith content, it retains a very similar character throughout the drilled intersections examined. Contacts between olivine-rich and ash-rich sections of the core, as well as between xenolith-rich and xenolith-poor zones, are typically gradational and distinct geological boundaries or markers are not evident. For the purposes of geological modelling, all RVK material (as well as associated minor intersections of mudstone and siltstone) has been allocated to a single, crater phase that dominates the Koala North pipe. This material is believed to have formed by slumping and reworking of pyroclastic material and surface sediments into the kimberlite vent.

In addition to the RVK described above, a small lens of coarse-grained olivine-rich rich primary volcaniclastic kimberlite occurs internally in the upper northern portion of the pipe. This rock type is similar in appearance to olivine-rich RVK in that it is dominated by macrocrystic olivine set in a dark fine-grained matrix. It is distinguished by a more uniform olivine distribution and massive appearance, a lack of any bedding, an absence of quartz, a less friable texture and a greater degree of competence (i.e. apparent greater rock strength). Xenolithic components commonly make up between 10 and 20 % of the kimberlite and include small mudstone clasts, typically well-rounded unaltered granodiorite cobbles and rare carbonized black wood fragments. The interclast matrix is dominated by fine-grained serpentine. This material is interpreted to represent a remnant of an earlier pyroclastic deposit preserved on the margin of the pipe.

PRE - MINE DEVELOPMENT GEOTECHNICAL INVESTIGATION

Feasibility level geological and geotechnical information was obtained from the surface core drilling program as no underground development was available.

DRILLCORE GEOTECHNICAL DATA

Basic geotechnical information was obtained from the exploration drillholes. Laubscher's RMR classification system (1990) was used to log the drill core. It was very clear that both RVK and PVK kimberlite are relatively competent rock masses. However, within the RVK clay rich intervals show low rock mass competency and also high weathering susceptibility. Geotechnical data was input into spreadsheets and various parameters were calculated. Data were also entered into a Gemcom database and used to construct a geotechnical domain model.

GEOTECHNICAL DOMAIN MODEL

Geotechnical data were superimposed onto the basic geological model. Based on the physical properties of the rock mass, eight geotechnical domains were identified. The rock mass parameters are illustrated in Table 1 below and the schematic geotechnical domain model is shown in Figure 3.

Table 1: Rock mass rating 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

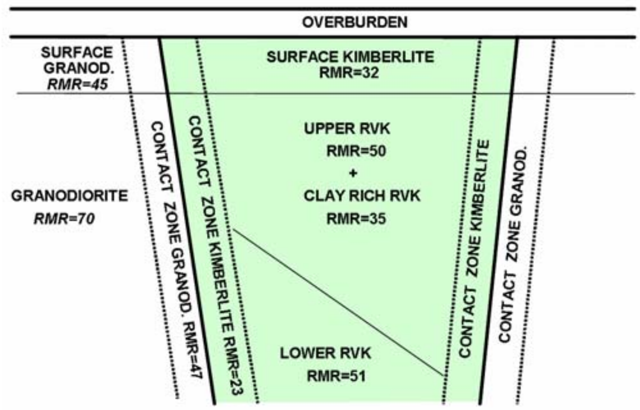

Figure 3: Schematic geotechnical domain model of Koala North kimberlite pipe

GEOTECHNICAL ISSUES

Two main geotechnical issues were identified during the investigation:

- Pipe contact zones
- Competency and weathering of weak clay rich kimberlite (RMR=15-30)

Pipe Contact Zones

The contact zones are variable both in the granodiorite and in the kimberlite. Typically, as the development approaches the country rock/kimberlite contact there is a zone of "shattered" granodiorite approximately 1m to 5m (or greater in some areas) in width. It appears that the emplacement of the kimberlite has overprinted the regional jointing. There is also a narrow (approximately 1m to 2 m) transition zone at the pipe contact in which kimberlite stringers occupy joints within the granodiorite. The quality of the contact zone will impact the development cost and amount of country rock dilution.

Kimberlite weathering

The weathering susceptibility of the kimberlite is mainly governed by the presence of clay minerals. Weathering of the kimberlite can adversely impact on several mining activities such as ground support, production blasting and trafficability. Weathering can also promote the generation of mud in the muck pile and it is clearly an important issue that needs to be addressed in any kimberlite mining.

While the majority of the Koala North kimberlite appears to have low weathering susceptibility from the mining point of view, it was noticed that certain clay rich kimberlite will disintegrate after exposed to elements. Such materials appear to form zones of limited dimensions (up to 5 m).

In order to assess the impact of weathering on mining a series of accelerated weathering test was conducted on the drill core (Figure 4).

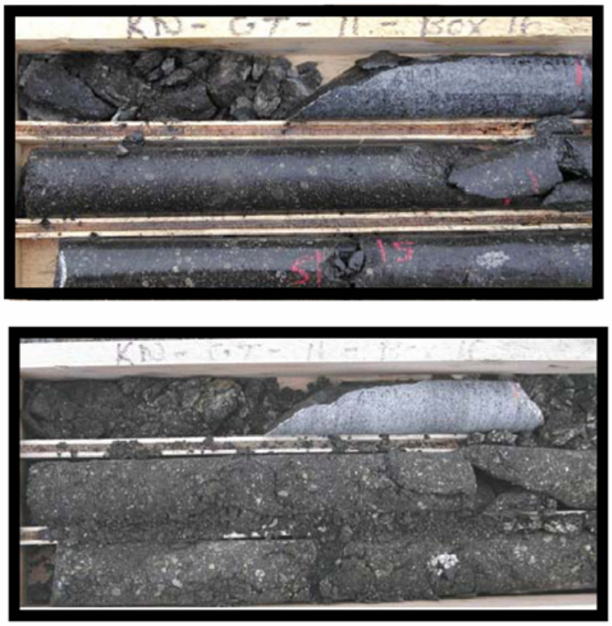

Figure 4: Accelerated weathering test of the clay rich kimberlite reveal high weathering susceptibility of this rock type. Top photo illustrates fresh rock and bottom photo shows the same interval after several wetting and drying cycles. For scale, the diameter of the drill core in the top photo is 4.5 cm.

MINING METHOD

Koala North is being currently developed and operated as a highly mechanized operation utilizing a trackless diesel powered fleet of equipment. A key function of the mine is to serve as a learning experience for underground kimberlite mining in the northern arctic environment. The project will be dealing with a unique set of mining conditions in a harsh environment. Although this mining method was successfully used on several De Beers diamond operations in South Africa it has not been tested in the arctic environment.

Ramp

Access to the underground workings is from a ramp developed from surface. The profile of the ramp is 5.5m x 5.5m. All of the drilling in the granodiorite is done using a brine solution due to the presence of permafrost and cold air temperatures.

Level Access Drifts

Production access drives are being developed off the ramp at regular intervals, to access the kimberlite pipe. These provide access for stope production, exploratory diamond drilling, and installations of mining infrastructure, including sumps, refuge bays and electrical installations (see Figure 5).

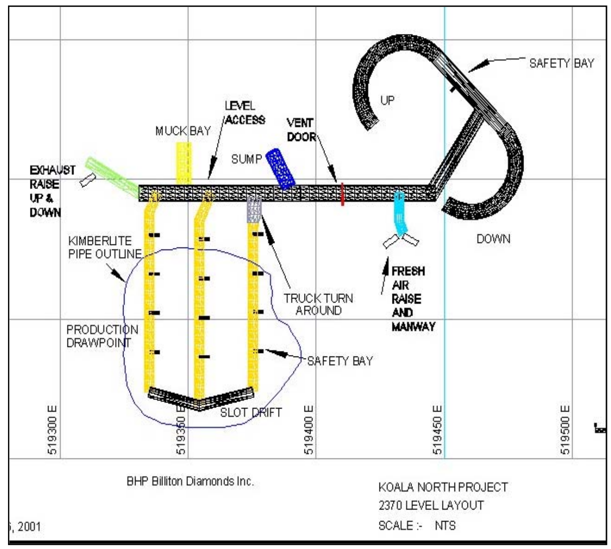

Figure 5: Schematic layout of development on a production level. Each grid cell is 50m x 50m for scale.

Current designs call for the level access drifts to be developed at 5.0m wide x 5.0m high with a flat profile.

Draw Points

Production drawpoints are being developed into and across the kimberlite pipe for slot access, stope drilling and production mucking. These cross cuts are currently designed in an arched profile at 4.0m wide x 4.0m high.

Due to the geomechanical and weathering characteristics of the kimberlite, development and production blast hole drilling will be done dry. A two-stage dust filtering system has been developed to collect and filter returns air from drillholes and remove dust in coarse and then fine fractions.

Production Stopes

The mining method to be used at Koala North is open benching. As noted above the unique mining environment and climatic conditions at Ekati Diamond Mine™ will involve adaptation of the method.

The method is a top-down retreat mining system, similar to sub level caving but without the caved waste behind the drawn ore (see Figure 6).

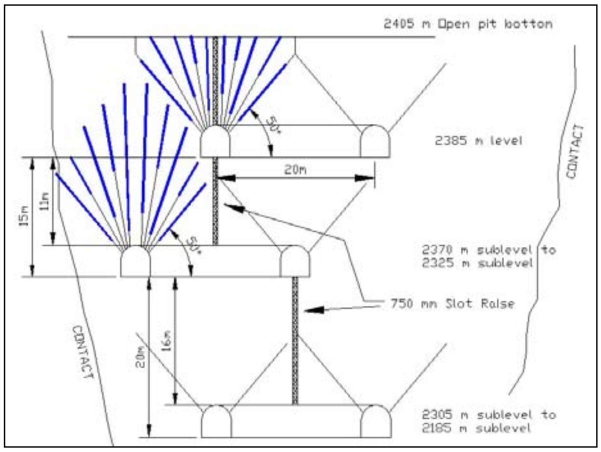

Figure 6: Schematic vertical section with individual production level geometries.

GEOTECHNICAL INVESTIGATION DURING MINE DEVELOPMENT

Underground excavations combined with underground drilling program provide truly 3D geological and geotechnical data. Such information is input into a Gemcom database and the initial pipe geological model is adjusted accordingly. This information provides invaluable technical input to Mine Planning and Engineering Department as well as to the development contractor. It facilitates adjustment and optimization of mine layout and ground support design.

GEOLOGICAL AND STRUCTURAL MAPPING

Basic geology data are collected on daily basis as mining faces advance. Sketch maps of the development including major geological contacts and structures are constructed and a digital photograph of the face is taken. Geological contacts and major structures are plotted on plans and projected to the next mining level.

GEOTECHNICAL MAPPING

The geological sketch map of the development acts as foundation for the rock mass classification assessment. Laubscher's updated IRMR (2001) classification system is used to describe the main geotechnical parameters such as intact rock strength, joint frequency, number of main joint sets and joint conditions. Field sheets are compiled into rock mass classification maps and geotechnical domains are delineated. Information from the geotechnical mapping is used for optimizing the layout and for assessing support requirements. Such requirements are communicated on a daily basis with the development crew.

Both geological and geotechnical mapping have to be completed on daily basis because advancing ground support (including shotcrete) rapidly covers the entire face and prohibits any further rock mass assessment.

CONCLUSIONS

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. The geotechnical and mining investigations will serve as a learning experience for underground kimberlite mining in a northern arctic environment. Although this mining method is successful when used on several De Beers diamond operations in South Africa it has not been tested in this setting.

Ongoing geological and geotechnical investigation during the mine development is vital for a mining operation to succeed. At Koala North, both geotechnical and geological sections are fully integrated into a Technical Services Department. This enables important information and suggestions related to the ground support and mine development to be forwarded to the mining contractors without delays. Proper communication between the miners and engineers is of paramount importance to ensure a safe and successful operation.

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