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Application of ground penetrating radar to identify the locations of sub-surface anomalies at Kansanshi Mine, Zambia

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Abstract

Geotechnical zones within the North West Pit and Main Pit of Kansanshi Mine consist of a regolith profile with isolated marble blocks, referred to as 'boulders' within a highly weathered, unmineralised saprolite. The majority of the regolith is free-dig area with pre-split blasting to target boulders and create a smooth face. A serious rockfall risk is associated with irregularly-shaped boulders protruding from the batter face if not effectively treated during pre-splitting. Due to the random distribution of boulders within the regolith profile, drilling used a closely spaced pattern, with a large number of rigs, and this proved to be very costly. A ground probing radar system utilising a 50 MHz, unshielded, Rough Terrain Antenna (RTA) to scan a predetermined grid over a planned blast pattern, is able to detect subsurface anomalies such as boulders and cavities. Scan data can be imported into Surpac™ and manipulated to create a three dimensional boulder model from which an effective blast pattern could be designed.

Results have indicated several significant benefits; up to 80% cost saving in terms of drill and blast, more effective utilisation of drilling resources in hard rock areas, effective presplitting of boulders on highwall faces reducing rockfall risk and reduced equipment damage through identification of subsurface cavities.

1 Introduction

Kansanshi Mine is an open cast copper (Cu) with minor gold (Au) mine 80% owned and operated by First Quantum Minerals PLC (FQM) and 20% owned by Zambian Consolidated Copper Mines International Holdings (ZCCMIH). The deposit is located in Northwest province, Zambia, 10 km north of the provincial capital Solwezi and approximately 160 km west of Nchanga Mine (Figure 1) in the central African Copperbelt (Broughton and Hitzman, 2002). Kansanshi mining company produced 265,000 tonnes of copper and 136,000 ounces of gold in 2012, operating from two open pits, Main Pit (M) and Northwest (NW).

The deposit is composed of a series of clastic rocks capped by a layer of marble termed the 'upper marble'. This unit is close to surface and generally heavily weathered forming a soft micaeous, biotite rich saprolite residuum. Often large pieces of more resistive marble (occasionally dolomite) remain in the weathered saprolite as floating Boulders (Figure 2). Typically the size ranges from 2 to 3 m, up to a maximum of 12 m. Generally these soft weathered areas are free dug however the boulders are very difficult to see and cause significant damage to excavator buckets when hit. The usual practice of digging around the boulder, exposing it and then secondary blasting is time consuming; furthermore the fly rock associated with secondary blasting of exposed boulders is a serious safety concern. From a geotechnical view point, wall stability in these upper heavily weathered areas is critical. The mine design requires a bench height of 10 m and a batter angle from toe to crest of 50° with a berm width of 10 m. Floating boulders often protrude from the face of the wall creating a zone of potential instability. During the wet season (October to March) high rain fall causes erosion around the boulders (Figure 3) allowing them to dislodge and roll down to the pit floor. The remaining cavity often becomes saturated increasing the probability of circular failure.

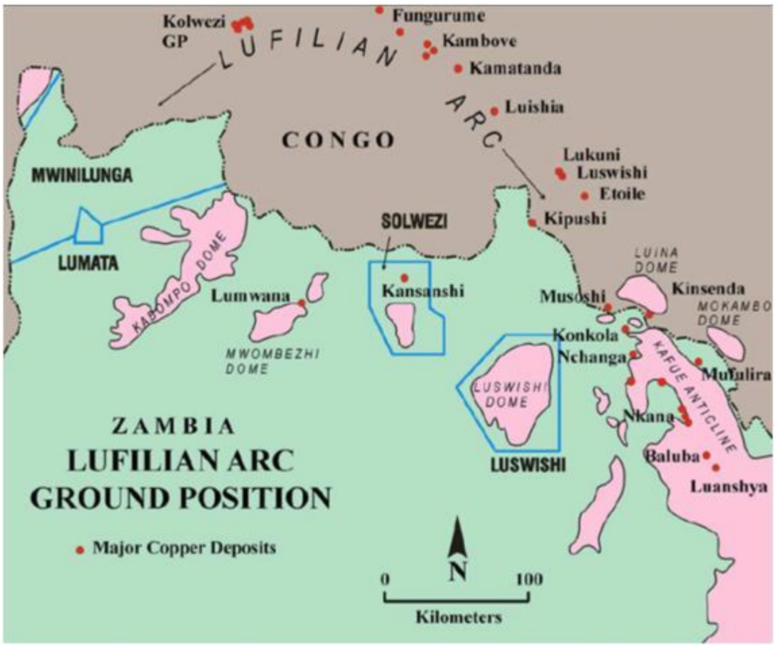

Figure 1 Location map of Kansanshi Mine (GRD Minproc, 2002)

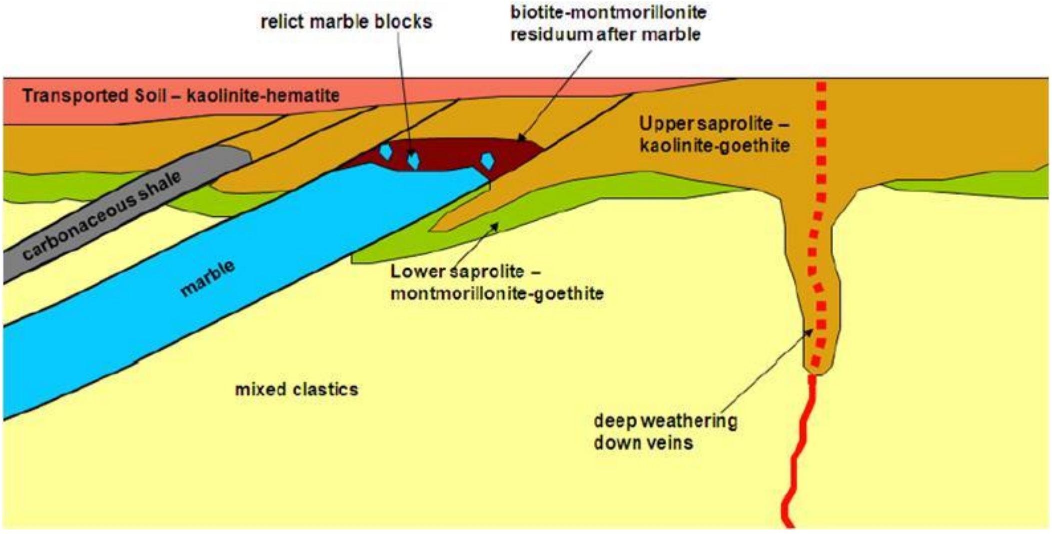

Figure 2 Kansanshi regolith profile indicating the marble blocks referred to as 'boulders' (Jigsaw Geosciences, 2008)

Figure 3 **Protruding boulders in the northern cutback of North West Pit (left), boulders exposed on the mining area, at risk of toppling (right)**

In order to overcome the issues mentioned, a closely spaced drilling pattern (3 × 3 m) would be designed and holes that intersected a boulder could be identified from the drill chippings. Holes would then be charged and fired to try and break the boulder in situ. This method has several major drawbacks;

1. Very costly to drill many holes.
2. Utilised a significant number of drilling resources that had not been scheduled for that particular area.
3. Very slow and would hold up production.
4. Drill holes often penetrated through the boulders and thus explosive energy would be lost at the bottom of the hole failing to break the boulder effectively.

By using a ground penetrating radar (GPR) it is possible to predict the location and size of boulders and voids, model them and determine the most cost effective method to deal with them.

2 What is a ground penetrating radar

GPRs come in various sizes and frequencies depending on the particular application. Essentially they consist of four parts:

1. Transmitter.
2. Receiver.
3. Control unit (housed in the backpack).
4. Monitor (fixed on a bracket and rests on the operator's chest for easy viewing).

The transmitter and receiver are housed in the antenna which can be either shielded or unshielded. Shielded antennas focus the pulse into the ground and eliminate background interference; however these shields tend to make the antennas bulky. In general lower frequency antennas have deeper penetration but tend to be large, heavy and need relatively flat terrain to operate in. Higher frequency antennas are smaller and have a shallower depth of penetration. At Kansanshi Mine a 50 MHz, unshielded, Rough Terrain Antenna (RTA.) is being used, and due to its rugged snake-like design, makes it ideal for the uneven terrain encountered in this mining environment (Figure 4). Electromagnetic pulse penetration is 20–25 m. This unit is easily transported and assembled at the site and can be operated by one person if required, however two people are recommended.

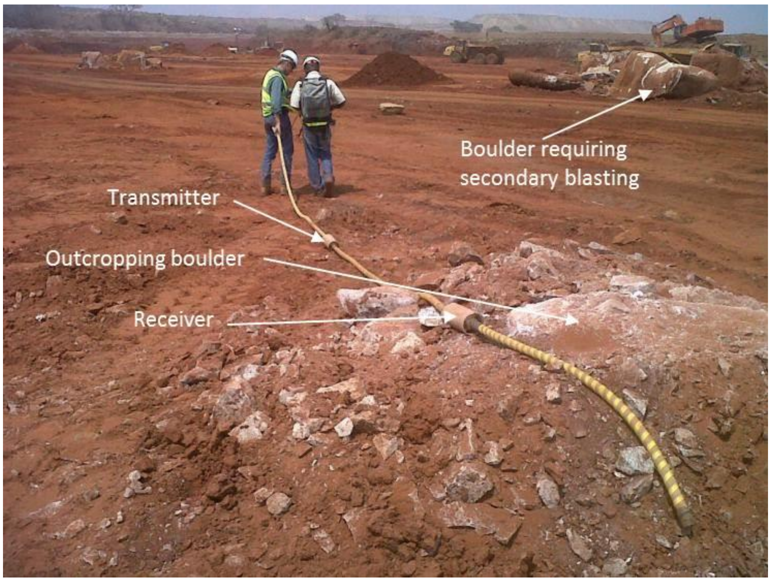

Figure 4 Performing a scan in the boulder rich cutback using the 50 MHz RTA. The transmitter and receiver can be seen mid-way on the antenna

The recorder is activated when walking the scan line by means of a biodegradable thread housed in the hip chain (Figure 5). This thread needs to be attached to a fixed point at the start of the scan line that turns the wheel as you move away from the start point. The length of each scan is limited as a result of the thread sagging over distances longer than 150 m (100 m in windy conditions); sagging of the thread results in inaccuracies in horizontal distance measurements. Splitting the scan into two shorter distances has proven to be more effective. By using an onboard GPS receiver, longer scan distances can be achieved. This GPS system acts independently of the mine surveyors and eliminates the need for scan lines to be picked. An additional benefit of the onboard GPS is the direct import of the scans exact path to Surpac.

Figure 5 Hip-chain housing the thread, wound around the wheel to activate the recorder while walking each scan line

Advantages of using an RTA ground penetrating radar are:

1. Ease of use.
2. Fast set-up and quick data interpretation.

Disadvantages of using an RTA ground penetrating radar are:

1. Not suitable for use in the rainy season due to water logged conditions in the areas to be scanned.
2. Short distances of scans due to the limitations of the hip chain thread. This can be overcome by using the onboard GPS receiver setup.

3 Scanning and data interpretation methods

Before a scan commences, it is important to set several parameters; soil velocity, finite impulse response (FIR) filter and time gain filter (TGF). A soil velocity of 100,000,000 m/s (radar settings are in m/μs) is commonly used and is an average for most geological materials (Table 1).

Table 2 shows commonly used FIR and TGF settings. In signal processing, a finite impulse response (or response to any finite length input) is of finite duration, because it settles to zero in finite time (Wikipedia, 2013).

Table 1 Table of radar responses for various materials (modified after Davis and Annan, 1989)

Material	Dielectric Constant	Conductivity mS/m	Velocity m/s	Attenuation dB/m
Air	1	0	300,000,000	0
Distilled water	80	0.01	33,000,000	0.002
Fresh water	80	0.5	33,000,000	0.1
Sea water	80	30,000	10,000,000	1,000
Dry sand	3–5	0.01	150,000,000	0.01
Saturated sand	20–30	0.1–1.0	60,000,000	0.03–0.3
Limestone	4–8	0.5–2	120,000,000	0.4–1
Shale	5–15	1–100	90,000,000	1–100
Silts	5–30	1–100	70,000,000	1–100
Clays	5–40	2–1,000	60,000,000	1–300
Granite	4–6	0.01–1	130,000,000	0.01–1
Dry salt	5–6	0.01–1	130,000,000	0.01–1
Ice	3–4	0.01	160,000,000	0.01

Table 2 Finite impulse response filter and time gain filter settings commonly used with the GPR system at Kansanshi

FIR Filter		Time Gain Filter	
Purpose	**Setting**	**Purpose**	**Setting**
Background removal	25 samples	Start sample	30
Low pass	5 samples	Linear	1,000

	Exponential	7

There are three general methods that can be used to scan and interpret data:

1. Evenly Spaced Traverse

   An operator chooses a start point and marks it with a peg. They then walk for a predetermined distance, usually defined by the perimeter of a blast design. A second peg is placed at the end point of the traverse line. Multiple traverse lines are made roughly parallel to each other. Coordinates for the start and end points of each traverse line are then picked up by survey at a later stage. Anomalies can then be superimposed on to these lines manually or digitised in Surpac. This data is then transferred to the drill pattern design, indicating where to (and not to) drill.

2. ‘Peg and Go’ Method

   Interpretation of boulders can be made directly in the field. As an operator scans over the ground, they can peg areas of suspected anomalies (boulders or cavities) directly as they see them on the monitor. Survey can then pick up the peg coordinates later. Coordinate data can then be imported into Surpac and used to define a suitable drill pattern targeting the identified anomalies.

3. Survey Grid

   A predetermined grid is pegged out on the floor by a survey team. Scans are conducted in perpendicular directions using the pegs as a guide. This method will give a higher level of definition and resulting data can be digitised in to Surpac to create a boulder model that would be used in drill and blast planning.

Methods one and two are most commonly used at Kansanshi Mine. They provide relatively accurate data, quickly and there is no need for complex modelling work and data processing.

4 Data processing

There are two software packages that are commonly used to assist in the interpretation of scan data. Ground Vision is a freeware package available for download from the internet, and ReflexW which is a commercially available software package. The advantage of ReflexW over Ground Vision is greater data manipulation power such as rotation of scans in the direction of traverse and filtering of interference patterns.

Ground Vision has proven advantageous as a field technician without any formal training in geophysics can be quickly trained to operate and effectively interpret data.

The aperture of the wave front is 45° in the direction of the antenna and 20° perpendicular to it. The aperture of 45° along the line yields the hyperbolic shaped reflector (Figure 6). This is due to the anomaly being detected before the antenna is above it, as well as continuing to detect it while moving away from it. This shape is sometimes masked by other interfering signals, especially for odd-shaped anomalies such as boulders.

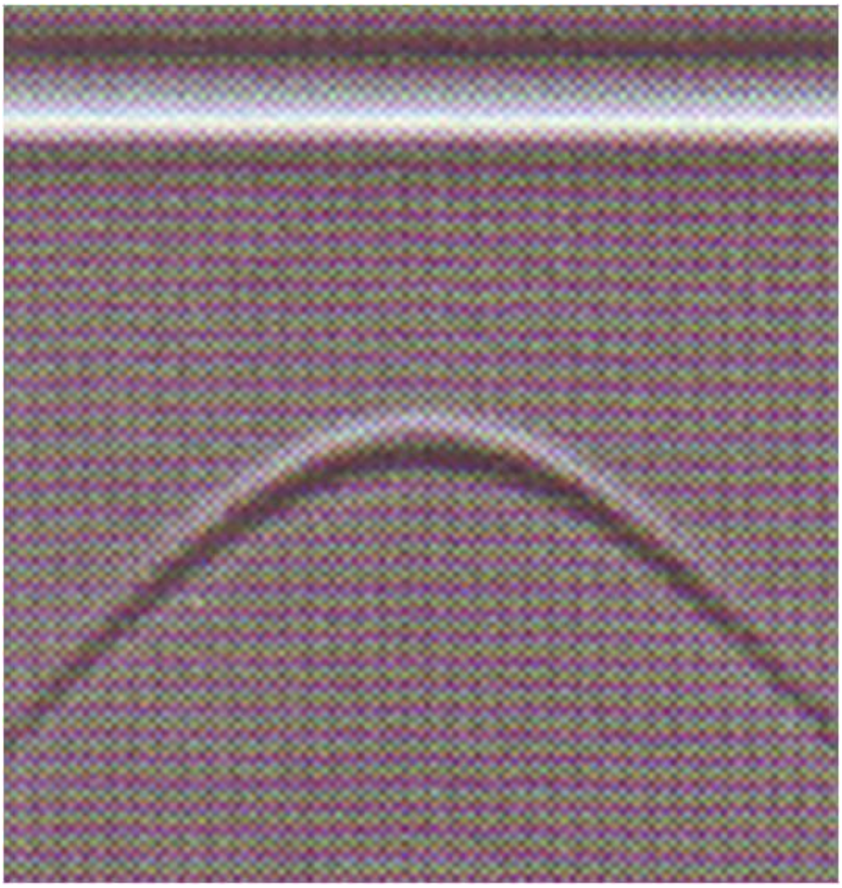

Figure 6 A typical hyperbolic shaped reflector, indicating the presence of an anomaly

Figure 7 shows a signature shape indicating the presence and extent of some boulders (outlined in red) within the soft medium.

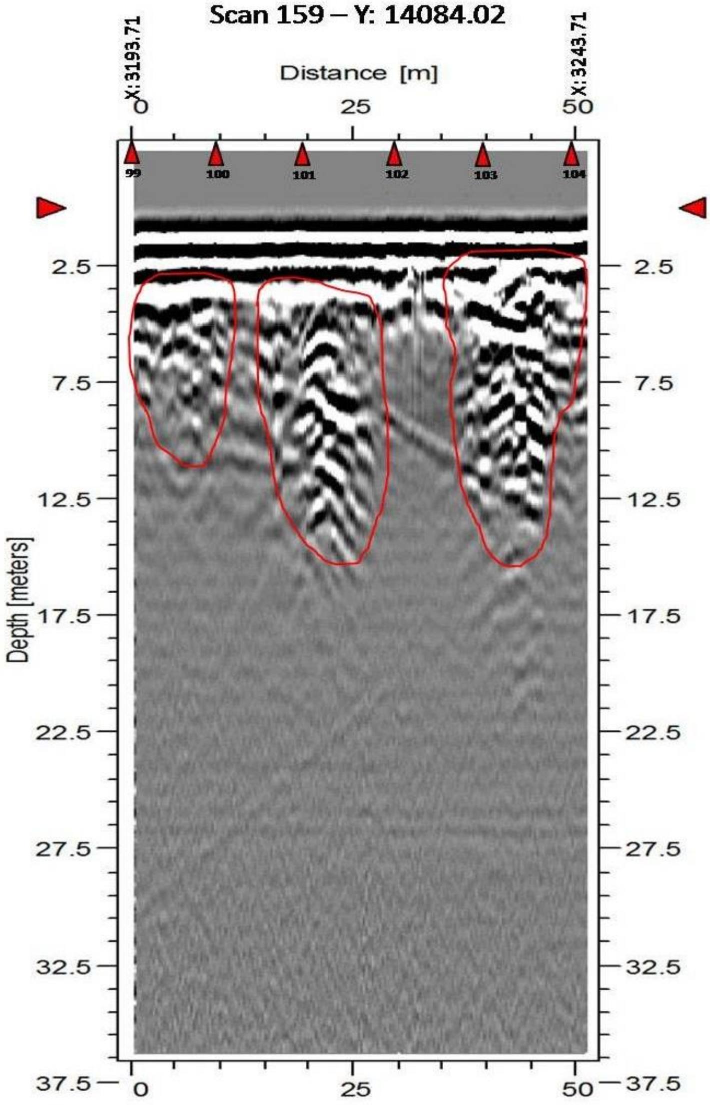

Figure 7 **Example of scan 159 (using GroundVision software) indicating detected boulders as well as the grid points along scan line. Boulder depth is to approximately 15.5 m**

5 Case studies from Kansanshi Mine

The three techniques are examined as case studies.

5.1 Evenly spaced traverse case study

During the testing phase at Kansanshi Mine, the GPR was used to scan the top of a bench where boulders had been exposed on the face, in order to correlate the anomalies with the exposed boulders. Figure 8 illustrates the accuracy of the GPR in detecting the presence and extent of the boulders.

Using the ‘evenly spaced traverse’ method, an area in the northern part of Main Pit was scanned to determine the potential for sub-surface boulders. Start and end points of each scan were pegged and picked by survey in order to orientate the scan lines in Surpac with respect to the pit. Anomalies from each scan are indicated on the trace line and high concentrations of large anomalies are manually demarcated in order for drilling patterns to be overlayed. Figure 9 shows a manually drawn anomaly map depicting representative radargrams from two trace lines; scan 106 and scan 116.

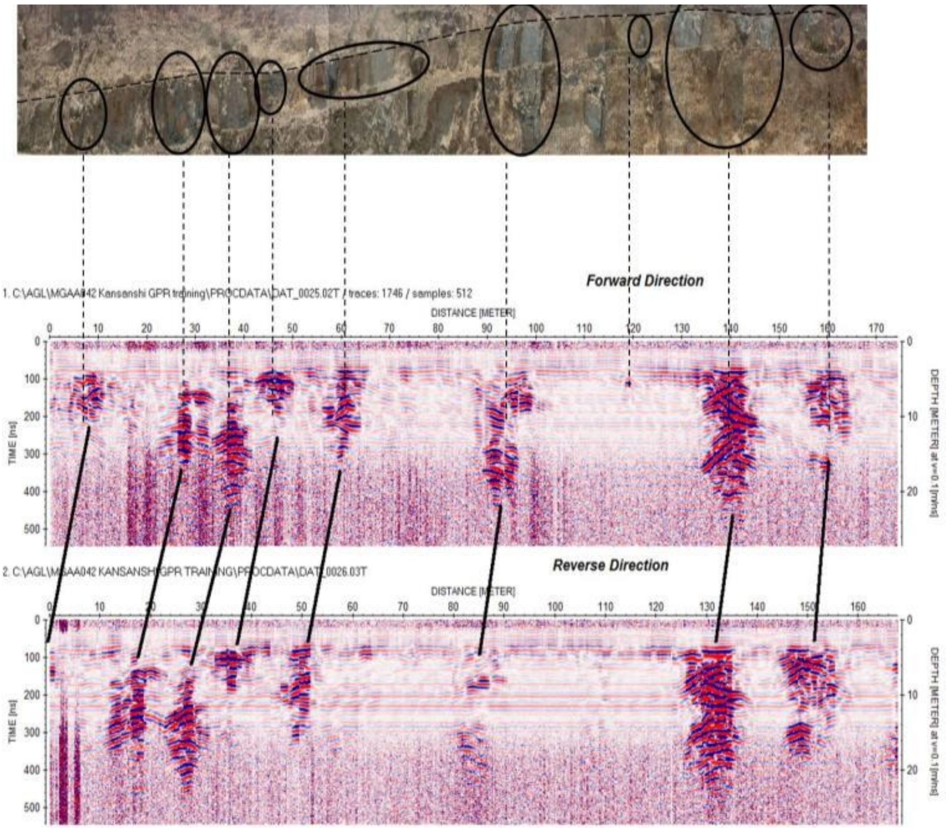

Figure 8 **Correlation of actual boulders to two closely spaced scan lines along a bench crest in North West Pit (using ReflexW software)**

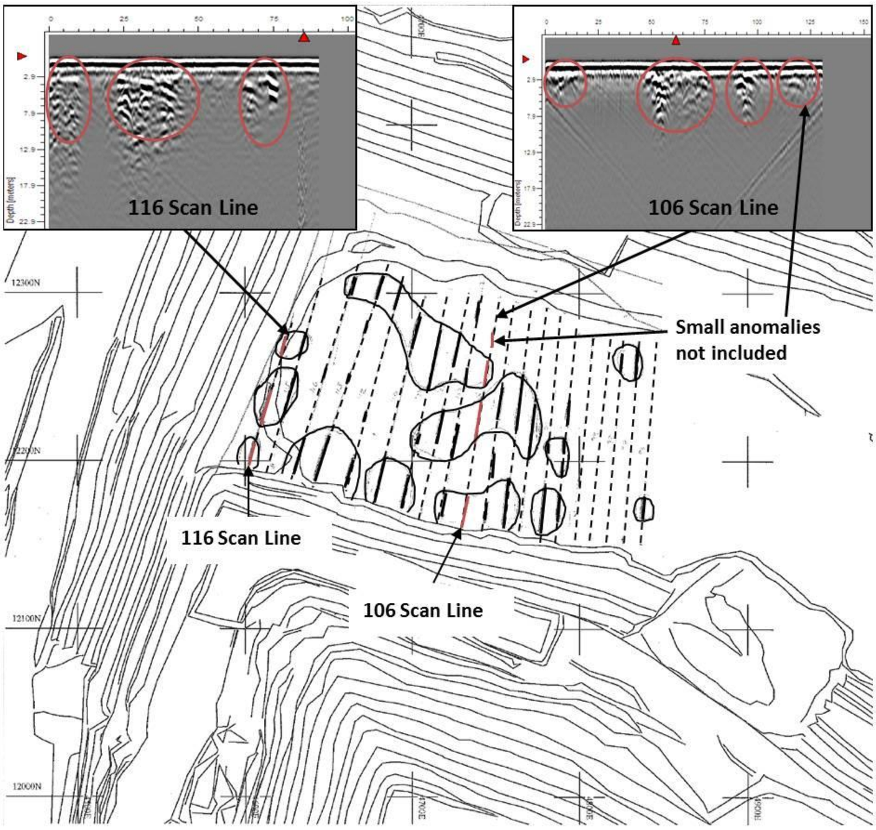

Figure 9 **Manually drawn anomaly map of main 5 in Main Pit using measured offset distances of scan lines. Radargrams processed using GroundVision software**

Figure 10 shows the scanned area on completion of mining. Hard areas identified by the radargram are now visible after mining.

Figure 10 Image of the scanned area on completion of mining. Hard areas indicated by the radargrams are now visible on the benches

5.2 Peg and go case study

Using the ‘peg and go’ method, an area of North West Pit (N6) was scanned. The identified anomalies were marked in the field as the scan progressed. These points were later picked up by survey and digitised in to Surpac. The drill and blast planner was then able to design a suitable drilling pattern. Figure 11 shows the digitised anomaly map as well as the area identified for drilling.

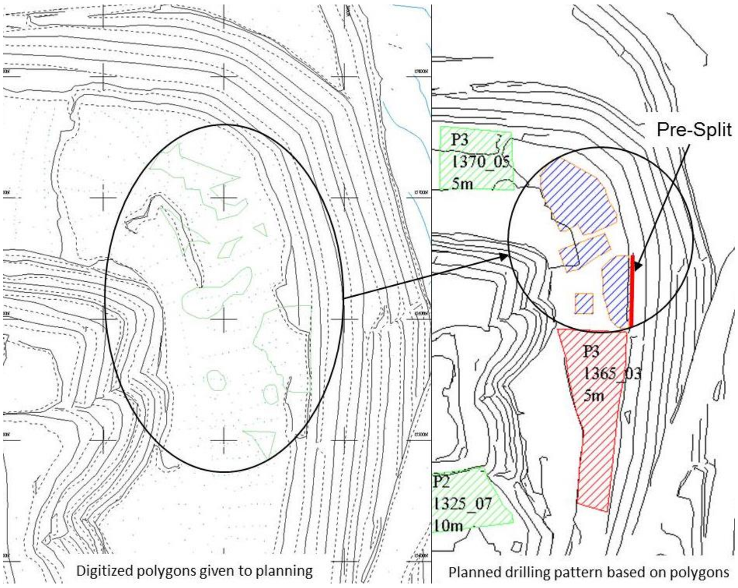

Figure 11 (left) Digitised anomaly map of N6 in North West Pit using survey pick-ups of markers placed in the field during scanning, (right) planned drilling pattern based on anomaly map provided

Figure 12 is an image of N6 after the completion of mining. The effective pre-splitting of the boulder as well as other boulders, located to the north of the pre-split that were identified from the anomaly map are easily visible.

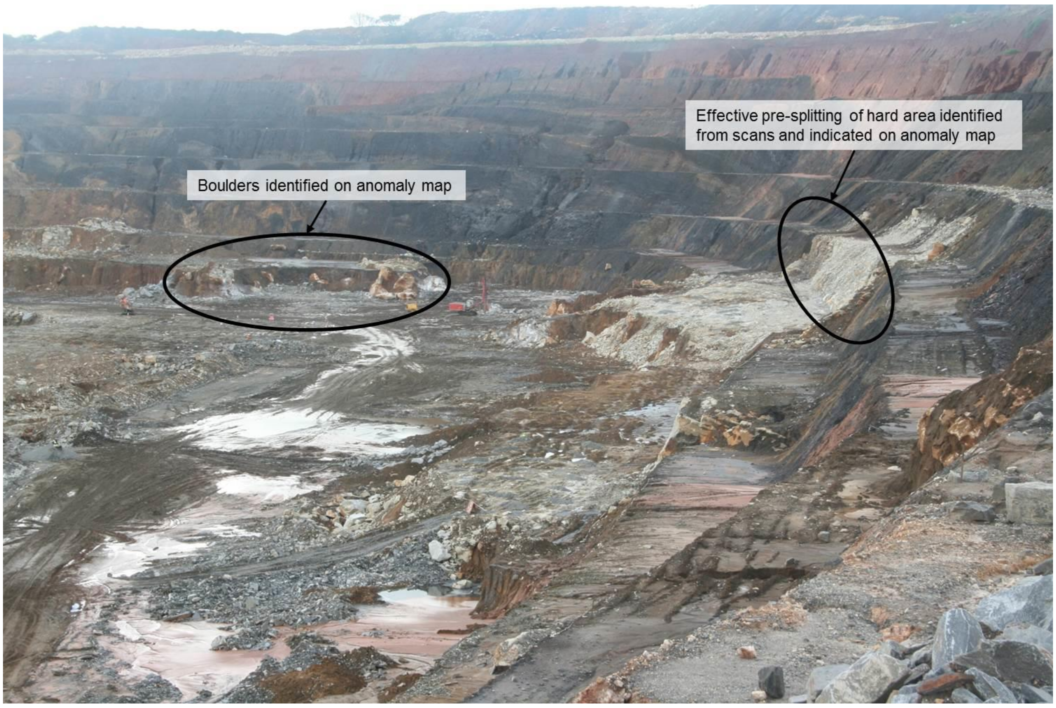

Figure 12 N6 in North West Pit indicating effective pre-splitting of hard area identified by scanning and indicated on the digitised anomaly map, also note additional boulders to the north identified by the scan

An area of North West Pit (S2) was also scanned after a drilling pattern had been laid. The contractor requested an extension of the drilling pattern, and a new block was designed (original design block – Figure 13). This block was scanned using the GPR and indicated that only a small portion of the extension needed drilling (modified block) and the required drilling was significantly reduced (Figure 13). The reduction in the pattern area resulted in an 80% cost saving and allowed rigs to concentrate on other production areas (see Table 3).

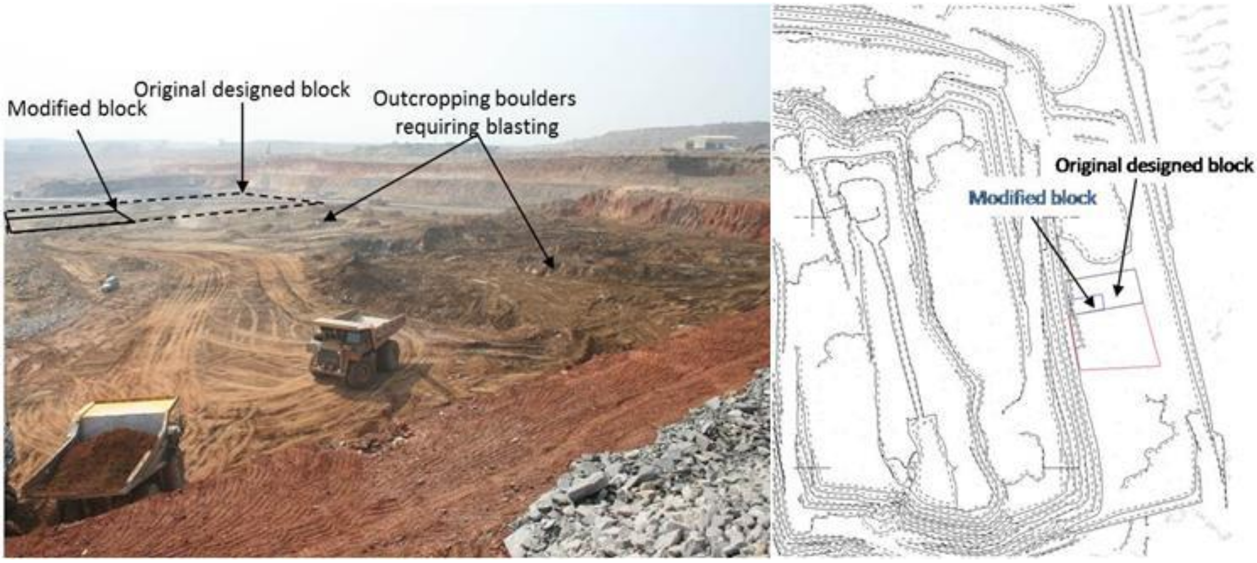

Figure 13 North West Pit (S2) indicating the original designed block and the modified block which was identified as containing hard material or boulders

Table 3 Planned versus actual figures of the dimensions, drilling metres and volume

Parameter	Planned	Actual
Pattern area	9,980 m^2	2,066 m^2
Drilled metres	9,265 m	1,917 m
Drilled block volume	49,930 m^3	10,330 m^3

5.3 Survey grid case study

A 10 × 10 m grid was laid on a bench floor of North 3 pit and scans where completed in both directions (north–south and east–west). Figure 14 shows the grid layout, the direction in which each scan was conducted and the scan number. Each scan line peg was numbered and assigned X, Y and Z coordinates. Intersections of the scanlines where identified by means of placing a surface marker during each scan. In order to digitise the boulder outline, three coordinate points are needed, an X or Y coordinate (depending on whether the scan was completed in the north–south or east–west direction) and a Z coordinate (elevation), assigned from the bench elevation. Figure 7 shows a typical radargram used for digitising. Digitised scan lines where then imported into Surpac as string files to model boulders in three dimensions (Figure 15).

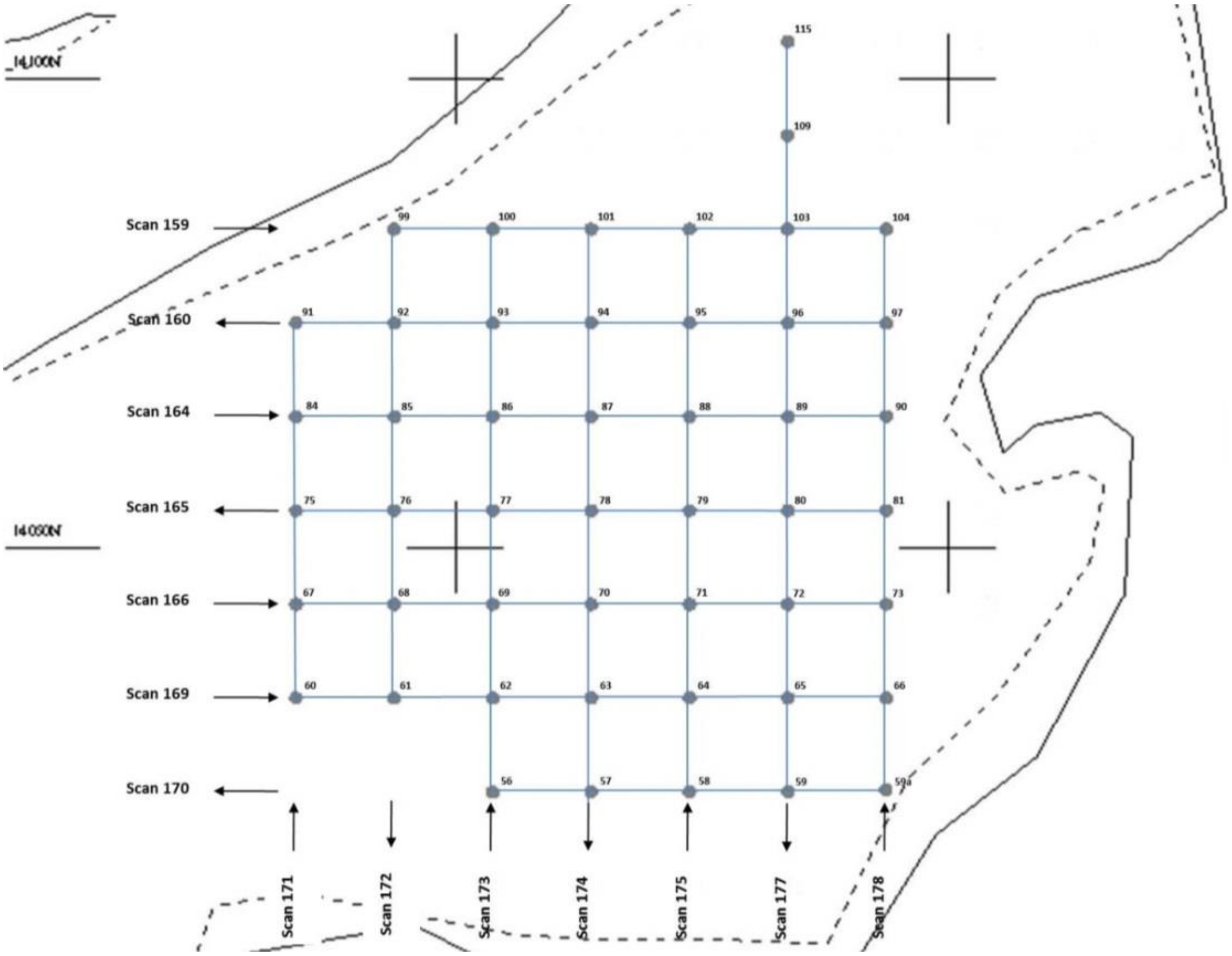

Figure 14 Scan grid in North 3 with points spaced 10 × 10 m. The direction of scan is indicated, as well as each scan number

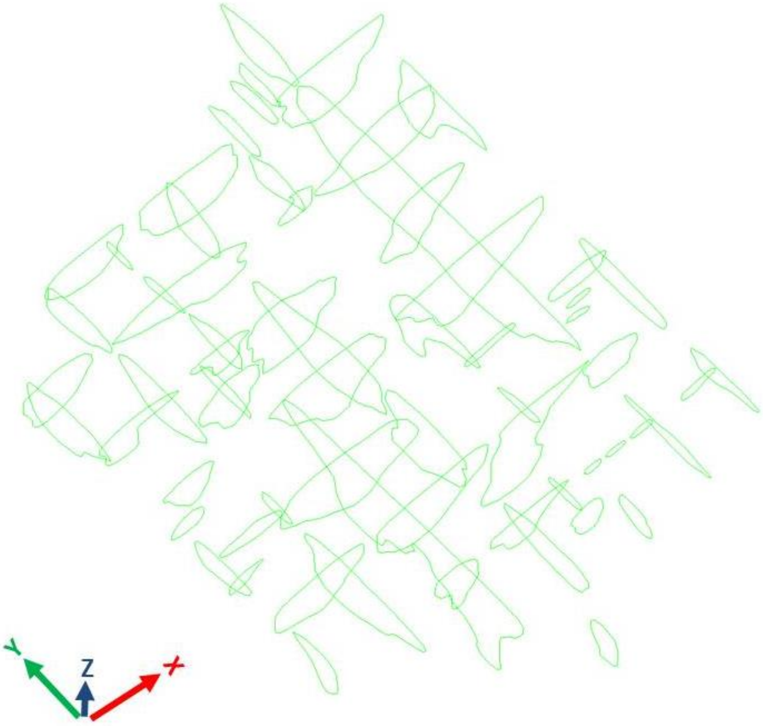

Figure 15 String files of boulders in North 3 digitised using Surpac from data gathered by GPR scanning

Figure 16 shows a Boulder solid model created from radargram data; it also shows section views in the X and Y directions. Due to the fact that the wave aperture is 20° perpendicular to the antenna, shallow objects may be detected laterally which can make interpretation difficult and time consuming.

As a result, the Survey Grid method is not used at Kansanshi, as the other two methods of scanning and interpreting data possess significant advantages. However, for areas with high concentrations of boulders, a closely-spaced drilling pattern will inevitably be required rendering a GPR scan needless. However, in areas where boulders may be widely spaced, the Survey Grid method will prove useful particularly for modelling features in subsequent benches.

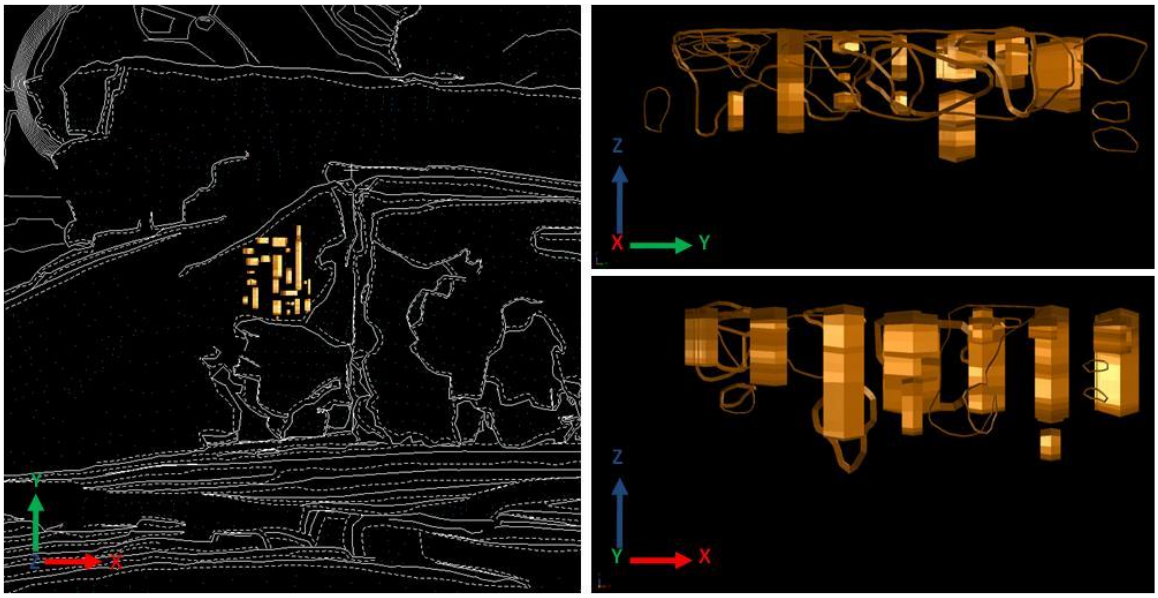

Figure 16 Plan and section views of the boulder solid model created from the survey grid method, and it's relative location in the pit

6 Additional applications of the GPR

In the south-eastern corner of Main Pit historical underground mining activities (Figure 17 [left]) targeted high grade veins leaving behind open stopes and associated development headings. Due to incomplete survey data for the historical phase of underground mining, the significant risk associated with open pit activities breaking in to subsurface voids had to be alleviated. The GPR system proved versatile in identifying the location and depth of potential subsurface voids below an active open pit mining area.

Sinkholes and solution cavities pose a safety risk to men and machinery if undetected (Figure 17 [right]). Sinkholes generally occur in the upper marble where either weathering to create karst features forms voids by volume reduction, or where soft material in the residuum has been washed out around boulders. Often sinkholes on the working benches of the mine can be as deep as 3 m and wide enough to accommodate an unsuspecting light vehicle! During the process of scanning for boulders, data can be simultaneously collected to identify the location of potential sinkholes. Information is immediately passed to the shift boss, to barricade off hazardous area.

Using the GPR equipment, surveys have been conducted on all new proposed tailings storage facilities and solution ponds around the Kansanshi processing plant. Results of the scans allowed sinkholes to be successfully targeted and destroyed by; drilling, imploding and re-compacting. This creates a safer and stronger ground surface for construction work and mitigates the potential environmental risk of tailings flowing in to a subsurface water course.

Figure 17 (left) Exposed underground workings in the highwall of the south-eastern corner of Main Pit; (right) Deep sinkhole developed in soft material as a result of washout around boulders

7 Conclusion

Three methods of identifying and representing the presence of boulders have been presented. Although the ‘evenly spaced traverse’ and ‘peg and go’ methods are somewhat crude, they have proven to be sufficient for the purposes of identifying areas requiring drilling and blasting. The ‘survey grid’ method of generating a 3D boulder model is more visually appealing and can be used for subsequent benches where boulders are sparsely spaced, but the time and effort generally required makes it inefficient. This method will be useful in future mining areas where time allows the model to be generated. The use of the GPR at Kansanshi Mine has proven to be an invaluable tool in reducing the risks associated with sub-surface anomalies as well as having significant cost benefits.

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