The application of in-mine electrical resistance tomography (ERT) for mapping potholes and other disruptive features ahead of mining

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Synopsis

The bulk of the world's platinum production originates from the Merensky and UG2 reefs within the Bushveld Complex, South Africa. Both the Merensky and UG2 reefs are disrupted by faults, dykes, potholes and iron-rich ultramafic pegmatite bodies (IRUPs)—features that impact negatively on production, planning and safety. It is therefore advantageous to know of their presence and geometry ahead of mining. To date, no geophysical technique has been successfully applied to the routine mapping of mine-scale potholes and IRUPs. These disruptive features may vary from a few metres to several tens of metres in diameter. In this paper the applicability of in-mine electrical resistance tomography (ERT) to map potholes and other disruptions to the continuity of the Merensky and UG2 reefs ahead of mining is demonstrated using two case studies.

Introduction to ERT and the proposed in-mine application

Unexpected pothole, IRUP and dyke occurrences are disruptive to platinum mining in that they result in production losses. An added complication is that they impact on the quality of mining in that an adapted development plan is usually required to get through them. This re-development is costly and adds to the base mining cost. If contingency ground is not immediately available, mining is slowed, which has a cost implication as it equates to lost production. Relatively large potholes, say, with a diameter greater than 100 m, can severely affect a level's production in the short–term because of a shortage of mineable ground. Pothole occurrences also result in poor ground quality, which increases support requirements and impacts negatively on safety. If unknown potholes in the solid between raises can be delineated before mining commences, an appropriate mining layout can be designed to optimize production. No geophysical technique is currently used to routinely map these mine-scale features ahead of mining. In this paper the use of in-mine ERT to address this problem is advocated.

ERT is an established geophysical imaging technique whose the theory and application are well documented in geophysical research literature[2–5]. The ERT technique is similar to the medical imaging technique known as electrical impedance tomography (EIT). EIT involves placing a large number of electrodes around an area of interest, for example the human torso. Electrical signals are then transmitted through selected electrode locations while electrical potential measurements are recorded at numerous other locations. This process is repeated systematically for many different source-receiver combinations and the resulting data-set enables the reconstruction of a cross-section through the survey area. The cross-sectional image, or tomographic slice, depicts a spatial distribution of electrical resistivity, which is closely related to the internal structure of the body. In this way medical scientists can, for example, monitor lung and cardiac processes or scan for unusual features such as tumors. In a similar fashion, contrasts in the electrical properties of different geological materials enable earth scientists to non-invasively map structures in the subsurface.

ERT is arguably best suited to small-scale, near-surface targets and borehole applications in the fields of geohydrology, environmental science and engineering[6,7]. The technique has, however, been used successfully in mineral exploration and mining applications[8–11].

In this paper, the novel in-mine application of ERT is demonstrated through two case studies from the Bushveld Complex platinum environment. It should, however, be stressed

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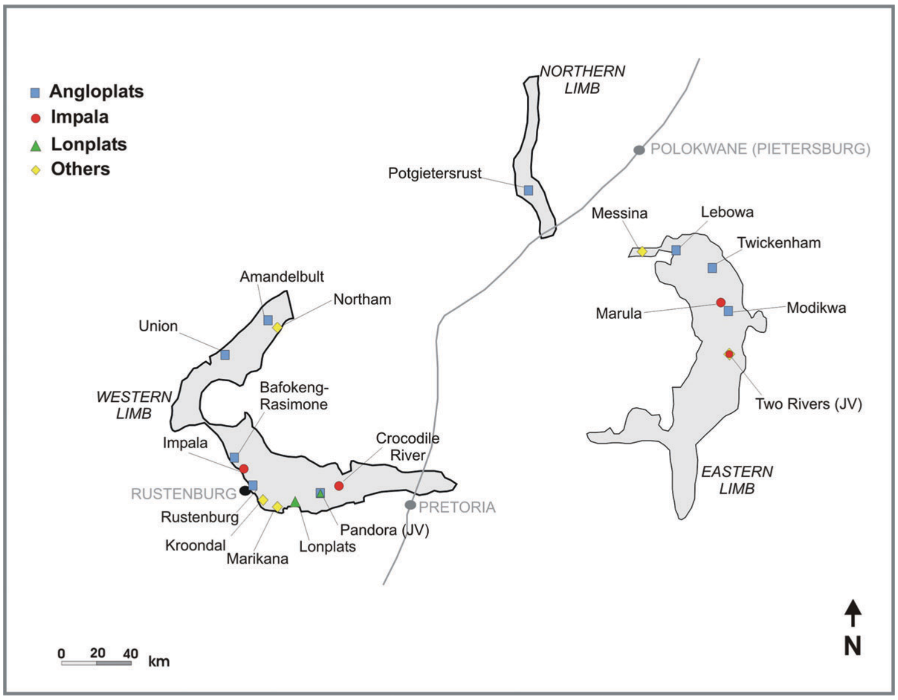

Figure 1—South African platinum mines within the Bushveld Complex[1, 13]

that the applicability of in-mine ERT is not limited to the platinum environment and the technique could potentially be used in other mining environments where there is a need to map disruptive geological features ahead of mining.

The in-mine ERT data acquisition process is similar to the approach used in medical EIT and in conventional surface ERT surveys. A standard electrode configuration, the dipole-dipole array, is used to acquire both in-line (the source and receiver pair are placed in the same tunnel or borehole) and tunnel-to-tunnel or borehole-to-borehole measurements where the source electrodes are placed in one tunnel or borehole and the receiver electrodes are placed in the other tunnel or borehole. Several hundred transfer resistances (observed voltages normalized using the source current) are measured during a typical survey.

The raw ERT data is converted to a cross-sectional image of relative resistivity values through an iterative image reconstruction technique, also referred to as tomographic inversion. The principle behind inversion is to match the response of an estimated two-dimensional resistivity distribution to the observed data. Once a statistically acceptable solution is found, it is presented in the form of a colour-coded image. Ideally, there should be a good correlation between the estimated resistivity distribution and the geological structure of the survey area. Target features may, for example, manifest as highly resistive zones (warm colours in the output image) in an otherwise moderately resistive background (cold colours in the output image). The inversion is done using an algorithm based on a finite-element technique for forward modelling and a multiplicative variant of the simultaneous iterative reconstruction Technique (MSIRT) for tomographic inversion[12].

Case studies

Western Platinum Mine

A trial ERT survey was conducted at Western Platinum Mine (WPM) during October 2003 to determine if disruptions to the continuity of the Merensky Reef could be mapped in virgin blocks ahead of mining. A schematic plan view of the WPM test site is shown in Figure 2. The site was selected on the basis that known disruptions in the form of potholes and IRUPs occurred in the area and existing mine plans could, therefore, be compared with the ERT results. The inferred pothole and IRUP interpretation was based on historic mine plans and an underground visit with mine geologists at the time of the survey.

For the WPM survey, a total of 24 electrode locations were defined (Figure 2). A current dipole length of 15 m and a voltage measuring dipole length of 7.5 m were employed. Galvanic contact with the rock was established by using brass rawl-bolts that were secured into pre-drilled holes. Custom resistivity cables, deployed in the developments surrounding the survey area, linked up the various electrode locations with the control or measuring station, which was located near the intersection of Raise 19E6 and the strike-parallel development or stope preparation drive (Figure 2).

Discussion of results

The output ERT image for the WPM survey is shown in Figure 3. The resistive anomaly (A) located in the centre of the ERT output image correlates well with the observed signs of potholing in the mining developments. The ERT image suggests that this pothole is sub-round and that it may even

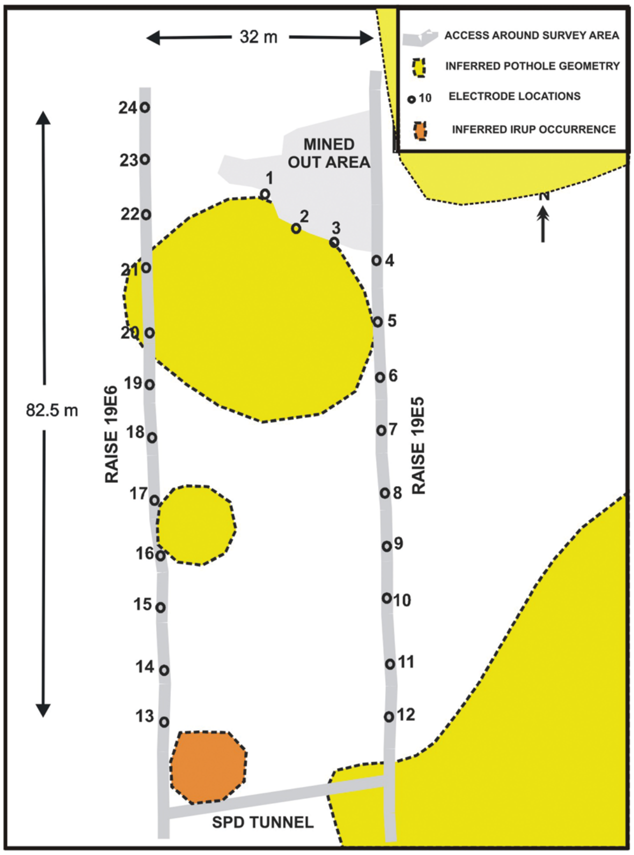

Figure 2—A schematic plan of the Western Platinum Mine survey area, based on recent underground observations and historic mapped sections

be linked to a larger pothole to the north-east of the survey area (Figure 2). The extremely resistive anomaly (B) in Figure 3 is interpreted as a combined effect of the inferred smaller pothole close to electrode 16, the IRUP or partial replacement occurrence in the south-west corner of the survey area, and the pothole extension observed in the SPD tunnel (Figure 2).

Disruptive features, such as potholes and IRUPs, are generally expected to manifest as resistive anomalies on in-mine ERT output images. These features effectively act as obstacles to the electrical current field that would have existed in an undisturbed scenario—essentially a layered earth, i.e. an earth comprising horizontal layers of rock with differing electrical properties. In the undisturbed scenario, it is expected that preferential current flow will occur along a plane closely associated with the reef horizon. A distortion or disruption of this conductive plane implies a distorted or disrupted route for current flow, resulting in a localized high resistance zone associated with the disruptive feature.

Two Rivers Platinum Mine

CSIR Mining Technology conducted an experimental in-mine ERT survey at Two Rivers Platinum Mine (TRP) during September 2004. The purpose of the survey was to assess the applicability of ERT for mapping geological features that disrupt the continuity of the UG2 Reef ahead of mining. This survey differed from the WPM survey in that down-dip in-reef boreholes (TRP166 and TRP167) were utilized instead of on-reef tunnels to gain access to the area of interest.

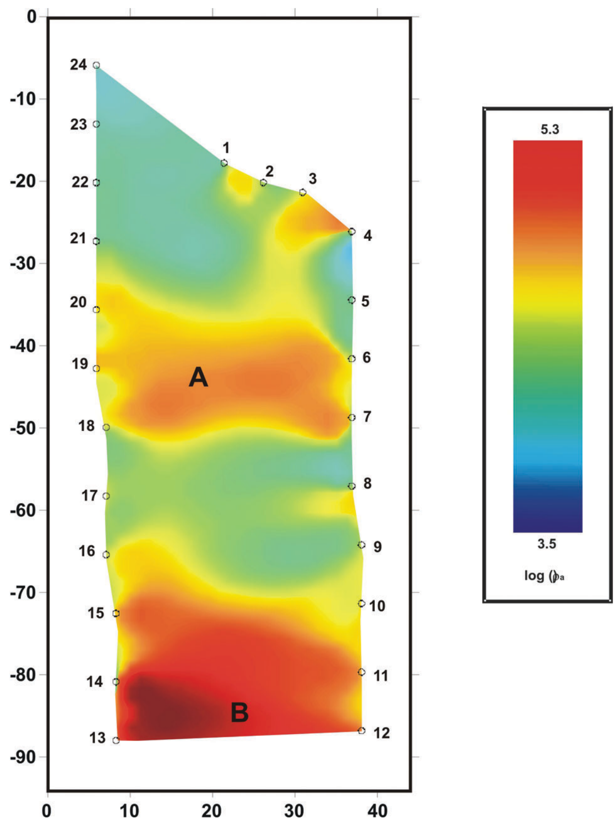

Figure 3—ERT output image for Western Platinum Mine

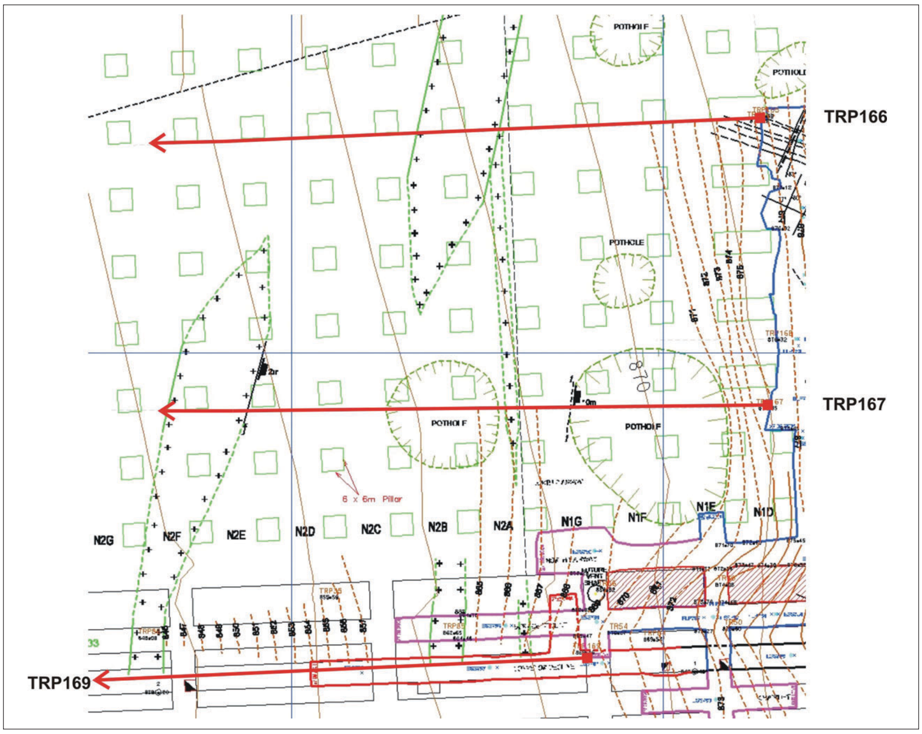

Figure 4—Mine plan from Two Rivers Platinum Mine showing the ERT survey area and pothole and dyke geometries as inferred from geological, borehole and ground magnetic information

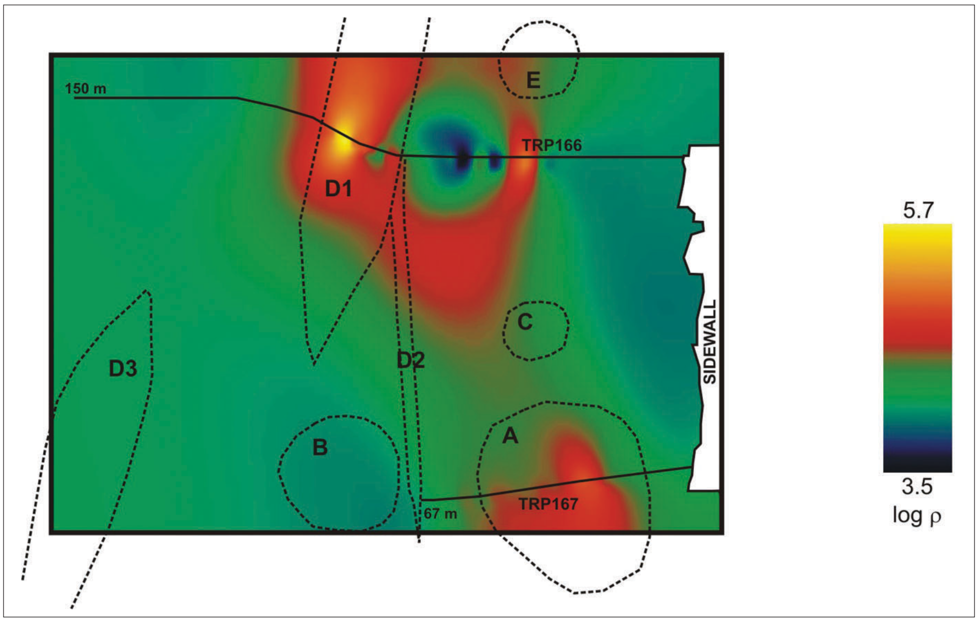

Figure 5—Final ERT image for Two Rivers Platinum Mine. Structures inferred from geological data are overlain

Figure 4 shows the TRP survey area, including pothole and dyke positions as inferred from geological, borehole and ground magnetic information. Two down-dip boreholes, spaced approximately 77 m apart, were made available for the ERT experiments. These boreholes have a dip of between -7° and -10°, in a westerly direction. Unfortunately, on the day of the survey, it was discovered that borehole TRP167 was blocked at a down-hole depth of approximately 67 m. The survey was, nevertheless, conducted between the first 67 m of TRP167 and TRP166, which was open down to approximately 150 m. A combination of in-line and cross-borehole dipole-dipole measurements was acquired. Some measurements were also taken in both boreholes for several source dipole locations along the north-south sidewall between the respective borehole collars. The primary ERT targets were the inferred pothole and dyke structures that lie within the survey area defined by TRP166, TRP167 and the sidewall.

Current and voltage dipole lengths of 4 m were employed during the survey. In total, more than 400 transfer resistances were measured.

Discussion of results

The output image for the TRP survey is shown in Figure 5. In this case study, the correlation between the inferred geology and the ERT output is not great. The inclusion of this case study, however, serves a dual purpose: firstly, it demonstrates a specialized ERT application that may be of great future relevance to mechanized or bord-and-pillar platinum operations. Secondly, the fact that a less than ideal mapping accuracy inevitably results from unfavourable survey geometries, is highlighted.

The known pothole A was detected by the ERT technique; however, its zone of influence appears to be smaller and shifted marginally to the south and west compared with the inferred map.

The combined anomalous response of dyke portions D1 and D2, where it intersects TRP166, can be clearly seen as a large resistive anomaly. This resistive anomaly does not follow the inferred extent of dyke D1, but rather assumes a circular geometry, looping back towards, and then intersecting, TRP166 at a down-hole depth of approximately 40 m. This apparent distortion of the most prominent anomaly in the image can be attributed to a combination of factors: firstly, the lack of sufficient cross-borehole coverage due to the blockage in borehole TRP167 results in a severe degradation in resolution between the central portion of the output image and the area where the dyke (D3) intersects TRP167. Secondly, the distorted anomaly has a definite trend towards the inferred potholes C and E. This suggests that the presence of these features contributes to the observed ERT response, but that they cannot be resolved as individual features due to the masking effect of the distorted anomaly. Furthermore, pothole E lies outside the effective survey area and can therefore not be properly resolved anyway.

An anomaly more resistive than the background correlating well with the inferred position of pothole B, is present at the end of TRP167. Unfortunately, the blockage of TRP167 made the resolution of this potential pothole feature, as well as the mapping of the dyke portion D3, impossible.

The zone running parallel and to the west of the sidewall is the response of the mined-out cavity to the west of the sidewall. The cause of the two relative conductive anomalies along TRP166 is uncertain. They may be related to localized mineralization or variations in reef thickness or texture.

Conclusions and recommendations

The in-mine application of ERT to map disruptive geological features that affect the continuity of the Merensky and UG2 reefs ahead of mining has been demonstrated through two case studies. In both case studies there was a good correlation between known potholes, IRUP and dyke occurrences and the observed field results. These disruptive features manifest as prominent resistive anomalies on ERT output images.

Although in-mine ERT has the potential to become a routine strategic tool in short- to medium-term mine planning, it is relatively novel and immature. Continued research and development is strongly advised, in the form of further trial surveys and theoretical model studies to better understand the underlying physical mechanism.

Finally, for future experimental surveys, proper groundtruthing, for example, through follow-up drilling or by selecting survey blocks that are to be mined out in the near future, is recommended.

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Platinum price to consolidate in 2005 as supply and demand remain broadly in balance*

Improved jewellery and auto demand unlikely to lift palladium price as excess supply continues

The platinum market was more or less in balance last year and will remain so in 2005, according to Johnson Mattey (JM) in 'Platinum 2005', published in May. With demand and supply both expected to increase moderately, the platinum price should continue to be supported around recent levels. The price of palladium, despite large increases in 2004 in its jewellery, autocatalysts and investment products, is likely to remain capped by excess supply.

Demand for Platinum in 2004 edged up by less than 1% for the second year in succession, rising by just 50 000 oz to 6.58 million oz. Mine supply rose by 300 000 oz to 6.5 million oz as South African output exceeded 5 million oz for the first time, resulting in a narrow deficit of 80 000 oz.

Demand for platinum for autocatalysts rose by 7% in 2004 TO 3.51 million oz, spurred by growing European diesel car products and by tightening emission limits for cars in Europe and for heavy vehicles in Japan. Industrial demands climbed by 11% to 1.53 million oz, mainly due to rising production of LCD glass in Asia. However, jewellery demand fell by 12% to 2.2 million oz in reaction to the high and volatile prices in March and April 2004, when platinum reached $937 per oz.

Supplies of platinum are forecast to expand in 2005, largely as a result of Anglo Platinum scaling back its production targets in South Africa. Further increases in demand can be expected from the auto and industrial sectors. Purchases in 2005 to date by the Chinese jewellery trade suggest that platinum jewellery demand in China could match last year's level. If so, the overall market for platinum will be more or less in balance.

This suggests that in 2005 platinum will continue to trade around levels seen in the first quarter of the year, when the price averaged $864 per oz. However, as in 2004, the actions of hedge funds and other investors, driven partly by their reaction to movements in exchange rates, could have an overriding effect on the prices. JM expects platinum to trade between $830 and $930 per oz for the next six months.

Demand for Palladium climbed steeply in 2004, rising by 22% or 1.18 million oz, to 6.6 million oz. More than half of this increase came from the jewellery sector, led by the rapid development of palladium jewellery manufacturing in China.

Autocatalysts demand went up by 10% to 3.81 million oz, as US companies, having run down their palladium stocks in 2003, increased their purchases from the market. Electronics demand increased by 6% to 955.000 oz in response to the growth in sales of electronic consumer goods, while greater demand for palladium bars and coins in North America raised investment demand to 210 000 oz.

Jewellery demand rose nearly fourfold to 920 000 oz, of which 700 000 oz was consumed in China. Jewellery manufactures and retailers were able to increase profit by selling palladium jewellery, which met a spreading desire for high purity white metal jewellery among consumers who cannot afford platinum.

Growth in demand, however, was almost exactly matched by a rise in supplies, with mine production in South Africa and North America increasing and a considerable volume of Russian metal being sold from stocks greater recovery of palladium from scrapped autocatalysts. Total supply jumped by 18% to 7.62 million oz, and for the second year in a row the palladium market was in surplus by over 1 million oz.

The palladium price, supported by hedge fund buying, hit a high of $333 in April 2004 but fell to $178 in December. With production and stocks of palladium more than adequate to meet demand, the prospect of a sustained rally in the price seems remote unless there is further substantial speculative buying. JM expects a trading range for palladium of $160 to $230 per oz for the coming six months.

Platinum 2005 is Johnson Matthey's latest market survey of platinum group metals demand. This report, widely regarded as the world's principal source of information on platinum group metals, is free of charge. It is available in printed form on request from Johnson Mattey at the address bellow or can be viewed and downloaded at www.platinum.mattey.com/publications ◆

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