ROUTINE APPLICATION OF RADAR IN UNDERGROUND MINING APPLICATIONS

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ABSTRACT

R & D into in-mine geophysics was initiated by the South African mining industry in the 1980's when a need was identified for techniques to routinely delineate geological structures from underground excavations. Since then ground penetrating radar (GPR) has been established as a routine tool in underground mining in South Africa for geological structure delineation and roof integrity studies. Routine underground application of GPR requires reliable ruggedized instrumentation and innovative survey methodologies. To this end the RockRadar system was developed, which provides excellent data quality in the harsh confined conditions encountered underground. The system allows for rapid data acquisition and in-mine data processing and interpretation. GPR is best used as a complementary tool to in-mine exploration drilling, enabling more complete characterization of sites. GPR is seldom used as a "blind" technique where little information is available about the geology ahead of mining. This strategy has enabled the successful routine underground use of radar while other in-mine techniques such as radio tomography and in-mine seismics have as yet developed limited routine implementation. Applications in metamorphic, igneous and sedimentary environments have been developed. These include ore-body delineation, mapping of faults and intrusives, and delineation of roof discontinuities. In this paper, data will be presented from the gold mines (delineation of ore-body and faulting), platinum mines (delineation of roof discontinuities and ore-body disruptions), and base-metal mines (delineation of roof discontinuities).

INTRODUCTION

The rapid development of electromagnetic techniques since the 1970's, and specifically ground penetrating radar, for the first time offered a real possibility for the development of a routine underground geophysical imaging tool. Due to practical mining considerations, such a tool must be able to rapidly image a target area with minimal disruption to mining operations. It must also be sufficiently ruggedized to be operational in the harsh conditions encountered in underground mining operations. GPR offers rapid imaging capabilities and a choice of operating frequencies, resolution and penetration. These considerations led to the development of the RockRadar ground penetrating radar system. The RockRadar is a mineworthly radar system and is sufficiently ruggedized and portable to be accepted as a routine geophysical tool by the mining industry.

In this paper, the routine application of the RockRadar in gold, platinum and base-metal mining in South Africa is discussed and case studies are presented. The following applications are discussed:

- Delineation of faults and ore-bodies in gold mining.
- Delineation of potholes and bedding plane separations in platinum mining.
- Delineation of domes in chrome mining.

THE ROCKRADAR GROUND PENETRATING RADAR SYSTEM

Ground penetrating radar (GPR) was the first geophysical technique to be thoroughly tested in underground applications in the Witwatersrand Gold Mines in South Africa. Apart from a few ad-hoc trials in the mid 1980's, proper trials began in 1989 with the importation of a SIR-8 system (Geophysical Survey Systems Inc.). Trials with the SIR-8 showed promise, and programs were initiated to develop a mineworthy GPR system.

The RockRadar ground penetrating radar system was developed by ISS International Ltd and ISS Geophysics (Pty) Ltd, South Africa. Underground mining in South Africa, especially within the ultra-deep gold mines, is characterized by extremely harsh conditions. These include:

- Depths below surface of up to 4000 m (with plans to go to 5000 m), resulting in long traveling times to and from sites.
- Temperatures in the range 30-36 ºC, coupled with 100% condensing humidity, which limits the amount of time-on-site available to the operator.
- Narrow ore-body mining, with reef-to-floor separations of 1.0 -1.2 m, requiring highly portable (small) equipment.

Various prototypes were developed in an interactive development cycle through an extensive underground testing program in two of the major gold mining complexes in South Africa. Logistical and technological issues were identified in typical working environments and could thus be effectively addressed and solved.

The RockRadar is a truly robust and mineworthy impulse GPR system which performs equally well underground and on surface [White 1997]. Three shielded 60,175 and 400 MHz centre frequency antennas are currently available. True 16-bit analog-to-digital conversion is performed in the antennas. Communication between the antennas and the datalogger is achieved through heavy duty fibre-optical cables, minimizing coherent system noise to a large extent. Customized Windows NT data acquisition and processing software are used to acquire and process data.

UNDERGROUND APPLICATIONS OF GPR

Large-scale trials of the feasibility of utilizing the RockRadar in routine applications for the delineation of geological structures were conducted at Western Deep Levels (now Anglogold West Wits Operations) East and South Mines and at Vaal Reefs (now Anglogold Vaal River Operations). These trials took place in 1996 and 1997. Applications were also simultaneously developed in other underground mining environments such as chrome and platinum (The Bushveld Igneous Complex) and coal mines within the Karoo Sediments.

Two main classes of applications can be regarded as routine. These are:

- Geological mapping, which includes applications such as the delineation of ore-bodies, faulting and intrusive bodies such as dykes.
- Mapping of roof discontinuities. Roof discontinuities are a major cause of falls-of-ground (FOG) in South African mines. GPR is routinely used to map roof discontinuities and to assist in the identification of potential hazardous areas.

The routine application of GPR in underground mines in South Africa was achieved by addressing the following key issues:

1. Development of a robust and mineworthy ground penetrating radar system.
2. Introduction of GPR as a complementary and not a “solve-all-problems” tool.
3. Real-time data processing.
4. Data interpretation by the site expert and not the geophysicist.

The first step, as discussed previously, was the development of a truly mineworthly ground penetrating radar system (the RockRadar) which was developed in close conjunction with the mining industry.

The second key part of the strategy was to present GPR as a complementary tool to mining geologists and rock engineers, rather than a tool which will replace existing information tools such as exploration drilling and mapping. As with all geophysical techniques, GPR is best used to complement existing tools and cannot substitute these methods.

A key contributing fact to the success of GPR has been the implementation of data processing at the survey site during, or immediately after the survey. The RockRadar system allows for real-time processing. This allows for the immediate underground mapping of features by geologists and/or rock engineers while still at the survey site. Immediate data processing also allows for the selection of the optimum data acquisition parameters for a specific environment and application.

Data interpretation is often the phase in which the success or failure of a project is determined. It is also often the wrong person who interprets the results and who makes a wrong or incomplete interpretation. Results only achieve large scale acceptance if the interpretation is done by a person who has extensive knowledge of the area of investigation. This person is usually the site geologist or geotechnical engineer and by placing the responsibility of data interpretation in the hands of this person, the probability of the project being successful can be drastically increased.

CASE STUDIES

Gold Mining

Gold mining has played a major role in the economic development of the domestic economy of South Africa, currently contributing approximately 30% of foreign exchange earnings.

South Africa's thin but extensive tabular gold placer deposits often lie several kilometers beneath the earth's surface, dipping at up to 45 degrees. Gold is mostly mined in an area which is called the Witwatersrand Basin. This Basin lies inland, approximately 500 km from the coast, between 26º30' and 29º15'E, and 26º00' and 28º15'S. Surface elevations range from 1340 - 1820 m above sea level. Most of the conglomerates containing economic quantities of gold occur in the Upper Witwatersrand. Extensive major faulting has taken place along the strike of the beds, which have furthermore been displaced by numerous minor strikes and traverse-faults. Many of the faults are occupied by (usually) basic dykes [Coetzee 1976].

The RockRadar is used in the following applications in gold mining:
1. Delineation of reef.
2. Delineation of faulting.
3. Delineation of roof discontinuities.

Two examples are presented to illustrate the above applications. The delineation of faulting and reef (Tau Lekoa Mine - Vaal River Operations, Anglogold, Orkney) and the delineation of faulting (West Wits Operations, Anglogold, Carletonville) are presented.

CASE STUDY 1: DELINEATION OF A FAULT AND A BLOCK OF VENTERSDORP CONTACT REEF (VCR)

The Ventersdorp Contact Reef (VCR) is mined at Tau Lekoa Mine which is situated in Orkney in South Africa. The dip of the VCR is approximately 30 degrees. Typically, the VCR consists of a bed of conglomerate varying from a pebbly grid to a massive conglomerate, sometimes more than 3 m in thickness, comprising pebbles, cobbles and boulders (sometimes up to 40 cm in diameter). “Buckshot” pyrite is the common form of mineralization. The VCR lies on a bed of interleaved quartzites, and is overlain by the Ventersdorp lava, often having a pillow structure. In this case study a GPR survey was conducted in the floor of a raise development to delineate a block of VCR which had been displaced by a normal fault. The data was acquired with a 175 MHz antenna pair, using fixed station spacing of 0.5 meters. A mine cross-section and the data is shown in Figure 1. The radargram clearly shows the VCR position as well as the fault. Using GPR the termination point of the reef could be determined, as well as the dip of the fault plane.

CASE STUDY 2: DELINEATION OF FAULTING AHEAD OF MINING

This particular profile was acquired at Anglogold West Wits Operations (previously known as Western Deep Levels). Stoping is carried out on the Carbon Leader Reef which occurs within the Central Rand Group of the Witwatersrand Supergroup. The Carbon Leader is a thin seam of carbon-rich quartzite containing much pyrite and pyrrhotite, overlain by a pebble band between 5-30 cm thick. The pebble band in turn is overlain by a compact olive-green shaly quartzite (the Green Bar) [Coetzee 1976]. Both Gold and Uranium are extracted from the Carbon Leader. Frequent faulting, volcanic intrusions (sills and dykes), quartz veining, jointing and phyllonites (micro planes of movement) occur above, within and below the reef. The reef dips at approximately 22 degrees from north to south and has a regional strike of 76 degrees.

A radar survey was conducted in Panel 102E2 to delineate any possible faults ahead of mining. Data was acquired with a 175 MHz antenna pair, using fixed station spacing of 30 cm. The data and a mine cross-section are shown in Figure 2. A major reflection can be observed between 8 and 14 meters depth towards the end of the profile.

Subsequent mining confirmed this reflection to be a 1 m upthrow fault. In addition to this major interface, a number of minor interfaces can also be observed, corresponding to smaller faulting and jointing [Hofmann 1997].

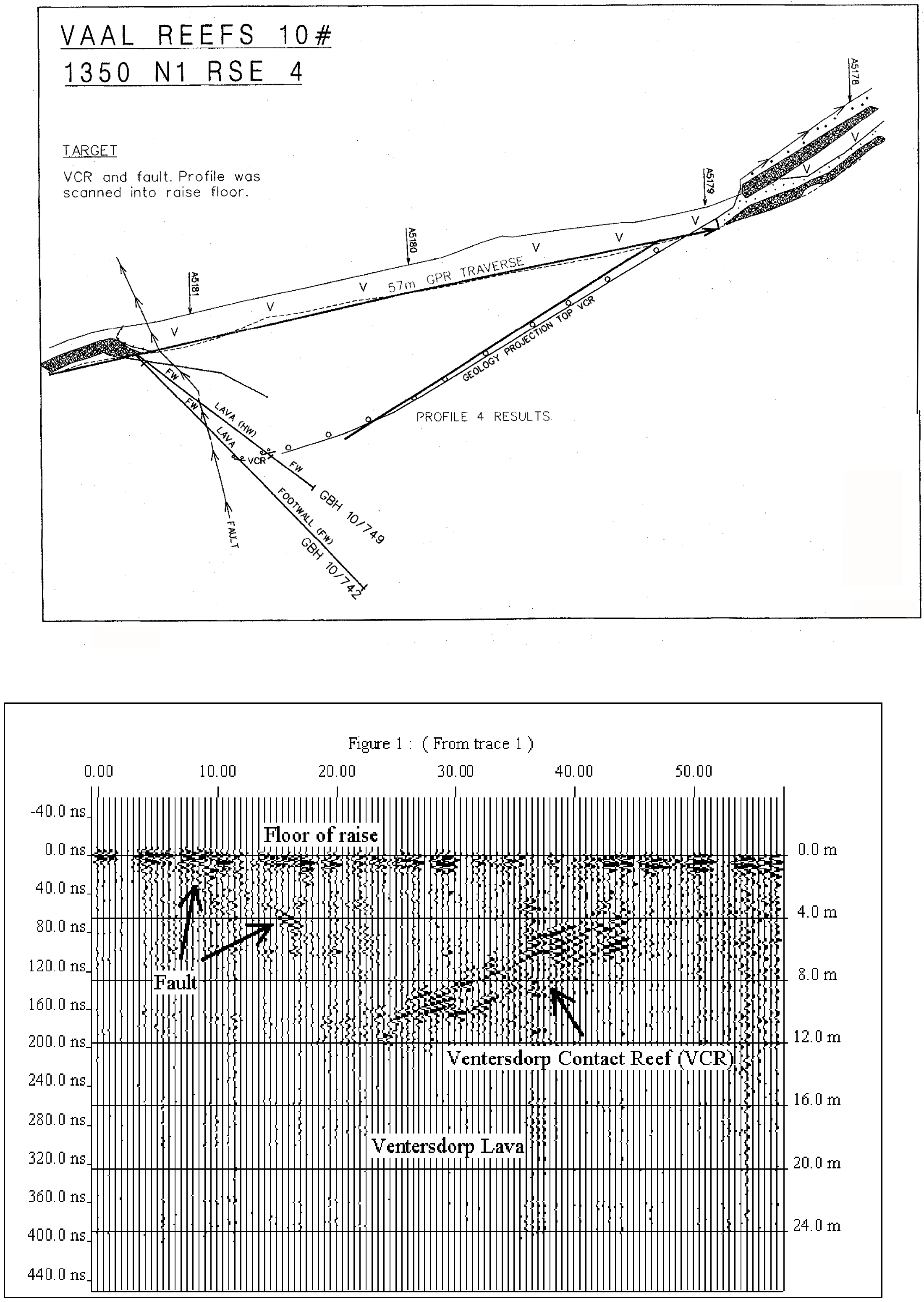

Figure 1. Mine cross-section and GPR results for delineation of a fault and a block of Ventersdorp Contact Reef (Vaal River Operations).

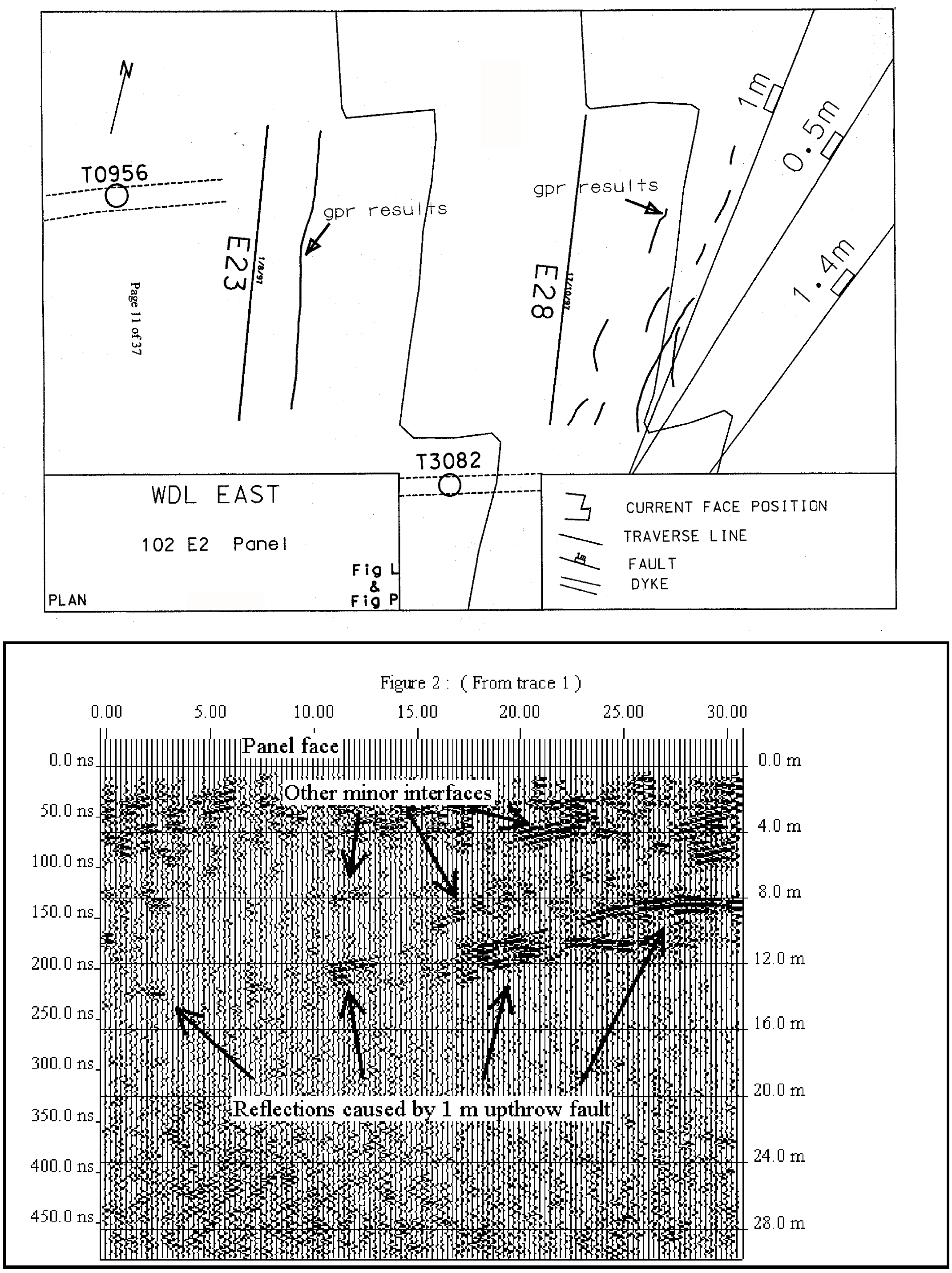

Figure 2. Mine cross-section and GPR results for delineation of faults ahead of mining (West Wits Operations).

Platinum and Chrome Mining

The Bushveld Igneous Complex (BIC), situated in the Northen Province in South Africa, contains the world's largest known deposits of platinum group metals (PGM). The BIC extends for more than 400 kilometers and contains three PGM-bearing reefs. The Merenksy Reef is currently the source of most of South Africa's PGMs. PGMs are also found in the UG2 reef which is also rich in chromitite. The BIC also contains the worlds' largest known reserves of chromitite.

Platinum occurs as a thin, tabular reef covering an extensive area. The Merensky Reef package (comprising the Merensky pyroxenite, chromitite and pegmatoid) is characterized by the occurrence of potholes. A cross section through a typical pothole is shown in Figure 3. Chrome occurs in chromitite layers which are grouped in a lower, middle and upper series commonly known as the LG, MG and UG series. The dip of these layers is approximately 13 degrees.

Typical applications for GPR in platinum and chrome mining include:

1. Characterization of hanging wall geology (delineation of the Merensky Reef and disseminated layer in the hangingwall).
2. Delineation of pothole structures ahead of mining.
3. Roof integrity studies including the delineation of curved joints in the roof and bedding plane separations.

Curved joints, also commonly known as domes, are a major cause of FOG in chrome mines. A dome is a roof structure with a dip of normally less than 45 degrees. In chrome mining the interaction of domes with vertical joint sets causes weak roof areas which can lead to a FOG. The disseminated layer, which is also found in some chrome mining areas, is another shallow roof feature which can lead to FOG's. The introduction of GPR in chrome mining allows for the rapid delineation of the spatial extent of dome structures, allowing a more complete characterization of roof areas. The size of domes can be determined and pillars can be placed appropriately to prevent FOGs.

Platinum data examples are presented from Impala Platinum mine and Lebowa Platinum Mine (Amplats). The chrome mining examples was acquired in Western Chrome (Samancor).

CASE STUDY 3: DELINEATION OF POTHOLES AT LEBOWA PLATINUM

The occurrence of potholes at Lebowa Platinum is such that there is an 80 percent chance that a mining block will intersect a pothole. Before GPR was used, mapping of potholes were limited to expensive exploration drilling and the mapping of pothole intersections in pre-mining excavations. The RockRadar is now used as a routine tool to delineate potholes ahead of mining. A typical profile is shown in Figure 4. The data was acquired with fixed station positions of 10 centimetres. Twenty-five metres of profiling are presented. Data were acquired with 60 MHz centre frequency antennas. A clear footwall and hangingwall contact of the pothole intersection with the reef can be observed in the data.

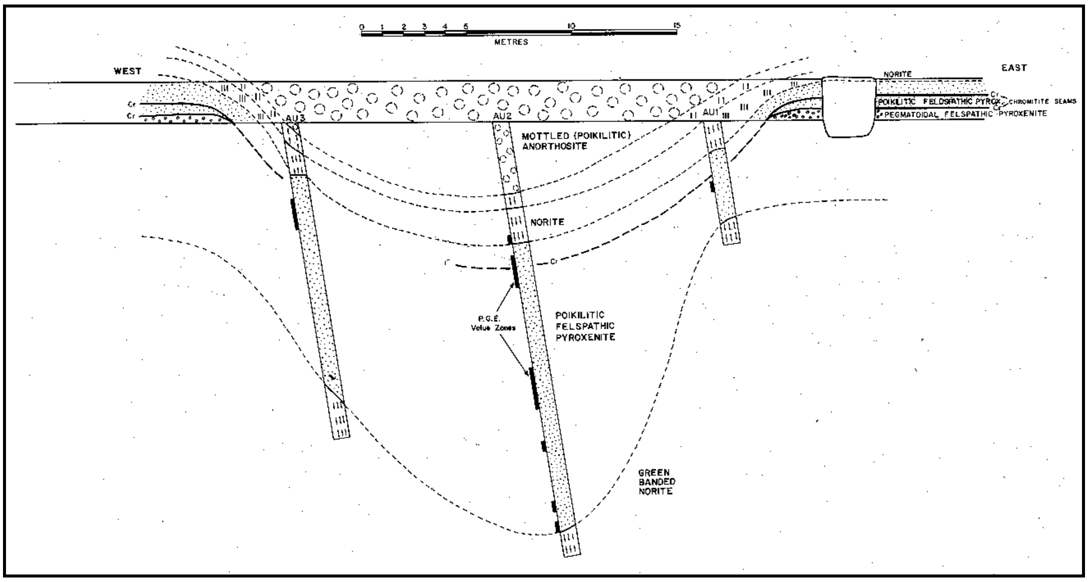

Figure 3. Cross section through typical pothole in platinum mining.

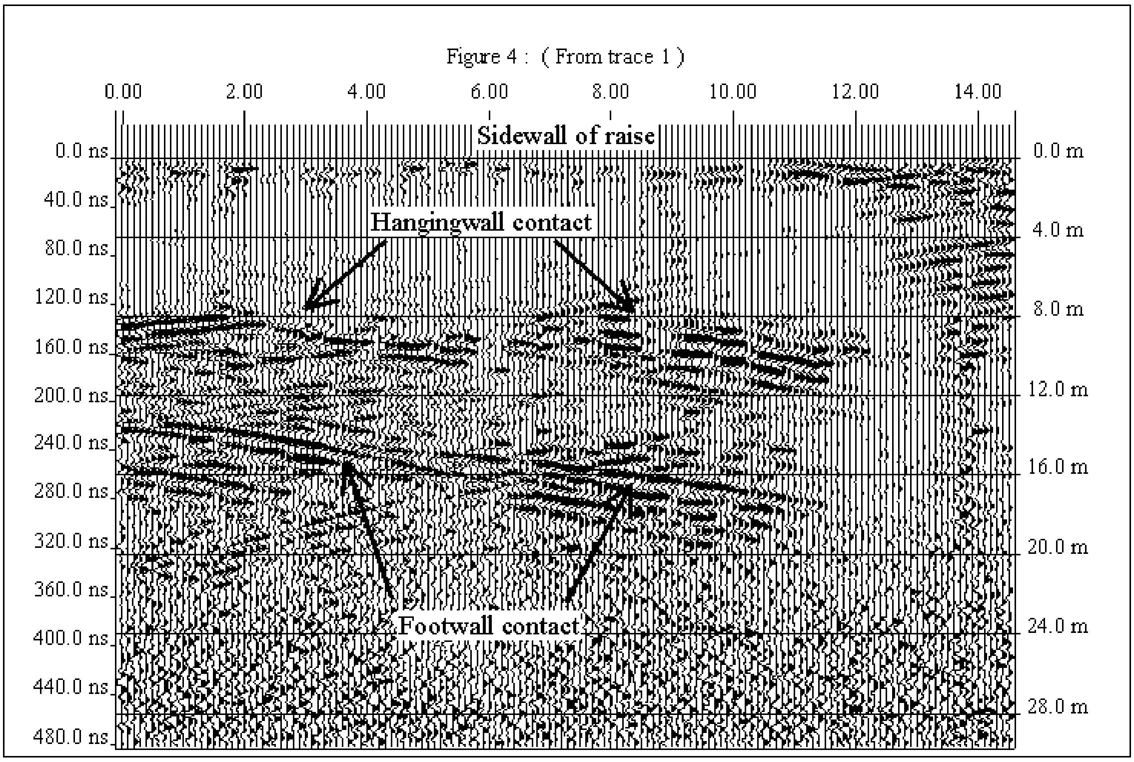

Figure 4. Delineation of potholes (Lebowa Platinum Mine).

CASE STUDY 4: DELINEATION OF ROOF BEDDING PLANE SEPARATION AT IMPALA PLATINUM

In Figure 5 an example of data collected at Impala Platinum is presented. The RockRadar 175 MHz system was used in continuous mode of profiling. A profile length of 22 metres is shown with marks at every 2-metre chainage. The contact of the Bastard Reef can be observed at a distance of 12 metres into the roof. The position of a Bastard reef/pothole separation can be observed as indicated. In addition to these major features, a number of minor bedding plane separations can also be observed.

CASE STUDY 5: DELINEATION OF DOMES AT WESTERN CHROME

An example of the delineation of a dome is shown in Figure 6. The data was acquired in the roof of a panel where the roof intersection of the dome was clearly visible. A clear reflection can be observed which corresponds to the contact of the dome plane.

CONCLUSIONS

The routine underground use of GPR has been demonstrated in the gold, platinum, and base-metal mining industries. Routine applications have been developed in the gold, platinum and base-metal mining industries while applications in other mining industries are continuously being investigated. The routine application of GPR in the underground mining was achieved through the development of the RockRadar ground penetrating radar system and the implementation of a strategy to overcome typical barriers against the routine implementation of GPR.

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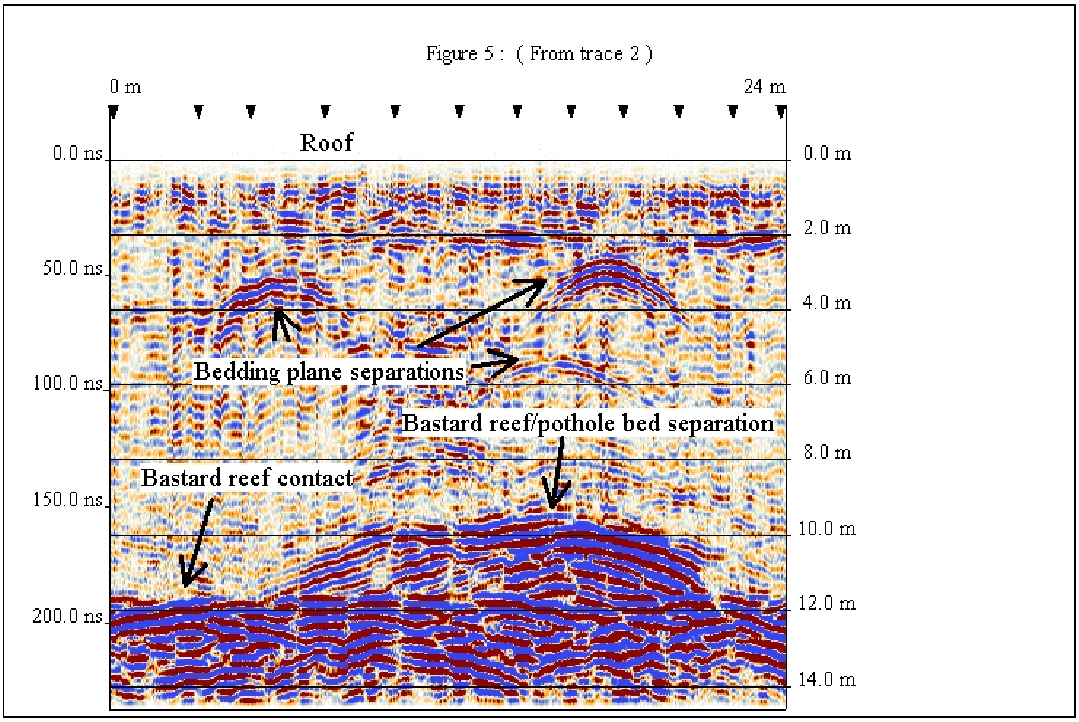

Figure 5. Delineation of bedding plane separations (Impala Platinum).

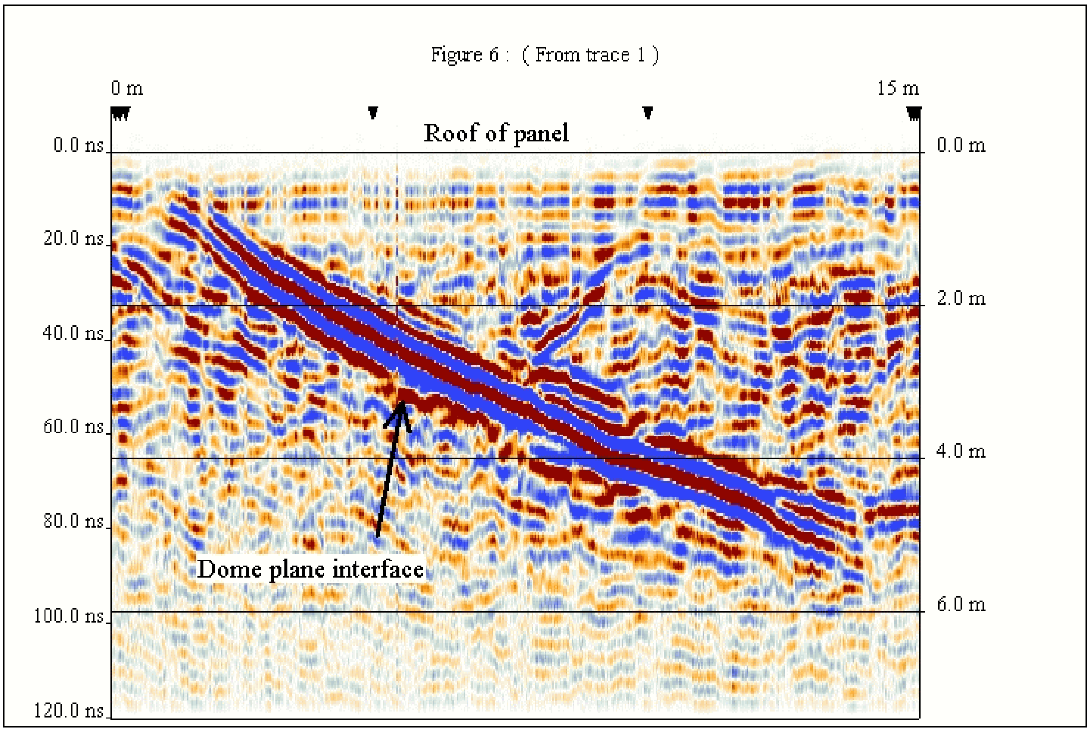

Figure 6. Delineation of dome in roof (Western Chrome).