Borehole radar mapping of orebodies

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Every day, miners go underground after the blast on our gold and platinum mines to find that the reef has disappeared or the hanging wall conditions have suddenly deteriorated. What can be done to take the surprise out of these events?

Both the Bushveld Complex and the Witwatersrand Basin consist of enormous orebodies, with lateral extents of tens to hundreds of kilometres, and extents down dip going to depths well below what we can currently mine. Both are superficially simple geologically, with limited structure interfering with the continuity of the orebodies.

Even at mine level the situation is relatively simple: mines are planned to take advantage of the huge lateral extent of the orebodies, and areas are demarcated by the large faults or dykes in the area. However at panel level, individual panels routinely encounter unexpected changes in the reef. On the Bushveld platinum mines these can be potholes, on Wits gold mines they can be rolls, while both suffer from small faults and dislocations due to dykes.

Unexpected discontinuities obviously affect production: a crew that arrives on site in the morning to find that the reef has disappeared after the blast are unable to produce that day. Instead they must involve a geologist to determine whether the reef has moved up or down and by how much, then a decision must be made on how to redevelop.

Apart from the economic problems, a dislocation is often associated with poor ground conditions. Both on the edges of potholes and the slopes of rolls, the hanging wall is often fractured and of poor quality, leading to falls of ground and having the potential to injure or kill workers.

These risks to people and production can be minimised if miners know where the orebody is going to be tomorrow, over the next week and the next three months. Miners are then well prepared for the blast that exposes a fault, have already developed to the new reef elevation, and can continue mining without delay. Knowledge of oncoming rolls or potholes can be used to prepare improved support in advance, managing the safety risk.

Drilling was the geologist’s best weapon for understanding reef topography, and is the standard tool used on all mines for long term planning. For short term, the cost and delay associated with drilling are high, and the need for skilled interpretation makes it impossible to apply on the scale required to map the future of every panel.

Borehole radar

Over the last fifteen years, the CSIR has introduced and proved borehole radar as a tool that can provide information about reef topography quickly and cheaply, with a high level of accuracy. While it still requires a borehole, that borehole does not have to intersect every feature that requires mapping – the borehole radar can look out from the borehole.

The radar sends radio wave pulses into the rock. These pulses reflect off changes in rock type, particularly off changes in the dielectric property of the rock. For radar to work well, the host rock has to be resistive. It is fortunate that in our gold and platinum mines the host quartzites, anorthosites and norites are all highly resistive, so it is possible to achieve good radar ranges, 50 m to 70 m in good conditions in the Bushveld.

After a resistive host rock, the next thing that is required is a contrast between the host rock and the target. In the Bushveld this is almost always there – the Merensky pyroxenite or UG2 chromitite is very different to the surrounding rock and makes an

Fig. 1: Example radar response from the VCR, showing rolling reef, reef topography and a small fault.
Fig. 2: The Fresco modelling environment, showing the boreholes, candidate targets, and measured radargram with the modelled radargram overlaid on it.

excellent target. On the gold mines, things are a little different. In the case of the VCR, the lavas above the reef give an excellent contrast from the reef and its footwall rocks. However, for reefs like the Carbon Leader or Kimberly reef, the reef itself is nearly identical electrically to the host rock. Fortunately, in the case of the Carbon Leader, there is a shale marker, the Green Bar, that lies a metre or two above the reef, which is a good radar target. If discontinuities in the Green Bar map to discontinuities in the reef, the structure of the reef can easily be inferred.

The other property that makes for a good radar target is a sharp contact between two materials with different electrical properties. In all the cases already mentioned, that sharp contrast is there. In cases where a quartzite fines gradually into a shale, for example, although the electrical properties are changing, there isn’t a good sharp contrast, and there won’t be a good radar echo.

Radar targets don’t need to be other rocks. Air or water-filled openings also make excellent radar targets. Ground penetrating radar, which is similar to borehole radar but applied directly on the rock surface, and not in a borehole, is excellent for picking up lost raise-bore pilot holes or drain holes that have not intersected a haulage and are probably some distance into the sidewall.

Given a resistive host rock and a contrasting target, radar will work, but it will only work well if the target runs roughly parallel to the access. In the case of borehole radar, the borehole needs to run parallel or sub-parallel to the target that is going to be imaged. If the access is perpendicular to the target, only a small part of the target will return radar energy to the radar, so only a small part of the target will be seen. The situation can be compared to driving in a car in heavy traffic: from the driver’s seat, only the car in front, and perhaps a couple of cars in front of that can be seen. A traffic helicopter, which travels above the busy road, can see many more cars, and can therefore give information about what is going to happen many kilometres further along the road than the driver can see. In the same way, a borehole radar survey can give information much further along the reef than a survey conducted from the face.

The final piece of the puzzle is the minimum range: a borehole radar has a dead zone close to its antennas in which it cannot give information. For the CSIR Aardwolf radar, this is approximately 5 m. In other words, an ideal borehole will run nearly parallel to the target, and 5 m or more away from it.

Using borehole radar

An example of a radargram is illustrated in Fig. 1. The radargram itself shows distance along the borehole on its horizontal access, and time to target on its vertical access. The time, given in nanoseconds on the left vertical axis, can be mapped to a distance from the borehole in metres. The exact mapping depends on the rock type, but is typically about 5 cm/ns. In the radargram, the estimated distance to each reflector is given on the right vertical access, in metres. The radargram itself shows the intensity of reflections as shades of grey. The strongest negative reflections are black, while the strongest positive reflections are white. Although the target has an annotation line drawn over it, it can still be seen as the strongest reflection in the radargram.

Below the radargram is the interpretation. In general, the interpretation will take into account the curvature of the borehole, which has not been done here. However, the major features are immediately obvious: there is clear topography, with slopes, terraces and a likely roll, and a small dislocation, due to a fault with a throw of about 2 m.

In this case, a miner coming in after a blast would not be surprised to see that the reef had disappeared: borehole radar had shown exactly when it would happen, and had also shown that it would continue 2 m into the hanging wall on the other side of the fault. Knowing that, the miner may have already started developing up to the new reef elevation, so no production will be lost.

The illustration in Fig. 1 shows both the power of borehole radar and its challenge: if there is a problem, borehole radar will map it accurately. If there is no problem, the borehole radar has provided no additional information. It is insurance: it needs to be there for problems, but it still needs to be undertaken when there are no problems, just in case.

The third dimension

Borehole radars radiate in all directions away from the borehole. Radargrams are often presented in section, as in Fig. 1, but in fact the target could just as easily lie in the horizontal plane away from the borehole. It is essential that the interpreter understands the geometry of the situation, and maps targets to their most likely positions. This isn’t usually a problem: if the borehole is drilled below the reef, then the target in the radargram can be assumed to lie above the reef.

It is still important to remember that the target could lie in any direction around the borehole. CSIR resolves the ambiguity by placing the borehole and the radargram in a 3D synthetic modelling environment known as Fresco, in which targets can be
manipulated to produce the measured radargram. Although several targets could still produce the same radargram, the manipulation in 3D space forces the interpreter to choose reasonable solutions.

In Fig. 2, the process is illustrated.

The exact location of the borehole influences the locations of targets, and is determined by borehole survey. Note that a single borehole only gives a single illumination line on a reef target. It is only the coordinates of that line that can be stated with reasonable certainty – borehole radar does not map the whole reef in 3D.

Fresco is usually used to create the model of the reef or other targets in response to borehole radar. It is then possible to export the coordinates of the illumination line into the mine’s mapping system, to become part of the mine’s geological information.

If several boreholes are available in the same area, it is possible to map the reef over a large area, matching it to the response from each borehole. Fig. 3 shows a portion of the VCR mapped between two raise lines.

While the type of mapping shown in Fig. 3 is expensive, as it requires the drilling of several boreholes, it can pay off its cost many times if the area is known to be complex, simply by removing surprises. Particularly in the highly faulted Eastern Bushveld, borehole radar has become an essential tool to ensure that mine planners know about reef topography into the future.

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Fig. 3: A surface model of the VCR showing the topography determined from geological mapping in two raise lines, and borehole radar mapping from five boreholes. A slope, terrace and roll are all visible, as is a small fault.