Borehole Radar Delineation of the VCR: an Economically Important Sedimentary Deposit

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Abstract—It has been shown previously that borehole radar is a suitable tool for mapping the Ventersdorp Contact Reef (VCR) and other thin tabular orebodies in South African gold and platinum mines. However, the economic basis for using the tool has not yet been justified.

Radargrams were acquired in three boreholes above a VCR mining block. The three radargrams have been interpreted in a 3D visualization environment, and show continuity of features on the VCR target horizon. The case study shows how borehole radar can add useful information about reef elevation to the existing geological model.

If confidence in the model can be improved to the point where planning can be undertaken to place pillars in low grade areas, sterilization of high grade ore can be avoided. Extraction planning and resource evaluation can also be improved.

Keywords-VCR; borehole radar; tabular reef, 3D modeling, visualization;

I. INTRODUCTION

Given the cylindrical ambiguity of its data, borehole radar is particularly applicable for delineating thin tabular reefs, because the geometry of the reef greatly simplifies interpretation. In South Africa, there are a number of economically important tabular reefs that are good radar targets, in particular the Ventersdorp Contact Reef, or VCR. The reef itself has a sedimentary footwall with a lava hangingwall. The contrast in physical properties makes it a good target for seismic or radar surveys.

The VCR was formed when the Ventersdorp lavas covered a terraced palaeo-landscape approximately 2700 million years ago. As shown in Fig. 1 the landscape consisted of a complex drainage pattern comprising braided streams confined by terrace risers [1]. The unconformal contact between the sedimentary landscape and lavas contains significant gold deposits. The gold is concentrated in palaeo-river channels situated on the terraces. The terrace risers or slopes contain no gold and are therefore the most suitable candidates to be left as support pillars when mining.

Borehole radar has proven that it is applicable for mapping the VCR in deep level gold mines [2,3] but it has not yet proven that it provides cost effective information. The case study here shows the value of mapping features such as slopes and terraces in a single mining block on the VCR using borehole radar.

CSIR Miningtek’s Aardwolf BR40 system was applied in three boreholes approximately 20 m above the reef in a 200x200 m block, providing three lines of reef elevation across the extent of the block. The radargrams and 3D visualization from these boreholes, together with additional information from cross-cuts and sampling drill holes can be used to show continuity of features on the VCR horizon. Mine planning can then be adapted so that pillars can be designed to coincide with slopes. The improved confidence in the geological model has an immediate impact on resource estimation, with related financial benefits.

II. CASE STUDY GEOMETRY

Borehole radar was applied in three boreholes, drilled from the same cross-cut at Anglogold’s Mponeng Mine. The holes were drilled in hangingwall lava, and were designed to remain in the lavas, 30 m to 50 m above the VCR. The case study geometry is given in Fig. 2: Development is above reef; a haulage in the strike direction provides access to a cross-cut from where three boreholes are drilled. Borehole 1 is 50 m north of Boreholes 2 and 3 and was drilled at an inclination of 15°. Boreholes 2 and 3 were drilled at inclinations of 0° and -25° respectively. The dip of the VCR is 22° in a southerly direction. Where available, the directional surveys of these holes, were taken into consideration when interpreting the data.

Figure 1. Diagram showing the genesis of the Ventersdorp Contact Reef.
III. RESULTS

The radargram for Borehole 3 is illustrated in Fig. 3, and is representative of results for the other two boreholes. A velocity of 0.1 m/ns is assumed based on rock property measurements [4] and corresponds to a relative dielectric permittivity of 9. The depth from the collar of the borehole is given along the top axis of the radargram. The time in nanoseconds is given on the left Y-axis, while the equivalent depth from the borehole is given on the right Y-axis. At the collar position of the borehole a prominent reflector is seen on the radargram, at a distance of approximately 20 m from the borehole. This reflector is interpreted as the contact between the lava and the footwall, because it occurs where the VCR is expected based on other drilling and mapping evidence. Topography is visible in the radargram, and can be interpreted as slopes and terraces once the inclination of the borehole is taken into consideration (Fig. 4).

IV. INTERPRETATION

Borehole radar data suffers from azimuth ambiguity. For
tabular orebodies, it is possible to interpret radagrams with some confidence when they are used together with other a priori information, such as expected target dip, and target locations fixed by drilling or mapping. Interpretation can be enhanced through the use of a fast forward modeling and visualization package. Software has been developed that shows the borehole in 3D space. The user can then place a candidate flat reflector at its expected location, dip and strike, and see a modeled reflection superimposed on the acquired radagram.

The modeled reflection is created using a simple straight ray path forward model. The system needs to generate modeled responses in real time, in response to user driven changes in the shape or position of the candidate reflector, so speed is more important than accuracy.

Once the flat reflector is roughly positioned, it can have topography overlaid in one dimension. Two dimensional topography was not included, as it permits the interpreter too many degrees of freedom. As topography is introduced, the forward model is brought into close correspondence with the measured radagram. It should be noted that it is still possible to make gross interpretation errors, but they are less likely because the 3D environment forces interpretations to be reasonable and to fit the a priori information that is available.

As shown in Fig. 5, this technique was used to produce a 3D model for the three holes surveyed. In the visualization, the three boreholes are obvious, together with the candidate target planes in their final interpreted positions. On each target plane, the illumination line is highlighted. Note that while the candidate surfaces have considerable areas, borehole radar only provides information about the illumination line. The model locates the illumination line in three dimensions, allowing it to be exported in a format that is compatible with geological modeling packages in use on the mine.

Migration is the process of moving a reflector from its apparent position on a radagram to its true position in space. It can be difficult to migrate borehole radar data because the borehole cannot be assumed to be straight. The migration must be undertaken assuming the direction of the reflectors relative to the curvature of the borehole [5]. The fast forward model removes the need for migration because fitted planes already exist in true space, while their modeled reflections are placed in their apparent positions on the radagram. The system also models the diffraction hyperbolae produced by point targets or at the edges of planar scatterers.

In Fig. 5, the 1D nature of the topography on the candidate planes is visible. In each case, the plane has had topography applied in the direction perpendicular to the line of the borehole. This creates the incorrect visual impression that features do not correspond from borehole to borehole. In fact, if only the illumination lines are considered, correspondence of features between boreholes is good.

The 3D coordinates of the illumination line for each radar survey were exported to Surfer and used together with other information such as measurements of reef elevation in crosscut intersections and raise lines to compile a elevation model of the VCR within the mining block. Using this model, the position of slopes were estimated, as shown in Fig. 6.

![Model built in Surfer, using the radagrams from Boreholes 1, 2 and 3 as well as a priori information. This model can assist with planning pillars when mining.](image)

**V. DISCUSSION**

It is routine to leave pillars of unmined ground to support the hangingwall of the excavation. The pillars are usually positioned on a regular grid. If the position of slopes can be defined several months prior to mining, pillars can be planned to correspond with slopes to minimize gold loss. The unmined ground then contains a minimum of gold.

Table 1 shows the cost implication if a pillar is left at the location of a known slope. If the pillar had been left in an area of average grade, US$ 2.1 million of gold would have been lost within the pillar. By leaving the pillar in a barren
area, that gold can be recovered from the area where the pillar might otherwise have been located.

Detailed knowledge of the reef topography may also reveal the position of palaeo-channels. If channels are present, they are associated with higher gold grades. Knowledge of the position of channels enables the mine to optimize their extraction schedule, to remove high grade areas when required, rather than simply when encountered.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>HYPOTHETICAL CALCULATION OF THE VALUE OF GOLD CONTAINED IN A TYPICAL PILLAR.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of pillar: 30m</td>
<td>30 x 200 x 1.5m</td>
</tr>
<tr>
<td>Length of panel: 200m</td>
<td>= 9000 m³</td>
</tr>
<tr>
<td>Height of pillar: 1.5m</td>
<td>24,750 tonnes</td>
</tr>
<tr>
<td>Density: 2.75 tonnes/m³</td>
<td>148.5 kg (5238 oz) of gold</td>
</tr>
<tr>
<td>Average gold grade: 6 g/t</td>
<td>Gold price: $400 / oz</td>
</tr>
<tr>
<td>(Mar 2004)</td>
<td>$2.1 million</td>
</tr>
</tbody>
</table>

The model presented in Fig. 5 was created using borehole radar data together with other geological information. In a classic scenario, the information available without drilling is limited to mapping in development. Exploration boreholes are then drilled to determine grade and to investigate areas where mapping, previous experience, or data from already mined areas indicates that uncertainties may lie. Each borehole gives one or a very small number of reef intersections that are used to model the elevation of the reef.

Before mining starts, raise lines are developed in the reef plane, above or below the cross-cuts. When the raise lines are finished, the data available to model the reef elevation consists of two lines of elevation, from the two adjacent raise lines, and a number of points, from exploration drilling within the block.

Borehole radar greatly enhances the elevation model by providing continuous lines of reef elevation in the area in the centre of the block and in lines perpendicular to the cross-cuts or raises. It therefore enhances confidence in the geological model exactly where confidence is lowest, in the centre of the unmanned block.

VI. CONCLUSIONS AND FUTURE WORK

A number of radagrams from separate boreholes within one mining block can add significantly to the confidence in the geological model for the block. A 3D visualization environment assists in removing directional ambiguity from the radagrams by forcing the interpreter to consider a priori information while creating the interpretation.

Being able to predict changes in topography on the VCR has a significant cost implication when mining. Borehole radar is an efficient method of making those predictions. If a model can be developed with high confidence for a mining block there are a number of economic benefits:

- Blocks are generally mined according to a pre-defined plan. If a flexible mining system is being employed and there is a good geological model, features associated with high grade can be accessed preferentially according to a plan, rather than according to when they are encountered.
- The information that is delivered can be used to improve the geological model used by the mine for planning and resource evaluation.

The technique and much of the discussion presented here apply equally to other thin tabular reefs, including South African gold and platinum reefs and the vertical tabular reefs often encountered in Canada.

This case study clearly shows the impact that borehole radar can have within a single mining block, but it has not yet demonstrated the financial benefits of undertaking borehole radar surveys. It is intended to extend the case study to add further boreholes and to accurately quantify both the costs and benefits of applying borehole radar.

ACKNOWLEDGMENT

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REFERENCES