Borehole radar for mapping geological structure near the borehole

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Classical geophysical borehole logging tools provide information about the rock in the immediate vicinity of the borehole, to distances of a few centimetres. Borehole radar expands the detection range to metres or tens of metres by using radio waves to illuminate the rock. The principle is the same as that of Ground Penetrating Radar: short pulses of electromagnetic energy are radiated into the earth from an antenna. The pulses reflect off discontinuities in the electrical properties of the surrounding rock, are received by another antenna and recorded.

There are three requirements for effective use of borehole radar: the host rock should be resistive, to allow transmission over significant ranges; there must be a sharp contrast in electrical properties between the host and target rocks; and the target must not lie perpendicular to the borehole. In addition, it is very useful if the borehole intersects the target, so that the target reflector can be unequivocally identified.

The quartzites of the archean Witwatersrand Basin are an excellent host for radar. Resistivity is high, with typical loss tangents of between 0.04 and 0.15. The loss tangent is a frequency independent estimate of the attenuation that can be expected from a particular rock type. It is analogous to the inverse of the seismic property Q. From the loss tangent, the typical range can be estimated as between 15 and 40 wavelengths. The actual range in metres then depends on the frequency that is selected. Typical Witwatersrand quartzites have permittivities of about 9, leading to a radar wave velocity of 100 m/µs. The Miningtek Aardwolf borehole radar has a centre frequency of 40 MHz and has achieved ranges of 15 m to 50 m in quartzite, depending on the maturity. Resolution is typically better than a metre.

Faults, by their nature, offer sharp discontinuities, but the fill material will determine if a fault is a good radar reflector. Changes in rock texture without changes in mineralogy are unlikely to produce good reflectors. Faults that are open, and filled with fluid or air are expected to produce good reflectors, as are faults running along the boundary between two different rock types. Borehole radar is not limited to imaging the fault directly; it can also be used to measure the dislocation in marker horizons intersected by a fault.

The directional ambiguity is the major challenge in interpreting borehole radar data. A directional antenna requires a borehole diameter that is a significant fraction of the wavelength being used. The Malå RAMAC system includes a directional antenna operating at 60 MHz in a 48 mm diameter probe. In narrower boreholes, or at lower
frequencies (corresponding to longer ranges), directional antennas have poor performance. If omni-directional antennas are used, it is necessary to process borehole radar data in association with other data available from the survey site to produce accurate interpretations.

Borehole radar surveys in Witwatersrand gold mines have concentrated on imaging the reef or marker horizons. Figure 1 shows how the Green Bar shale marker above the Carbon Leader Reef has been mapped. From a mining point of view, 80 m of reef has been shown to be clear of faulting. If a fault had intersected the target, the throw could be measured, and some indication could be gained of the strike. The maximum range is restricted to about 15 m, because the quartzite is argillaceous.

![Figure 1. Borehole radar image of the Green Bar shale above the Carbon Leader Reef.](image-url)