# First Magnetic/Gamma-Spectrometry Survey for Hydrocarbon Exploration in Brazil Identifies Micro-Seepage Anomalies

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## Abstract

We performed the first high-resolution land magnetic and gamma-spectrometry survey with the objective of identifying micro-seepage anomalies for the exploration of oil and gas in Brazil. A total of 120 km along 26 profiles of High Resolution Ground Magnetics (HRGM) and gamma-spectrometry data were acquired. The data were jointly interpreted and five anomalies were preliminarily interpreted and related to the location of hydrocarbon micro-seepages. These anomalies were also related to fault structures as observed in the residual magnetic anomaly map. These anomalies will be tested by drilling later this year.

## Introduction

The last 10th Bid Round for oil and gas exploration performed by ANP (National Petroleum Agency) in Brazil offered only onshore properties. The need to explore these areas also renewed interest in non-seismic methods which are usually non-invasive and the methodologies pose little or no environmental impact. These are important features if we consider that most of the operators of onshore blocks are small independent companies and that the environmental agency (IBAMA) imposes severe restrictions to methods that cause potential impacts.

In this work we show the first application of magnetic and gamma-spectrometry for oil exploration in Brazil. The method has been used in Canada and Australia, but published work is centered on proof over known areas. Our application here is purely exploration and also helped the operator optimize the design for the seismic acquisition.

## Theory and Method

The method used is based on the principle that there is always exudation of oil and gas from a reservoir, even for the best sealing rock (LeSchack and Van Alstine, 2002). The material that exudes flows to the surface as micro bubbles where it alters the environment creating several geochemical and geophysical anomalies, including increase in the concentration of Uranium, reduction in the concentration of Potassium and altering the magnetization of the soil. Since these anomalies appear in the surface, the variations on the level of Uranium and Potassium can be observed in gamma-spectrometric surveys and the magnetic variations, even the weakest ones, can be detected in high-resolution magnetic surveys.

Magnetic surveys have been applied to directly identify hydrocarbon reservoirs by mapping the shallow magnetic anomalies formed diagenetically through geochemical alteration caused by the gases originated from the escape of hydrocarbons. The chemical and bacteriological degradation causes diagenetic changes that alter the magnetic mineralogy at shallow depths, producing magnetite and pirrotite and destroying the hematite.

This effect happens in a context that can be locally correlated to radiometric anomalies from Uranium and Potassium. The concentration of CO2 in the groundwater forms carbonic acid that reacts with clay minerals (calcium silicate, for example) to liberate secondary calcium carbonate. The destruction of clay minerals by organic and carbonic acids can liberate potassium and uranium for removal through groundwater. Thorium is not altered in this process. The effect of hydrogen sulfite produced microbialy is to create a reducing environment that can result in increase of the uranium concentration with time. Uranium, in its oxidized for, the uranil ion (UO2++), is soluble in groundwater. In a reducing environment it converts to UO2, uraninite, and precipitates. Therefore, uranium will tend to migrate from an oxidizing to a reducing environment where its concentration will grow with time. Consequently, the growth of uranium in surface sediments can be an indicator of hydrocarbons. Also, in this process, thorium is not altered (LeSchack and Van Alstine, 2002).

## Field Acquisition

The survey was constituted by 26 parallel lines in the N-S direction, with spacing between profiles of 400 m and length of 4,700 m. The spacing between coincident magnetic and gamma stations was 50 m.

The data were georeferenced using the WGS-84 Datum. It was not possible to realize the full design of the survey since the southern part of the blocks was located over a lake. A total of 2,380 measuring points were acquired for HRGM and gamma-spectrometry. The relief of the area can be classified as flat over its extension. The access could be done through a few dirt roads using a 4x4 vehicle and the other roads only by foot. Vegetation is of “caatinga” type (thorn forest only found in the northeast regions of Brazil) of high density and it was necessary to open trails (Figure 1).

The High Resolution Ground Magnetic survey (HRGM) comprehended measurement of the total component of the earth’s magnetic field (F). A fixed magnetic base station was utilized for the whole survey in order to correct for the diurnal variations. The choice of location for the installation of the base station considered the security of the equipment, to be placed inside the area of the blocks, and to be free of electric and magnetic interferences. The farthest distance from a measuring point and the base did not exceed 10km. A moving station was used for the measurements of the magnetic anomalies over the survey points. Both the moving and the base station had their magnetic sensors oriented to the magnetic north and distant 2m from the ground. The magnetometers used for both the base and moving stations used Overhauser technology with a resolution of 0.001nT.

The gamma-spectrometric survey also resulted in 120km of profiles and data was collected over the same points as the HRGM. The measurements made were of the total count (TOT) of uranium (U), thorium (Th) and potassium (K). All units were total counts per second (cps) and also TOT measurements (ppm), U (%), Th (ppm) and K (ppm). The time used for the radiometric measurement with potassium iodate was 30 seconds for each reading. For the background noise measurement caused by the atmospheric radiation, we made daily measurements over the surface of a lake located nearby. For the repetition test measurements and to test the assurance of the readings made with the gamma equipment, we made daily measurements over the same point.

## Data Processing

During the magnetic data processing, diurnal variation and the IGRF were removed. Several filters were applied to maximize the anomalies of interest generating maps of residual magnetic anomaly and maps of residual magnetic anomaly from the horizontal second derivative.

During the processing of the gamma data, the effects from the atmospheric radiation and other noise were removed during the treatment of the data. Since the thorium does not suffer alteration from the presence of hydrocarbon it was used to normalize the measurements of uranium and potassium. Some mathematical procedures were performed in order to emphasize zones more prone to the micro-exudations of hydrocarbons, as the calculation of differences of deviation of U and K, normalized by Th. These calculations generated anomalies with negative deviations in the Potassium associated to positive deviations in the Uranium. The deviations DU and DK cited here are the real values measured for the ideal values in each point. These results represent the relative deviations expressed as a fraction of the ideal values for the measurements.

## Interpretation

The map of residual magnetic anomaly (Figure 2) shows a strong structural geologic control with direction NE, in accordance with the regional trend, where some producing wells are located. These structures are interpreted as being grabenform structures formed by normal faults that can facilitate the migration of oil. Other structures are interpreted as faults cutting the grabens with direction NW and appear very significant marking certain structural control that can also be important for the migration of oil.

In the joint interpretation of HRGM and gamma-spectrometry data we can visualize some targets indicated by the dotted circles that can be associated with micro-exudations. These targets are situated close to the normal faults associated to the graben structures interpreted (Figure 3).

In the map of the second horizontal derivative we can identify a total of five targets that are possible locations of micro-exudations. The dipoles indicated as targets in the map of second derivative show correspondence with the variations in the concentrations of U and K that could have been altered by the presence of hydrocarbons. These variations in the elements U and K are proved when the values of U deviation are close to zero and positive and when the values of deviation of K are close to zero and negative. The best indication for the occurrence of micro-exudations is when the difference between U deviation minus K deviation show large positive values. These are shown in the map of difference between U and K as large positive values of red/pink color (Figure 3).

## Conclusions

We reported on the first joint magnetic and gama-spectrometry survey in Brazil for exploration of oil and gas. The map of residual magnetic anomaly shows accordance with the structural trend in the preferential NE direction, in an area with several producing wells located NE to the area under study.

This work identified five HRGM and gamma-spectrometry anomalies that can be associated to micro-exudations of hydrocarbons. These anomalies on the surface might have been caused by migration to the surface through normal faults in the grabenform structures with direction NE and through faults that cut this structure in the NW direction. The data collected is of very high quality, providing confidence on the results presented. Confirmation of the anomalies will come later in the year from drilling.

## Acknowledgments

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## References

LeSchack, L. A., and D. R. Van Alstine, 2002, High-resolution ground-magnetic (HRGM) and radiometric surveys for hydrocarbon exploration: Six case histories in Western Canada, in Surface exploration case histories: Applications of geochemistry, magnetics, and remote sensing, D. Schumacher and L. A. LeSchack, eds., AAPG Studies in Geology No. 48 and SEG Geophysical References Series No. 11, p. 67–156.

Figure 1: Caatinga ecoregion found in the work area.

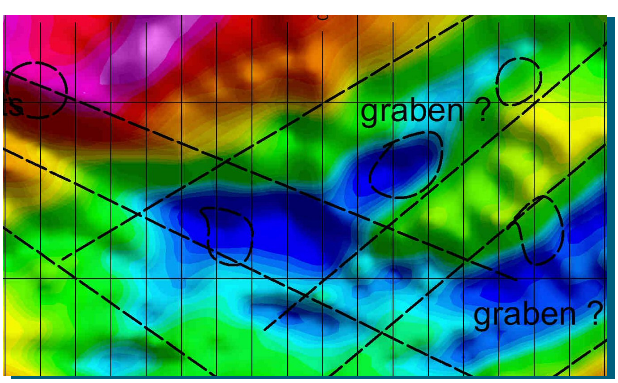


Figure 2: Residual magnetic anomaly map showing grabenform and fault structures that could have allowed the microseeping identified by the dotted circles.

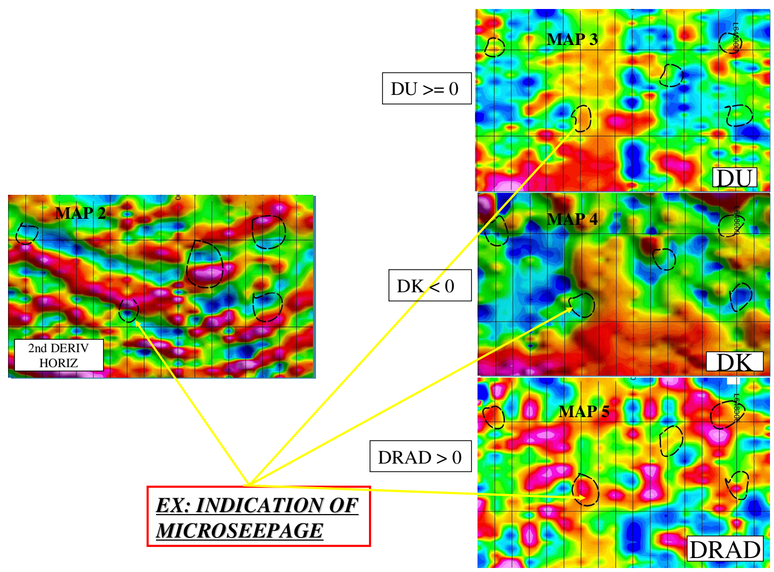


Figure 3: 2nd derivative of the horizontal magnetic field map (MAP 2) showing dipole anomalies associated to DU and DK (MAP 3 and MAP 4) . MAP 5 shows DU-DK which enhances the radiometry anomalies.