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Prospecting for iron ore in the Bedong area, Kedah using geophysical techniques

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Abstract: Geophysical studies were conducted in the Sungai Tok Pawang locality in Bedong, Kedah on sites which had been mined for iron ore as well as areas adjacent to them. Reconnaissance magnetic profiling over three old mining sites did not locate any anomalies significant enough to warrant further investigation. However, ground magnetic, gravity and electrical imaging surveys carried out along a network of traverses in an unmined area, adjacent to some old mining pools, detected a previously unknown probable iron ore deposit. Integrated mathematical modelling of the magnetic and gravity data shows a sizeable ore body with physical characteristics similar to previously mined deposits in the area. Follow-up detailed geophysical surveys and drilling are needed to further delineate this new iron ore body.

Abstrak: Kajian geofizik dijalankan di kawasan Sungai Tok Pawang di Bedong, Kedah atas tapak-tapak yang pernah dilombong untuk bijih besi serta kawasan-kawasan berhampiran. Pemprofilan magnet peringkat awal atas tapak perlombongan lama tidak mengesan sebarang anomali yang cukup bererti untuk penyiasatan selanjutnya. Akan tetapi, tinjauan-tinjauan magnet daratan, graviti serta pengimejan elektrik yang dilaksanakan pada suatu rangkaian rentasan di suatu kawasan yang tidak pernah dilombong, berdekatan dengan beberapa kolam lombong lama, telah mengesan kemungkinan suatu longgokan bijih besi baru. Pemodelan matematik bersepadu dengan data magnet dan graviti menunjukkan suatu jasad bijih yang agak besar dengan ciri-ciri fizikal yang serupa dengan ciri-ciri longgokan bijih yang telah dilombong di kawasan ini. Tinjauan geofizik lanjutan serta penggerudian diperlukan untuk menentukan dengan lebih terperinci kedudukan jasad bijih baru ini.

INTRODUCTION

The Sungai Tok Pawang locality, approximately 8 km southeast of Gunung Jerai, near the town of Bedong in Kedah, has been mined for iron ore since 1958. The area of interest in the present study is located on land held under mining lease by the South Island Mining Company Sdn. Bhd. (SIMCO) and the adjacent rubber estates under their management. Mining operations ceased in 1998. However, the ore treatment plant is still in operation, processing ore which had been stockpiled from earlier mining operations.

The earliest recorded geological study in the area was by Willbourn (1926) who did reconnaissance mapping of Kedah and Perlis. More detailed mapping was undertaken by Bradford (1972) as part of his investigations of the Gunung Jerai area. Burton (1988) gave a detailed account of the Bedong area but his area of coverage lies just outside the present study area, to the southeast. Nevertheless, his descriptions of the general geology are relevant to this present study. Bean (1969) gave a description of the iron ore deposits in the area.

As far as geophysical investigations are concerned, the earliest work related to this area was the aeromagnetic and radiometric survey conducted in 1956-57 over certain areas of the Malay peninsula (Agocs & Paton, 1958). This area was subsequently studied as part of a regional gravity survey in northwest Peninsular Malaysia by Lee *et al.* (1983). Ong (1983) and Jamalludin Othman (1983) carried out more detailed geophysical surveys in the study area as an academic exercise. A more detailed regional gravity survey in this northwestern region was carried out subsequently (Burley & Jamaludin Othman, 1990).

The primary objective of the present study is to attempt to delineate iron ore bodies in the area, including partially mined out localities as well as yet unmined prospects. For this purpose various geophysical tools were used to investigate the subsurface.

GENERAL GEOLOGY

Located in the southeastern foothills of the Gunung Jerai massif, the area of interest is generally low-lying rolling country with low lateritic hills. The rocks consist of black shales and mudstones, commonly ferruginous. A minor arenaceous facies of sandstones and orthoquartzites usually forms the more prominent topographic features. Bradford (1972) mapped these rocks as the Sungai Patani Formation of possible Silurian age. It has since been shown that this is homologous to the Mahang Formation of known Silurian age, based on fossil evidence (Burton, 1988).

The original iron ore deposits mined by SIMCO consist of a 6 m to 10 m layer of boulders of hematite with some magnetite, containing about 60% of Fe, lying beneath an overburden of a few metres of lateritic clay containing low-grade hematite-limonite nodules and concretions. The boulders average about 1.5 m in diameter, with some as large as 6m. This high-grade layer is underlain by a lower grade horizon, about 3m thick, of rounded to subrounded boulders, containing about 40% of Fe. These lower grade boulders are set in a matrix of clay with quartz pebbles and flakes of muscovite. Although the boulder ore appears to occur in definite horizons, they are laterally discontinuous. Beneath the lower grade layer is barren homogeneous clay, possibly weathered shale bedrock (Bean, 1969; Bradford, 1972). More recent mining activities in adjacent areas have shown that the layer of boulder ore can be much thicker and deeper in certain localities.

Bradford (1972) believed that these residual iron ore deposits were derived from primary metasomatic replacement ore bodies which were formed in the shale country-rock in close genetic relationship with pegmatites. The primary ore was believed to consist of both hematite and magnetite. Surface weathering converted most of the magnetite to hematite and concentrated them as a residual near-surface layer. He further believed that it is likely that the underlying unweathered bedrock contains unaltered primary ore material. More recent mining records have not revealed any evidence for this. However, this is due to the fact that no excavation was done beyond the boulder ore horizon and no deep boreholes were ever drilled in the area.

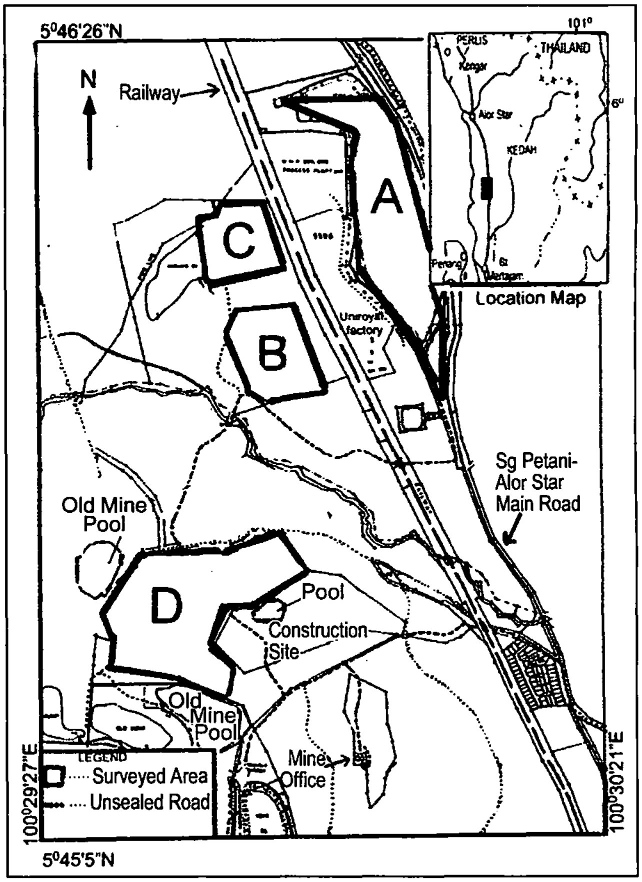

Figure 1. Location map showing surveyed Areas A, B, C and D.

GEOPHYSICAL INVESTIGATIONS

Fieldwork for this study was conducted in late 2000 and 2001. Initially reconnaissance ground magnetic surveys were carried out over old mining sites and their adjacent areas such as Areas A, B and C in Figure 1. The objective was to detect the remnants or extensions, if any, of the known ore deposits which have been mined or the possible presence of primary ore material at depth. However, this was hampered by problems of access as many areas have been, or are being, developed for housing and other uses, or are otherwise covered with thick undergrowth. In any case, no significant anomalies were detected which would warrant more detailed follow-up surveys.

Reconnaissance magnetic profiling in areas farther to the south located significant anomalies in the rubber estate on Lot 1294. This area is designated Area D in Figure 1. Initially five parallel traverses numbered PBEL1 to PBEL5 were surveyed (Fig. 2). Subsequently four cross traverses numbered CBEL1 to CBEL4 were run. Finally four more lines parallel to the first set numbered PBEL6 to PBEL9 were surveyed. The spacing between parallel lines was 40 m and that between stations along the lines was 25 m or less (where necessary in localities of steeper magnetic gradients). The lengths of some of these traverses were limited by inaccessible areas such as old mining pools, development sites and other obstructions. The magnetic survey was conducted with a Geometrics G856 Proton Precession Magnetometer which measured total magnetic fields to a resolution of 1 gamma (or nT). To monitor the diurnal variations a similar model Geometrics G856AX Base Station Magnetometer was set up in a magnetically quiet area in the vicinity to automatically record the total field every 60 seconds.

Significant magnetic anomalies were detected along profiles PBEL3, PBEL4, PBEL5, PBEL7, PBEL8, PBEL9, CBEL2 and CBEL3. Consequently gravity profiling was conducted along PBEL3, PBEL4, PBEL5, CBEL2 and CBEL3 to get a better handle on the shape, size and depth of the causative bodies in the subsurface. A Scintrex CG2 Worden gravity meter, reading to 0.05 mgal, was used in the survey. This utilized the stations used in the preceding magnetic surveys. Where deemed necessary, however, intermediate stations at 12.5 m intervals were also used. To monitor instrumental drift gravity base stations were reoccupied every 30 minutes or so. The station elevations were determined by levelling with a theodolite.

In addition to gravity and magnetics, two-dimensional electrical imaging surveys were conducted along ten of the profiles, viz. PBEL2 to PBEL5, PBEL8, PBEL9 and CBEL1 to CBEL4. An ABEM LUND Imaging System was employed for this purpose, using the Wenner array with an electrode spacing of 5m. The resistivity data acquired was used to assist in the interpretation of the magnetic and gravity anomalies.

Iron ore and rock samples were collected from the areas surveyed and their densities and magnetic susceptibilities were determined in the laboratory. Densities

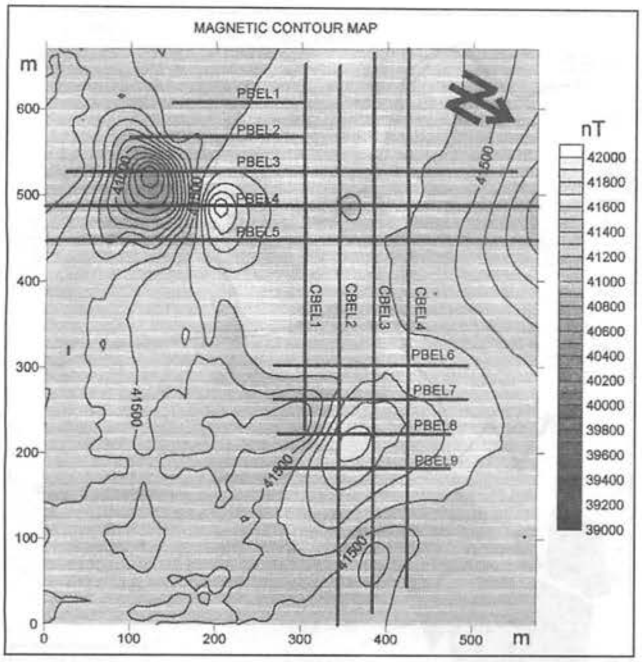

Figure 2. Magnetic contour map of Area D with location of traverse lines.

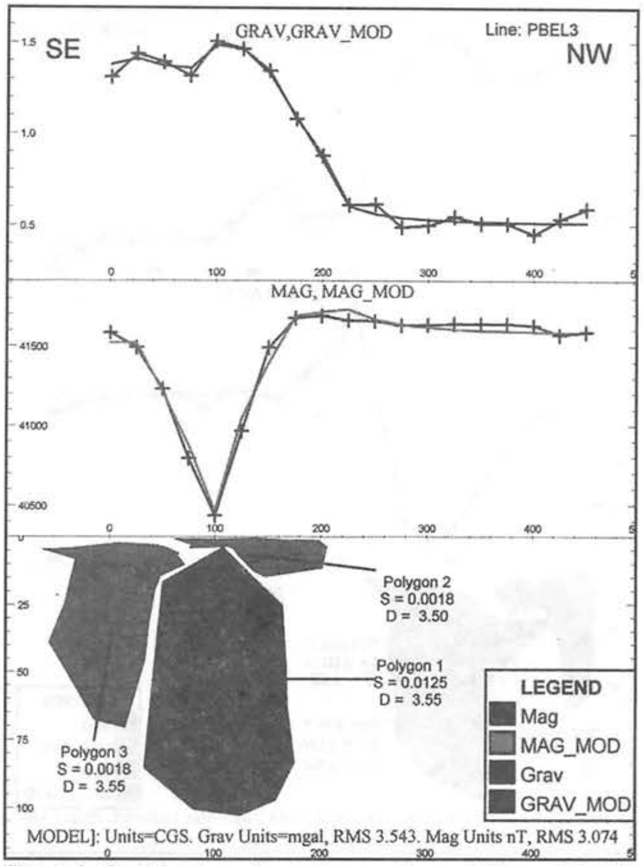

Figure 3. Combined gravity and magnetic modelling of Profile PBEL3. (Horizontal units are m; vertical units are mgal, gamma and m respectively)

ranged from 2.9 to 4.4 gcm^{-3} while magnetic susceptibilities ranged from 0.0013 to 0.1 cgs, depending on the hematite and magnetite content. These values were used as a guide in selecting the physical parameters in the subsequent modelling of the data acquired.

DATA PROCESSING, MODELLING AND INTERPRETATION

The total-field magnetic data were corrected for diurnal variations by subtracting the latter, as recorded by the base station magnetometer, using the software supplied with the equipment. These corrected values were then plotted and contoured, resulting in the magnetic contour map of Figure 2. The gravity data were subjected to the standard corrections for drift, free-air and Bouguer effects. The electrical imaging data were processed with the built-in software. Before inversion to obtain resistivity models, some bad data points were first removed to reduce overall errors.

Since the main magnetic anomalies with well-defined positive and negative lobes are located at the southeastern ends of the profiles PBEL3, PBEL4 and PBEL5, we shall confine our discussion here to these three lines. These profiles are suitable for detailed mathematical modelling. The magnetic anomalies are of the order of 1,000 gammas peak-to-trough. The maximum amplitude of 1367 gammas was recorded along profile PBEL4. These three profiles also show positive gravity anomalies, of the order of 1 mgal, corresponding to the magnetic anomalies. Initially the magnetic anomalies were modelled using polygonal bodies whose shapes, sizes, depths and magnetic susceptibilities were iteratively adjusted to provide the best fit to the observed data. In the absence of any data to the contrary, the direction of magnetization was assumed to be the direction of the Earth's present field. Gravity modelling was similarly carried out using appropriate density contrasts and similar shapes. Ultimately, however, it was found that it was feasible to do integrated modelling of both magnetic and gravity anomalies simultaneously with shape parameters, susceptibilities and densities which would satisfactorily fit both the observed magnetic and gravity data. This approach can be expected to give better and more realistic models. These combined models are shown in Figures 3, 4 and 5 for profiles PBEL3, PBEL4 and PBEL5 respectively. On profile PBEL3 the model consists of a main polygon (Polygon 1 in the figure) approximately 120 m wide, with a depth extent from 5 m to 105 m, a susceptibility of 0.0125 cgs and a density of 3.55 gcm^{-3}. The two smaller adjacent polygons have a susceptibility of 0.0018 cgs and densities of 3.50 and 3.55 g cm^{-3} respectively. Model PBEL4 shows one irregularly shaped main body with a susceptibility of 0.0125 cgs, a density of 3.50 gcm^{-3} and a depth extent of 5 m to 100 m. Two smaller adjacent bodies with a density of 3.55 g cm^{-3} and susceptibilities of 0.0018 and 0.0016 cgs respectively are needed to adequately model the finer features of the anomalies. Profile PBEL5 gets a bit more complex, showing a wider irregularly shaped main causative body with a susceptibility of 0.0125 cgs, a density of 3.55 gcm^{-3}

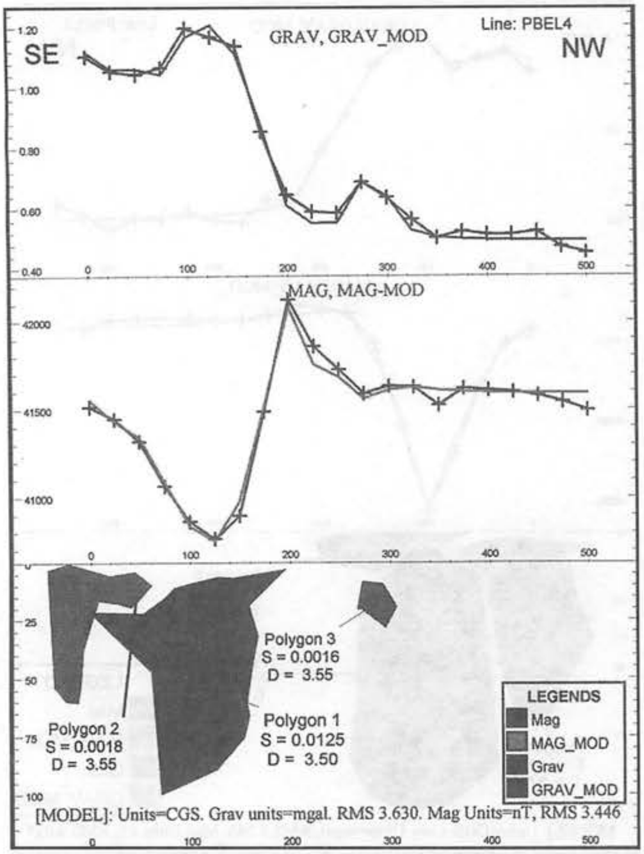

Figure 4. Combined gravity and magnetic modelling of Profile PBEL4. (Horizontal units are m; vertical units are mgal, gamma and m respectively)

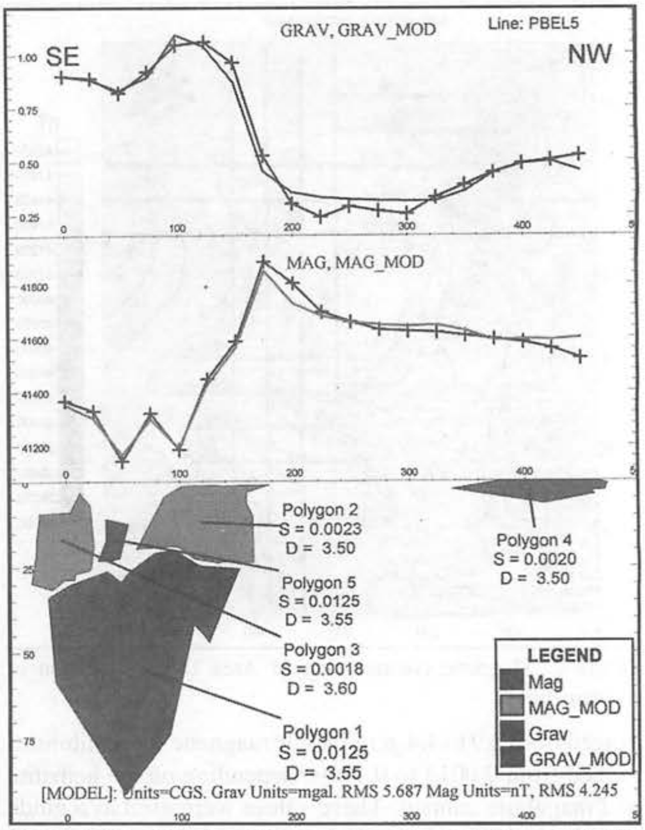

Figure 5. Combined gravity and magnetic modelling of Profile PBEL5. (Horizontal units are m; vertical units are mgal, gamma and m respectively)

and a depth extent of 20 m to 85 m. Four other smaller polygonal bodies are required, including a near-surface one at the northwestern end to account for the small positive gravity anomaly there.

Ideally, the three profiles should have been modelled together three-dimensionally but the software used, unfortunately, could not handle this level of sophistication. One has to bear in mind, however, that these computer models are meant to provide a very general overall picture of the physical parameters of the causative bodies. One also needs to mentally link the models from profile to profile which are spaced only 40 m apart. Thus, in this sense, one should not see too much into the finer details of the shapes of the polygonal models but rather use them as a guide to get a general idea of the probable location, size, shape, orientation and depth extent of the causative bodies as well as their physical properties of density and magnetic susceptibility.

The resistivity models for these three profiles are shown in Figure 6. Comparing them to the models obtained from the magnetic and gravity data, the southeastern end (left on the profile) of line PBEL5 shows a highly resistive zone (more than 500 ohm-m) at depths of between 5 m and 50 m (approximately) which corresponds to the causative bodies of the magnetic and gravity anomalies. However, the highly resistive zone near the northwestern (right) end of the profile has no magnetic or gravity expression, being offset about 100 m to the southeast from the small positive gravity anomaly. The smaller resistive zones at and near the surface can be attributed to irregular patches of laterite observed along the traverse. Profile PBEL4 shows a small highly resistive zone (more than 500 ohm-m) about 150 m to 220 m from the southeastern end and between 5 m and 25 m in depth. This coincides approximately with the topmost portion of the main causative body of the magnetic and gravity anomalies. The deeper horizons, however, become more conductive. This may be attributed to presence of groundwater and/or clay. At the southeastern end of PBEL3 is a low resistivity zone (less than 100 ohm-m) where the ore body is supposed to be. This relatively conductive zone is most likely due to groundwater. A deep old mining pool is situated close to this end of the profile. Below this conductive zone, from a depth of about 30 m, the resistivity increases rapidly downwards to over 500 ohm-m at a depth of approximately 50 m. This is consistent with the probable presence of the ore body there.

DISCUSSION AND CONCLUSION

A significant magnetic anomaly exists in an unmined location in Area D. Coinciding with this magnetic anomaly is a gravity anomaly. Both anomalies are amenable to integrated magnetic and gravity modelling using polygonal

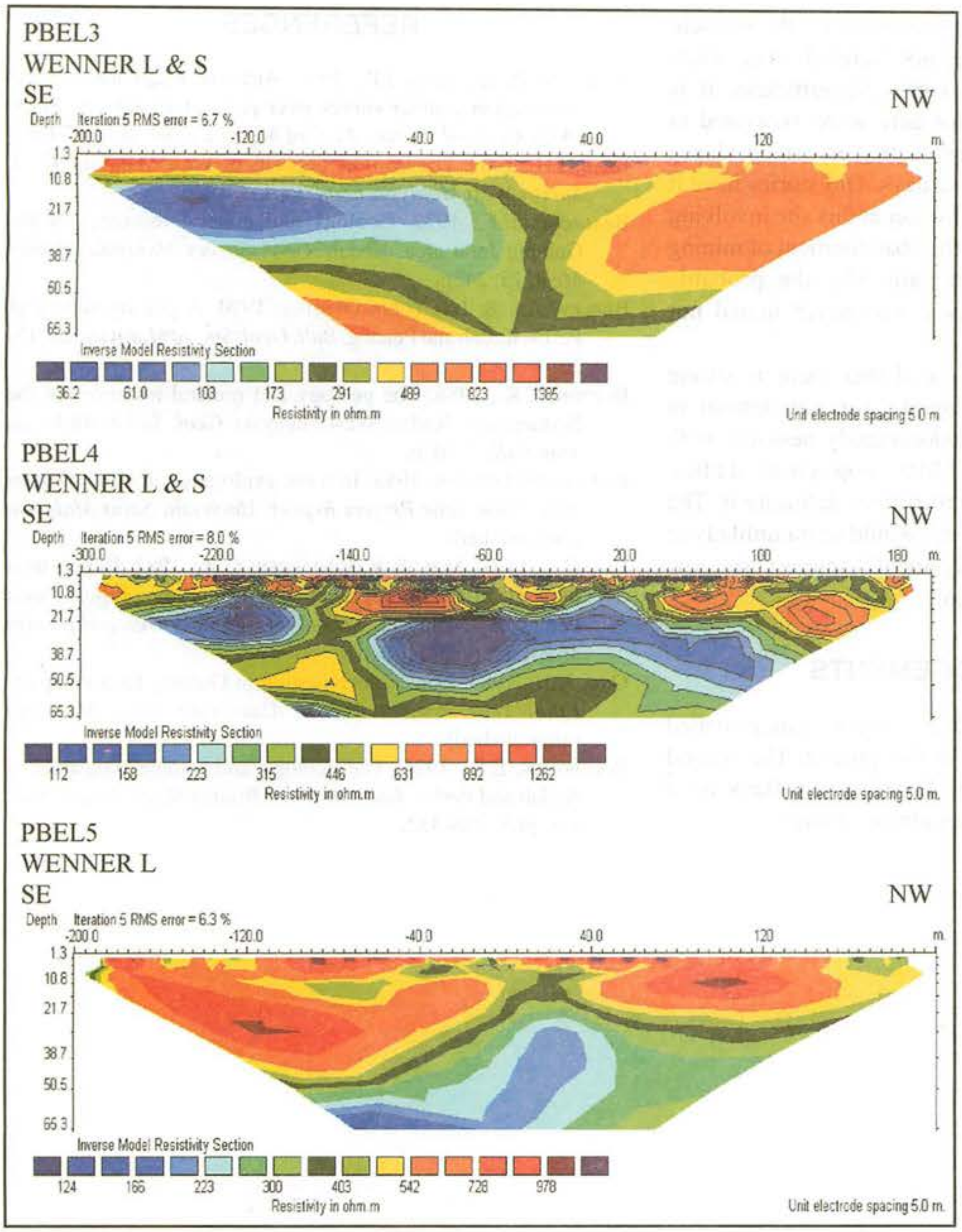

Figure 6. Resistivity models for Profiles PBEL3, PBEL4 and PBEL5.

bodies as sources. The rather complex combinations of three to five bodies for profiles PBEL3, PBEL4 and PBEL5 should not be taken too literally but rather as an indication of spatial variations in densities (from 3.50 to 3.60 gcm^{-3}) and magnetic susceptibilities (from 0.0016 to 0.0125 cgs) of a very irregularly shaped three-dimensional ore body. These values of density and susceptibility are typical of hematite ore samples collected from the old mines in the vicinity. The relatively low values of susceptibility, and hence the relatively small amplitude of the magnetic anomaly, reflect the fact that the ore material here consists principally of hematite, with only minor amounts of magnetite found in isolated boulders or localized patches within the main ore bodies. Thus the range of values of susceptibility in the models represents these spatial variations in magnetite content.

The resistivity data are generally, but not completely, consistent with the magnetic and gravity interpretation. This is due to the fact that other factors, such as water and clay content, also come into play in the resistivity pseudosections. Thus one would not expect to see an exact correspondence between these two types of anomalies arising from different physical attributes of these highly weathered residual deposits.

The polygonal models mathematically represent probable iron ore bodies in the subsurface. Positive confirmation would require expensive drilling. Unfortunately, no boreholes have been drilled in this area or its immediate vicinity by the mining company or any other organization, as far as can be determined. However, seismic methods can be used to more precisely delineate the ore body.

The presence of three old mining pools adjacent to Area D is evidence of past mining activities here. However, according to the current mine management the anomalous area itself has never been mined. No records of these past mining activities are in the possession of the present management since they were not handed over when ownership changed hands in 1980. Nevertheless, it is believed that the old mine holes here were excavated in the 1960s and were very deep, with very steep slopes which were not benched in those days. Old stories have it that there was indeed a mining disaster at this site involving a collapse of slopes, leading to the abandonment of mining activities here. This could explain why the probable sizeable ore body discussed here was never mined nor prospected.

In conclusion, it can be stated that there is strong geophysical evidence for a sizeable iron ore deposit in Area D. This appears to be predominantly hematite with minor amounts of magnetite. More geophysical studies, including seismics, are needed to further delineate it. The ultimate confirmation, by drilling, would seem unlikely at this time since the mine management's interest has now shifted to property development.

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