Geophysical techniques and their application to mechanized mining

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1 Introduction

The platinum-bearing layers of the Bushveld Complex exhibit remarkable lateral continuity on a regional scale (Cawthorne, 1999, SACS, 1980). However, as one zooms in to mine scale, the picture often changes dramatically. Geological features such as potholes, iron-rich ultramafic pegmatite (IRUP) bodies and faults frequently disrupt the lateral continuity of the Merensky Reef and UG2 chromitite layer (Carr et al., 1994; Scoon & Mitchell, 1994). The occurrence of these features results in the loss of mineable ground and compromises mine planning and safety.

If one zooms in closer to the on-reef development ends and prospective stopping panels, small-scale deviations from the ideal, non-undulating and laterally continuous reef scenario often lead to further mining complications. Sudden changes in the reef elevation may lead to difficulties for mechanized mining equipment, while sudden changes in the position of layers or parting planes in the immediate hangingwall have important implications for support design and safety.

This paper illustrates how the integrated use of three high-resolution geophysical techniques can provide valuable geological and rock engineering information ahead of mining. This information can be exploited to increase the efficiency of mechanised mining operations within conventional mining layouts, while at the same time contributing to a safer working environment. The geophysical techniques considered are electrical resistance tomography (ERT), borehole radar (borehole radar) and ground penetrating radar (GPR).

The three techniques are described in the next section, followed by case studies illustrating their use. All three case studies were undertaken within the PlatMine collaborative research programme. The conclusion discusses how each of the three techniques can be applied at the appropriate stage of mining: initial development, raising and stopping.

2 Basic principles of in-mine ERT, GPR and borehole radar

2.1 Electrical Resistance Tomography (ERT)

ERT (also known as Resistivity Tomography or RESTOM) exploits on-reef development ends (raise lines and strike-parallel development) surrounding an unmined block to probe for disruptive features within the block. The ERT technique is based on a combination of conventional resistivity profiling and tomographic imaging principles (Griffiths & Barker, 1993; Daily et al., 1995). Electrodes are attached to the rock at intervals along the developments. Pairs of electrodes are used to apply current to the rock while potentials are measured between other pairs of electrodes.

The output from an ERT survey is a two-dimensional colour-coded image of the reef plane showing spatial variations in the electrical resistivity. A disruption or distortion of a
platinum-bearing horizon or associated marker horizon will manifest as a resistivity anomaly on the output image. Consequently, both known features, intersected by developments or boreholes, and unknown features can be delineated. The ERT technique is applicable to imaging blocks of up to 200 m x 200 m at a resolution of approximately 5 m. Larger blocks can be surveyed with lower resolution.

ERT is an excellent reconnaissance tool for use after raise lines have been developed, to determine whether disruptions can be expected when mining the enclosed block of ground. If disruptions are expected, the mining operation can be planned to take into account the expected location of the disruption. When mechanized equipment is applied, implying high face advance rates on a smaller number of faces, it is particularly important to know whether to expect reef discontinuity in an area.

ERT is at an early stage in its development. Trial surveys have proved the concept, and acquisition equipment is currently being customized to make data acquisition fast and cost effective. The large area that can be quickly imaged with relatively high resolution will make ERT a very exciting tool for routine use.

2.2 Ground penetrating radar (GPR)

GPR is a high frequency electromagnetic technique for imaging in the earth (Turner, 1993). An antenna transmits pulses into the ground that are reflected from discontinuities. The reflections are detected and can be displayed in real-time and stored for later analysis. The output from a GPR survey resembles that of a seismic record. The typical operating frequency for in-mine GPR applications is between 250 MHz and 500 MHz, which equates to a maximum range of approximately 5-8 metres in typical Bushveld rocks. Modern GPR systems are lightweight, portable and capable of providing real-time data display.

The niche application for GPR is to probe the immediate hanging wall to determine distances to specific interfaces, layers or partings. This information can assist with support design for rock engineering purposes. GPR can also identify hazardous geological features such as angled joints or faults. It can thus play a key role in monitoring hanging wall integrity. In mechanized stopes where tendon support is employed, GPR is particularly useful for determining whether the tendons are supporting the required beam.

GPR is a mature technique. Highly effective equipment is available from a number of manufacturers.

2.3 Borehole radar

Borehole radar is essentially GPR applied in boreholes. A borehole tool, consisting of a radar transmitter and receiver, is profiled along the length of the borehole while radar signals are transmitted and recorded at regular intervals in time. The borehole radar tool is supported by a portable winch and boreholes of any orientation, including up-holes, can be surveyed. Geological interfaces will reflect some of the transmitted radar energy back to the receiver, making it possible to determine the distance between the target and the tool at points along the profile defined by the borehole. CSIR Miningtek’s Aardwolf BR40 system operates at a centre frequency of 40 MHz, which implies a maximum range of up to 50 m in Bushveld rocks, with a resolution of 1 m.
Because borehole radar is applied from boreholes, it can be targeted to examine areas of reef well ahead of mining, where discontinuities are expected. The boreholes that are used can either be routine geological exploration boreholes, or they can be boreholes drilled specifically for the purposes of radar imaging.

Borehole radar is a relatively new technique for routine application. While routine surveys are being undertaken in South African platinum and gold mines, the services are not yet routinely available from multiple suppliers.

3 Case studies

3.1 Using borehole radar to map a UG2 pothole from the end of a haulage

A borehole radar survey was conducted in a horizontal borehole drilled from the end of a haulage developed at Western Platinum Mine. The borehole, which intersected the UG2 chromitite seam at a steep angle is located in the hanging wall of the UG2 seam. The radargram shows several strong reflectors (Figure 1). Where the UG2 seam intersects the haulage it is dipping at 30°, and an extension of this is clearly seen on the interpreted radargram, highlighted in red. From the local stratigraphy, the straight (orange) reflector, approximately 10 m above the UG2 seam, is the contact between the hangingwall pyroxenite and mottled anorthosite. The curved (yellow) reflector is related to slumping, in a different plane to the stratigraphy. It is most likely a dome structure, similar to those found above the Merensky horizon and UG2 seam in the vicinity. A linear feature extends downwards from approximately 55 m. It is interpreted as the effect of an almost vertical structure, such as a fault. At approximately 75 m along the borehole another strong reflector can be seen at depth. If the nature of potholes in this region is taken into consideration, it looks like the UG2 seam slumps and then resurfaces closer to the borehole. In this case borehole radar has proven that the UG2 seam dips at too steep an angle to be mined further, confirming that mining in the area should cease.
Figure 1: Western Platinum borehole radar result shown with and without interpretation.

3.2 Using ERT to map Merensky potholes and IRUPs between raise lines

A trial ERT survey was conducted at Western Platinum Mine to demonstrate that ERT could be used to map disruptions to the continuity of the Merensky Reef in unmined blocks of ground. The survey site is developed on the Merensky Reef and was chosen on the basis that known disruptions of the Merensky Reef occurred within the block so the ERT results could therefore easily be validated.

The output ERT output image is shown in Figure 2. The resistive (red) anomaly (A) located in the centre of the image correlates well with the observed signs of potholing in the developments. The image suggests that this pothole is sub-round and that it may even be linked to a larger pothole known to exist further towards the north-eastern corner of the survey area. The extremely resistive composite anomaly (B) is interpreted as the combined response of the a known pothole (B₁), a confirmed IRUP or partial replacement occurrence in the southwest corner of the survey area (B₂) and a further potholing (B₃) observed in the strike-parallel development, a few metres below electrode positions 12 and 13.
3.3 Using GPR to map UG2 chromitite stringers and associated curved joints

Two GPR case studies are presented here. In the first survey, GPR was used to track the position of the “triplet” chromitite stringers at Bleskop Shaft, RPM Rustenburg Section over a distance of approximately 80 metres. A typical output radargram with interpretation is shown in Figure 3. This profile was acquired along the length of a raise line. The triplets manifest as a clear package of reflectors at an average distance of 1 - 2 metres into the hangingwall. This result represents an example of how GPR can be routinely applied by rock engineers for mapping the middling distance or beam thickness.

Figure 3: Mapping the triplet chromitite stringers over large distances at Bleskop Shaft, Rustenburg Section.

It is not possible to determine whether the topography seen on the stringers is real, or an artefact caused by topography on the hangingwall. However, at any point along the
hangingwall, it is possible to give an accurate distance to the stringers. For example, at 50 m along the profile, the stringers are located 2.4 metres from the surface of the hangingwall. The support requirements for the area can now be determined.

The second case study shown is from Waterval Mine at RPM Rustenburg Section, where the aim was to determine whether GPR could map the position of the Leader Seam above the UG2 seam and also whether GPR could detect curved joints. A profile was conducted directly over a known curved joint occurrence. Of particular interest to the mine was whether these joints extended beyond the Leader Seam into the hangingwall, as this has an impact on roof stability. The resulting radargram is shown in Figure 4. Several curved joints can be identified as indicated. The GPR output does not indicate that these features extend beyond the Leader Seam. The apparent disruption of the Leader Seam at about 7 metres is due to antenna positioning errors on the highly irregular hangingwall surface, rather than changes in structure. The result proves that GPR can be used to map the middling to the Leader Seam on Waterval Mine. Curved joints and their vertical extent can also be mapped.

Figure 4: Mapping the Leader Seam and known curved joints at Waterval Mine, Rustenburg Section.

There has been some resistance to the routine application of GPR in platinum mines, due mainly to the difficult logistics of applying GPR systems, as well as concerns regarding the application of GPR near roofbolts. Commercially-available modern GPR systems require only two persons to operate, or even one person with specific equipment. It has also been shown that roofbolts do not affect the quality of data that is acquired.

4 Summary

ERT, borehole radar and GPR can be applied in an integrated fashion to optimise mechanised mining by improving mine planning and safety. The application of each geophysical technique depends on the stage of mining:
Stage 1: Development of haulages and cross-cuts to define mining layout / grid.

As development approaches to within a few tens of metres of the orebody, borehole radar can be applied from boreholes drilled from the haulages towards the reefs to obtain profiles of reef continuity and elevation along the borehole direction.

This can be done at regular intervals; for example where raise lines are planned boreholes can be drilled to detect any major potholes, IRUPs or faults that the raise line would encounter before it is developed. Cross-cuts and raise lines can thus potentially be optimally placed to avoid severely disrupted blocks. If major structures are encountered in the development of cross-cuts, borehole radar can be used to evaluate the extent of the disruptions within the to-be-mined block.

Borehole radar can also simply be applied in exploration or cover boreholes that are already being drilled. It can then be used to ensure that development remains at its design distance above or below particular horizons.

Stage 2: On-reef development of raise lines and strike-parallel development.

During this stage, GPR can be routinely applied to monitor marker horizons within the immediate hangingwall. The number of boreholes normally required to obtain information for support design purposes can be significantly reduced.

ERT is best applied at this stage of mining. Once adjacent raise lines have been developed, cross-raise ERT can be applied to delineate disruptive features within the unmined blocks. Inferred pothole and IRUP distribution maps can thus be updated to reflect the true geometries of these features more accurately.

If ERT or other evidence suggests the presence of disruptions, exploration boreholes can be drilled from within raise lines towards the disruption to apply borehole radar. The radar results will accurately map the position of the edge of the disruption. If the disruption results in a change in elevation of the reef rather than its replacement, borehole radar will also accurately determine the elevation difference and the slopes of the discontinuity. This information can be used to plan how, or indeed whether or not, to mine the disruption.

Stage 3: Ore extraction.

Once mining commences, GPR can be used routinely to monitor hangingwall conditions and to determine support requirements. The concept of mounting GPR systems on mechanized mining equipment is therefore strongly advocated. Continuous monitoring of the hangingwall structure as the mining face advances can be of great benefit, as any hazardous geological features that need special support requirements, as well as any off-reef deviations by the mechanized mining equipment, can be identified in real-time.

5 Conclusion

Geophysical techniques offer additional information that can mitigate the risk of changes in geology ahead of mining. The three techniques described here have been selected and developed because they can supply information at the resolution required for local scale mine planning and for mining. Each has its own application, with associated costs and
benefits, but all three can add information to the decision making process that will result in more cost effective, safer mining.

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References


