The use of borehole radar in detecting disruptions in platiniferous horizons in the Bushveld Complex, South Africa—the financial implication

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Synopsis

Robust borehole radar tools were developed for application in South Africa's gold mines in the late 1990s. These tools are needed to operate under extreme underground mining conditions characterized by high temperature, high humidity and corrosiveness. Once borehole radar was proved as a delineation tool for the flat tabular gold reefs, the technology was tested on similarly orientated platinum reefs. Due to the extremely favourable dielectric contrast of these platinum orebodies with their host rocks, borehole radar has been successful in identifying small-scale disruptions in these reefs that may affect mining them. Slim-line borehole radar tools are deployed in boreholes drilled parallel to sub-parallel to the platinum reefs to delineate disruptive structures such as dykes, faults, slumps (called potholes) and iron-rich ultramafic pegmatites (IRUPs), which change the normal reef composition. Advance knowledge of how the reef is displaced affects how the orebody is mined. Mine planning can be adapted to mine the ore body more economically and potential hazardous situations can be negated. This paper presents examples of where borehole radar was used to delineate disruptions to the reef plane in two platinum mines. It is shown that applying borehole radar prior to mining has a significant financial benefit. Finally, development directions for future borehole radar technology are recommended.

Introduction

South Africa's Bushveld Complex contains over 70% of the world's platinum reserves[1]. Platinum is present in two orebodies called the Merensky and UG2 reefs[2].

Borehole radar has been used successfully in many of South Africa's underground platinum mines to delineate both the Merensky and UG2 platinum reefs[3,4]. These reefs are generally shallow dipping tabular orebodies that have been traced over kilometres using exploratory drilling and seismic methods[5]. On a mining scale, the reefs can be disrupted by various smaller-scale features such as dykes, faults, slumps (called potholes) and iron-rich ultramafic pegmatites (IRUPs). Predicting the location of these disruptions prior to mining affects resource calculation, mine planning, the extraction of the orebody, as well as mine safety.

Borehole radar for platinum reefs

Geological problem

The locations of boreholes drilled for the application of borehole radar are limited by the access available from mining excavations. Platinum reefs are traditionally mined using a conventional breast stoping mining method (Figure 1).

Radar boreholes are usually drilled below the reef, either from haulages or cross cuts and are orientated parallel or sub-parallel to the reef plane (Figure 2) in order to give fair warning of the reef topography before an area that is approximately 200 m × 200 m is mined.

Instrumentation

Generally a series of regularly spaced single-borehole reflection surveys are conducted using slim-line borehole radar instruments

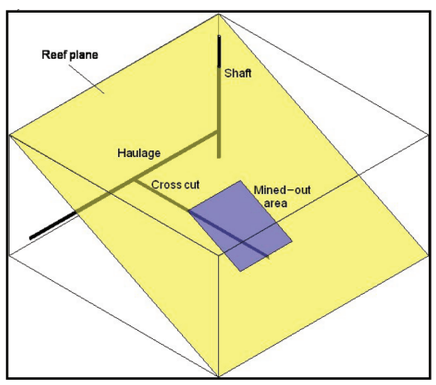

Figure 1—Diagram showing the simplified methodology for conventional breast stoping[4]

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with a centre frequency of approximately 50 MHz. These instruments are designed to fit into exploratory geological drill holes with diameters smaller than 48 mm. Instrumentation has improved from bi-static probes connected via fibre optics[6] to monostatic 'single-stick'[7] radars with onboard technology so that radar surveying can begin on the drill rods directly after the boreholes are drilled, in the same manner that borehole deviation surveys are conducted. The latter technique ensures that the entire length of the borehole can be surveyed, because it does not rely on fixing an anchor at the end of the borehole, which usually blocks the borehole while it is being deployed.

Case study I: Bleskop

Introduction

Borehole radar test surveys were conducted in 2003 at Anglo Platinum's Bleskop shaft close to Rustenburg (South Africa) in order to:

- Detect disruptions in the UG2 reef
- Demonstrate that borehole radar can be used to optimize mine layouts
- Test the viability of applying borehole radar in underground platinum mines.

The borehole radar surveys were conducted with GeoMole's first generation bi-static radar probes, which operate at a centre frequency of 50 MHz. Borehole radar was applied in five boreholes to cover a mining block spanning approximately 20 000 m^2. A contour map was produced using the borehole radar nadir lines along the UG2 reef surface, as well as all available a priori geological information.

GeoMole made the following conclusions from the borehole radar contour map (Figure 3):

- This mining block was interpreted to be a synclinal valley with a gradient of 1 in 4, which could hamper trackless mining
- A narrow corridor of mineable UG2 reef was identified in the centre of the block
- A deep pothole was identified in the eastern portion of the block
- The western flank of the block was dominated by a large borehole radar anomaly.

Subsequent mining of this mining block (green panels in Figure 4) showed that the first three conclusions drawn by GeoMole were true, and that the large anomaly identified on the western side of the block was a significant reef roll.

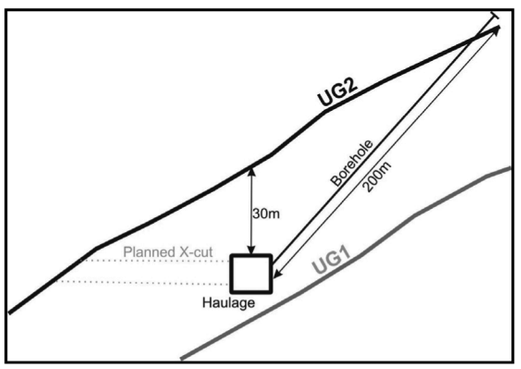

Figure 2—Schematic of borehole radar survey design as seen in profile

Financial implication

The borehole radar trials at Bleskop shaft were conducted when the technique was still considered to be experimental and untested in the underground platinum environment. Borehole radar results were not received in time to influence the mine design and planning and hence avoidable mining and development took place within the pothole defined in the western portion of the mining block (Figure 5).

This trial dataset does, however, provide us with the opportunity to show how borehole radar could have saved the mine on mining and development costs within the Bleskop

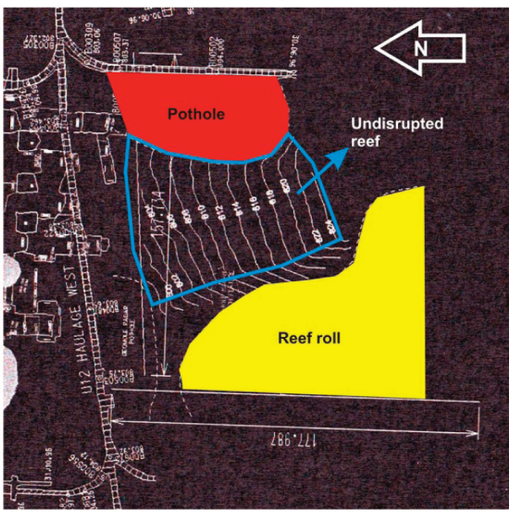

Figure 3—Borehole radar interpretation for the Bleskop mining block

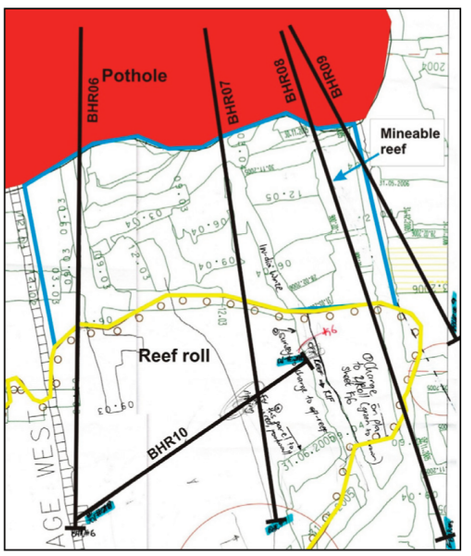

Figure 4—Geological features encountered during subsequent mining of Bleskop mining block

mining pothole.

All costs used are based on November 2007 platinum group metal (PGM) prices as well as generalized costs for mine development and drilling at South African platinum mines as published in annual reports[8].

The costs that could have been saved within the Bleskop pothole, if the borehole radar results had been used, are summarized in Table I.

This historical example serves to demonstrate the importance of good communication between borehole radar service providers and their clients. It also highlights the very short time frame in which borehole radar interpretations have to be received in order to have an impact on mine design and planning.

Case study II: Brakspruit

Introduction

Borehole radar was applied at Anglo Platinum's Rustenburg Section's Brakspruit shaft in order to delineate the geoloically complex Brakspruit pothole[9]. At Brakspruit mine the normal Merensky Reef succession has been disrupted by a large pothole. The economic Merensky Reef cascades down onto its footwall markers and can form mineralized reef on each of these markers (Figure 6).

Borehole radar was used at Brakspruit mine for two reasons, to:

- Identify portions of extractable reef
- Sterilize areas that are too disrupted to mine.

Borehole radar results

Borehole radar data were acquired using GeoMole's bi-static slim-line borehole radar instrument, which has a centre frequency of 50 MHz. In the case study area, 11 boreholes were surveyed[9]. These holes were approximately 30 m apart. Radar reflectors were linked to geological units by making use of a priori geological information such as borehole intersections. Radar reflectors with similar characteristics

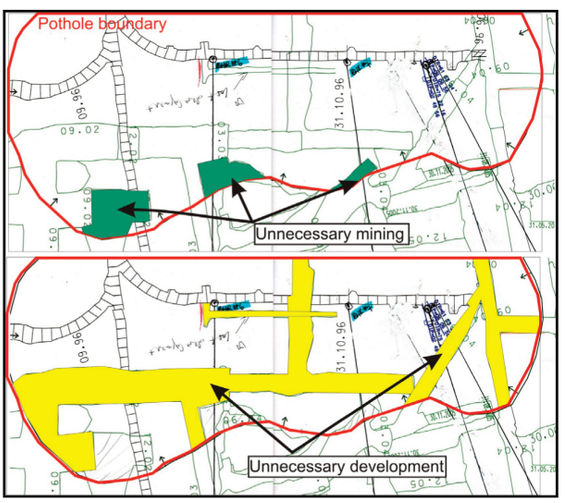

Figure 5—Unnecessary mining and development that took place within the Bleskop pothole

Table I

Financial impact summarized

Item	Extent	Tons	Cost
Avoidable mining	4 300 m²	14 400	$1.03M
Avoidable development	338 m²		$230 000
		Total	**$1.26M**

were identified on adjacent radar sections (Figure 7), and their nadir lines on the Merensky Reef plane were exported in order to construct three-dimensional surfaces for portions of mineable reef.

Borehole radar interpretation and financial implication

The three-dimensional surfaces constructed for two portions of potentially mineable BB4-reef are shown in Figure 8. A

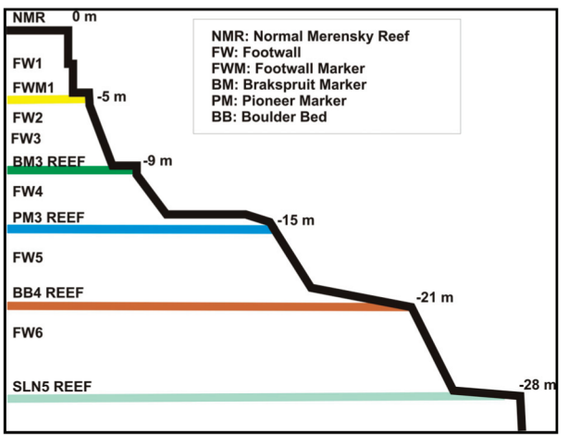

Figure 6—Various Merensky Reef facies that can be present within the Brakspruit regional pothole[8]

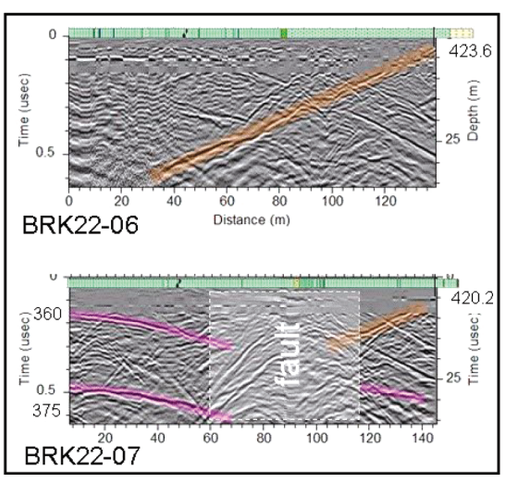

Figure 7—An economic footwall reef, called the BB4-reef (orange line) was traced from borehole BRK22-06 to BRK22-07. The highlighted pink reflectors were interpreted to be geological layers below the boreholes

cost-benefit analysis was conducted for the 11 borehole radar surveys that were conducted to identify these portions of reef. An area of 57 600 m^2 was covered by the 11 evenly-spaced reflection borehole radar surveys. Mine development had been placed according to conventional breast stoping practices, but once stoping began it became apparent that the Merensky Reef was highly disrupted. Mine development ceased in this portion of the mine until geologists could develop a better understanding of the reef model in order to assist mining engineers with their planning.

After the application of borehole radar, a total area of 9 525 m^2 was identified as potentially mineable. Using a stope width of 0.97 m this equates to 36 495 t of PGM ore, worth $14.2 million.

A total cost of approximately $190 000 was incurred for drilling, deviation and borehole radar surveys in order to identify $14.2 million worth of ore, in other words a 78-fold return on investment. This area could potentially have been written off if borehole radar had not been applied.

Conclusions

The case studies presented in this paper reiterate that borehole radar, if applied correctly, can significantly contribute to lowering the operating cost of a platinum mine. Intuitively, it makes sense that conducting borehole radar surveys during the correct phase of the mining cycle:

- Improves the geological knowledge about the orebody
- Leads to appropriate mine design and planning (including the efficient deployment of mining teams)
- Avoids income being deferred to a later date
- Can identify additional resources in structurally complex areas of the mine
- Sterilizes areas that are too disrupted to mine.

This paper has now attempted to add an approximate monetary value to support the integration of borehole radar in the mining cycle.

At Anglo Platinum, borehole radar has since moved beyond the realm of trial surveys and is being routinely applied as a geological mapping tool at various mines.

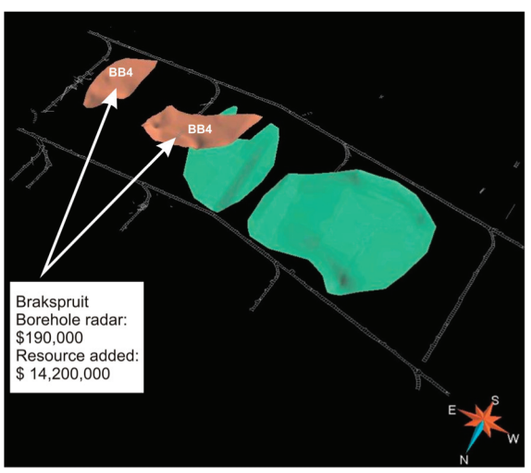

Figure 8—Two portions of mineable BB4-reef were identified using borehole radar

Recommendations

The borehole radar systems currently being used in underground platinum mines make use of omni-directional probes that operate at a relatively low (50 MHz) centre frequency. Slim-line directional borehole radars will be able to improve the positional accuracy of radar reflections emanating from, for example, pothole boundaries. The geometrical constraints of shrinking directional borehole radar instruments is a challenge, but one that will hopefully be overcome as technological advancements are made.

Furthermore, cross-hole radar reflection and tomography are not often used in underground platinum mines, due to the logistical complexities of working underground. The development of robust user-friendly cross-hole and tomography borehole radars and matching software could also find specific applications in some of Anglo American's mines.

Acknowledgements

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