Radiometric and magnetic methods applied to identification of anomalous heavy minerals concentrations in beach ridges in the northern state of Rio de Janeiro, Brazil

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Abstract

This paper presents the results of geophysical survey in beach ridges to identify anomalous heavy minerals concentrations. The magnetic and radiometric surveys were conducted simultaneously. The interpretation and modeling of the data have indicated that the magnetic anomalies associated with the concentrations of ilmenite are small in amplitude (5 nT), but its modeling can be allow in terms of depth. The results show magnetic sources at different depths in the same location. The concentrations in zircon and monazite were identified by the method of radiometric total count. Moreover, the radiometric crests observed at the site of investigation corresponding to the top of the ridges, and there is a correlation between the concentrations of radioactive minerals and ilmenite. The superposition of magnetic and radiometric sources presents NE-SW direction, which should correspond to the main direction of the beach ridges.

Introduction

The Brazilian Nuclear Industries (INB) have an area of exploitation of minerals rich in iron and titanium (ilmenite and rutile) and radioactive minerals (zircon and monazite) in the north of the Rio de Janeiro state (Brazil) (Figure 1). The ore is hosted in sedimentary rocks deposited in marine terraces in the region between the mouths of the Paraiba do Sul and Itabapoana rivers (Figure 2). This work aimed to define a research strategy to guide the exploration geophysics and locate new deposits. A magnetometer and radiometric survey was conducted to detail a contiguous area of an active mining front. The main aim of this survey was to identify anomalous concentrations of ilmenite, zircon and monazite that occur within the ridge of sandy layers. Ilmemite has a magnetic susceptibility whose intensity allows the detection by magnetometers. However, we must be alert to the fact that in this type of survey is possible detect deeper sources magnetically predominantly, which are more intense those have been searched in this survey, so much of the measured signal originates from deeper sources.

Geological Context

In the central part of the Brazilian coast occur larges plains, some of these are located near the mouths of rivers. These plains are characterized by long beach ridges constituted by sedimentary rocks that were deposited on ancient beaches, which are formed by the rise of the sea (8 ± 2 m above current sea level) in the Pleistocene (120,000 years ago) (Flexor et al., 1984).

There is a vast plain with beach ridges in the northern region of the state of Rio de Janeiro (Figure 2). Ridges in the delta of the Paraiba do Sul river are well developed and have maximum widths of up to 20 km (Figure 2). The region where this study was conducted is situated at the northern of the delta. The set of beach ridges has much less expressive width, of a maximum of 1.5 km. They exhibit direction approximately NE-SW in this area as can be seen in Figure 2.

According Flexor et al. (1984) there are two basic designs for the formation of ridges from: i) a high crest of sand and ii) an ante-bar sand. In both cases (Figure 3), you can verify that the retreat of the sea leaves a small elevation in asymmetric topography, which corresponds with the position of the old beach and the package of sediments is thicker. This topographic crest, however smooth, nowadays can be identified as an ancient beach line over long distances.

Together with the sandy sediments from rivers that old beaches have received from the erosion of the gneiss and granitic rocks were also deposited heavy and resistant minerals. In this case an anomalous concentration of ilmenite, rutile, monazite and zircon was formed. These concentrations occur as thin layers or pockets intercalated into sandy layers.

Method

The magnetic and radiometric surveys were conducted simultaneously. The survey was conducted through profiles with NW-SE direction, transverse to the direction of advancement of an active mining. Thus, the profiles were located spaced 20 m from one to another in the direction 292°Az, with stations spaced of 5m (Figure 4). In the 21 surveyed profiles were performed 955 simultaneous radiometric and magnetic measurements (Figure 4).

In the radiometric survey was used total count, which is the sum of all environmental radioactivities in counts per second (cps). For this, it was used a scintillation GR-110G/E. Throughout the measurement, the operator of the equipment had remained the sensor at an average of

Figure 1 - Geographical localization of the studied area.

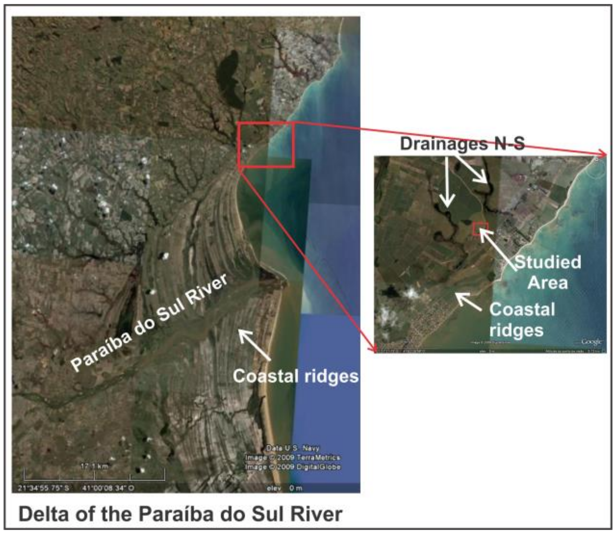

Figure 2 - The studied area in the delta of the Paraiba do Sul River. Observe the extensive area of beach ridges that occur in the delta plain. In the northern part of the delta, in the studied area, the beach ridges occupy a relatively minor region. In particular, observe that the studied area is situated between two drainages with N-S direction.

approximately one meter of distance from surface. In this survey, the goal was to identify anomalous concentrations of zircon and monazite located within the sandy layers of costal ridges. However, unlike the magnetic method, the research is limited to the soil surface. It is a consequence of the must of deeper radiation sources can be suppressed by the presence of non-radioactive obstacles (such as no mineralized quartz sand) situated between the sensor and the source.

In the magnetic survey the magnetic susceptibility (k) is the parameter that allows recognizing as a rock can be magnetized by the Earth's field. In the case of ilmenite the average value of k is 0.0018 SI (Telford et al., 1990). Measurements made with a Kappameter KT9 in a sample of ilmenite showed a mean value of 0.002 SI. However, the measured values of k in a sample of rutile were on average 10 times lower, but it still is within the detection level of equipment. The magnetic survey was conducted to measure the magnetic total field of the earth with a magnetometer type GSM-19TG and the vertical gradient of the total field with sensors vertically separated by a distance of 100 cm.

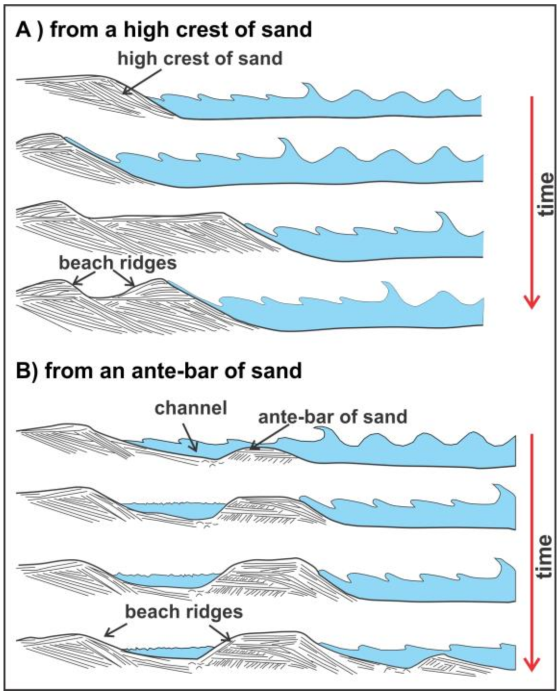

Figure 3 - Two possible evolution models to formation of beach ridges from evolution of a beach submitted a regression process of the shoreline over time. Adapted from Flexor et al. (1984).

Figure 4 - Localization of measuring stations. There were 955 simultaneous measurements of radiometry and magnetic data, with an interval of 5 m along the profiles. The region without reading at the time the survey was flooded.

Results

The radiometric raw data were interpolated by minimum curvature method in a square mesh size of 5 m. The result is shown in Figure 5. Because of the absence of spurious alignments was not necessary to perform additional processing. In interpolated grid (Figure 5) it is observed that in the E-SE of the area there are two paired anomalous alignments with NE-SW direction (the direction of the coastal ridges in this region), in which the crests have anomalous peaks up to 1,000 cps. In the W-NW area are not observed significant alignments, except for weak N-S direction. In this region of the area the radiometric values fall sharply and reach minimum values of 70 cps.

The magnetic data were interpolated by the minimum curvature method in a square mesh size of 5 m. For noise removal has been used a directional cosine filter (figures 6 and 7). In figures 6 and 7 is observed that in total field grids occur N-S alignments, which should have geological origin. But they are not compatible with the known ridges directions. It was very evident that the ridges directions are NE-SW in the radiometric data, related to the rocks that contain radioactive minerals (Figure 5). As in this case there is a consortium between the radioactive minerals and ilmenite, it is obvious that the source of the magnetic alignments N-S has no origin in pockets or layers contained in ilmenite placers investigated. This issue can be resolved as follows: (i) assuming that the N-S magnetic alignment comes from magnetic sources deeper than the ilmenite mineralization and (ii) explaining the origin of these sources.

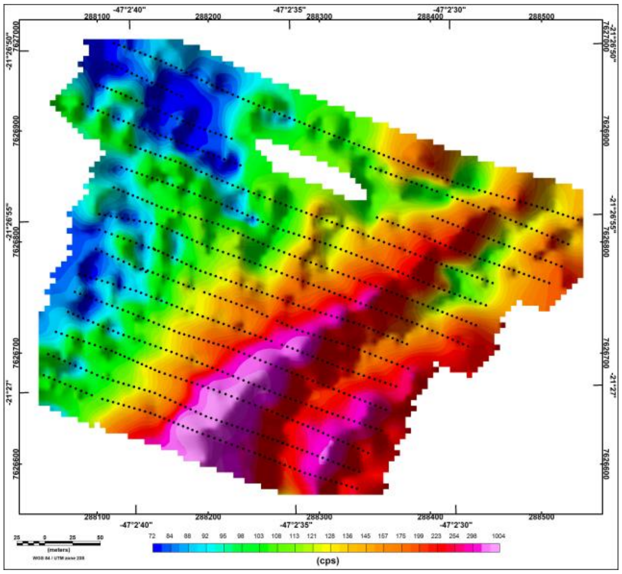

Figure 5 - The total count radiometric data. Observe that two crests occur in the eastern of the radiometric map. Possibly, they are related to the top of ridges.

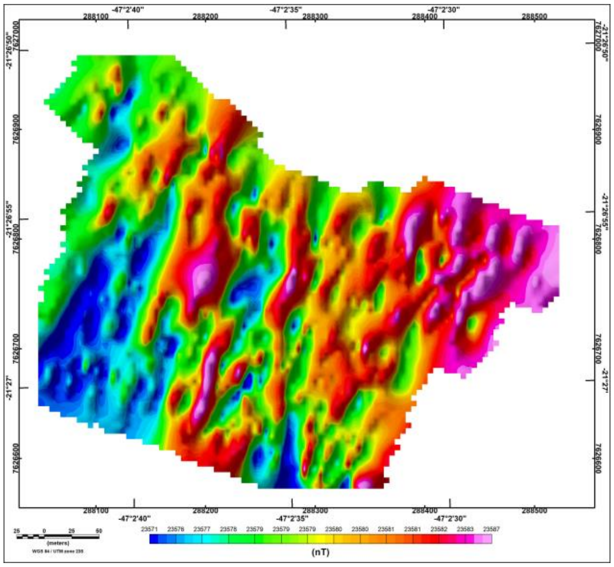

Figure 6 - The total magnetic field data corrected for diurnal variation and filtered to remove the directional noise. Observe the existence of N-S alignments produced by deeper more intense magnetically sources than the signal of the ilmenite concentrations.

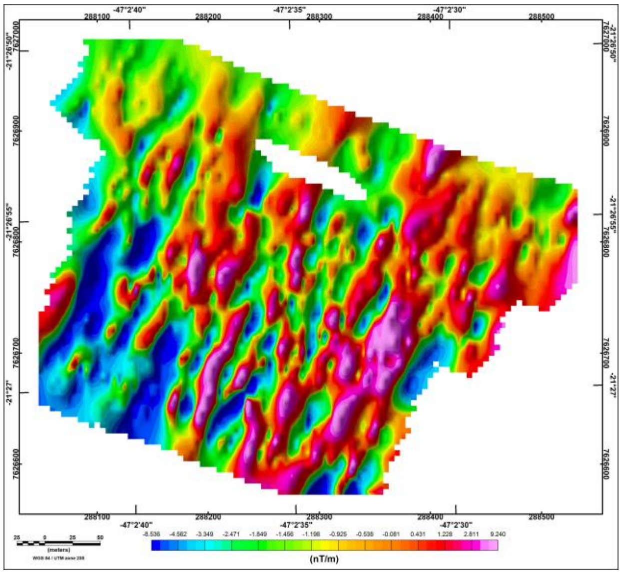

Figure 7 - The vertical gradient of the total magnetic field data filtered to remove the directional noise. Observe the existence of N-S alignments produced by deeper more intense magnetically sources than the signal of the ilmenite concentrations.

The shoreline in the Paraíba do Sul river delta has approximately N-S direction. The studied area is located between two drainages with N-S direction (Figure 2). So we can assume that a geological event with N-S direction and is older than the formation of ridges (possibly the formation of the Mesozoic continental margin) may be the source of the N-S magnetic alignments. This event can be printed on the substrate crystalline or Cenozoic sediments which occur stratigraphically below the ridges. These drainages can have their directions controlled by N-S geological structures.

Based on these interpretations was made a filtering of magnetic alignment with N-S direction. The results are shown in Figures 8. In this figure can be clearly seen the existence of magnetic sources aligned in NE-SW direction, in accordance with the directions of the coastal ridges and radiometric anomalous trends. The maximum amplitude is small anomalies (5 nT), but consistent with the presence of weakly magnetic minerals (as is the case with ilmenite) dispersed in a host rock devoid of magnetism (as is the case of quartz sand).

Data modelling

Until now the magnetic data were treated qualitatively and these interpretations are totally valid. However, interpretations of geophysical data gain greater consistency when dealing quantitatively. Namely, when the data are added anomaly numeric parameters such as the depth of a source. In this case, a three-dimensional inverse modeling method called 3D Euler Deconvolution. In this modeling the apparent depth of a magnetic source can be derived from the Euler equation homogeneity (Euler deconvolution). The process relates the magnetic field and the gradient components for locating the anomalous sources, with the degree of homogeneity expressed by a structural index (SI), which is a measure of the rate of decay of the magnetic field function of the distance from its source (Reid et al., 1990).

The Euler deconvolution method was applied by means of routine calculation developed by Mushayandebvu et al. (2001) available in Oasis Montaj software. (Geosoft ®). The procedure adopted solutions to calculate a target (magnetic anomaly) that can be geologically interpreted in accordance with the selected structural index (SI). In this case was employed structural index SI = 1 (threshold), which is the index that best fits the style of mineralization (layers). After some tests, the procedure was configured for a window size of three cells (each 5 x 5 m) and tolerance of 15% of maximum error. The end result was filtered to eliminate the solutions with depths greater than 8 m, considering that deeper sources than this value would not, at present, prospective interest.

Discussions and conclusions

The results of modeling are superimposed on the filtered total field magnetic grid (Figure 9). The depth solutions for each target are graphically presented as small squares, with size proportional to its depth (see caption). As expected, the solutions have alignments in the magnetic anomalies trends. The solutions depth modeling occurs over the magnetic negative axes, as it normally takes place in regions of low magnetic latitude. Can be also observed that occur a superposition of solutions in different depths. It indicates that at the same point can appear ilmenite concentration at different depths, as expected in stratified rocks.

Giving consistency to the results of the modeling, it was done a superposition of solutions with the analytical signal of total magnetic field (Figure 10). This transformation technique in low magnetic latitudes allows the visualization of magnetic sources as a single positive (MacLeod et al., 1993). This transformation permits the interpretation that the magnetic source is near the center of the positive pole facilitating the geophysical interpretation. Moreover, it emphasizes the shallower sources that naturally have higher prospective interest. As can be seen in Figure 10, the agglomerates of depth solutions in most cases are on the positive peaks of the analytic signal.

Finally, the modeling result was correlated with the radiometric data (Figure 11). In this case, it is important to have an understanding of the fact that the data reflect radiometric surface sources (as previously discussed). Possibly the radiometric alignments correspond to the top of the coastal ridges. With the reworking of the soil, which occurred after the formation of the beads, modifying the ancient topography, filling the channels (Figure 3) by younger sediments not mineralized. In this context, the radiometric alignments are an important prospective tool, because they can indicate the locations where the mineralization is shallow. In this correlation, another important aspect is the coincidence of the results of quantitative modeling of magnetic anomalies with radiometric crests. The cases where there are magnetic sources without radiometric sources can be interpreted in two ways: (i) the radiometric source is deeper and so its signal cannot be detect on the surface, or (ii) the placers are rich in ilmenite, but are poor in zircon and monazite.

Acknowledgments

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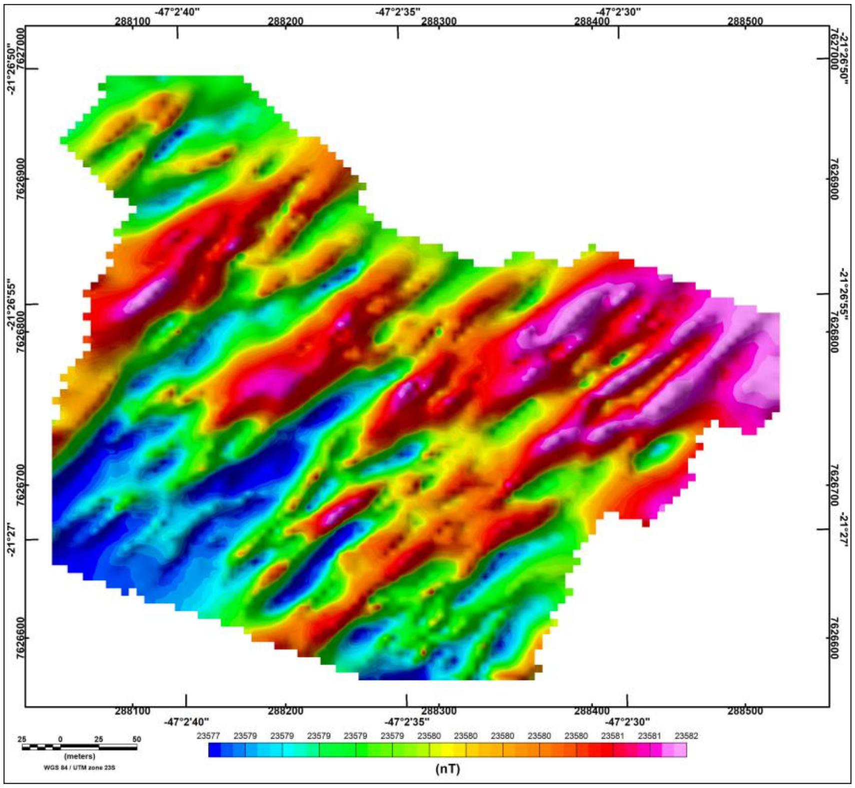

Figure 8 - The total magnetic field data corrected for diurnal variation and filtered to remove the directional noise and N-S alignments produced by deeper sources, magnetically more intense than the magnetic anomaly of the ilmenite concentrations.

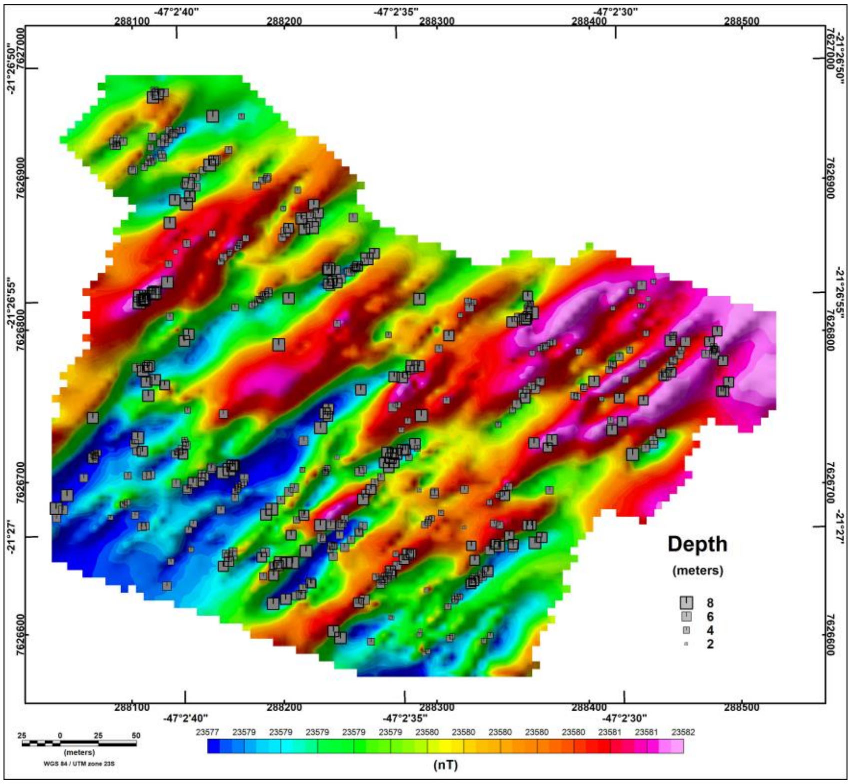

Figure 9 - Euler deconvolution results superimposed on the filtered total field magnetic anomaly grid. The depth solutions for each target are presented graphically as small squares with size proportional to its depth (see caption).

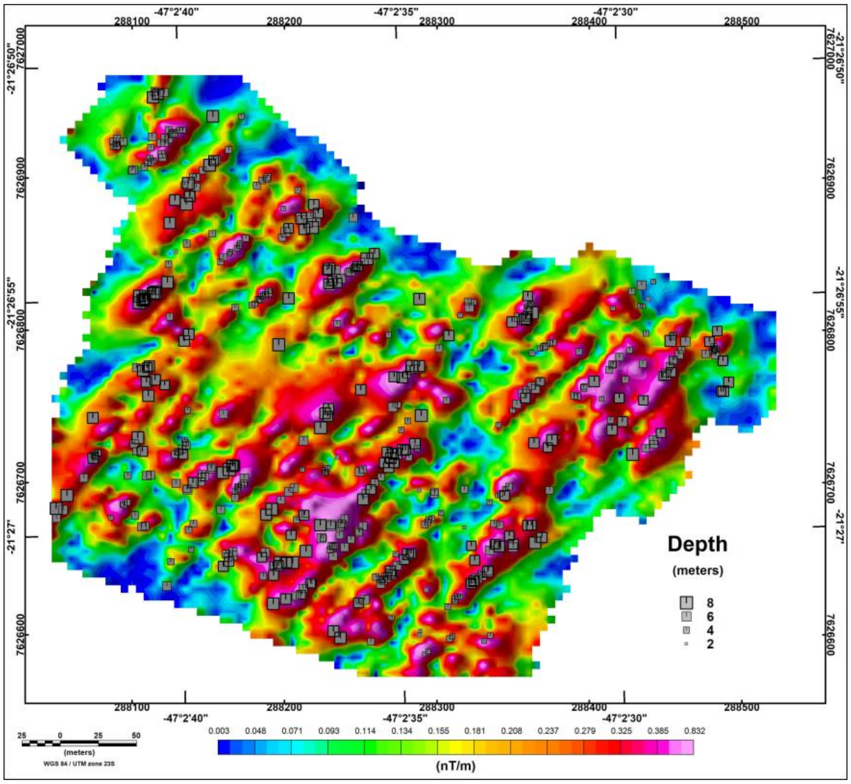

Figure 10 - Euler deconvolution results superimposed on the analytical signal of the total magnetic field anomaly grid. The depth solutions for each target are presented graphically as small squares with size proportional to its depth (see caption).

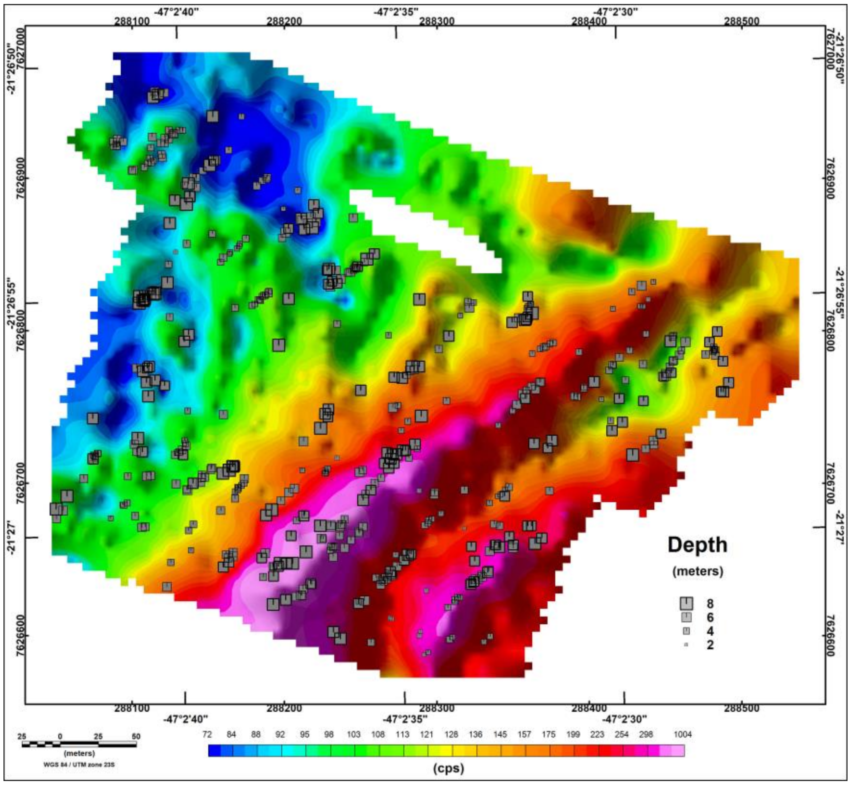

Figure 11 - Euler deconvolution results superimposed on the radiometric data grid. The depth solutions for each target are presented graphically as small squares with size proportional to its depth (see caption).