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RADIOMETRIC AND MAGNETOMETRIC STUDY OF THE LAGOA REAL URANIUM PROVINCE, BRAZIL

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ABSTRACT

The 3D Euler Deconvolution is a potent technique to locate regional magnetic sources. This data, associated with the regional uranium count through their radioactive properties can lead to a fuller characterization of the geological structures associated with uranium mineralization zones. In this paper, the Lagoa Real Uranium Province in Brazil, whose radiometric and magnetic data were the base to determine strategic points, was studied to advance a new local research looking for the nuclear fuel. Uranium radiometric anomaly and Euler Deconvolution maps were made. The superposition of these maps showed the most interesting regions for promotion of local research.

KEYWORDS: *Radiometry, Magnetometry, Uranium Research, Lagoa Real Uranium Province*

I. INTRODUCTION

Brazil has important uranium reserves and dominates almost all the technology of the nuclear fuel production cycle. In addition, Brazil has recently become a group member of the few countries that develop the uranium enrichment process through the ultracentrifugation. Only few countries possess a strategic combination of the ^{235}U enrichment technology and large uranium reserves such as Brazil. All this mixed with the recent utilization of nuclear submarines and heavy demand for uranium by Angra I and Angra II power plants promote the hard requirement of studying and reevaluating the Brazilian uranium reserves [1].

The Lagoa Real Uranium Province is situated in the State of Bahia. It was discovered after airborne surveys from studies of uranium in the Quadrilátero Ferrífero. It plays up the pioneering surveys carried out at the regional scale: Espinhaço Septentrional Project (1975), Diamantina Project (1976) and Urandi Project (1976/1977). The strong uranium radiometric anomalies obtained of Lagoa Real Province enabled the implementation of São Timóteo gamma spectrometry and magnetic survey in the year of 1979. This survey corroborated the existence of uranium occurrence series [2].

Since the execution of the Lagoa Real Project in 1978, ten prospecting areas in the course of 12 radiometric anomalies were considered deposits. The appraisal for these areas is a heritage of more than 100,000 tons of uraninite (U_3O_8), with a level of 2,100ppm (parts per million) [3]. The information received from the São Timóteo Project through CPRM (geological survey of Brazil) comprises a great deal of magnetic and gamma spectrometry data. These data provide a capital chance to hold out a combined study involving different physical realities (magnetism and radiation) of rocks in an area of large economic interest and with reservations in exploration. Pascholati *et al.* (2003) [2] correlated gamma ray spectrometric data of uranium, thorium and potassium with geological data and remote sensing. Santos (2006) [4] used the same radiometric data for environmental studies in radiation dose distribution absorbed in the air. Guimarães and Hamza (2009) [5], by employing techniques such as vertical derivative, analytic signal and Euler Deconvolution, identified several faulting regions and structural features in the study area.

Thus, in this paper, Section 2 presents the characteristics of the subject area as location, topography, geology, some results of previous studies and the data used in this study. Section 3 summarizes the theoretical basis of Radiometry and Euler Deconvolution that were the techniques used in this study. Section 4 identifies the data processing and demonstrates the results using maps. Section 5 summarizes the principal results obtained and the endings of this paper. Finally, proposals for future work are suggested in Section 6.

II. STUDIED AREA CHARACTERISTICS

The Lagoa Real Uranium Province was found while doing a serial publication of aerial surveys, between 1976 and 1977, when 19 mineralized areas were distinguished. Later, another 14 uranium occurrence were identified in the region, totaling 33 cases that make up the backlog. The start of the mining and processing activities on the unit of uranium concentration (INB - Indústrias Nucleares do Brasil - Caetité) (Figure 1) started only from the year 2000 [6]. The uranium extraction occurs through the static leaching in ore piles of about 25,000 tons and can get up to 35,000t [7].

Figure 1. Uranium concentration plant (URA)

1-Wastewater tanks; 2-Jaw crusher; 3-Leaching yard; 4-Liquor tanks; 5-Industrial area and

6-Administrative area [7]

This area is located in the south-central mountainous region in the State of Bahia, Brazil. The Lagoa Real Uranium District is bounded by geographical coordinates with latitudes of $45^0$13'S and $14^0$13'S and longitudes of $42^0$04'W and $42^0$32'W. It is inserted in the quadrilateral formed by the Caetité, Lagoa Real, Maniaçu and São Timóteo counties [6].

The geology of the Lagoa Real Uranium Province is primarily composed of metamorphic rocks such as gneisses (Figure 2). The metasomatic albitite, which is the host rock of uranium mineral, is found as black regions on the map. The metamorphic basement called Lagoa Real Granite-Gneiss Complex (central range of the geological map) is the main interest area because a heavy portion of the radiometric anomalies are linked with the albitites. Structural features include albitite zones in form of arches and shear zones.

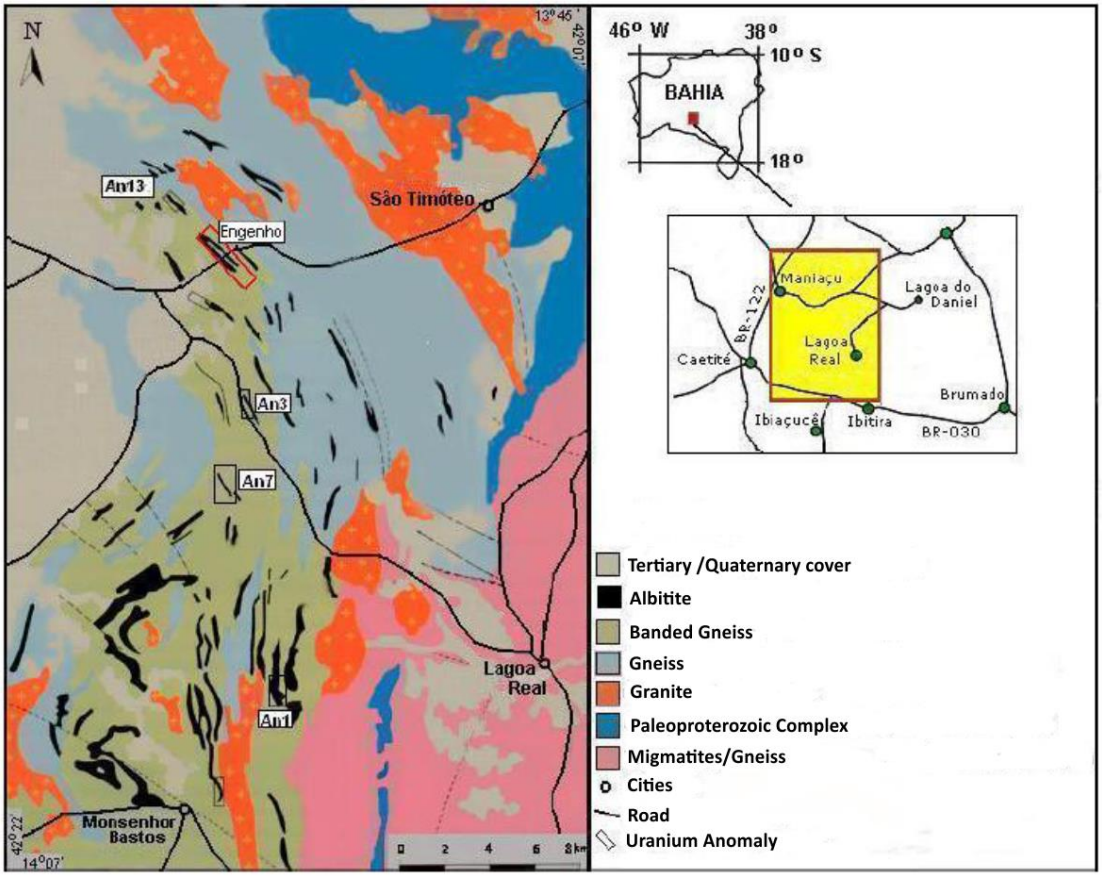

Figure 2. Geological map of the Lagoa Real Uranium Province [8]

The topographic map of the Lagoa Real region was taken through satellite data from TOPEX model V 18.1. The region topography is presented in Figure 3.

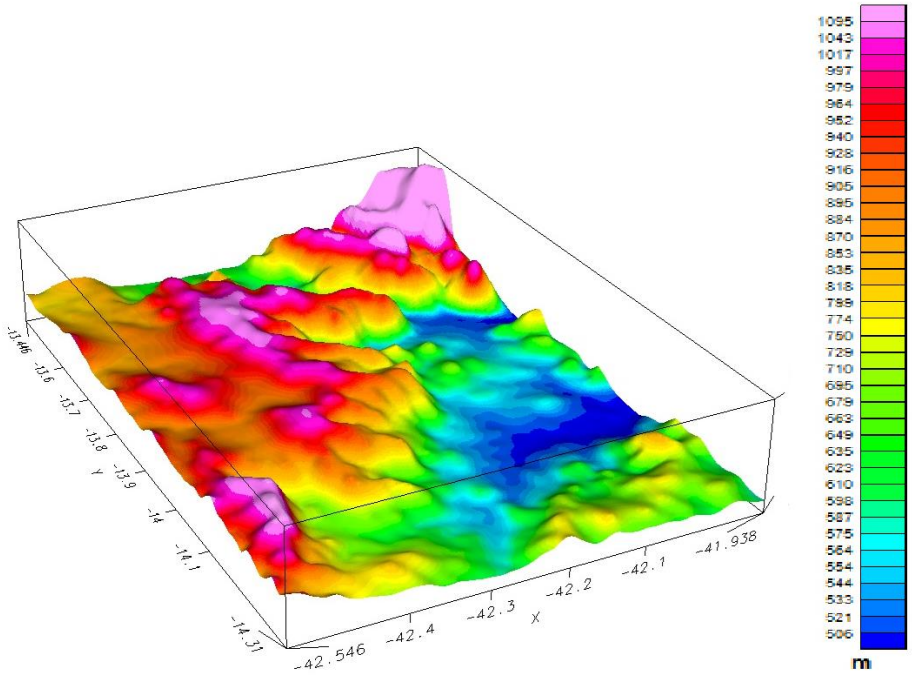

Figure 3. Topographic map of the Lagoa Real region

Local relief is composed of three main units: the unit plan, which is the high topographical; the unit slope that is the intermediate topography; and alluvial lowlands that occupy the gutters and flood plains of the main drainage of the region [7].

III. METHODS

3.1. Radiometry

Some isotopes of various elements may disintegrate spontaneously. In this process, they emit particles and electromagnetic radiation that can be detected and allow the source location. This phenomenon is known as radioactivity and stems from the core of unstable atoms. Therefore, the radiation is not thought a physical attribute, but a property of the atomic nucleus [9].

According Kearey, Brooks and Hill (2002) [10], the Radiometry studies the distribution of radioactivity in terrestrial materials. The method takes into account, in especial, the electromagnetic radiation emitted in typical energy windows for the Uranium, Thorium and Potassium (Figure 4) by nuclear disintegration.

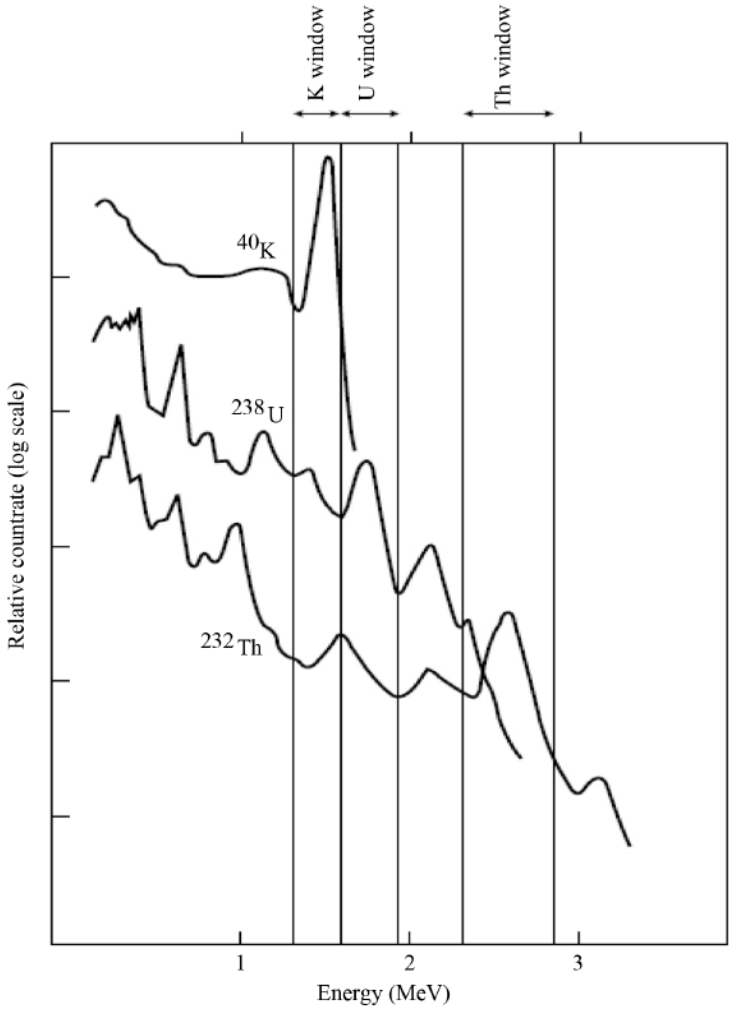

Figure 4. Typical power windows of Uranium, Thorium and Potassium detection [10]

Radiometric air surveys, usually maintained in concurrence with the magnetometric method, involve repeated measurement of gamma-ray spectrometry involving one or more detector mounted on a aircraft.

The data are adjusted to variations in elevation, atmospheric radon and cosmic microwave background radiation and processed to produce results expressed in counts per second or concentrations of potassium, uranium and thorium. The calibration data are collected over sources of known concentrations. So test flights over land regions of known concentrations and radiation levels are performed [11]. Despite the outstanding improvement in instrumentation, the interpretation of radiometric survey provides data mostly qualitative. This is partially due to the small depth (shallowness) penetration possible with the method [12].

According Kearey, Brooks and Hill (2002) [10], various sensor types are available for radiometric surveys. The answers are shown conventionally as the emission counts over a specified time. The principal ones are Geiger counter, scintillation counter, gamma-ray spectrometer and the radon emanation measurement system [13].

3.2. The Euler deconvolution process

The Euler Deconvolution 3D technique is a form of inverse modelling using the potential field spectrum of information that can be gravity or magnetism [14]. The method makes it possible to calculate the position, depth and also the nature of the potential field source of data evaluated:

$$(x-x_0)\frac{\partial F}{\partial x}+(y-y_0)\frac{\partial F}{\partial y}+(z-z_0)\frac{\partial F}{\partial z}=N(B-F) \quad (1)$$

in that (x_0, y_0, z_0) is the stance of the generating source whose total field F is measured at the point (x, y, z), B is called regional field and N is the index which is linked up to the morphological nature of the field source and its decay with the origin distance. By solving the Euler equation within a total field mobile window and its derivatives through orthogonal least squares, is possible to obtain the location (x_0, y_0, z_0) and their uncertainties for the structural indexes that are selected through the source geometry [15].

When the technique is applied, it is advisable to make a structural index according to the prospected source. The solutions with uncertainty exceed a specified threshold must be thrown out and the position of the sources is suitable when it comes about a low solution dispersion (Figure 5) [16].

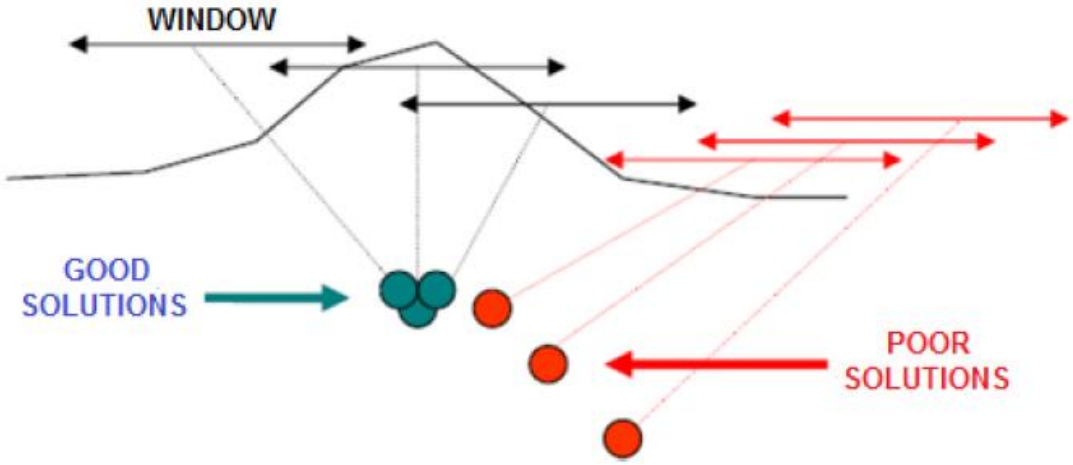

Figure 5. Quality of the Euler Deconvolution solutions [16]

According Guimarães (2009) [14], the N structural index represents a change rate measure of the anomalous magnetic field in the distance (Table 1).

Table 1. Structural Index in Euler Deconvolution [14]

(SI)	Geological Feature
0	Contacts
1/2	Faultings
1	Dikes and Sills
2	Pipes
3	Spherical Sources

The uranium mineralization occurrence in Lagoa Real is associated with arches and shear zones in the region [2]. The Euler Deconvolution technique, especially with the use of the 1/2 structural index, can be used in the identification of faults and shearing regions. So the mapping of uranium radiometric anomalies combined with the use of this technique can help in the identification of the uranium mineralization regions.

IV. RESULTS

The São Timóteo Project through CPRM (geological survey of Brazil) data were processed. They comprise a broad range of magnetic and gamma spectrometry data. The data processing was carried out through the OASIS/MONTAJ software. Radiometric data were calibrated and adjusted. It was likewise raised the uranium radiometric anomaly map of the Lagoa Real Uranium Province. The Euler Deconvolution technique was applied to magnetic data using several sizes of windows and the 1/2 structural index. The results of Euler Deconvolution were associated with uranium mineralization zones in the area.

4.1. Uranium radiometric anomaly

The used data were obtained with 500 m spacing between measurement profiles (line) and direction of the measurement lines in E-W. The sampling interval was 1s (60m). The gamma spectrometer was the DIGRS-3001 Exploranium with 1,017.87 cubic inch detector crystals (crystals of sodium iodide activated by Thallium).

The raw information (Figure 6a) received routine radiometric method corrections as height corrections (High Level and Low Level), Compton Effect, Background and also an application of microleveling (ButterWorth Filter). It was then prepared the map of corrected radiometric uranium anomaly (Figure 6b). These maps were processed through a cell of 125 m and minimum curvature interpolation.

The uranium radiometric anomaly ranged around from 6 to 40cps. It was noted that in the central region, the anomaly found is more substantial, ranging between 15 and 40 cps, approximately. At the border regions, the variation was between 6 and 15 cps, approximately, indicating a weaker anomaly.

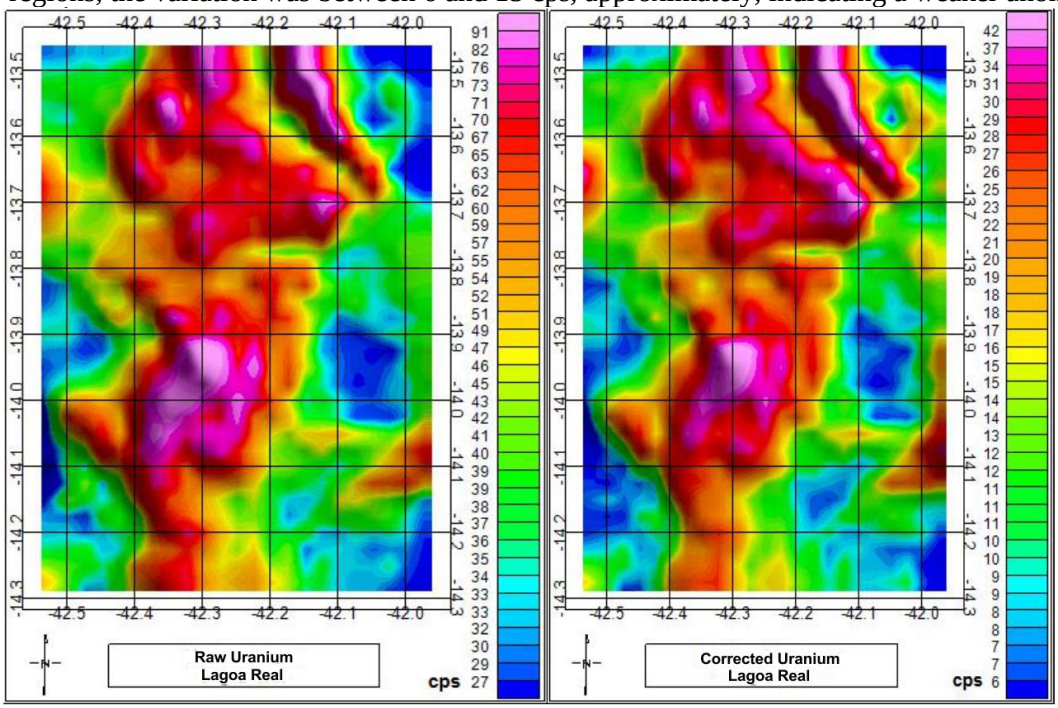

Figure 6. Map of raw uranium and corrected uranium counts

4.2. Magnetic data treatment

The used data were obtained with 500 m spacing between measurement profiles (line) and direction of the measurement lines in E-W. The sampling interval was 1s (60m). The magnetometer was the

Geometrics G-803. The maps were built with 125 m cells and minimum curvature interpolation. The acquired raw data (Figure 7a) received the diurnal variation correction related to the external magnetic field originating mainly from the Sun. Then, the corrected magnetic map by diurnal variation was obtained (Figure 7b).

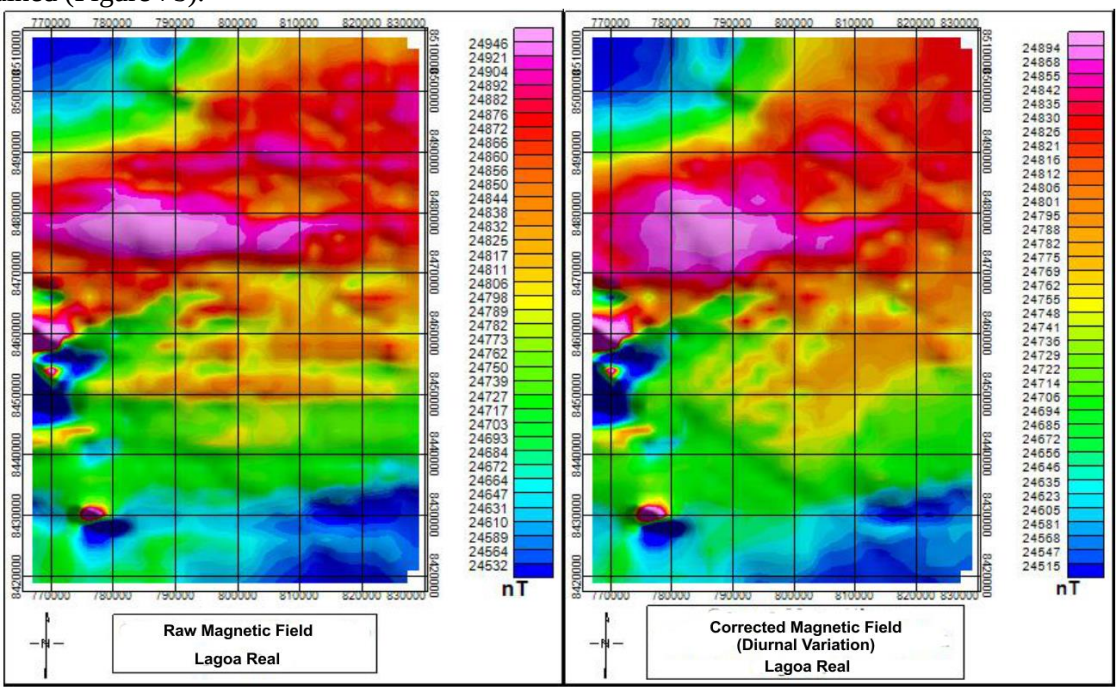

Figure 7. Map of raw magnetic field and corrected magnetic field (diurnal variation)

Afterwards on the removal of the core's magnetic field through the IGRF correction, the magnetic anomaly map was obtained. This map reveals the magnetism of the crustal rocks (Figure 8).

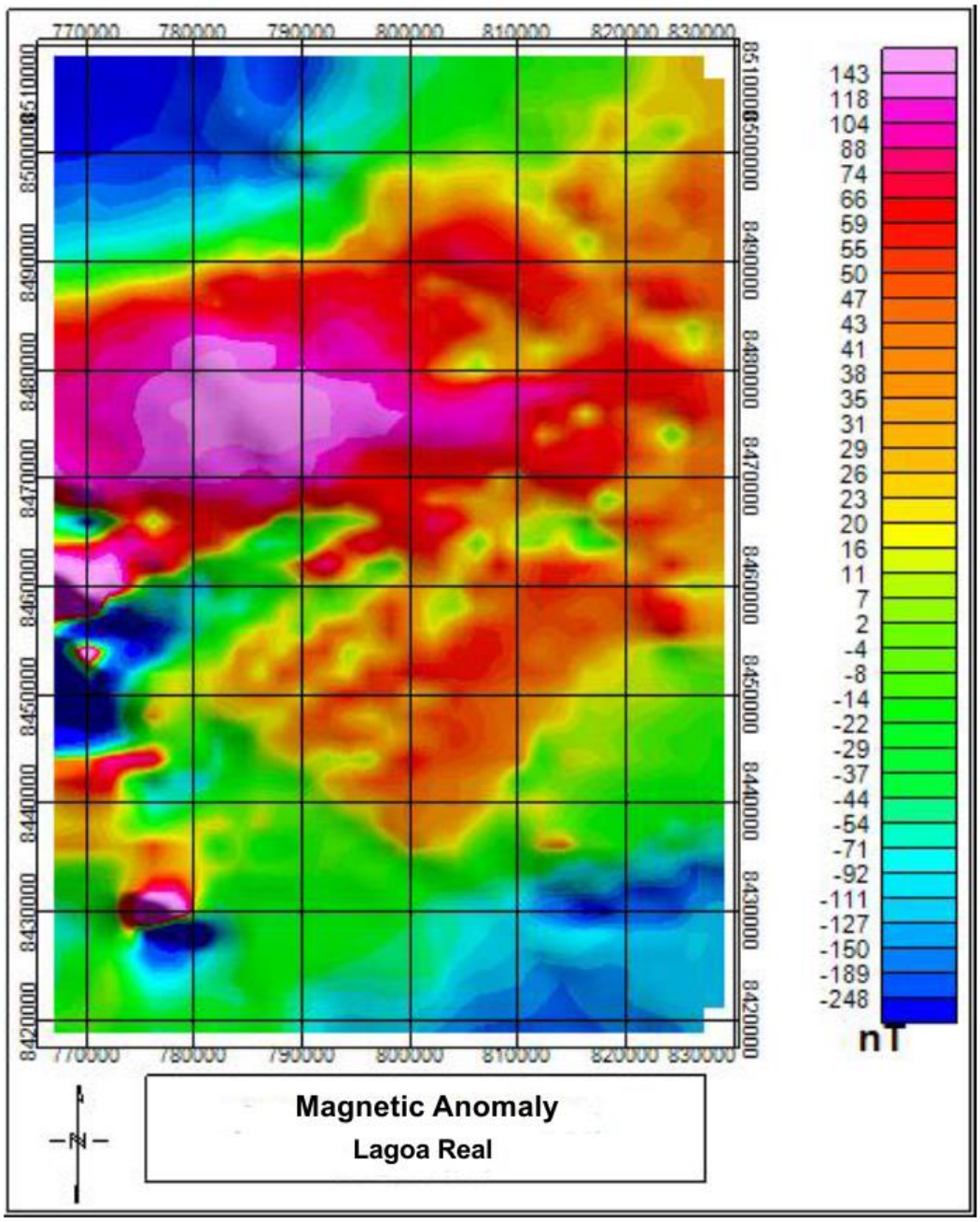

Figure 8. Magnetic anomaly map

The magnetic anomaly grid shown in Figure 8, that indicates the magnetism rising from crustal rocks, was used to carry out the Euler deconvolution of the area. For this procedure, it was used the 1/2 structural index which is able to observe regions of faults as arches and shear regions. As the uranium mineralization occurs in those regions, they were the research object.

The Euler Deconvolution was performed using windows of 20, 10 and 5 km and 20% tolerance to provide a great amount of solutions as shown in Figures 9, 10 and 11.

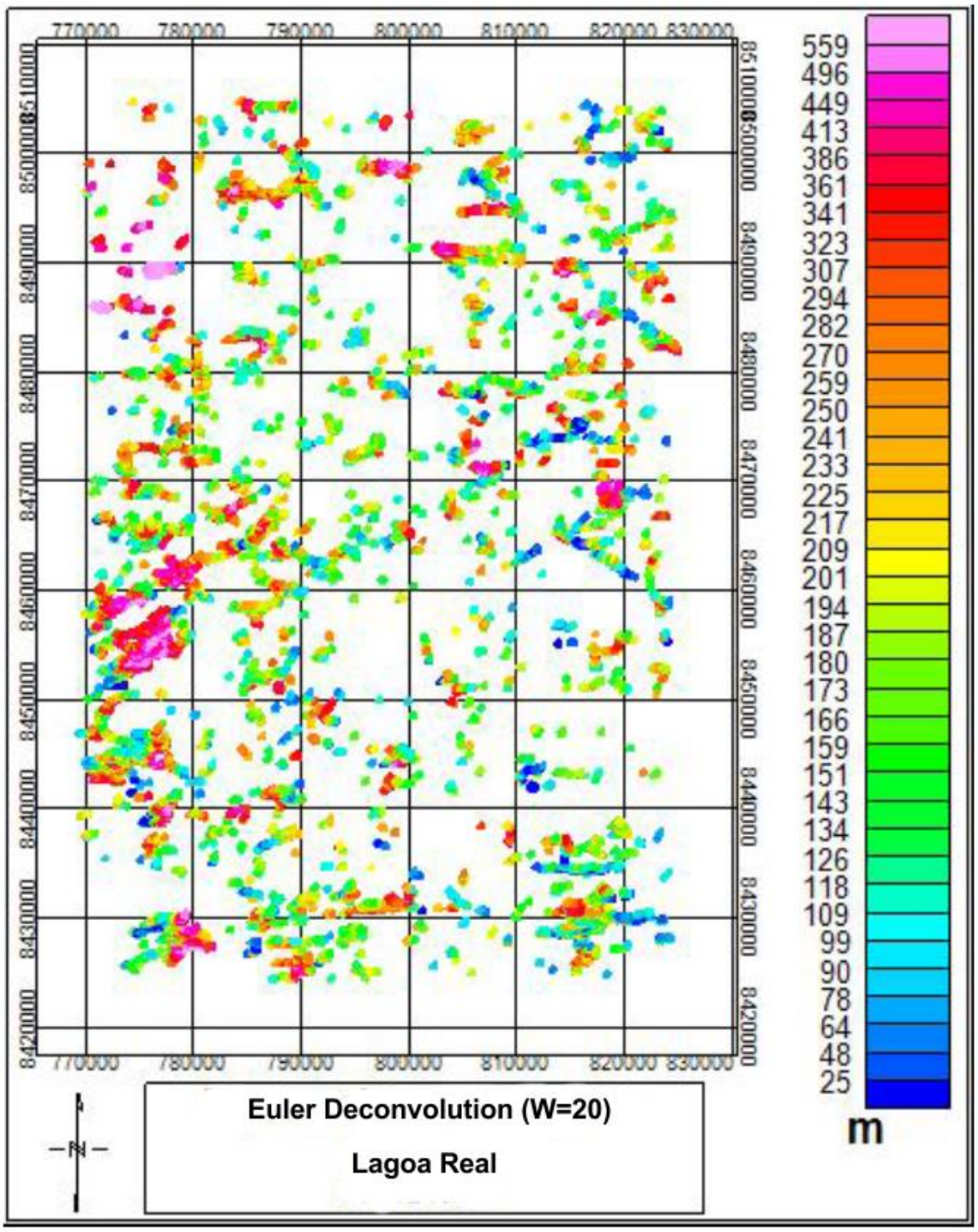

Figure 9. Euler Deconvolution map (W = 20)

The map of Euler Deconvolution with 20 km window (W) and 1/2 structural index allowed the recognition of faulty regions through major anomaly sources. The depths ranged from 25 m to around 560m. Most of the solutions were found in the range of 100 m to 200 m. Besides, there was a predominance of solutions in the west border and in the northeast.

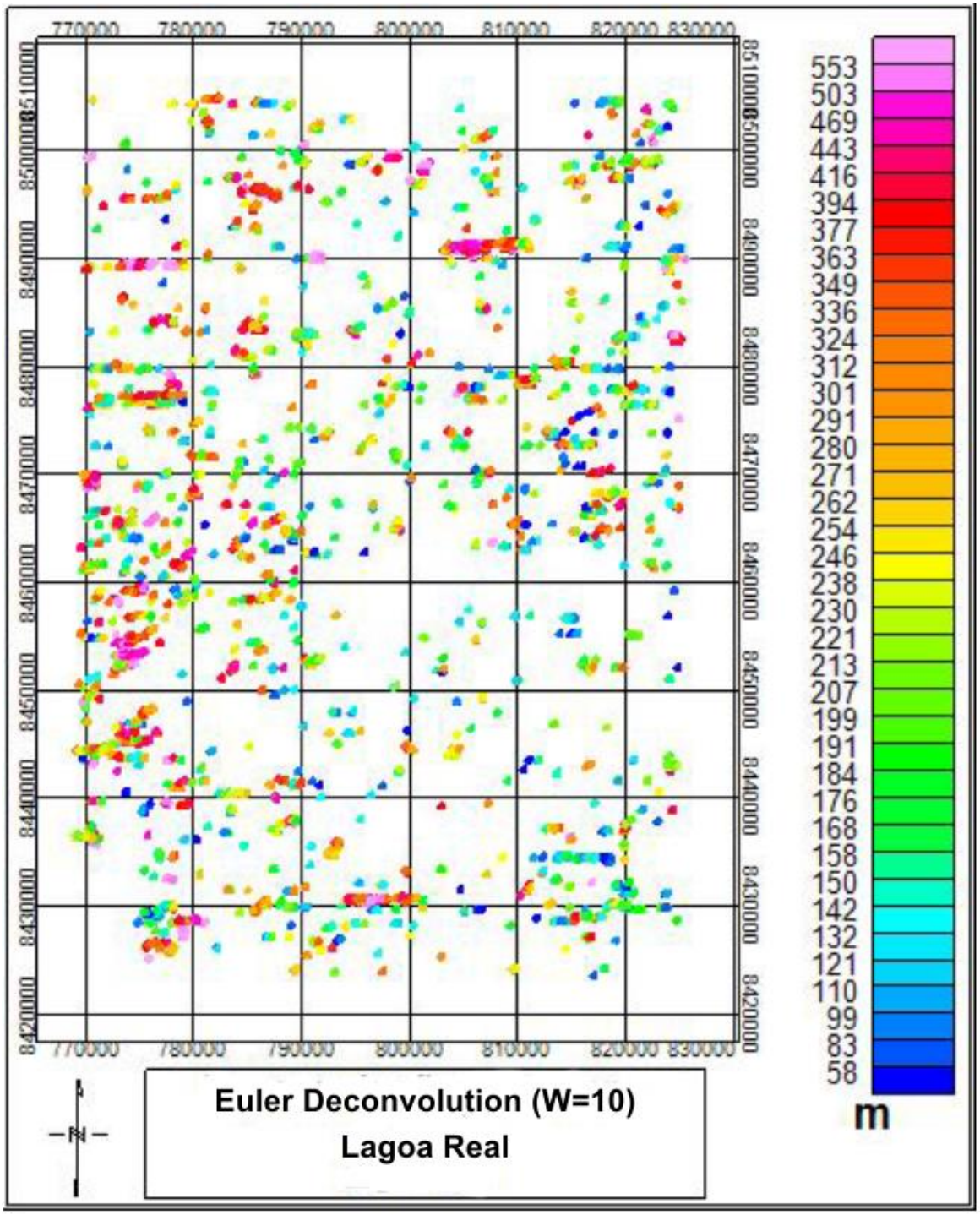

Figure 10. Euler Deconvolution map (W = 10)

The Euler Deconvolution map with 10 km window (W) and 1/2 structural index allowed the recognition of faulty regions through medium anomaly sources. The depths ranged from around 60m to 550m. As in Figure 9, there was a predominance of solutions in the west border and in the northeast.

The map of Euler Deconvolution with 5 km window (W) and 1/2 structural index allowed the identification of faulty regions through small anomaly sources. The depths ranged around 50m up to 380m. In general, there were no large concentrations of solutions in any region.

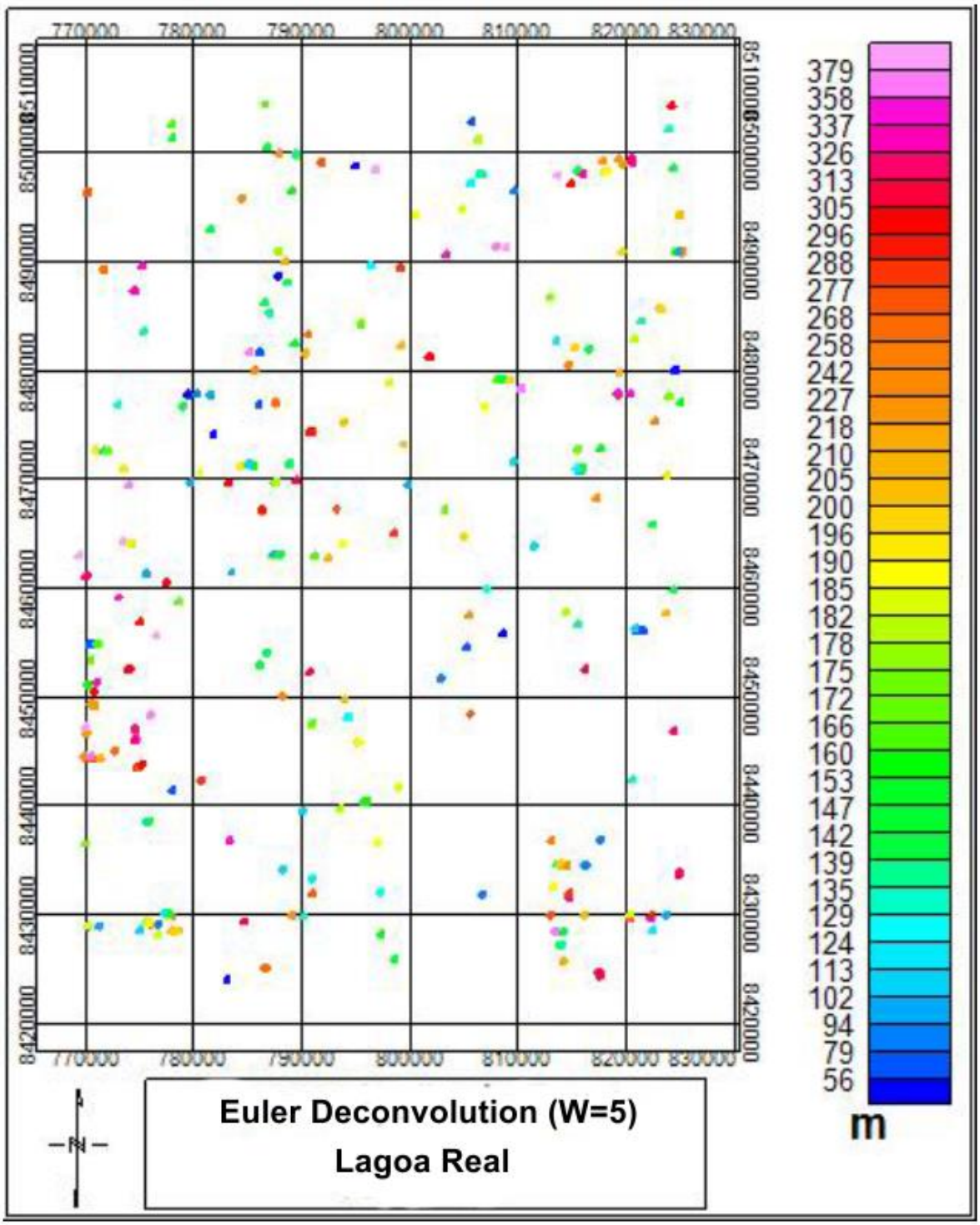

Figure 11. Euler Deconvolution map (W = 5)

Then it held the overlap of uranium anomaly maps with the maps of Euler Deconvolution only with the 20 km and 10 km windows that took in a bigger number of solutions as shown in Figures 12 and 13.

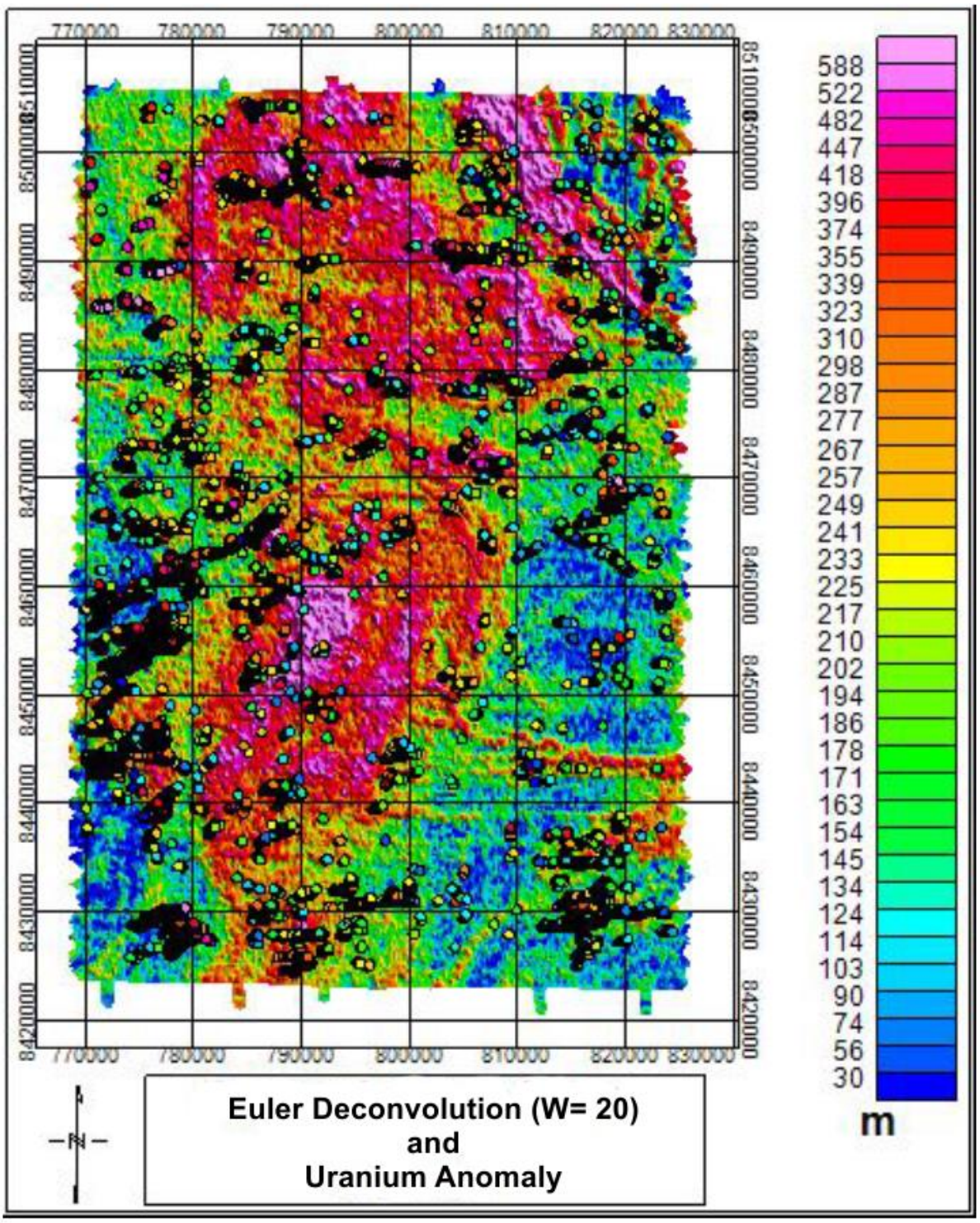

Figure 12. Overlap of the uranium anomaly map and the Euler Deconvolution map (W = 20)

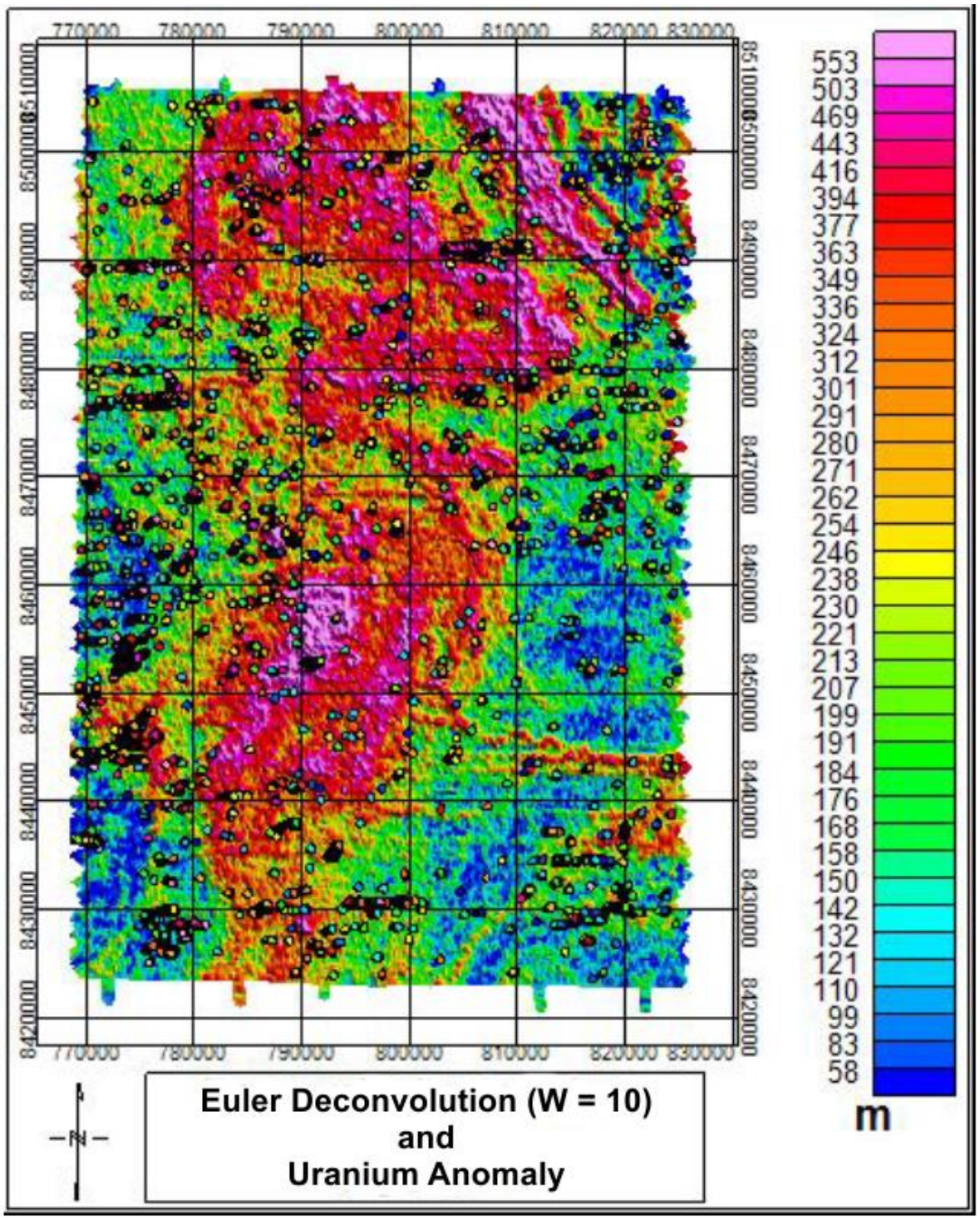

Figure 13. Overlap of the uranium anomaly map and the Euler Deconvolution map (W = 10)

The intersections of the large uranium count with the Euler Deconvolution aligned solutions were located. Therefore, the regions shown by two figures with strong magnetic anomalies and large number of aligned solutions are the most interesting to promote new local research.

V. CONCLUSIONS

The geological structures in the subsurface associated with uranium mineralization zones were characterized based on magnetic and radiometric information. The radiometric anomaly map shows that the central (area) is likely to contain higher uranium concentrations. The Euler Deconvolution technique allowed estimating the fault regions with depths ranging from 25 m to nearly 550 m. By

combining the radiometric and magnetic data, it was possible to determine which parts of the region are the most interesting to promote new local research. In these regions, there is a greater probability of finding significant uranium reserves.

VI. FUTURE WORK

As a suggestion for future work, it would be interesting to promote geochemical surveys in the intersecting areas of the Euler Deconvolution solutions and large uranium counts. Therefore, it may prove more local geological and geochemical features.

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