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Ground and airborne geophysical surveys identify potential subsurface acid mine drainage pathways in the Krugersdorp Game Reserve, Gauteng Province, South Africa

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ABSTRACT

Following the cessation of underground mining activities in the West Rand Goldfield in the late 1990s all pumping of water from the mine void was halted and water levels were allowed to recover due to ground and surface water inflows. In 2002 the water in the mine void reached the level of the lowest lying shaft and began to decant on surface. This water was of poor quality with low pH and high dissolved solids. Significant effort has been expended since on addressing the impacts of this water on the receiving surface water system. Far less effort has been expended on the groundwater systems in the receiving environment. Ground and airborne geophysical surveys have identified potential subsurface pollution pathways in the Krugersdorp Game Reserve, immediately adjacent to and down-gradient from the West Rand Goldfield.

Key words: groundwater, acid mine drainage, contamination, mining, West Rand, resistivity, electromagnetic, aeromagnetic

INTRODUCTION

Underground mining often requires the dewatering of workings to maintain an accessible and safe working environment. This has been the case in Witwatersrand gold mines since miners first ventured more than a few metres below the surface. Following the cessation of underground mining and associated dewatering activities in the West Rand Goldfield (Figure 1) in the late 1990s, the workings of four interconnected mines (Krige 2009) began to flood. The rising water level in the underground void reached the surface in September 2002, decanting from an abandoned shaft intersecting Black Reef workings in the northern portion of Randfontein Estates Gold Mine (Figure 1).

Initially this water, displaying a typical acid mine water chemistry characterised by low pH (≈3) and elevated (≈4500 mg/l) sulphate concentrations (Coetzee et al. 2002), flowed via the Tweelopie Spruit into and through the Krugersdorp Game Reserve (KGR) immediately to the north, with severe impacts on the ecology within the KGR. The mining company on whose property the decant occurred was eventually able to contain this water, albeit with varying degrees of success depending on rainfall-driven recharge volumes. Currently the only water released into the surface environment has been treated to remove iron, reduce the SO_4 concentration by roughly half, and neutralise the low pH.

The groundwater environment has not received the same degree of attenuation. Hobbs and Cobbing (2007) present a conceptual hydrogeological model of the area which indicates that significant groundwater impacts have been manifested.

GEOLOGICAL SETTING

The geology of the West Rand Goldfield has been described by Toens and Griffiths (1964), with the hydrogeology of the northern portion of the goldfield and the area immediately to the north thereof described by Hobbs and Cobbing (2007) (Figures 2 and 3).

The mining area itself is largely underlain by rocks of the Johannesburg Subgroup of the Witwatersrand Supergroup, with the Black Reef Formation of the Transvaal Supergroup outcropping as a thin surface layer over the underlying Witwatersrand rocks. In the northern part of the goldfield a number of outliers of Malmani Subgroup dolomite are found, separated from the larger expanse of karst formations to the north by a antiform structure where quartzites of the Black Reef Formation and West Rand Group are seen to outcrop. This structure bisects the KGR, and is the primary feature of interest in this study due to its location between the contaminated water present in the mine void of the West Rand Goldfield and the important karst aquifer associated with the Zwartkrans Compartment to the north.

GEOHYDROLOGY AND POSSIBLE CONTAMINANT FLOW

The area covered by the geophysical surveys encompasses three major geohydrological environments, namely:

1. The flooded mine void and overlying local karst aquifers containing acid mine drainage, and which extend into the southern portion of the KGR.
2. The dolomitic Zwartkrans Compartment to the north of the KGR, which is an important local source of water for domestic and agricultural use as well as being the *raison d'être* for the Cradle of Humankind World Heritage Site.
3. An antiform structure separating the above two environments, and which brings relatively resistant quartzite strata to the surface, potentially forming a barrier preventing the subsurface flow of contaminated water from the mine void northwards into the Zwartkrans Compartment.

Groundwater contamination with the chemical characteristics of West Rand Goldfield mine water has been detected at a number of sites in the dolomitic aquifer of the Zwartkrans Compartment. This, however, is attributed to leakage of contaminated surface water into the aquifer, rather than the migration of AMD-impacted groundwater from the decant area (Hobbs 2008).

GEOPHYSICAL SURVEYS

Airborne survey

An interpretation of aeromagnetic data (Figures 4 and 5) identifies the magnetic layers in the lower Witwatersrand Subgroup within the antiform structure. Although no obvious displacements are visible in this zone, suggesting that this structure may act as a barrier to the flow of contaminated groundwater, a NE-SW trending fault has been inferred from the magnetic data. Analysis of optical imagery, however, identifies a number of linear discontinuities which could represent water-bearing features within this zone.

Ground survey

The possibility of contaminant transport via fractures was investigated using ground-based geophysical methods. Two roughly perpendicular survey lines, trending north-south and east-west respectively, were surveyed using the magnetic, electromagnetic and resistivity tomography methods (Figure 1).

Magnetic data were collected at a nominal station spacing of 1.5 m using a Scintrex Navmag Caesium Vapour Magnetometer in automatic mode. A Syscal Pro-Switch 72 multi-electrode system was used to acquire resistivity data by running automated pre-programmed acquisition sequences. The method employed the dipole – dipole array for the resolution of vertical structures, and the Wenner-Schlumbeger array for the resolution of horizontal layering and higher signal- to- noise ratio. Data were collected on all arrays using a 10 m electrode spacing. The Geonics EM34-3 conductivity meter was used to acquire frequency domain electromagnetic data in the vertical coplanar mode with 20 m dipole separation.

Magnetic anomalies were found to largely coincide with outcrops of banded ironstone formations. The resistivity and electromagnetic surveys located two significant conductive zones, marked as Zone 1 and Zone 2 (Figures 6 and 7). It is suspected that these relate to water-bearing fractures possibly filled with contaminated, and therefore more saline, groundwater. Additional geophysical data are required to map out the spatial extent of these zones.

CONCLUSIONS AND RECOMMENDATIONS

Multiple geophysical methods have been used to detect possible groundwater pollution pathways linking groundwater contaminated with acid mine drainage in the West Rand Goldfield with the dolomitic aquifer of the Zwartkrans Compartment. Aeromagnetic data suggest the presence of a large fault bisecting the antiform structure in the Krugersdorp Game Reserve. Satellite imagery and localised ground geophysical surveys identify possible water-bearing structures that warrant further study.

Ground survey data have been collected using both the electromagnetic (EM34) and resistivity tomography methods. Since these methods both easily identify the anomalous zones, it is recommended that the electromagnetic method be employed as the primary mapping tool for future surveys as it provides acceptable results at lower cost than the electrical method.

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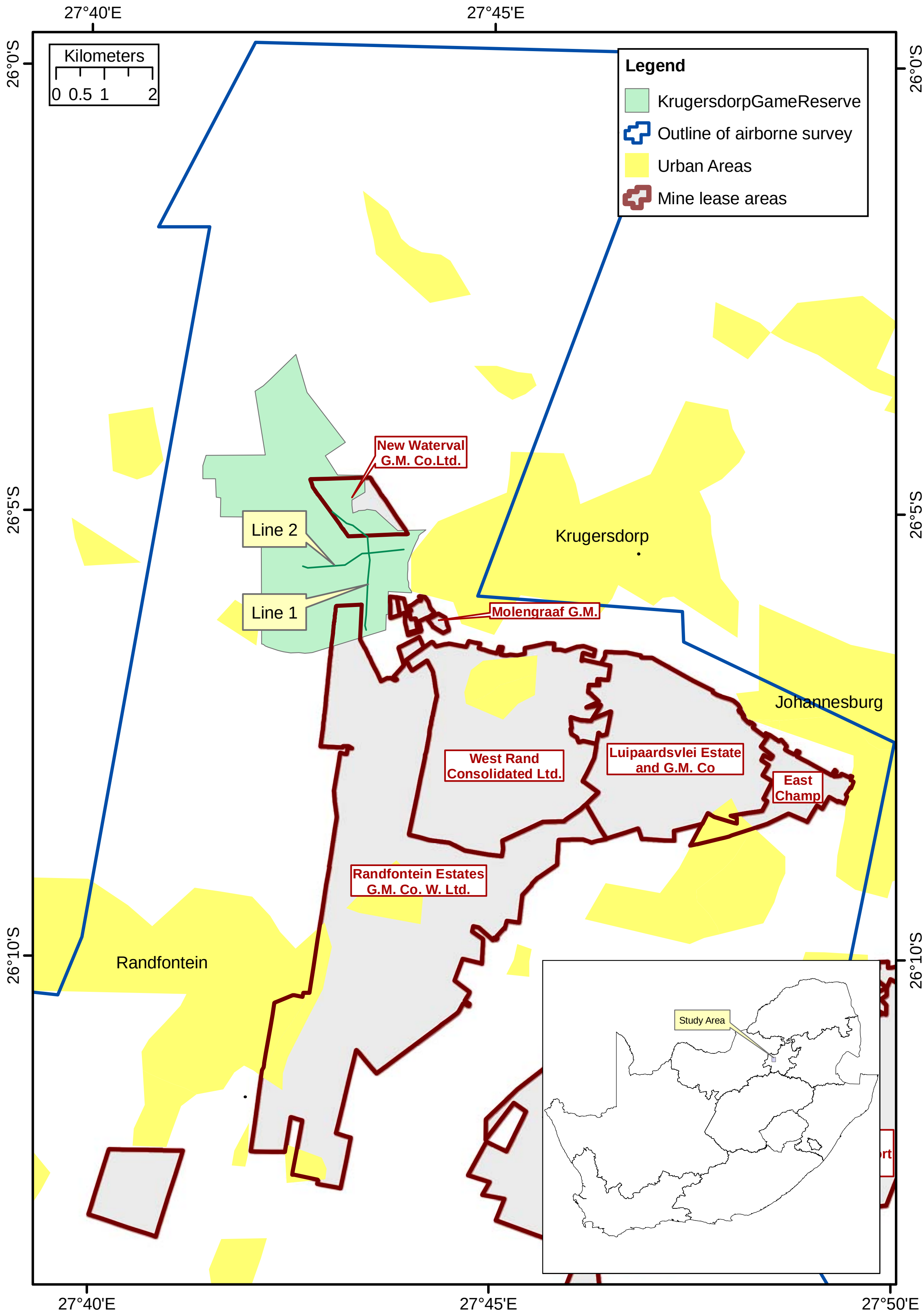

Figure 1. Locality of the West Rand Goldfield and Krugersdorp Game Reserve.

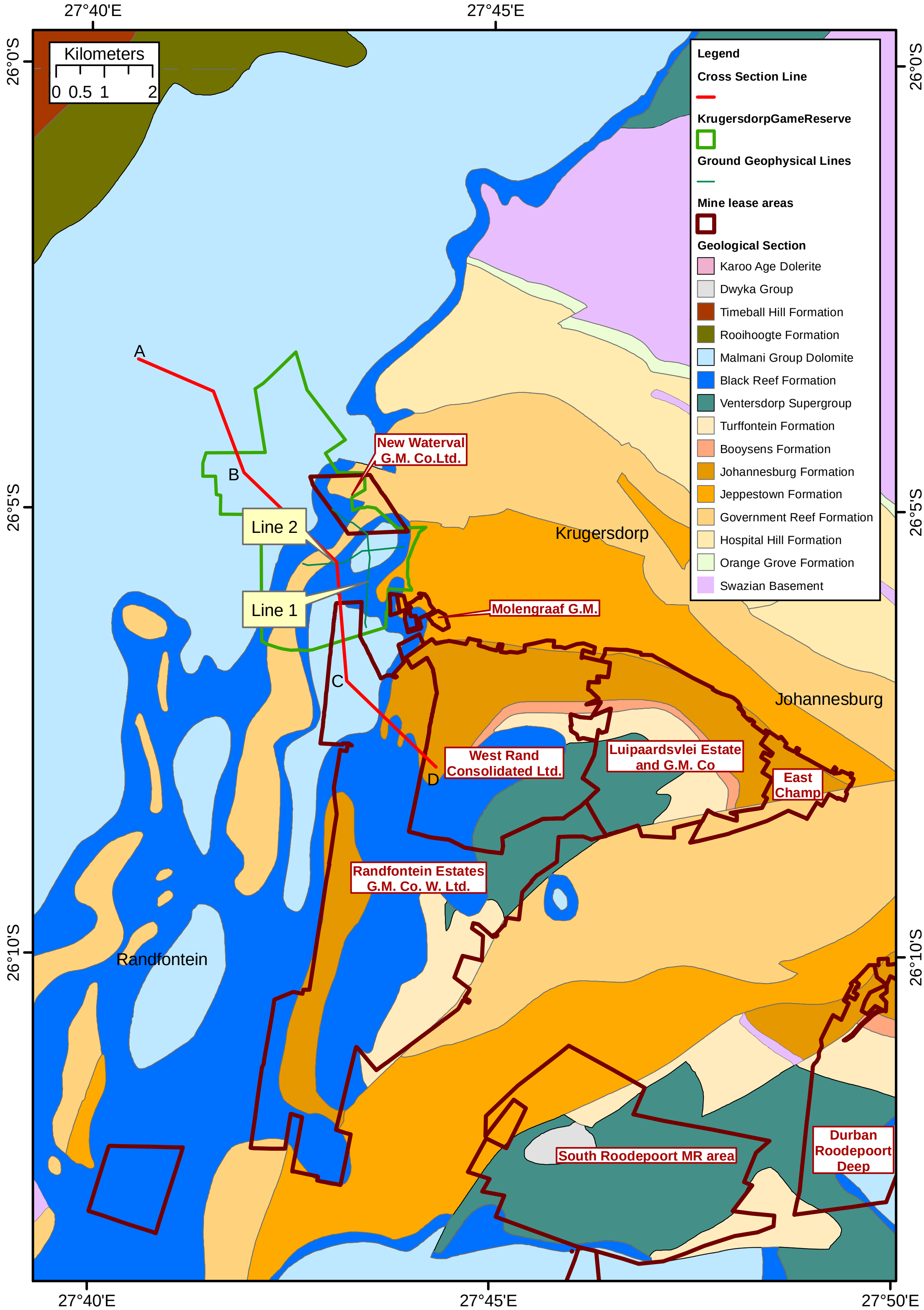

Figure 2. Schematic geology of the study area, showing cross section line ABCD.

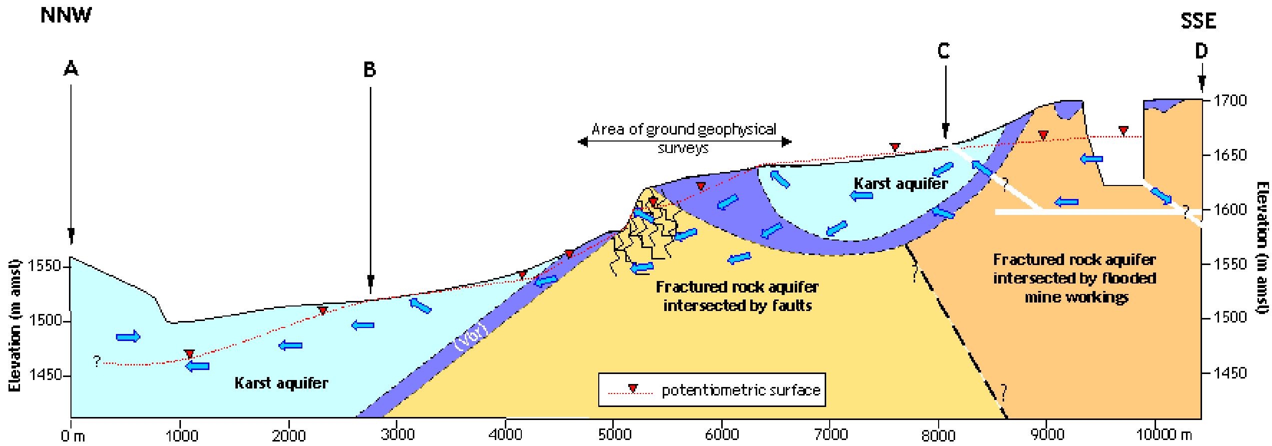

Figure 3. Hydrogeological cross section along section line ABCD (modified from Hobbs and Cobbing, 2007).

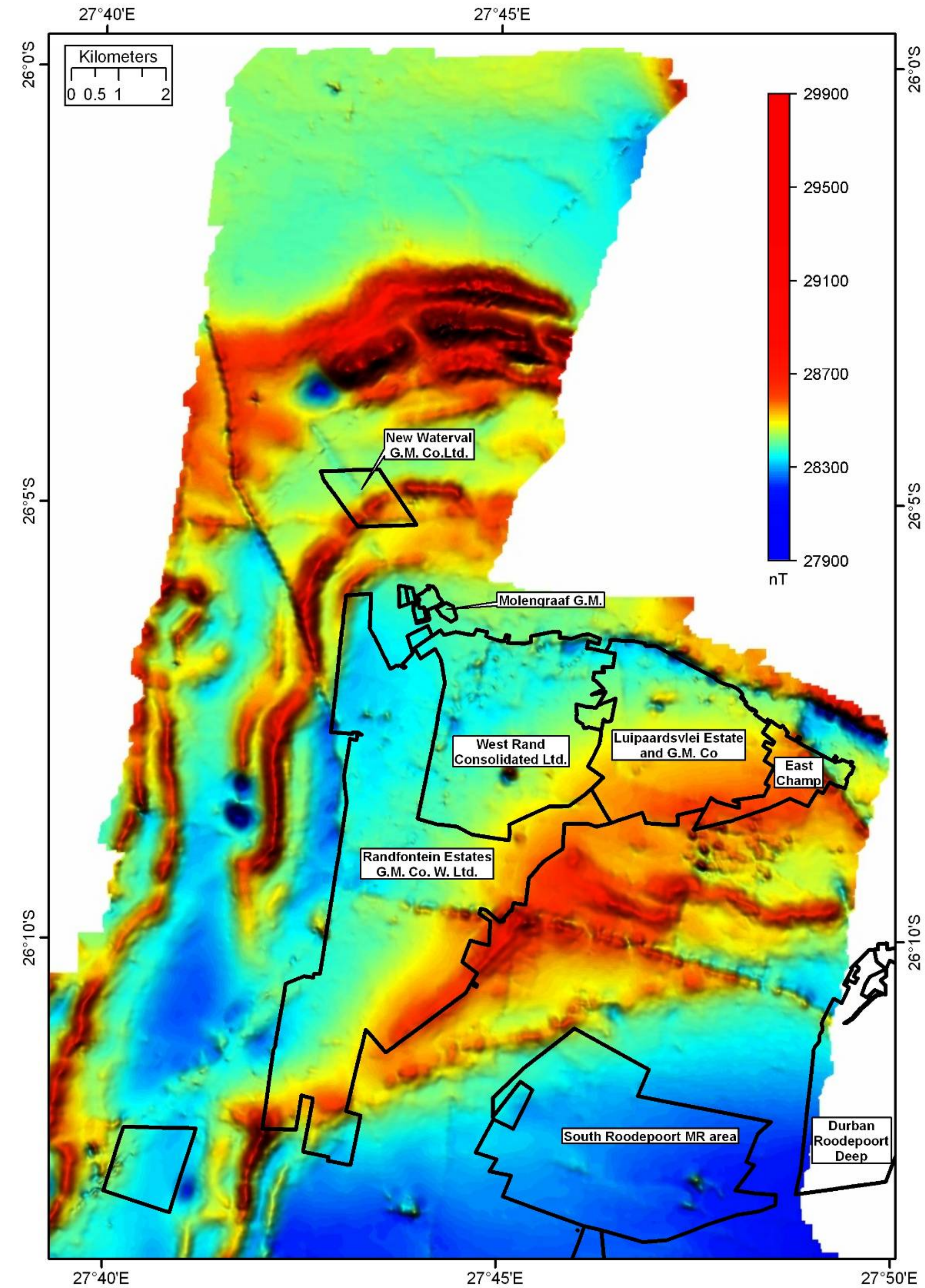

Figure 4. Study area: Total Magnetic Field Intensity.

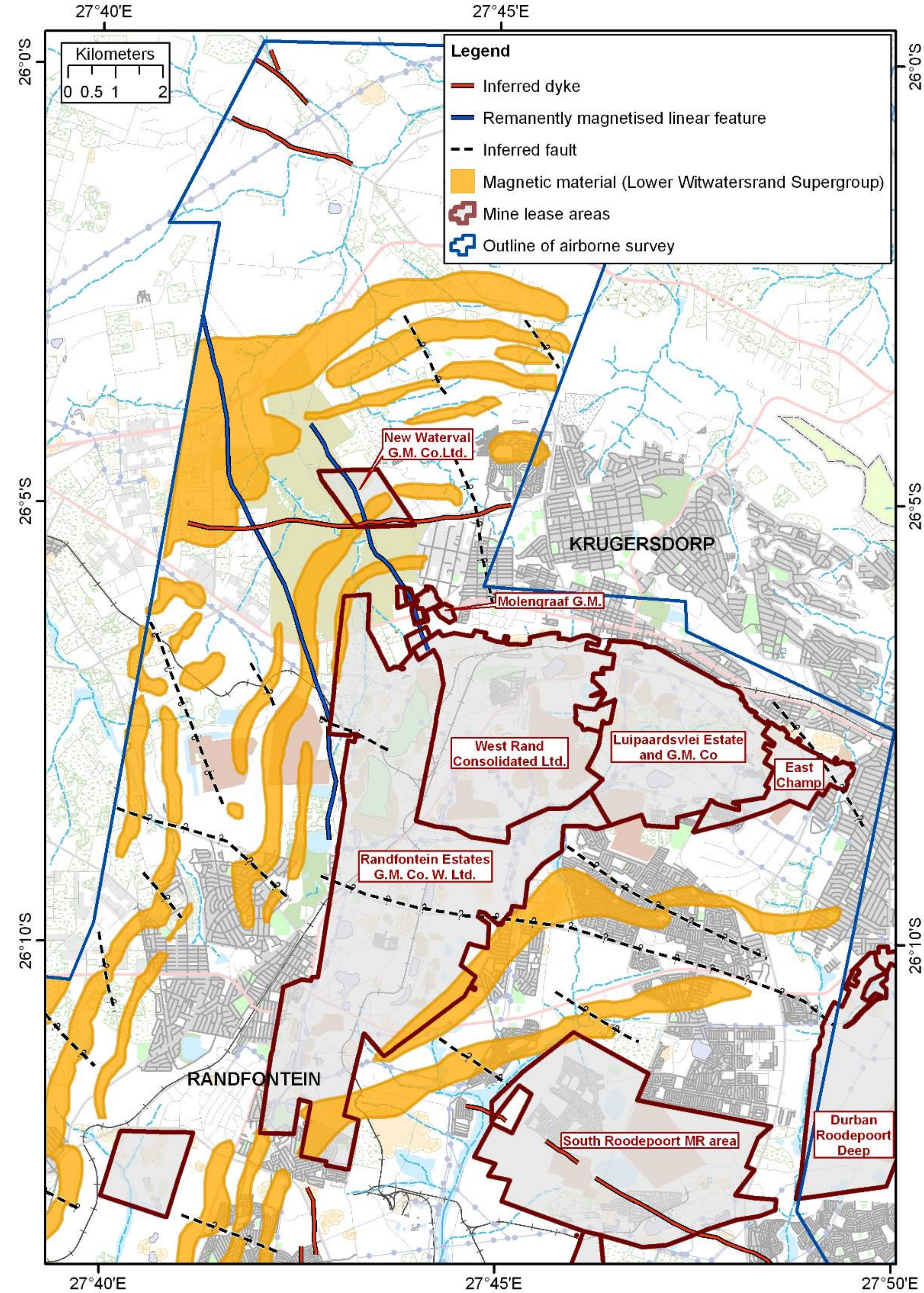

Figure 5. Geological interpretation of magnetic survey data.

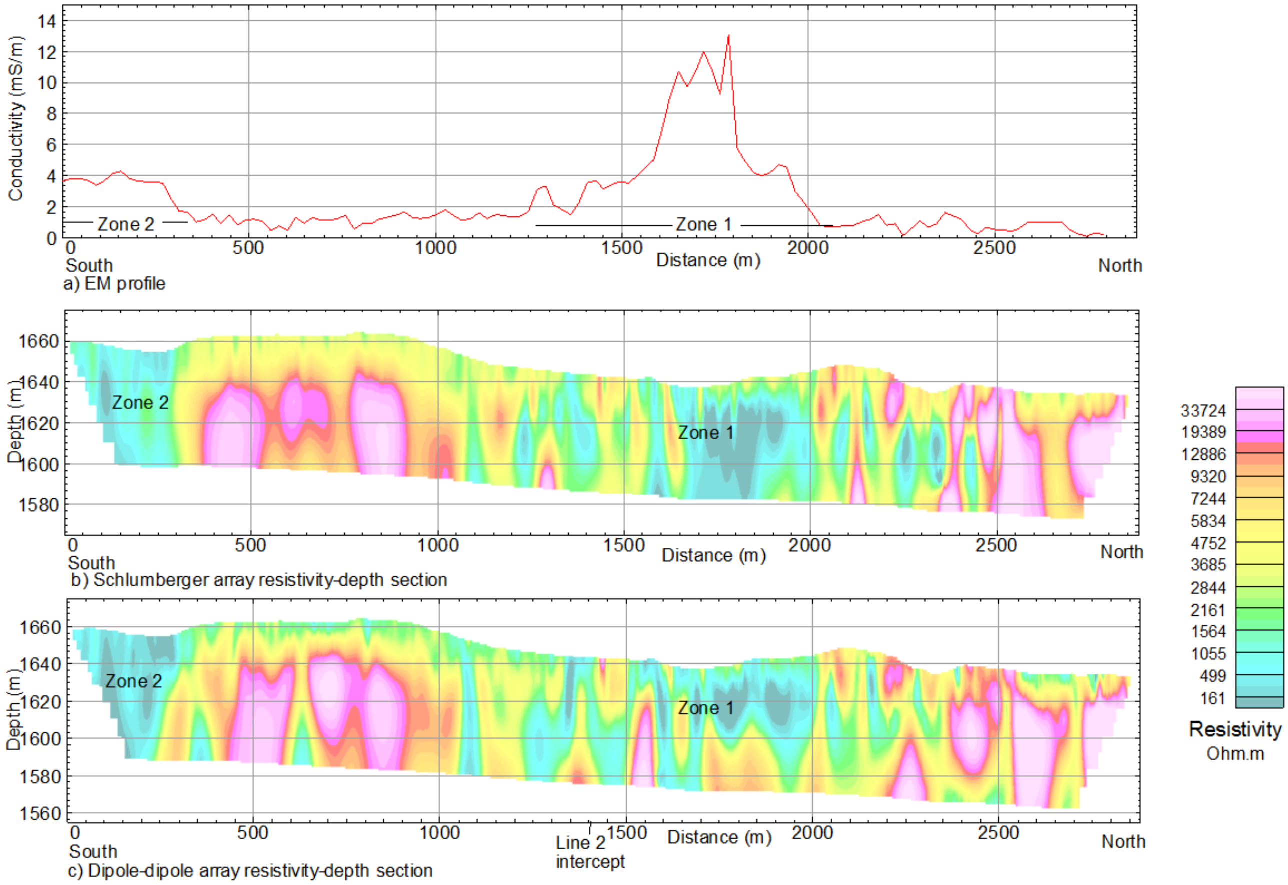

Figure 6. Ground geophysical results - Line 1.

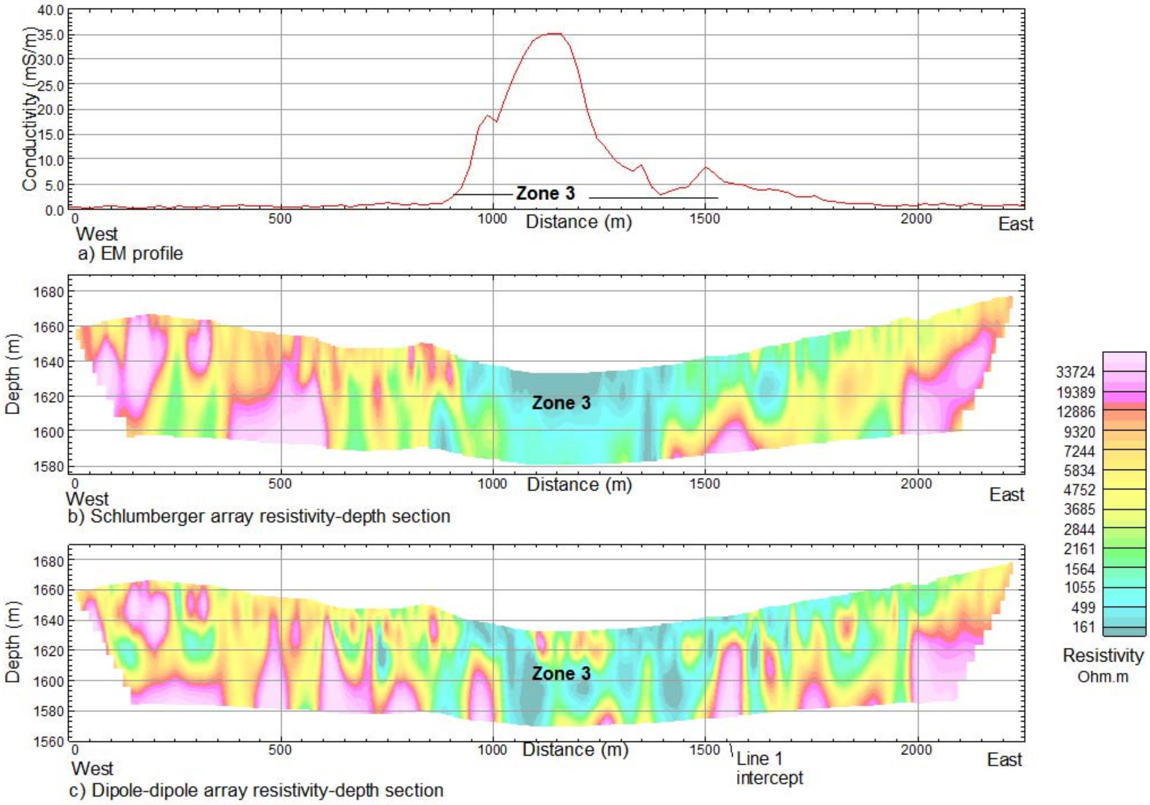

Figure 7. Ground geophysical results - Line 2.