THE APPLICATION OF BOREHOLE RADAR TO SOUTH AFRICA'S ULTRA-DEEP GOLD MINING ENVIRONMENT

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ABSTRACT

Borehole Radar has been identified as the most immediately applicable electromagnetic technique to delineate disruptions to gold reef in the South African DEEPMINE environment. The economically important Ventersdorp Contact Reef (VCR) has successfully been imaged over ranges of up to 95 m and with resolutions of less than a metre, using the Geosonde system with a centre frequency of 60 MHz.

INTRODUCTION

Although 3D surface reflection seismics has proven invaluable to the South African gold mining industry for strategic planning purposes, there is a need for geophysical technologies that address geological problems of a more immediate nature. These include the rapid detection and delineation of faults exhibiting throws in excess of 2m, dykes, water fissures, hangingwall parting planes and "rolls". A "roll" is the colloquial term for an undulation in the gold-bearing Ventersdorp Contract Reef (VCR). Many of the fatalities on mines that exploit the VCR are directly associated with these features, (Figure 1) (Roberts and Schweitzer, 1999), which are randomly located and highly variable both in amplitude (less than a metre to 180m) and orientation.

The future of South Africa's gold mining industry lies at ultra deep levels, exacerbating the current problems associated with ventilation, transportation of men materials and ore, as well as rock mass behaviour.

As part of a broad, industry-wide research programme known as DEEPMINE, two geophysical projects were launched in March 1998 to assess the applicability of electromagnetic and seismic technology to the prediction of orebody geometry ahead of mining. The following discussion focuses on results of the first and second years of the *electromagnetic* project.

WHY BOREHOLE RADAR?

One of the initial outcomes of the research initiative was the identification of Borehole Radar (BHR) as the most immediately applicable electromagnetic technique based on the numerous advantages it offers over standard GPR or radiowave tomography in the DEEPMINE environment. If strategically sited, boreholes provide improved access to the target in a relatively "clean" environment away from the interference of metallic support structures and mining induced fracture zone that envelops tunnels at depths in excess of ± 1.5km. Furthermore, in reflection mode, BHR provides improved resolution (sub-metre) over radiowave tomography in the electrically resistive South African gold environment. (Typical resistivities of the host quartzites are in excess of 1000 ohmmeters).

Another important consideration is that borehole core examination, by itself, does not allow for the unequivocal identification of faults and their displacement. Borehole Radar can be used to determine the location (and frequently the associated throw) of a fault and this information can be extrapolated to the reef horizon, where the range of the existing borehole radar system (# 85 m) is insufficient to image the reef directly.

As a proof of concept exercise, BHR surveys were recently conducted in two mines within the Witwatersrand Gold Basin under the auspices of DEEPMINE. In both instances, a system developed by Geosonde of Australia was utilized. This system was introduced to South Africa through a collaborative agreement between the Corporate Research Centre for Mining Technology and Equipment (CMTE), Sydney University and Miningtek in South Africa.

INITIAL DEEPMINE BOREHOLE RADAR RESULTS

The first survey successfully imaged the VCR as illustrated in the raw data, which is exceptionally "clean" with little evidence of ringing (Figures 2 and 3). The velocity of EM propagation is ± 125m/µs allowing for a maximum probing range of ± 45 m away from the borehole (Figure 3).

The range performance of any geophysical technique is highly site specific, as demonstrated by the results of the second survey undertaken in a relatively more conductive environment in the Free State (Figure 4). In this case, the target was a gold-bearing conglomerate, known as the Basal Reef, which is hosted in a pebbly, siliceous quartzite

The radar image of the Basal Reef intersects the time axis at a maximum value of 0.26µs, which is equivalent to a depth of ± 16m (given a velocity of 125 m/µs). The reef can be tracked continuously as it moves towards the borehole until 0.17µs (10.6m), where it is disrupted.

IMPROVED RANGE PERFORMANCE

Subsequent to the aforementioned surveys, significant improvements were made to the system hardware in an attempt to improve overall performance. To satisfy industry needs, borehole radar equipment must withstand an environment where virgin rock temperatures approximate 60°C and the humidity approaches 100%. The modified system was then utilized to survey the first 200 m of a long inclined borehole (LIB) (Figure 5), the collar of which is located at a depth of 3.3 km below datum[1].

LIB boreholes are used to probe totally undeveloped blocks of ground and, being semi-parallel to reef, are ideal for the application of Borehole Radar. By applying Borehole Radar from LIB holes, information can be provided before crosscuts are developed, possibly saving on such development if an early decision is taken not to mine an area. The surveyed hole was ± 1.9km in length and deviated substantially to intersect the target reef; viz. Ventersdorp Contact Reef (VCR), twice. It was drilled at 45º downwards into the hangingwall of the VCR and intersected the Reef at about 305 m downhole.

The results of the initial survey in this hole are illustrated in Figure 6. The VCR reflection can be tracked continuously from Trace 120 to Trace 380, where the system cable reached its maximum length. The effective maximum probing range is given by:

where: c is the speed of light 3 X 10^8 m/s
t is the two-way travel time of the event
ε is the dielectric constant.

Given that the intersection of the VCR at Trace 120 with the y-axis occurs at a two-way travel time of 1.62 µs and

$$d = \frac{ct}{2\sqrt{\varepsilon}}$$

that the average dielectric constant for the host quartzites is 6.5, then the maximum probing range is ± 95 m. With the exception of slight (<1 m amplitude) rolling (Figure 6), the reef is very continuous over the imaged distance. Correlation with the borehole core, indicate that the inverted "V-shape" reflections that intersect the borehole at Traces 80 and 110 correspond to intrusives / dykes.

The substantial increase in probing range with the modified Geosonde system is sufficient to allow for the strategic planning of development tunnels, at least six months ahead of mining.

CONCLUSIONS

The initial results confirm that the VCR is a good radar (10 - 100 MHz) target and can be probed at ranges up to ± 85 m. These highly encouraging results have provided the impetus for continued development and application of the technique in the DEEPMINE environment. Current efforts are focused on acquiring numerous 2D cross-sectional images from a "fan" of boreholes to build a pseudo-3D image of the interior of a mining block.

REFERENCES

Roberts, M. and Schweitzer, J.; 1999. *Geotechnical areas associated with the Ventersdorp Contact Reef, Witwatersrand Basin, South Africa.* The Journal of the South African Institute of Mining and Metallurgy, May/June.

ACKOWLEDGEMENTS

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Anglogold are also thanked for the provision of test sites and for their logistical support.

[1] For the Witwatersrand Basin Gold Mines, the datum is ± 1829 m above sea level.

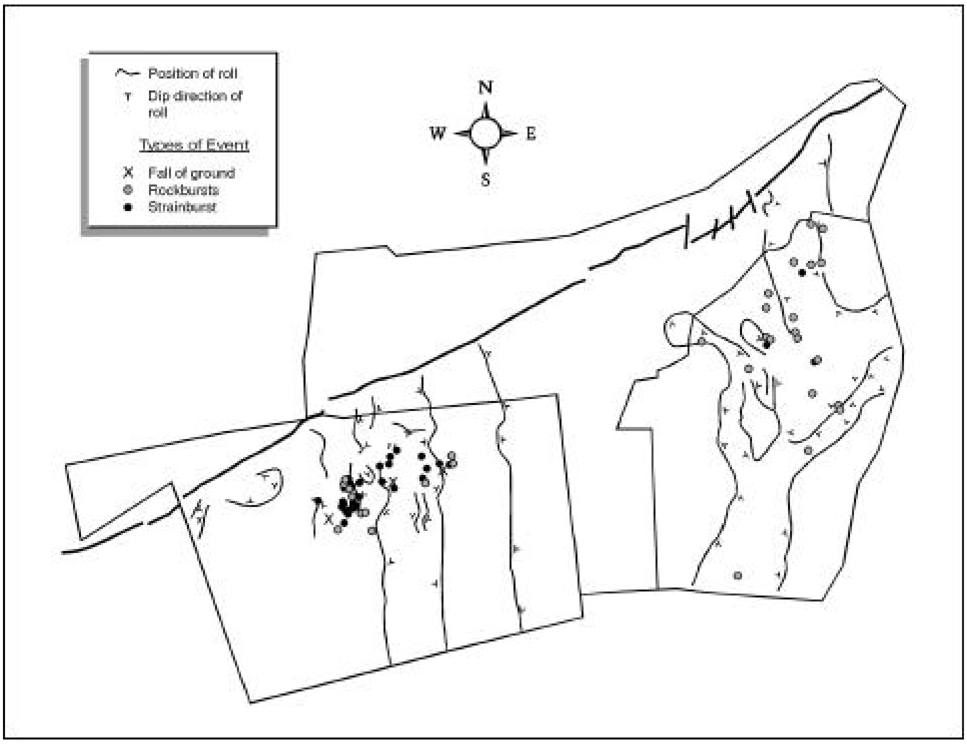

Figure 1: The occurrence of rolls at Western Deep Levels and Driefontein Gold Mines related to the occurrence of fatalities for the 1991 to 1995 period (modified after Roberts & Schweitzer, 1999).

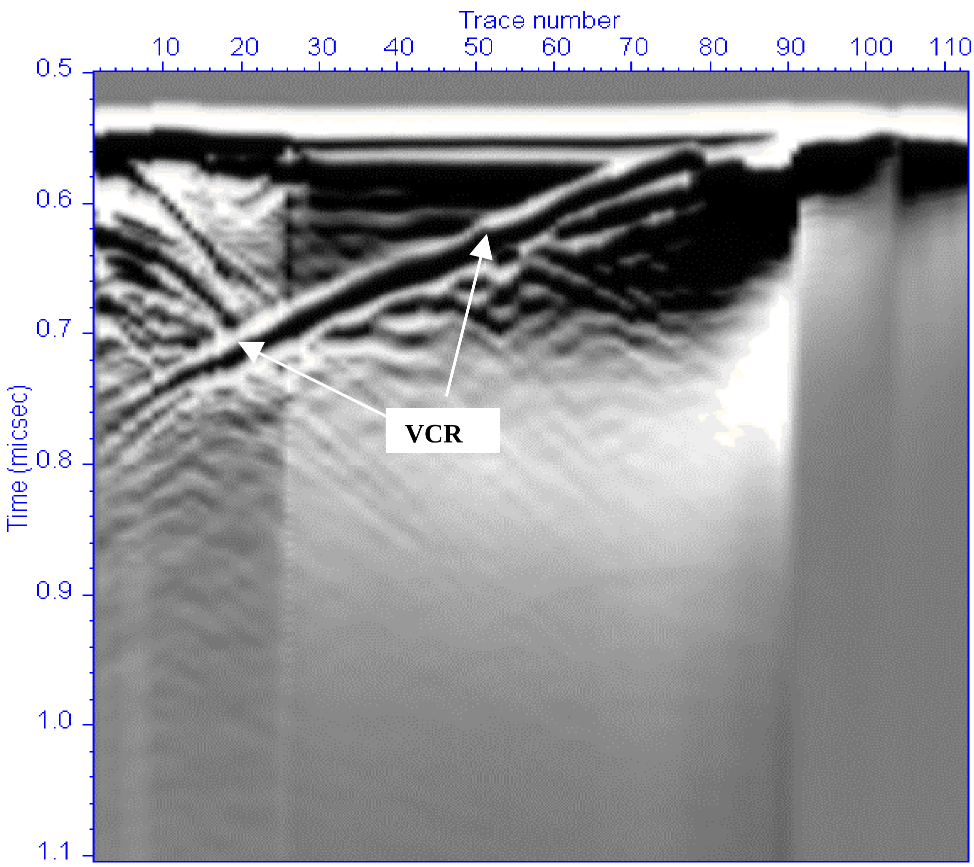

Figure 2: Pre-processed Borehole Radar data acquired from a borehole sited to intersect the VCR. (Figure 3 illlustrates the corresponding mine plan).

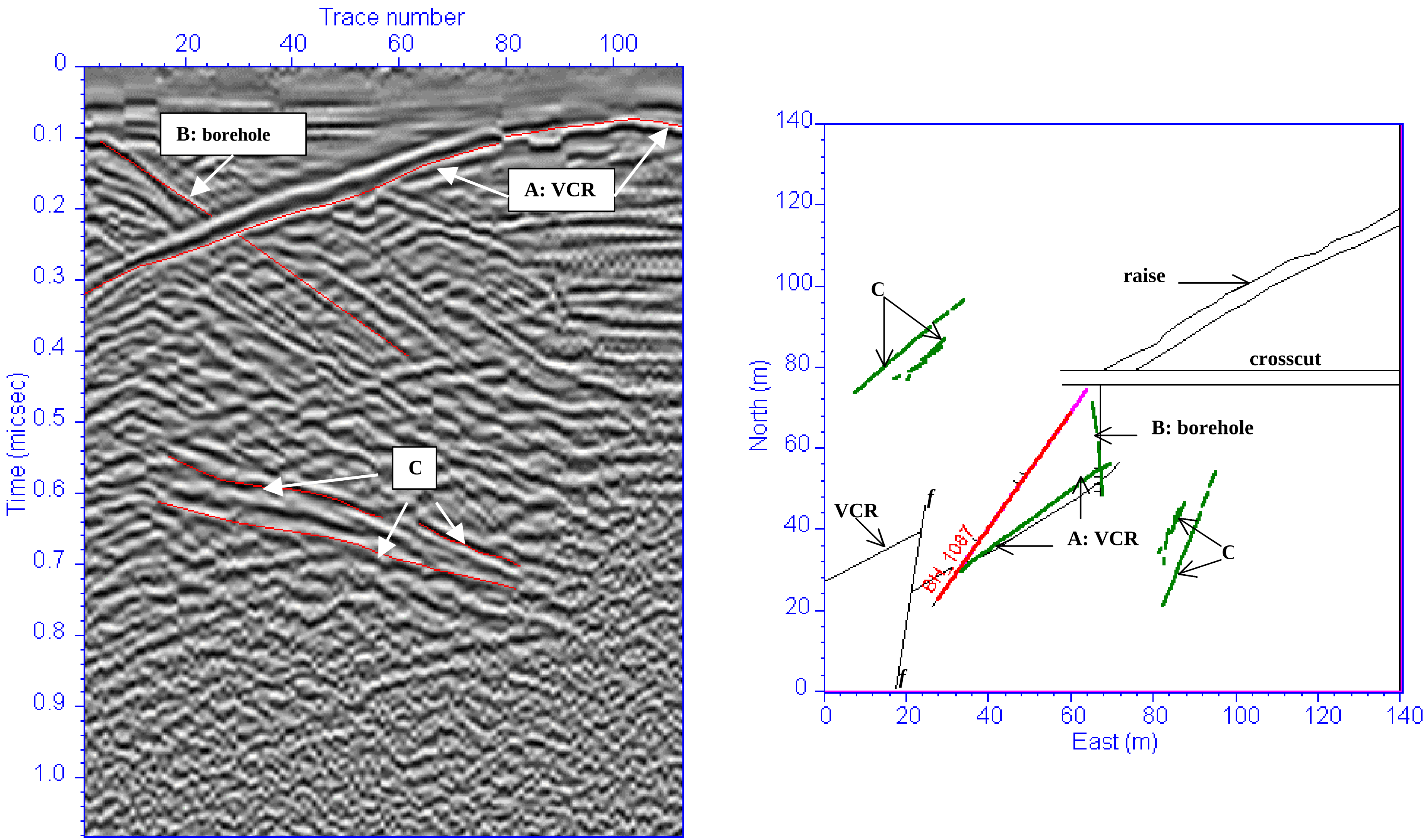

Figure 3: Processed radargram of data acquired from Borehole 1087 and the corresponding basemap showing the position of the VCR as derived from geological logs and interpreted on the radargram.

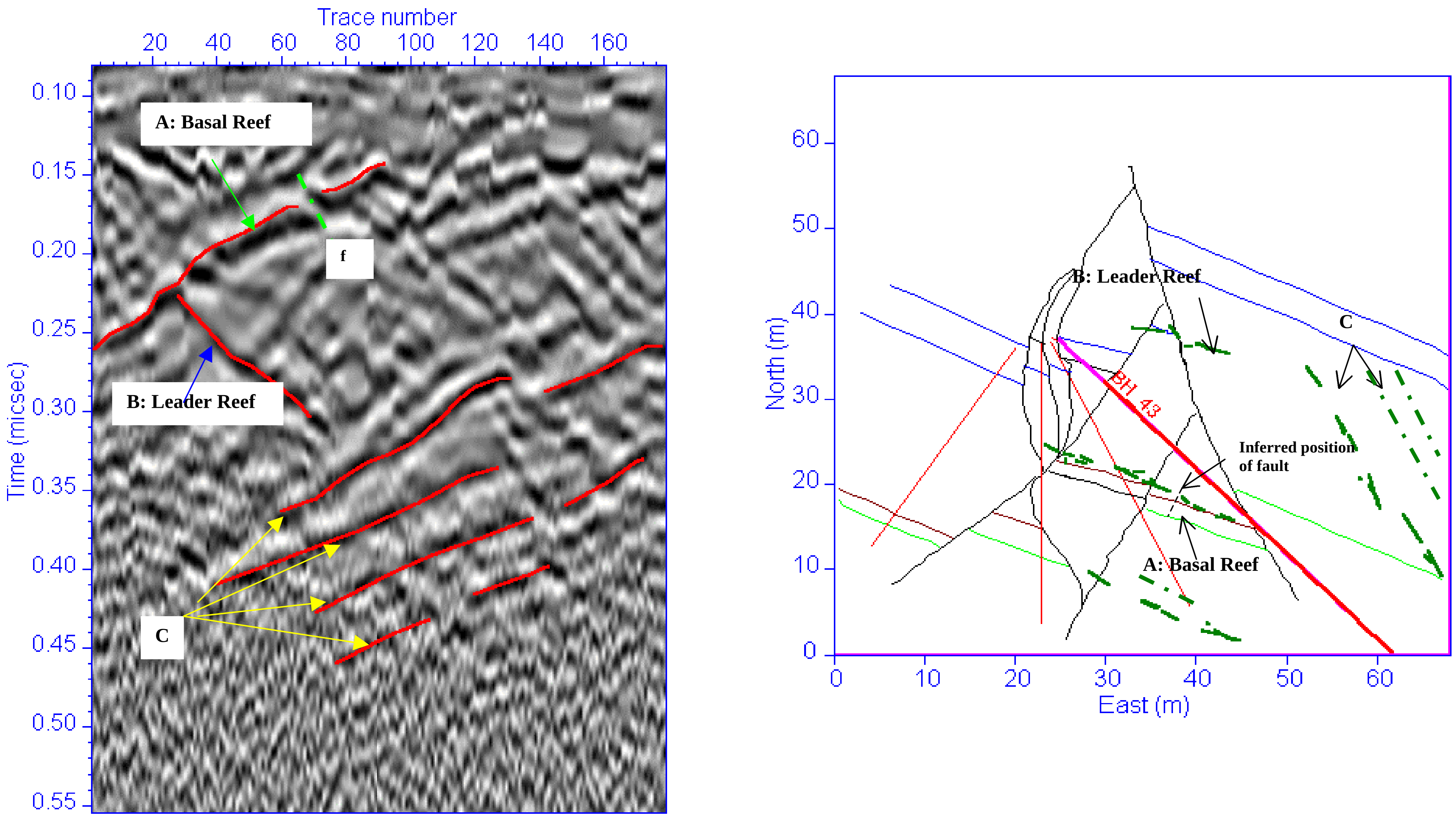

Figure 4: Results of a survey conducted in Borehole 43.
The primary reflections are interpreted on the radargram and their corresponding pos itions are plotted on the basemap.

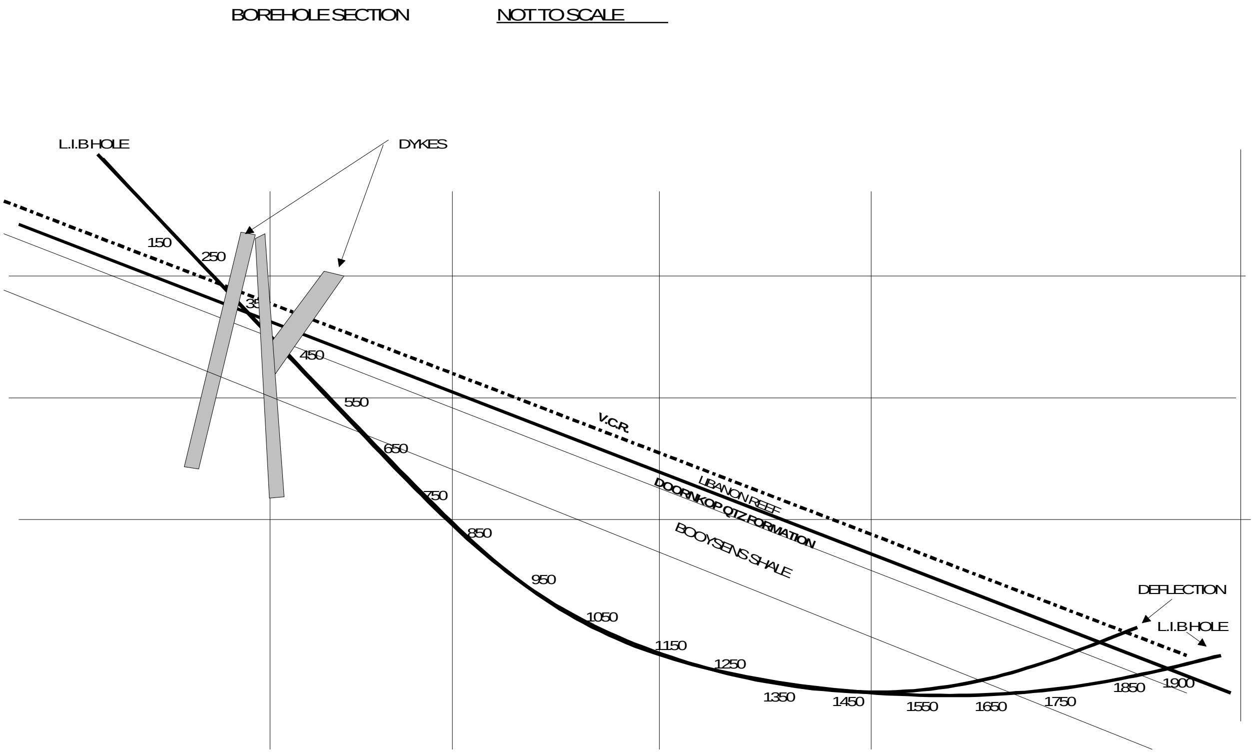

Figure 5: Cross-section of a long-inclined borehole (LIB) drilled to intersect the VCR twice.

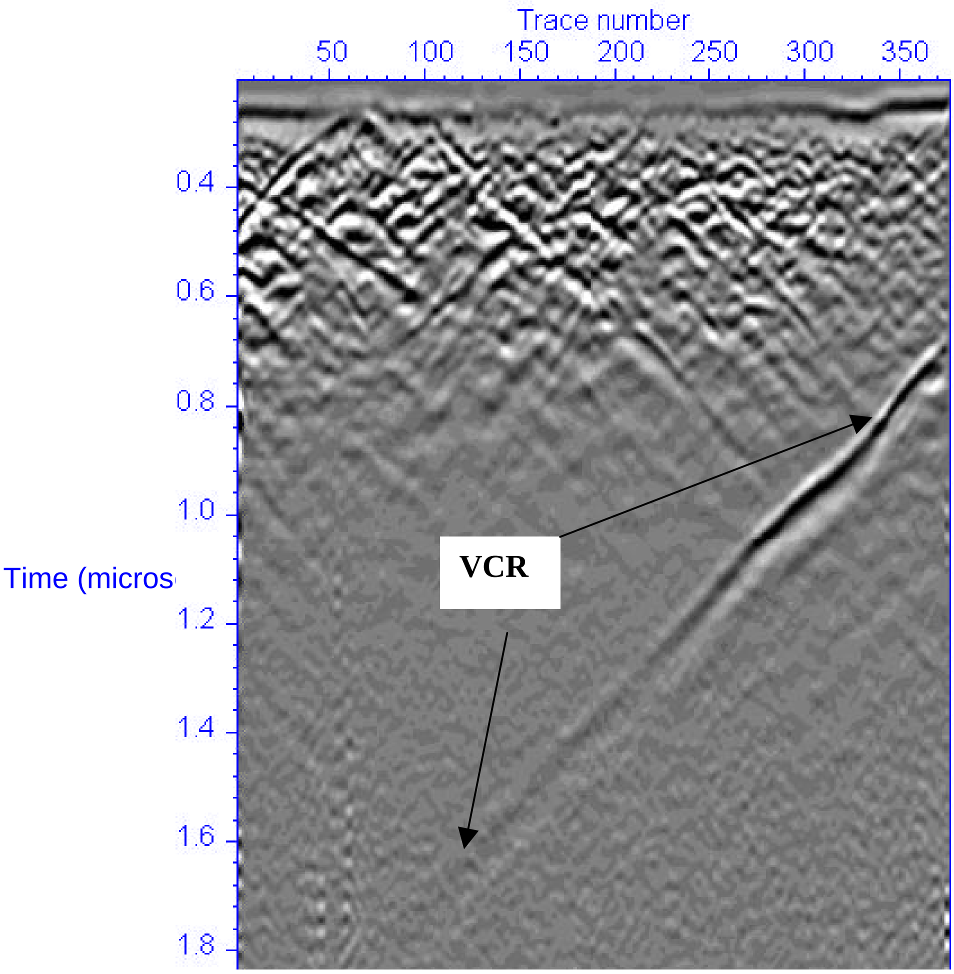

Figure 6: Results of a survey conducted in the LIB hole depicted in Figure 5. The VCR is tracked continuously from Trace 120 through to Trace 380 (Circa 95m).