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Borehole radar as a tool to optimise mine layouts and production

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INTRODUCTION TO THE GEOLOGICAL PROBLEM

The major gold and platinum deposits of South Africa occur in the Witwatersrand Basin (gold) and Bushveld Complex (platinum) (Henning *et al*., 1994; Carr *et al*., 1994; Cawthorn, 1999). While the origins and geology of the two structures have almost nothing in common, the resulting orebodies, known locally as reefs, share a number of physical similarities:

- They are thin, typically centimetres to a metre thick
- They are shallow dipping, typically with dips of 5° to 30°
- They are of great lateral extent
- They are tabular in geometry.

In both cases, the reefs appear flat on a regional scale, but have significant topography on a local scale. Bushveld platinum mines are disrupted by potholes and iron-rich ultramafic pegmatite bodies (IRUPs), gold mines by rolls and channels, and both face the geological challenges of faults, joints and dykes.

Figure 1 shows a convention mine layout that still dominates the gold and platinum industries, however, some mines are now mechanised. The overall mine layout can be designed from an understanding of the regional geology. Originally, this came from drilling, but it is now mostly from 3D seismic surveys that are limited by low resolution. When it comes to the actual mining of the reef higher resolution is required, and borehole radar (BHR) can offer the higher resolution.

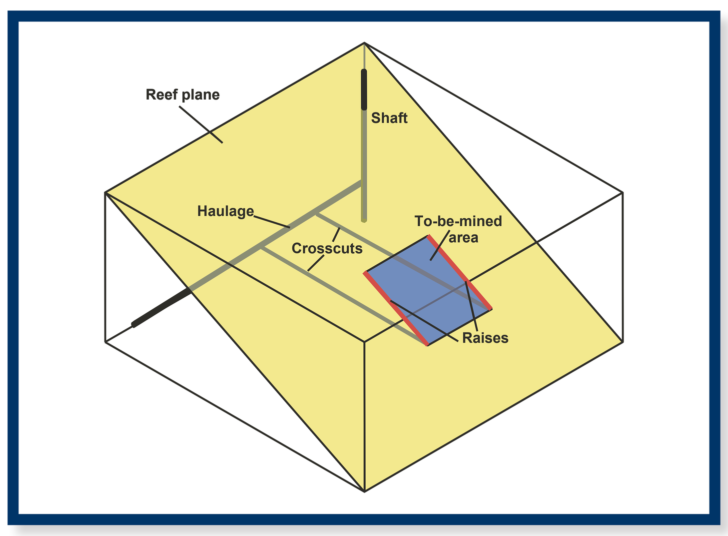

Figure 1: The geometry of a typical deep-level conventional gold or platinum mine. Raise lines are mined up-dip. Mining proceeds out from the raise line in one of a number of different layouts

GEOPHYSICAL APPROACHES

To detect structures using geophysics, a physical property constrast must exist between the target and the host medium. For the Ventersdorp ContactReef (VCR), and the Merensky and Upper Group 2 (UG2), there is a good contrast in the radar wave velocities of the reefs and the host rocks.

Initially Ground Penetrating Radar (GPR) was used for reef imaging but was limited in range. To achieve greater ranges required lower frequency antennas, which are impractical to use underground due to large size. BHR was proposed to overcome the problems with handling large antennas. From 1998 to 2000, the DEEPMINE collaborative research programme funded investigations of BHR (Trickett *et al*., 1999). In 2001, the CSIR embarked on development of the Aardwolf BR40 (Vogt, 2006). The DEEPMINE work showed that BHR for the gold industry worked very well for the VCR.

Following the success of BHR in gold applications, it was trialed by a number of platinum mines under the PlatMine collaborative research programme. It was a success, because the major platinum reefs are excellent radar reflectors.

DIRECTIONAL AMBIGUITY

Most BHR systems can determine the distance to a reflector (target), but not its direction. During the PlatMine trials, a program called Fresco was developed to assist in interpreting BHR data in 3D (**Figure 2**).

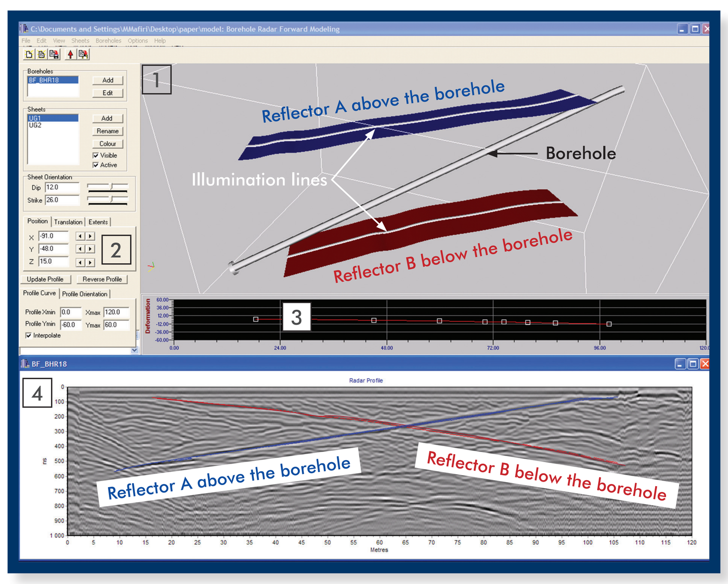

Figure 2: The Fresco BHR modelling and interpretation environment (Du Pinani and Vogt, 2004)

The only results obtained from the Fresco model are the illumination line coordinates that represent the target in 3D. The illumination line coordinates are used by the mines to improve their geological model of the reef.

BHR IN-MINE APPLICATIONS

Platinum reef imaging

BHR has been used successfully in delineating the topography of the platinum reefs (UG2 and Merensky) in the Bushveld Complex (Vogt *et al*., 2005).

A BHR survey was conducted in borehole A in a platinum mine, using the CSIR's Aardwolf BR40 BHR system. Borehole A was drilled approximately 20 m below the UG2 reef in the norite, along the strike of the UG2 reef. **Figure 3** shows the radargrams from borehole A.

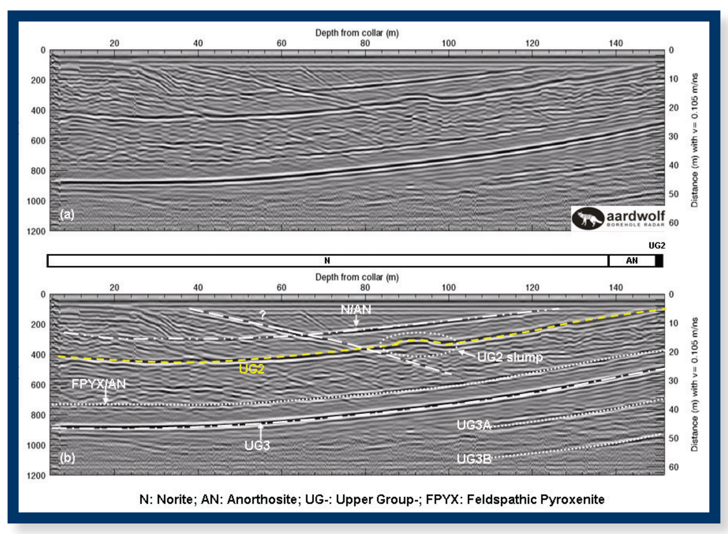

Figure 3: Radargrams for Borehole A: (a) without interpretation and (b) with interpreta- tion. A simplified geological log of the borehole is shown between the radargrams. The interpreted position of the UG2 reef is indicated by a dashed yellow line

The directional survey information as well as the radargram for borehole A were imported into the CSIR's Fresco software, in order to determine the elevations of the UG2 Reef reflector in the mine coordinate system in 3D. A more detailed 3D surface of the reef topography can be obtained by applying BHR in a group of boreholes (**Figure 4**).

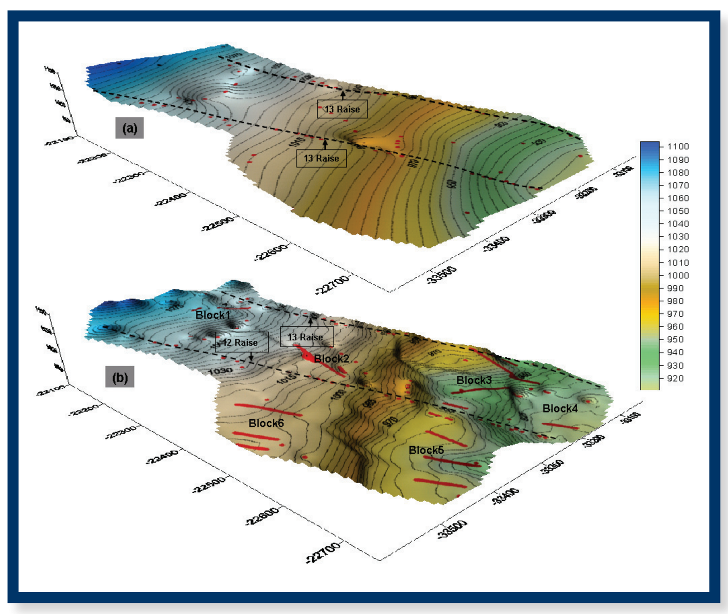

Figure 4: 3D model developed in Surfer showing: (a) the surface map before BHR application and (b): the surface map merged with illumination line coordinates results from 22 boreholes (red lines) and all points (from exploration drilling and geological mapping) used to build the reef topography (red dots). The black dashed lines represent the positions of the raises

Gold reef imaging

The Aardwolf BR40 BHR system was deployed in five boreholes in order to image the VCR in 3D geometry (Du Pisani and Vogt, 2004). The boreholes were drilled from two adjacent cross-cuts, at 30 - 50 m above and sub-parallel to the VCR. **Figure 5** shows the radargram for borehole 3 and **Figure 6** shows 3D model from 5 boreholes.

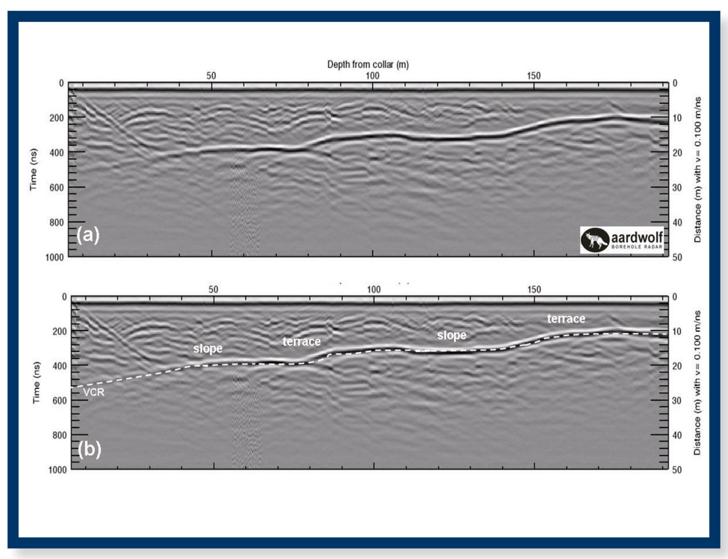

Figure 5: Radargrams for borehole 3, (a) without interpretation and (b) with interpretation. The interpreted position of the VCR is indicated by a dashed white line; slopes and terraces can be distinguished by rotating the radargram to its correct orientation (borehole 3 was drilled at inclination of -25°) (Du Pisani and Vogt, 2004)

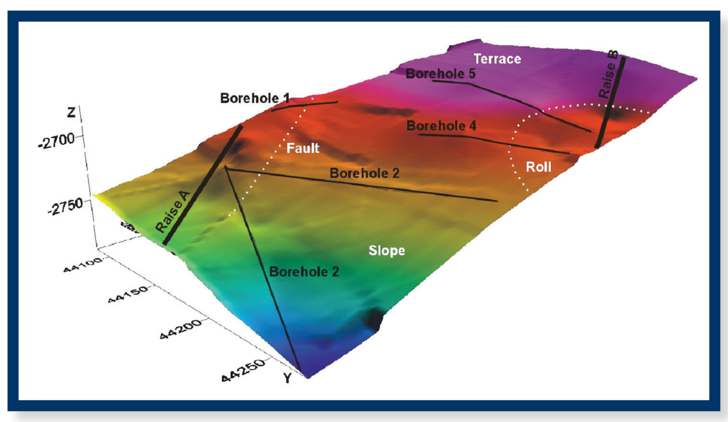

Figure 6: 3D Model for the VCR built in Surfer, using the illumination line coordinates from all the boreholes and geological information (Du Pisani and Vogt, 2004)

Financial benefits of using BHR

The financial benefits of using BHR have been analysed in detail by Du Pisani (2007), for platinum mining projects. The objective of the cost-benefit analysis was to determine if BHR could minimise unnecessary development and improve productivity across all phases of a mining cycle. From one of the case studies, involving the mapping of the topography of the Merensky Reef the cost-benefit analysis results revealed that it costs 23 times more to define a reef intersection point by drilling than it costs to obtain a set of illumination line coordinates by using BHR.

ON-GOING AND FUTURE RESEARCH

A BHR system that implements an array of four dipole antenna elements has been built at CSIR (**Figure 7**). Tests are currently being undertaken to ascertain if the system can determine the direction of real target reflectors as is predicted from numerical and scale modelling (Nyareli and Vogt, 2007).

The CSIR resumed research on electrical property measurements to improve data interpretation. Research and development are underway at CSIR for automating the manual method of deploying the BHR tool.

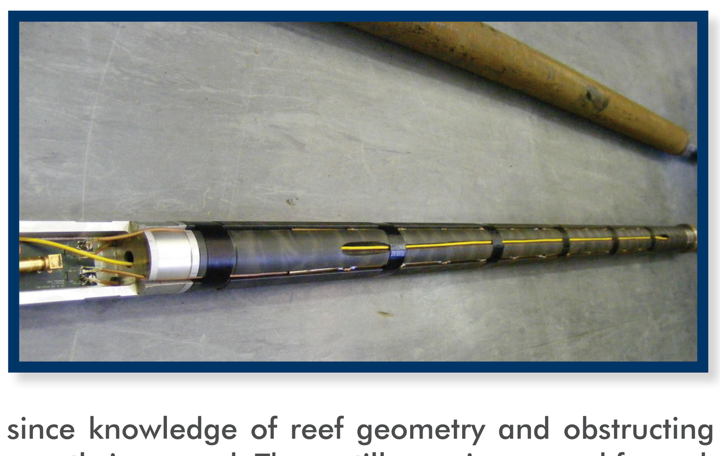

Figure 7: Directional BHR receiver with the four dipole antenna elements in a receiver probe

CONCLUSIONS

The application of BHR prior to and during mining is cost-beneficial. During mine planning, costly development is avoided since knowledge of reef geometry and obstructing structures and features is greatly improved. There still remains a need for radar research in the following areas: electrical rock properties, modelling radar wave propagation in rocks, directional BHR, and data analysis especially for optimizing information extraction and geotechnical characterisation of mine tunnels.

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CSIR researchers have developed a ground penetrating radar applied from within a borehole. It is used in mines to determine the reef continuity and geometry, enabling the mines to better plan their production.

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