

The Bore Hole Radar Trials at Rustenburg Section – A Case Study

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SYNOPSIS

The SAMREC code model in *Figure 1*, illustrates a requirement for increased geoscientific knowledge and confidence from an inferred to a measured mineral resource. In UG2 platinum group metals, the mineral resource definition is adequately achieved by employing various exploration techniques. However, the geological modifying factors that have the greatest impact on mining are not adequately defined and as a consequence the UG2 production personnel are faced with costly unpredictable mining disruptions. The disruptions arise from undulations and rolling of the UG2 reef and random occurrence of potholes. The impact of the disruptions are so severe that the production teams end up spending most of their time doing exploratory activities under unstable ground conditions.

The biggest impact on mining safety and UG2 ore grade delivered to the plant has been attributed to mining conditions arising from geological disruptions, hence the need for an appropriate technique to predict disruptive geological structures ahead of mining.

This paper identifies an appropriate technique for use in gaining sufficient information ahead of mining to enhance the integrity of the production mine plan in UG2 mining. The results of the GeoMole Borehole Radar trials at Rustenburg Section have proved the borehole radar is an appropriate tool to predict ground conditions ahead of mining operations. However this technique must be integrated with all the other systems that support the mineral resource management value chain.

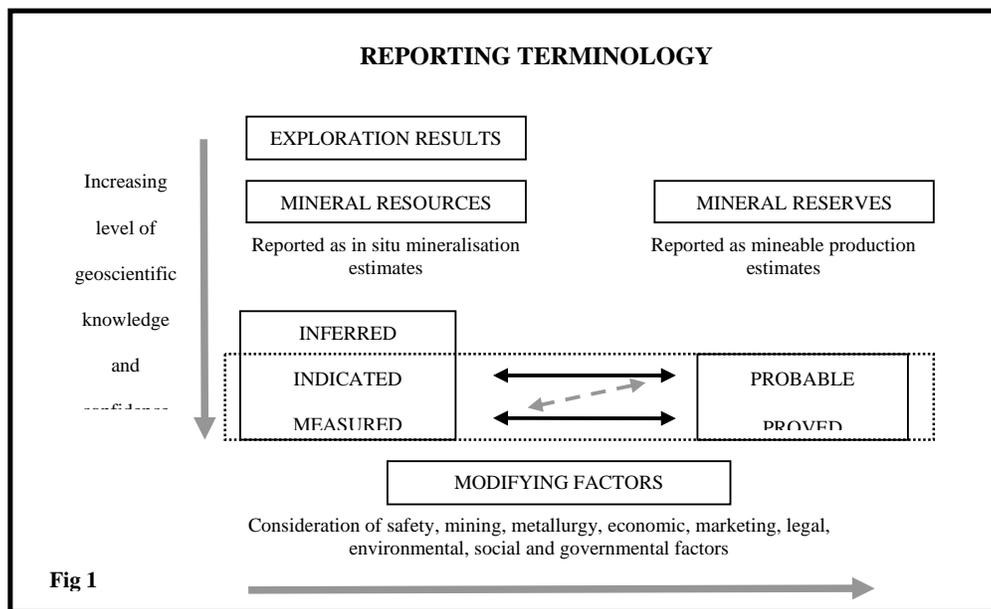


Figure 1

BACKGROUND

Interest in mining the UG2 reef at Rustenburg Section developed over a substantial period of time and was characterized by several peaks of interest, with limited feasibility studies being done during the years 1966, 1978 and 1982. It was not until the late 1980's and early 1990's that a more committed approach was taken to mining UG2. Mining of the UG2 reef at Rustenburg Platinum Mine began at Brakspruit Shaft in 1989, followed by Bleskop Shaft in 1994 and Paardekraal Shaft in 1997. Over this period a significant database has been compiled on both the UG2 and the underlying UG1 lithologies, enabling each Business Area to accurately interpret the behaviour of the UG2, as well as the associated group element mineralization. (*Economic Resources Department Technical Report dated 23 March 2000*).

Merensky production from current mining infrastructure has been on a steady decline as the top levels are mined out to the mining boundary and has been replaced by a steady build up of UG2 production. The Merensky reef was predominantly mined using conventional mining layouts; conventional breast and dip mining layouts.

The bulk of the UG2 production is from shallow mining areas accessed through declines and on-reef mining layouts. The on-reef mining layouts were adopted to facilitate mechanized mining in order combat shortage of skills due to HIV/AIDS pandemic and to minimize the risk of falls of ground.

One of the critical success factors in mechanized on-reef mining depend on gaining detailed geological information ahead of mining. In conventional breast mining layout, the detailed ore body information is gained during the ore reserve development and infill drilling. In the on-reef mining layout configuration this information is not readily available at the required level of confidence to define mining proved reserves of significant quantity.

The two biggest risks identified in UG2 mining were failure to meet production targets at the designed grade and unsafe mining conditions due to disruptive reef behaviour. It was therefore a strategic decision to carry out Borehole Radar tests in UG2 mining environment in order to minimize the risk of mining dilution, and unstable hanging wall conditions which lead to failure to meet the planned production.

REGIONAL GEOLOGICAL SETTING

The UG2 succession occurs within the lower feldspathic pyroxenite package of the UG2 unit and is known for its undulation over short distances. This is due to the para-conformable relationship with the footwall. It is important to note that the Main Seam demonstrates the sharpest undulation while the Leader Seam and Triplets respond less intensely. The Main Seam, Leader Seam and Triplets are not parallel everywhere, this results in further localized thickening and thinning of the package. (*Economic Resources Department UG2 Technical Report dated 23 March 2000*).

Potholes of varying sizes characterize the geological setting of the East Business Unit UG2 mines at Brakspruit and Bleskop. The pothole locations are difficult to predict from exploration diamond drilling. The mining disruption related to the potholes depends on the size and the geological structure of the pothole. Determination of the size and position of a pothole is critical for effective production planning. Small potholes are defined as less than ten meters in diameter and are easy to mine around with minimum disruption to the production volume and quality.

PROBLEM STATEMENT

The challenges of mining UG2 reef at Rustenburg Section were highlighted by Cilliers and Brown in their paper “Factors affecting the mining and platinum-group element recovery of the UG2 reef at Rustenburg Platinum Mines, Rustenburg Section.” Some of the factors highlighted were: “The relationships and stratigraphic variability between the chromitite layers are best illustrated by example stratigraphic columns, shown in *Figure 2*. It is clear from *Figure 2*, that considerable variation exists and it is therefore necessary to define the locality at which an investigation or valuation is to be undertaken in order to select the best-cut mining option.”

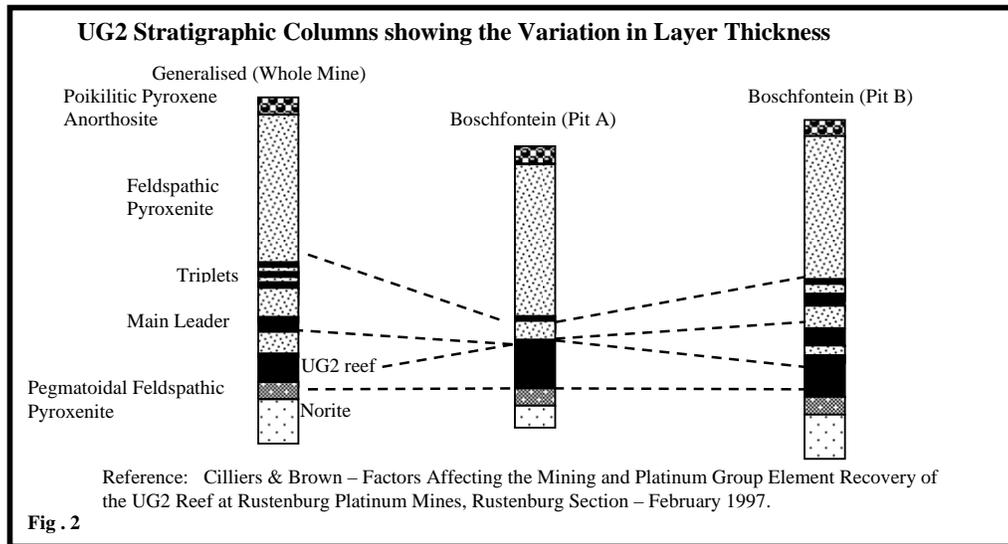


Figure 2

BOREHOLE RADAR TRIALS AT RUSTENBURG SECTION – PRE-ASSESSMENT INVESTIGATIONS

Borehole radars were deployed at Bleskop, Brakspruit and Waterval Shafts between September 2001 and November 2002. The objective was to evaluate the technology’s ability to locate geological structures that disrupt mining operations.

UG2 Core Sampling Tests

The GeoMole Borehole Radar trials were conducted by GeoMole South Africa. In July 2001 GeoMole South Africa conducted tests on UG2 core samples from the hanging wall and footwall for electromagnetic properties. The results were used in a computer simulation that predicted long range (in excess of 50 metres) electromagnetic wave propagation conditions in UG2 foot wall and hanging wall.

Borehole Radar Survey Procedure

Prior to conducting the borehole radar surveys preparation was undertaken by the GeoMole technical team and the mining personnel. The borehole radar assessment sites were carefully chosen to provide the mining personnel with useful planning information. The position and direction of the boreholes were planned to provide adequate coverage of the mining area.

Safety Precautions

Safety precautions were drawn up to comply with Mine Health and Safety Act and Regulations (29/1996) before any work related to the trials was undertaken underground. An operating protocol to minimize loss of core and radar equipment was also established.

Borehole Radar Survey Equipment

The following equipment was used for the bore radar survey:

- The GeoMole 32 mm diameter Slimline radar for use in 48 mm diameter borehole;
- GeoMole three-axis magnetometer and accelerometer with on-board digital recorder;
- Carbon fibre push rods;
- SeisWin software for data analysis.

BLESKOP AND BRAKSPRUIT INITIAL BOREHOLE RADAR ASSESSMENTS

A borehole radar assessment trial was conducted at Bleskop from a winze in the UG2 reef plane in September 2001. The objective was to determine radar propagation conditions of the UG2 footwall, chromitite layers associated with UG1.

In December 2001 a borehole radar survey trial was conducted at Brakspuit from 11 Haulage below the UG2. Two boreholes were drilled in an area disturbed by potholes. The objective was to demonstrate the possibility of mapping potholes and undulations in the UG2 from footwall boreholes.

The results confirmed clear profiles and cross-hole scans of pothole reef and reflections from intact smooth reef. Strong echoes from tunnels 50 metres to the borehole sides such as tunnels and raises were identified and allowed accurate placement of images on the mine plan. Potholes with a lateral extent of about 10 meters, slumps about 2 meters and other UG1 and UG1 geological features ahead of mining were clearly detected. The tests confirmed that the chromitite layers associated with the UG1 and UG2 offer enough contrast for them to be mapped by the radar with resolutions of less than one metre. The propagation of the radar pulses had good fidelity over at least 50 metres.

GeoMole South Africa technical team conducted the analysis and interpretation, with some assistance from the mine technical team. The analysis and interpretation required understanding of electromagnetic wave propagation in a stratified system. The initial positive tests then led to planning of a series of tests to confirm mine worthiness of the system and validation of the earlier test results.

**BLESKOP SHAFT BOREHOLE RADAR SURVEYS
JUNE AND SEPTEMBER 2002**

Over the period from June to September 2002 an assessment of the base of the UG2 chromitite reef at Bleskop was carried out. The bore radar survey covered an area approximately 15 000 square meters of the UG2 base.

GeoMole radars were deployed in two phases: first phase was conducted in June and consisted of a fan of five boreholes, each 100 meters long. The second phase was conducted in September and consisted of a fan of three boreholes, each about 150 meters long.

Bleskop Shaft Borehole Radar Surveys 10 – 14 June 2002

The Bleskop UG2 first phase borehole radar assessment was conducted between the 10th and 14th of June 2002. The assessment was conducted between Crosscuts 13-1W and 13-2W south of Haulage 13 West as per *Figure 3* below. A fan of approximately 5 000 m² (half a hectare) of the UG2 base was covered. GeoMole 32 mm diameter radars were deployed in five boreholes (48 mm diameter). Each borehole was about 100 meters long, and passed between the UG2 and the UG1.

Bleskop Shaft - Haulage 13West – Cross Cut 13-2W and 13-1W

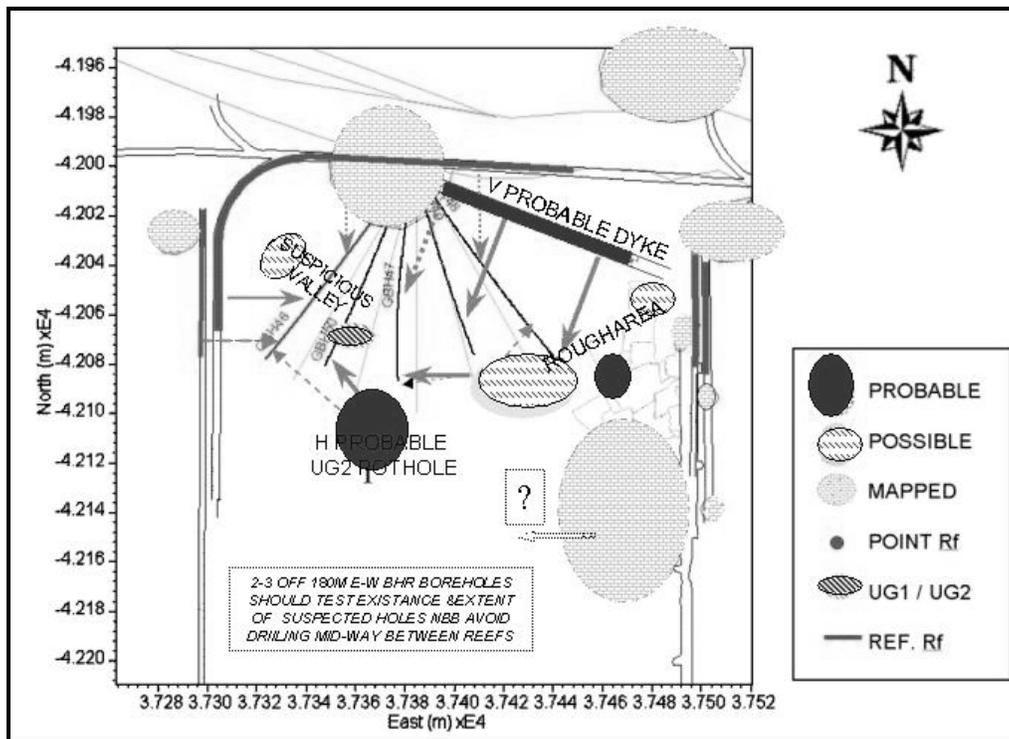


Figure 3

UG2 reserve at Bleskop, June 2002. The borehole fan lies between the UG2 and UG1. Some of the borehole trajectories deviate significantly from the straight-line projections in blue. The trajectories of all the boreholes were measured using a GeoMole instrument equipped with a three-axis magnetometer and accelerometer. It is essential to correct the radar data for borehole curvature.

Results

The objects indicated in red on **Figure 3** were imaged with high confidence, after correction for borehole curvature and data field migration.

- Known objects to the sides of the boreholes such as the haulage to the east and west of the borehole collars, crosscuts and raises to the east and west within 60 metre range were detected.
- Known objects above and below the boreholes such as the UG2 base, top of UG1 and the Bleskop marker were clearly imaged. However the radar pulses could not penetrate beyond the UG2 and UG1 because of their thick chromite layers. Thus the Leader and Triplets could not be imaged from below the UG2. The Bleskop Marker is semi-transparent because its chromite stringer is less than 10 mm thick.
- The radar survey picked up previously unknown objects such as the dyke cutting across the northeast corner and two UG2 potholes near the edge of the borehole fan.

A second borehole radar deployment was scheduled for August and September 2002 to confirm four disturbances of the normal UG2 plane may have been potholes. The research team had also to resolve the integration of SeisWin contour data and CadsMine survey planning data.

Refer to detailed GeoMole Progress Report 2002-1 dated 15 July 2002 by IM Mason and JH Cloete.

Bleskop Shaft Borehole Radar Surveys 9 – 13 September 2002

GeoMole made a second borehole radar assessment of the UG2 base at Bleskop from 9 to 13 September 2002. The area under assessment was the area south of Haulage 13 West, between Crosscuts 13-1W and 13-2W South, **Figure 4**.

The first assessment, in June from Haulage 13 West, used the five-borehole fan shown in **Figure 4**. It covered about 5 000 m² (half a hectare) of the UG2 base. The second assessment was done from Crosscut 13-2W South using the three-borehole fan, also illustrated in **Figure 4**. The boreholes ranged in length from about 120 to 165 meters, and covered about 10 000 m² of the UG2 base.

Bleskop Shaft - Haulage 13West – Cross Cut 13-2W and 13-1W

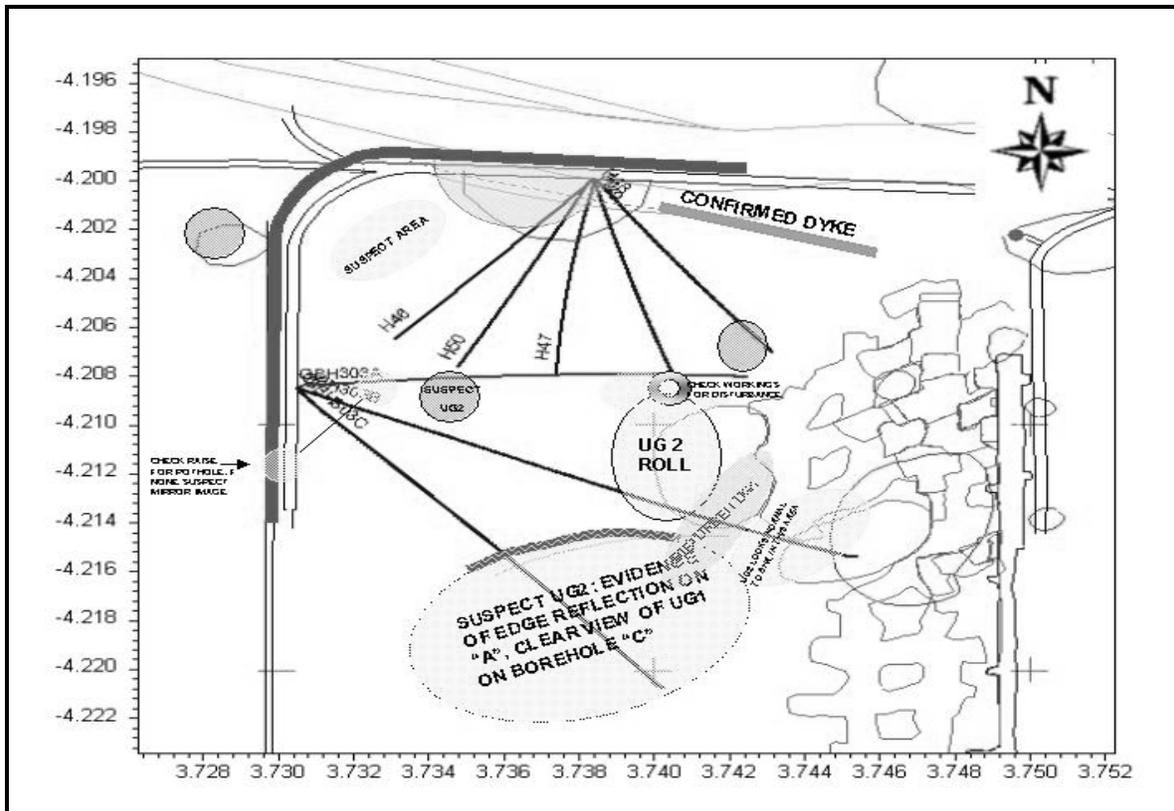


Figure 4

Borehole radar at Bleskop: June (5 borehole fan) and September 2002 (3 borehole fan)

Results

A total of about 15 000 square meters of UG2 at Bleskop was assessed from AXT coring boreholes (48 mm diameter) using GeoMole 32 mm diameter radars over the two phases. The same procedure of measuring borehole trajectories using the GeoMole borehole navigator was used.

The previous problem of incompatible SeisWin contours with CadsMine contour system was resolved. A contour map with a resolution below a metre of the UG2 base was extracted from the radar data, using GeoMole's SeisWin 3D image processing software. The contour map was then converted into a dxf format for integration with CadsMine contour system. The detection ranges were as previously achieved at 60 metres to the sides of the boreholes.

The following structures were imaged with confidence, after correction for borehole curvature and data field migration:

- UG2 base;
- Top of UG1;
- The Bleskop Marker;
- A deep roll in the UG2;
- A dyke;
- Man-made structures such as haulages, crosscuts, stopes and raises.

This survey confirmed that the borehole radar can detect potholes, reef undulations and rolls and dykes in the UG2 system. Borehole radar deployed from the footwall boreholes drilled sub-parallel to the UG2 can yield high-resolution (1 metre) profiles of the UG2 base and UG1. Profiles from adjacent boreholes, appropriately drilled, can be combined to produce 0.5 metre contour maps of the UG2 base. The contour maps could then be integrated with the mine CadsMine survey files to produce a three dimensional structural plan for mine design purposes. This would be the appropriate technique to get the required geological detail for meaningful production planning. A sub-metre resolution contour map of the UG2 base was extracted from the radar data, using GeoMole's SeisWin 3-D image processing software. Refer to *Figure 5* below.

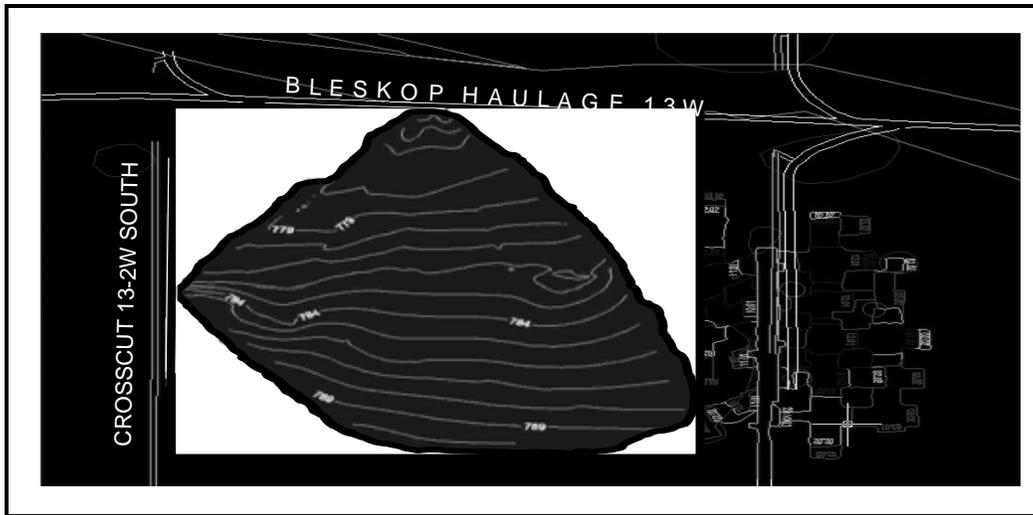


Figure 5

Local UG2 strike lines. Heights in the Bleskop coordinate system. Resolution is 0.5 meters between adjacent contours. Integrated June and September contours.

Refer to detailed GeoMole Progress Report 2002-2 dated 31 October 2002 by IM Mason and JH Cloete.

WATERVAL MINE BOREHOLE RADAR SURVEYS SEPTEMBER AND OCTOBER 2002

Further borehole radar trials were conducted at Waterval UG2 mechanized room and pillar mine during September and October 2002. The borehole assessment was conducted at Waterval Central Shaft Section 8 panels P2, P3 and P4. Two exploration holes were drilled in the reef plane to find the pothole edges and to plan the resumption of normal mining. WCC06: collar dip -10° , azimuth ENE 32° by 60 metres long and WCC07: collar dip -5° , azimuth ESE 113° by 89 metres long as illustrated below in *Figure 6*.

Both holes intersected UG2, then UG2 pegmatoid near end of hole. The pothole was thought to be roughly elliptical with an area of about one hectare.

A third borehole, WCC09, 103m, collar dip -25° azimuth ENE 72° was drilled both for BHR surveying and to fix the far wall of the pothole.

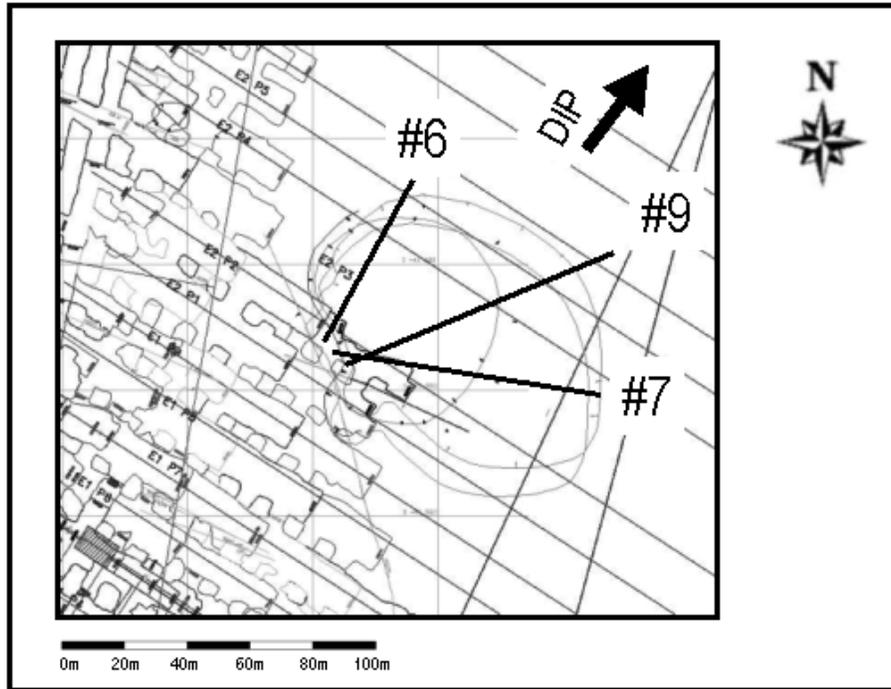


Figure 6

Waterval Central shaft. Sketch map of study area, showing stopes as at 27 September 2002

Preliminary Findings

This was the first attempt to examine the interior of a pothole from borehole radar assessment. This information is useful in determining whether to mine around or try and mine the pothole if the ore displacement is not too severe and ground conditions are favourable. The interpretation of the borehole radar assessment indicated a pothole that was shovel shaped. The northern rim indicated a south dip of 1in10. The floor of the UG2 in line with E2 P5 indicated a 10-metre displacement. Adverse roof conditions were possible and could impact on the decision to mine the pothole.

The borehole radar profiles were complex but offered some reasonable interpretation. The area of pothole assessment is critical and would provide valuable production information. Refer to GeoMole South Africa interpretation in *Figure 7* below.

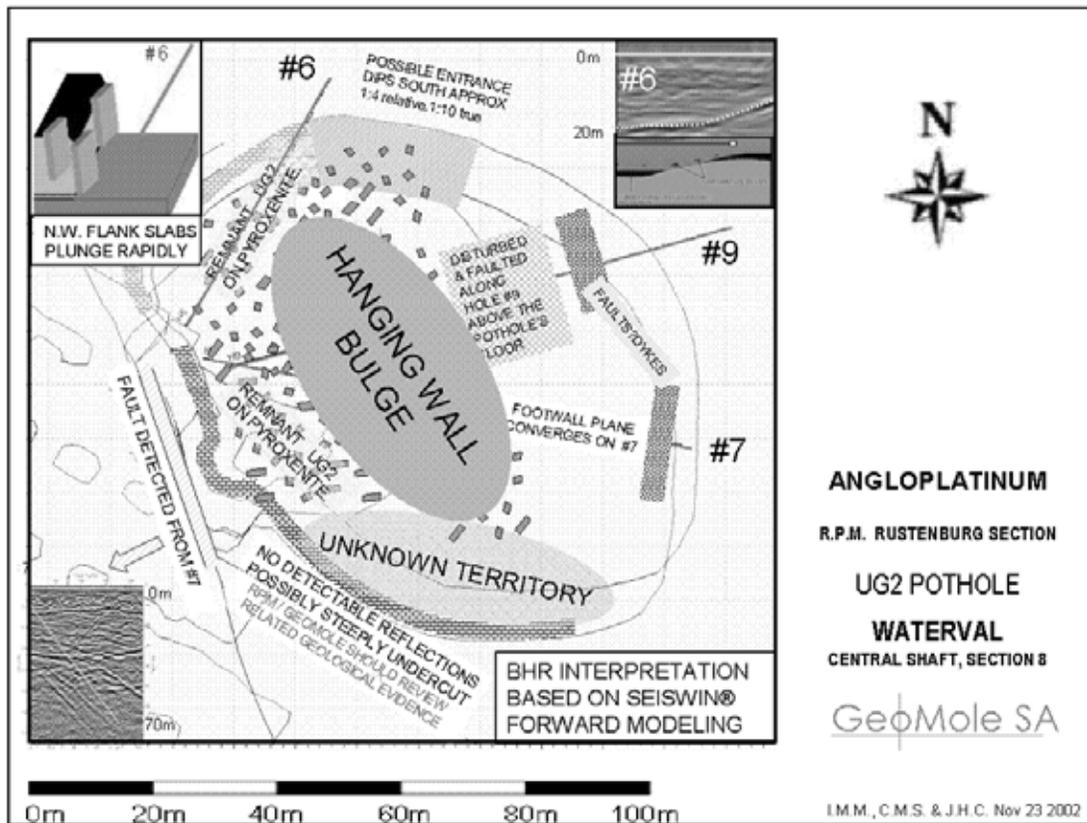


Figure 7
GeoMole South Africa Interpretation of borehole radar data from boreholes WCC06, WCC07 and WCC09

BOREHOLE RADAR COST ANALYSIS FOR A 200 M X 200 M UG2 PANEL

According to DJ Buchanan in his paper on the benefits of in-seam seismic survey in coal seam mining: “Any survey can only be of benefit if the information it provides can be acted upon. At one extreme, a survey may provide an additional panel of coal that would not otherwise be mined, and at the other extreme, perhaps a few weeks warning can be provided of a fault in front of an advancing long wall face. The cost benefit is essentially the value of the planning information provided by the in-seam seismic survey”.

This is an area that needs more research work, especially in mechanized mining section. The cost of equipment ownership must be taken into account to evaluate the impact of loss of production due to the geological disruption. The cost of re-establishment must also be taken into account and can be provided for if anticipated in advance. An assessment was done to estimate the cost of a borehole radar survey in comparison to the value of platinum group elements likely to be recovered. The cost was less than 1% of the value of recoverable platinum group elements. It is therefore concluded that the value derived from the borehole radar assessment information far exceeds the cost of the survey.

STATEMENT OF RESULTS

These were the conclusive findings of the borehole radar survey trials at Bleskop, Brakspruit and Waterval Mines.

- Borehole radar deployed from footwall boreholes drilled sub-parallel to the UG2, yields high-resolution 0.5 metre profiles of the UG2 and the UG1 base;
- Profiles from adjacent boreholes, appropriately drilled, can be combined to produce high-resolution contour maps of the UG2 base. However the SeisWin data must be converted to dxf files for compatibility with CadsMine system;
- Borehole radar can detect potholes and rolls and can provide useful planning information;
- Borehole radar can delineate dykes; shear zones; and faults in the UG2 system;
- Borehole radar can locate aquifers or water fissures;
- The borehole radar survey provided useful planning information that is essential for improving safety and accomplishing planned production;
- It was not possible to get the position of the Leader seam because the radar pulses do not penetrate through the UG2 reef from below.

FURTHER RESEARCH

In order to prove mine worthiness of the borehole radar, GeoMole Borehole Radar research team recommended that the radar be used during the shaft sinking operation at Boschfontein UG2 project. Borehole radar is to be deployed to provide cover for the new decline shaft at Boschfontein UG2 Phase 2 Project.

The borehole radar assessment procedure will be simplified in order for mine personnel will be able to perform the survey and the interpretation. The researchers are developing a strategy to deploy the radar assessment in such in a way that will provide cost-effective mine planning information without disrupting the production process.

In the trials it was confirmed conclusively that borehole radar can detect potholes and undulations. The next step is to develop the technology (borehole layout; data acquisition; image processing; and geological and structural interpretation) to the point where potholes can be classified as follows:

- Shallow or carrot shaped as per illustration below;
- Stable or disrupted UG2 base;
- Economical to mine or not;
- Condition of hanging wall in respect to stability.

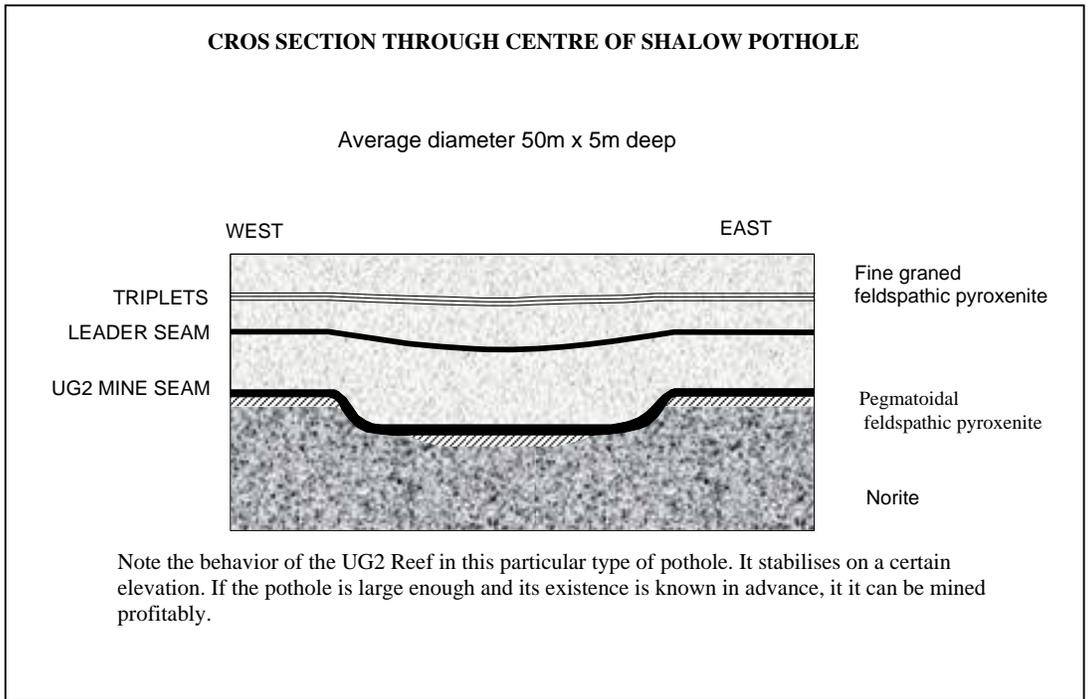


Figure 8
ERD Rustenburg UG2 Reef Technical Report - 23 March 2000

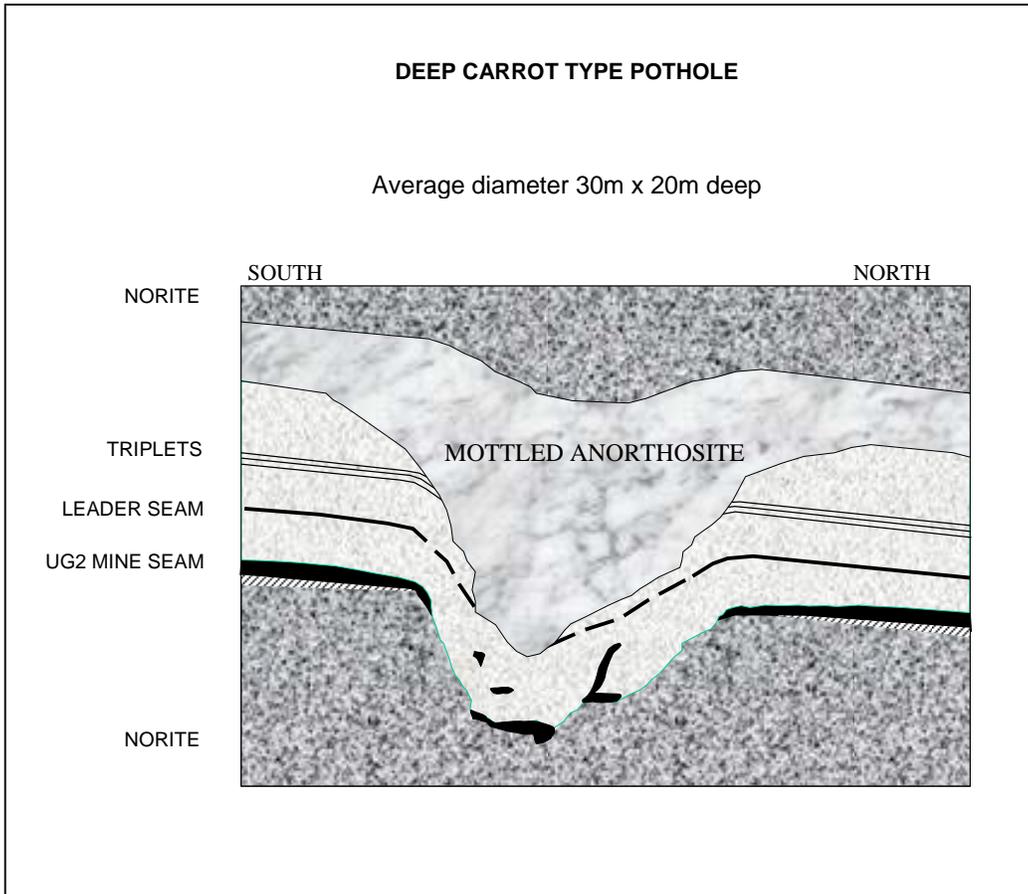


Figure 9
ERD Rustenburg UG2 Reef Technical Report - 23 March 2000

There are some serious production and safety implications related to mining through deep carrot type potholes. The consequences of mining through this type of pothole become more severe if there is lack of geological information prior to mining. It is not economically viable to mine this type of pothole. The appropriate mining plan would be to mine around the pothole and minimize the development in the pothole area.

POSSIBLE BENEFITS

If the borehole radar is deployed appropriately, there are several benefits that can be derived from the data. Here are some of the possible benefits that can be derived from the application of this technology:

- The borehole radar assessment could form part of a strategy to manage the risks arising from undulating, rolling and potholing UG2 reef. However, one limitation is that when boreholes are drilled between the UG1 and UG2 the radar will not be able to image the Leader seam and Triplets;
- The borehole radar could be used to locate aquifers, potholes, dykes, shear zones and faults within the UG2 environment. This information will be essential for effective medium to long term planning purposes;
- The borehole radar could be an effective tactical fast response tool to provide information for effective production planning;
- Data could be integrated with existing CadsMine contours to produce three- dimensional plan of underground workings;
- Borehole radar survey could be useful as an assessment tool to evaluate abandoned mining areas.

The benefits derived from the deployment of the borehole radar far exceed the cost of the survey.

CONCLUSIONS

Borehole radar is potentially a tactical, rapid response, high-resolution imaging technology. The results of the borehole radar surveys to date have confirmed that the technique can be used successfully in the UG2 mining environment to provide useful geological information ahead of mining. If correctly deployed the borehole radar can improve the confidence in the mine plan, provide useful geo-technical information and reduce mining dilution. This will improve safety, productivity and avoid costly production equipment and resources being used for “exploration” purposes.

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