

# **The Use of Ground Penetrating Radar (GPR) to Delineate Adverse Geological Structures at Samancor – Western Chrome Mines**

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## **SYNOPSIS**

At Western Chrome Mines (WCM), the gravity-induced fall of ground hazard is mainly due to the interaction of adverse geological structures such as joints and dome like structures. Although the majority of the falls of ground at WCM are less than 1,5 m in height, large, infrequent, falls of ground, having a high risk for damage or injury, can occur. Some falls of ground extending up to 14 m into the hanging wall, having a mass in excess of 1 000 tones have been experienced in the past. Although the dome like structures can usually be identified when they daylight into the mining excavation, the size, orientation, and extent of the potentially unstable block into the hanging wall, cannot be determined by the mining personnel. However, through the use of Ground Penetrating Radar (GPR), these unstable key blocks of ground can be proactively located and delineated, thereby either, enabling the timeously support of these major structures, barricading off of the affected area, or the abandonment of the stope panel, by the mining personnel. This paper details the use of GPR as a tool for the proactive recognition and prevention of major dome induced falls of ground.

## **INTRODUCTION**

Western Chrome Mines (WCM) is located in the Western portion of the Bushveld Complex and is situated between Brits and Rustenburg approximately 120 km north west of Johannesburg. Chromium ore is produced from the Lower Group (LG) and the Middle Group (MG) chromitite layers.

Mechanised mining operations take place at a current depth of 300 m below surface on the LG 6 and LG 6A composite seam, having a combined seam width of 1,7 m, at the Millsell Section. Using a bord-and-pillar configuration, having a maximum bord width of 14 m, with either strike or dip support pillars, having dimensions of 15 m x 6 m, with 6 m ventilation holings between pillars.

Conventional mining operations, using either a breast or updip mining configuration takes place at the Elandsdrift and Mooinooi Sections, on the MG 1 seam having a seam width of 1,3 m. Stope panels have a maximum span of 30 m and utilize support pillars having dimensions of 15 m x 5 m, with 2 m wide ventilation holings between pillars. A relatively small amount of mining has previously been mined, but is planned to continue in the future, on the MG2 composite seam, which has a combined stope width of 2,7 m.

While opencast operations are in progress at the Elandskraal Section, where the MG1, MG2A & MG2B, as well as the MG3 seams are mined to a maximum high-wall height of 30 m.

## **GEOLOGICAL SETTING**

### **Chromitite Seams**

The Western Bushveld Complex is sub-divided into five zones, namely the Upper, Main, Critical, Lower and Marginal Zones. The chromitite seams are confined to the Critical Zone and are grouped from the bottom upwards into the Lower (LG), Middle (MG) and Upper Groups (UG). The LG contains seven, the MG four and the UG two, chromitite layers in the Western Bushveld Complex.

All the layers of the Lower Group (LG) occur within pyroxenites of the lower Critical Zone. The Middle Group (MG) layers occur at the transition from the lower to the upper Critical Zone. The MG chromitite seams are either hosted by pyroxenites or by plagioclase-rich norites and anorthosites.

### **Lower Group Seams**

The LG6 & LG6A are the most important Lower Group chromitite seams, mined at present, having a combined average thickness of 1.65 m and an average dip of 9°. An internal pyroxenite waste parting, having an average thickness of 0.5 m separates the two seams. Contacts of the chromitite layers range from gradational to sharp. The LG6A is slightly poikilitic in parts and is fine grained. The LG6 consists of fine-grained massive ore, which has layers disseminated and poikilitic chromitite.

### **Middle Group Seams**

The MG 1 is a fine-grained, moderately packed, poikilitic chromitite unit ranging in thickness from 1.2 to 1.5 m. Both top and basal contacts are sheared in places, while the basal contact is sometimes highly sheared. The Middle Group seams dip 13° on average.

The MG 2 seam consists of three chromitite layers, namely, MG 2A, MG 2B and MG 2C, which is hosted in pyroxenite and is situated on average 12 m above the MG 1 seam. The chromitite of the MG 2 is fine-grained, moderate to well packed with sharp top and basal contacts. The total internal pyroxenite width between the various MG 2 layers varies between 0.4 and 2.4 m up to a 300 m depth below surface

The MG 1 seam has a higher chrome content and a high chrome to iron ratio than the MG 2 seam, which is why historically most of the mining operations have occurred on the MG 1 seam.

The MG 3 seam is situated 5 m on average above the MG 2 seam, while the MG 4 seam is situated 15 m on average above the MG 3 seam. Both the MG 3 and the MG 4 seams are not economically viable in the underground mining operations at present, due to low chrome content and low chrome to iron ratios.

## **Upper Group Seams**

The Upper Group (UG) layers occur within the upper Critical Zone below the Merensky Reef and are primary mined for their platinum content.

## **GEOLOGICAL DISCONTINUITIES**

Various types of geological discontinuities are present at WCM, which contribute to the fall of ground hazard, they either influence the hanging wall on their own, or act in conjunction with other geological discontinuities, these are briefly defined as;

### **Joints**

A prominent joint system is developed throughout the underground workings, trending NNW - SSE ( $156^\circ$ ) and E - W ( $96^\circ$ ). The joint set trending at  $156^\circ$  is locally known as the J1 set, (dipping mainly to the West) and the set trending at  $96^\circ$  is locally known as the J2 set (dipping mainly to the south).

This conjugate joint system is sub vertical and the spacing frequency varies throughout the mining area. It may be continuous or discontinuous on strike and dip. The degree of joint roughness can be classified as smooth and separation as tight.

### **Domes**

Low angled compressional structures, known as domes occur in both the MG 1 and MG 2 hanging walls. They range in size and extent and are usually characterized by slickensides, with serpentinitised or talc infilling along their contacts. They can have associated alteration of the hanging wall rock. The major domes usually intersect the chromitite seam with associated displacement in centimeters, the amount of displacement of the chromitite seam usually gives an indication of the size of the dome.

Although the major dome planes can be recognized when the dome plane cuts through the chromitite seam, the height and extent of the dome is an unknown factor. The majority of the dome planes are cohesionless, due to talc or serpentine infilling, the thicker the infilling, the larger the dome. These are the major contribution to the incidences of large falls of ground. Major dome planes are associated with J1 or J2 joint planes, i.e. the dome planes are orientated with their long axis parallel to the major joint plane.

Domes are the major contributor to large falls of ground, due to their size, low cohesionless plane, the interaction between them and major joint planes, and the inability by thee mining personnel to recognize them, when they do not daylight into the excavation.

Four types of dome orientations have been recognized at WCM, these are;

- Domes, which are cut off by major joints planes, and where only half of the dome daylights into the excavation.
- Domes where the complete dome plane daylights into the excavation, usually related to relatively small dome structures.
- “Piggy back” domes which are adjacent to each other and then converge against each other, resulting in a series of dome structures.
- “Stacked” domes, where a series of domes are parallel to each other and do not come together against each other.

### **Potholes**

Are large (10 to 60 m in diameter) “dish-or-pear” shaped slump type structures not usually associated with chromitite loss. Where pothole development occurs, a shear zone can develop along the rims of the potholes contributing to increased joint density and associated poor rockwall conditions.

### **Pegmatoid Intrusions**

Pegmatoid intrusions are either dyke-like structures or massive replacement bodies. Low angled fracture planes are usually associated with the dyke-like structures. Due to the mineralogical composition of pegmatoids, alteration can occur which could affect rockwall stability.

### **Disseminated Layers**

Thin disseminated chromitite bands or layers of chromitite situated in the immediate hanging wall can occur and contribute to thin beam type failures. These are commonly found above the LG6 & LG6A composite chromitite seam, the deeper the mining depth, the higher the disseminated layer is in the hanging wall

### **Shear Zones**

Horizontal shear zones, which vary in thickness, can occur in the footwall in certain areas of the MG 1 seam. When these shear zones are located close to the chromitite seam, the stability of the support pillars could be affected by time dependant yield or punching of the pillars into the footwall rock.

## **FALL OF GROUND HAZARD**

The falls of ground, which occur, on the chromitite horizons are all gravitationally driven and are characterized by the geological structures forming their boundaries. They are usually relatively small in extent and are fairly localized in the individual stope panels.

The majority of the falls of ground occur during the blasting operations, and are located between the stope face and the last line of permanent support. In the past, this distance could be in excess of 6.0 m after the blast, prior to the introduction of rock tendon support.

Large falls of ground, having a low frequency of occurrence, but with a high risk potential for damage, occurred due to the presence of major dome structures, and the insufficient support resistance of the support units.

These collapses occurred because the effect of the orientation of the major geological discontinuities responsible for the delineation of major key blocks were not recognized, since the inclination and extent of these major blocks could not be ascertained during mining operations, as the mining personnel could not “look into” the hanging wall.

### **Types of FOG's at WCM**

Three types of falls of ground are common to Western Chrome Mines, namely;

- Type 1. Block or Wedge shaped, associated with intersection of J1 and J2 joints. Up to 3.5 m in height, having a small arial extent.
- Type 2. Tabular or horizontal in extent, associated with layers, up to 0.9 m in height, having a small or large arial extent.
- Type 3. Dome shaped, associated with domes or intersection of joints and domes, up to 14 m in height, both small to large areal extent

### **Fall of Ground Statistics**

Back analysis of 398 incidents of falls of ground occurrence's, indicated that 96% had a thickness of 1,5 m or less, which are supported by the mines support design methodology.

However, in the past, large falls of ground, which fall within the remaining 4 % of the mines fall of ground statistics, having a low occurrence but a high risk, have occurred, due to the gravitational failure of major dome planes. These key blocks were not recognised at the time of mining, and insufficient support resistance was installed to support these major key blocks.

These collapses occurred because the effect of the orientation of major geological discontinuities responsible for the delineation of major key blocks were not recognised, since the inclination and extent of these major dome induced blocks of ground, could not be ascertained by the mining personnel during mining operations.

In most cases, the presence of the discontinuities were recognised, if they day-lighted into the stope panel, but their size, extent, orientation and interaction into the hanging wall was not realised.

### **Fall of Ground Strategies**

Once the fall of ground hazard was quantified, the following strategies were adopted;

- Systematic hanging wall rock-bolt support was introduced into the conventional mining sections, in addition to the elongate stick support units that were already in use in the conventional mining areas. These were installed at a maximum distance of 0,5 m from the face, prior to the blast.
- Blast on props were introduced to reduce the span between the face and the stick support units, the stick support units had a high blast out rate, due to the relatively high SG of the chrome ore, which was 4,2.
- Ideal panel and pillar configurations, maximum panel spans of 30 m and minimum pillar widths of 5 m were formulated.
- Training in geological hazard recognition was introduced.

However the large Type 3. falls of ground still occurred, due to the interaction between major dome structures and associated major jointing.

### **Case Study - Major Dome Collapse**

During night shift cleaning operations, in a 30 m wide breast panel at the Elandsdrift Section, on the MG1 chromitite horizon, a major collapse in excess of 1 000 tons occurred. At the time of the collapse, the night shift cleaning crew had withdrawn to a safe area, after it was noticed that deformation was occurring on the timber support units.

The fall of ground was bounded on strike by a major J2 strike joint at the top and the bottom of the panel, and a major J1 dip joint in the back area. The top was bounded by a major dome plane, which day-lighted into the panel at the stope face (the dome had been supported at the face, by the intact rock, prior to the previous blast).

The dimensions of the major collapse were approximately 20 m on dip and 25 m on strike having an average height of 1.5 m (maximum height of 3.0 m at the major dip joint position).

No indication of the adverse dome structure could be seen in the back area, prior to the collapse, since the panel had advanced from the strong side of the dome towards the weak side. The hanging wall conditions were considered to be good prior to the collapse, as seen in the back area.

As a consequence of the major dome induced fall of ground incident, it was decided to investigate means of locating and delineating dome structures, which could be present in the stoping horizon, but unseen to the mining personnel. As well as trying to delineate dome structures, which day-lighted into the stoping horizon, since these could be recognized, but their orientation and extent into the hanging wall, could not be determined.

### **GROUND PENETRATING RADAR**

GPR technology had previously been successfully used in a deep gold mining environment to map fracture patterns. It was decided to conduct a trial using a GPR, which was owned and operated by personnel from the CSIR Miningtek. An area known to be influenced by a major dome (a major collapse had already occurred on the one side, while the other side was supported by an in-stope pillar) was chosen. The trial was successful, since the in filling of the dome plane, proved to be a good reflector.

Due to the initial success, personnel from Intergrated Seismic Systems International, Geophysics (Pty) Ltd. (ISSI), conducted a further trial in a working stope using a GPR system which they had developed and which was commercially available at the time. This trial showed that dome structures could be delineated and that their orientation and extent into the hanging wall could be determined, prior to the collapse of the dome structure (ISSI, 1998)

With the positive results from the two trials conducted, it was decided to purchase a GPR from ISSI, for a sum of R 180 000, and to use the GPR in-house, as opposed to using consultants, as a tool for dome location and delineation in the stope environment.

#### **Basic Concepts**

GPR produces a two-dimensional pseudo-cross-section of the sub-surface that is similar in nature to a reflection seismic-section. GPR operates on the principle of the reflection of electromagnetic waves to delineate sub-surface structure. A transmitting antenna launches an electromagnetic impulse into the sub-surface, the wave spreads out as it travels through the sub-surface, until it reaches an object with different dielectric properties from the surrounding ground

Upon reaching the object, part of the energy is reflected back to the surface, while part of the energy continues to travel onward. A single trace records the reflected amplitudes as a function of time (depth). An increase in amplitude corresponds to a dielectric interface at a certain travel-time away from the transmit-receive antennas.

In practice, measurements are made by towing the antennas across the surface being surveyed. Data can be collected at fixed station spacing (usually <1.0 metre) or continuously as the antenna is dragged across the surface. The successive traces are plotted next to each other, so developing a pseudo-cross-section of the sub-surface.

Data can be presented in two forms, namely “line scan” or “wiggle” format. In the line-scan format (which is similar to a contour plot), the horizontal axis shows distance along the profile line the vertical axis shows time (depth) into the ground, and the color intensity shows amplitude of reflection. In wiggle-format, the successive amplitude vs. time traces are plotted next to each other.

## **Applications**

GPR can be used in both the surface and underground environment, the high-resolution capabilities of the 175 MHz antennas, enables it to be effective up to 16 metres in depth.

It can be used to delineate reef, faults, dykes, water fissures and underground excavations, as well as imaging fracture patterns around excavations. In opencast mining, GPR can provide bedrock profiles, ballast thickness, depth of weathering and fracture patterns. It can also reduce drilling costs by providing high-resolution continuous delineation of geological structures.

## **Data Acquisition and Processing**

Data can be acquired in many different ways, although for most applications “Fixed-Offset Bi-Static Continuous” or “Stacked Reflection” profiles suffice. At WCM the transmit and receive antennas are maintained at a fixed separation distance, and the data is collected continuously while dragging the antennas at a fixed velocity over the surface being scanned.

It is usually necessary to apply a suite of post processing tools to the data after acquisition. This is done in the office after data is acquired. Most of the post-processing algorithms are standard digital filtering algorithms.

There are limitations in the acquisition and processing of data, as well as the performance of ground radar, these are;

- Maximum depth of penetration
- The ability to delineate a subsurface interface
- The minimum size of a buried object
- The resolution and detection capabilities of a system for a given object depend upon the electrical properties (dielectric constant and conductivity) of the object and the surrounding medium. The maximum depth of penetration of a GPR system depends on



the electrical properties of the sub-surface, the center frequency of the antenna, the power output of the antenna and the dynamic range of the system.

Dry non-conductive rocks and soils yield the highest penetrations. Moist clayey soils (high conductivity) yield the lowest penetrations. In general, GPR works worst in a subsurface which contains a combination of clay, water and salts. Nevertheless, fairly good penetrations can be obtained in dry clay. The infilling (serpentine or talc) of the major dome structures, seems to be an ideal reflector for the GPR.

A number of other factors affect the ability of GPR to accurately delineate sub-surface conditions:

- Access to the survey site – often it is not geometrically possible to access a specific target from the best position.
- Man-made interference – all antennas are susceptible to receiving reflections from power lines, electrical cables, ventilation columns, rockbolts, etc.
- Depth calibration – although a GPR scan provides reasonably accurate depth estimations, a drill-hole is still the best method of calibration.

## **UNDERGROUND APPLICATION**

Initially At WCM the ISSI system, using a 175 MHz antenna was used for the capture of rock radar data. This was a bulky unit, which enabled the use of the radar to a depth of up to 16 m into the rock wall. Due to the size of the antenna and the weight of the rest of the equipment, a total of four personnel were used to capture data using the GPR in the underground environment. One at the data logger and three to manipulate the antenna along the hanging wall.

One person operated the data logger and interpreted the results (Strata Control Officer), and the other three people (Rock Mechanics Assistants) carry and operate the rest of the equipment.

At the demise of the ISSI GPR, a new GPR system, the SIR 3000 was purchased from Geophysical Survey Systems Inc. (GSSI) of the USA. Currently this system is used with a 400 MHz or a 900 MHz antenna, which can scan 8 m and 4 m into the rock wall respectively. Only two people are needed, one at the data logger, and one to move the antenna along the hanging wall.

Currently the GPR is used on a daily basis, in the underground environment at WCM, where the hanging wall of individual stope panels is scanned for adverse dome structures. During the early use of the mine purchased GPR, attempts were made to scan all of the stope panels in a systematic manner, however this proved practically impossible, at which time a decision was made only to scan problematic panels, those who were experiencing poor rockwall conditions, or negotiating dome structures.

Shift Supervisors, in problematic areas, request the use of the GPR, via a written request form, which is directed to the Rock Engineering Department. Areas or panels are prioritized, and the GPR is dispatched underground to the required area.

Ideally, all new Raise or Winze lines, are scanned with the GPR, prior to ledging operations, to ensure that additional pillars are left in-situ where necessary, to ensure the overall stability of the excavations.

In areas where dome structures are located, and the panels are re-established after the necessary pillars have been left in-situ, then follow-up GPR scans are done to ensure that it is safe to continue mining on the other side of the dome structures.

### **Principle of Operation**

Once the stope area has been selected for the GPR operations, the GPR is transported underground by the GPR Assistant, and the GPR Operator (Strata Control Officer). At the site, the antenna is connected to the data logger by means of a long (30 m) copper cable.

The strike or dip length of the required hanging wall needing be scanned is determined, and this is marked off in 1.0 m intervals, to enable the horizontal distance of the radar-gram as seen on the data logger, to be representative of the actual scale of the scan.

The GPR Assistant, holds the antenna against the Hanging wall, and on the Operators call, the scan begins. In the first pass, a 8 m high scan is made into the hanging wall, using the 400 MHz antenna, if necessary, the scan is repeated, to a depth of 4 m into the hanging wall, using the 900 MHz antenna if a more detailed scan is required. The data received is real time data, whereby the operator can take a decision at the scan site, to ameliorate any dome structures, which are observed at the scan site, in conjunction with the mining personnel present.

If a dome is located and delineated, then a decision is made on the position and size of an additional in-stope support pillar, to support the major key block, which has the potential to collapse, if the influence of the dome structure cannot be ameliorated, the area is either barricaded off, or the stope panel is abandoned.

Decisions taken, as well as details of the structures observed in the stope excavation, are recorded on a GPR report form, and submitted to the Mining Personnel for signature and future reference. With the details and dimensions of the dome structures, plotted on the 1:200 stope sheets, for use by Geology, Survey, Mining and Rock Engineering Departments.

### **Results**

Results and experience obtained to date, indicate that:

- The infilling of the dome structures is a good reflector, with the orientation, extent and size of all major domes, ensuring that all major dome structures can be delineated with GPR technology.

- The extent of the near vertical joints, in the stope hanging wall, cannot be located using GPR, as it is only suited to low angled planes or structures.
- Dome structures can be located and delineated, even though the mining personnel are unaware of them, since occasionally the domes do not daylight into the mining excavation.
- Difficult to see changes in rock types, if no distinct interface exists between them, eg. Horizontal pegmatoid intrusions.
- GPR equipment design, still needs to be developed further, to ensure that it meets the need for operating in the relatively harsh underground environment.

See Appendix A, which detail two examples of radar-grams: (Radar-grams appear to be upside down, this is a negative design feature of the data logger screen, since the GPR was initially designed to scan downwards from the surface)

## **CONCLUSION**

The Ground Penetrating Radar is a practical tool, which is readily accepted by mining personnel, which can be used in a proactive manner to delineate large, potentially hazardous, high risk falls of ground timeously. Thereby allowing for the real time interpretation of data in the work place, leading to the correct proactive placement of in-stope pillars, which offer sufficient support resistance thereby stabilising the potentially hazardous hanging wall. It can provide high-resolution data, and continuous delineation of adverse geological structures, without resorting to expensive and time dependant borehole drilling practices.

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## Appendix A