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WELL TO WELL CORRELATION BASED ON THE DSA OF IRM CURVES, GUAFITA OIL FIELD, VENEZUELA

Milagrosa Aldana[1], Belkys Andrade[1], Vincenzo Costanzo-Álvarez[1], Keyla Ramírez[2], Germán Bayona[3]

[1] Departamento de Ciencias de la Tierra, Universidad Simón Bolívar, Caracas, Venezuela.
[2] Coordinación de Ingeniería Geofísica, Universidad Simón Bolívar, Caracas, Venezuela
[3] Corporación Geológica Ares, Bogotá, Colombia.

ABSTRACT

A well to well correlation has been performed at the Guafita Oil filed, Western Venezuela, based solely on the decomposition of the Isothermal Remagnetization (IRM) curves of the studied samples. We have determined and quantified the main magnetic phases present in samples, taken at shallow depth levels (upper 1200 m) of the studied wells, applying a Direct Signal Analysis (DSA) of the IRM curves. At some of these levels, magnetic susceptibility (MS) anomalies were observed and they have been previously related to hydrocarbon migration. Applying the DSA, we obtained bar plots that display the vertical relative change of the main magnetic mineral amounts along the stratigraphic levels of the wells. These plots showed a clear variability that also allowed, at this field, to carry out a lateral correlation between strata with the same magnetic composition and the same relative proportion. These results were also compared with a well located at a relatively close field at the Colombian Llanos foreland basin. At the Colombian well it was found a level, with only hematite and goethite according with the DSA results, which has been associated with a thoroughly documented global regression. This level was also observed at the Venezuelan wells, suggesting their possible association with this palaeo environmental change.

Keywords: Well correlation, IRM curves decomposition, DSA method.

RESUMEN

En este trabajo se realiza una correlación pozo a pozo en el Campo Guafita, Oeste de Venezuela, basada sólo en la descomposición de las curvas de Magnetismo Isotermal (IRM) de las muestras estudiadas. Para ello, se determinaron y cuantificaron las principales mineralogías magnéticas presentes en muestras tomadas en niveles someros (primeros 1200 m de profundidad) de los pozos estudiados, aplicando un Análisis Espectral Directo (DSA) de las curvas de IRM. En algunos de estos niveles se observaron, en trabajos previos, anomalías de Susceptibilidad Magnética (MS) que fueron relacionadas con la migración de hidrocarburos. Aplicando DSA, se obtuvieron gráficos de barras que presentan la variación vertical relativa de las principales mineralogías magnéticas a través de los diferentes niveles estratigráficos de los pozos estudiados. Estos gráficos mostraron una clara variabilidad que permitió en este campo, adicionalmente, realizar una correlación lateral entre estratos con la misma composición y proporción relativa de minerales magnéticos. Estos resultados se compararon con los obtenidos en un pozo localizado en un campo relativamente cercano en la Cuenca de los Llanos Colombianos. En el pozo Colombiano se encontró un nivel que contiene sólo hematita y goethita y que ha sido asociado con una regresión global bien documentada. Este nivel se observó también en los pozos Venezolanos, sugiriendo su posible asociación con este proceso de cambio paleoambiental.

Palabras clave: Correlación de pozos, Descomposición de curvas IRM, método DSA

Introduction

Reservoir characterization typically requires the proper identification of the stratigraphic levels at the studied field. This characterization usually includes a well to well correlation, based on the available logs that measure petrophysical properties. Hence, Gamma Ray, Spontaneous Potential, Resistivity and Neutron Porosity, among other well logs, are used to properly identify and laterally correlate the main stratigraphic levels. In this work, we apply an alternative means for well to well correlation, based on the decomposition of IRM curves. In this fashion, we apply a Direct Signal Analysis (DSA) to the IRM curves (Aldana *et al.* 2011). The DSA method has been previously applied to IRM curves measured at shallow depth levels in wells at fields from Venezuela and Colombia. Those studies were intended to magnetically characterize the stratigraphic levels of the available wells. The main purpose was to obtain more information regarding the geochemical conditions that could have taken place during the diagenetic events that must have affected these rocks. Such conditions were related to either palaeoenvironmental changes during the deposition of the different sedimentary layers (Costanzo-Alvarez *et al.* 2012) or to the migration and/or accumulation of oil and gas in the studied fields (Costanzo-Alvarez *et al.*, 2012; Aldana *et al.* 2011). In fact, the quantification of the magnetic mineralogies along the studied ranges allowed the differentiation of the authigenic hydrocarbon related processes that could take place at them. Particularly, at a well at the Colombian foreland basin, the bar plots of relative mineral proportions obtained after applying the DSA method provided relevant information about the early and late diagenetic events that affected the Upper Cretaceous – Pliocene sequence of the distal Llanos foreland basin (Costanzo-Alvarez *et al.*, 2012). The record of these events seems to be encrypted in the way the magnetic mineral assemblages change down the sedimentary sequence. At this well, a level with only hematite and goethite was observed after the DSA and it has been associated with a thoroughly documented global regression that took place at the end of Middle Miocene times. Hence, if this kind of quantification could serve as an additional "stratigraphic" marker, these results could have direct applications in the Oil Industry not only in surface characterization of reservoirs, but also as a possible additional tool in well to well correlations and even to correlate global events.

Geographical setting and Samples

The Guafita oil field is located at the south-western end of Venezuela, Apure-Barinas sedimentary basin (Costanzo *et al.* 2002). Geologically, it is characterized by a series of NE-striking anticlines separated by normal and inverse regional faults (see Figure 1). The main hydrocarbon accumulations have been drilled at these structural features. It is also observed a main transcurrent fault that runs parallel to the strike of the Boconó and the Mérida Andes faults, the major structural features of the area. We have analyzed drill cuttings of three producer oil wells (GF-1X, GF-2X and GF-4X) taken from the first 1200 depth meters. The samples belong to the Guayabo Group (Parángula and Río Yuca Formations), a single group of molasses of apparently fluvial-delta provenance, far above from the producer levels of the Carbonera formation. Logs of Magnetic Susceptibility (MS) have been previously measured at these levels (Costanzo-Alvarez *et al.* 2000). These logs showed anomalous levels associated with the main presence of magnetite. Two kinds of anomalous MS levels have been identified. Levels A were related with the presence and migration of hydrocarbons that induced a reducing environment at shallow depths. This environment was responsible for the authigenic formation of spherical aggregates of magnetite observed by SEM analyses. Anomalies B were related to an atypical concentration of magnetic minerals, deposited during a change of the sedimentary conditions. These conditions were probably caused by isolated tectonic pulses such as the uplift of the Mérida Andean Range during Miocene/Pliocene times. At these anomalous B levels, mineral framboids were not recognized.

We compare the results of the Guafita´s wells with those previously obtained at the stratigraphic well Saltarín 1A (see fig. 2), located at the Llanos foreland basin (Colombia) (Costanzo-Alvarez *et al*., 2012). In this case, the studied depth range is characterized by lithological changes that give rise to a complex geological system. Different depositional conditions took place along the studied interval. In fact, the deepest rocks drilled in

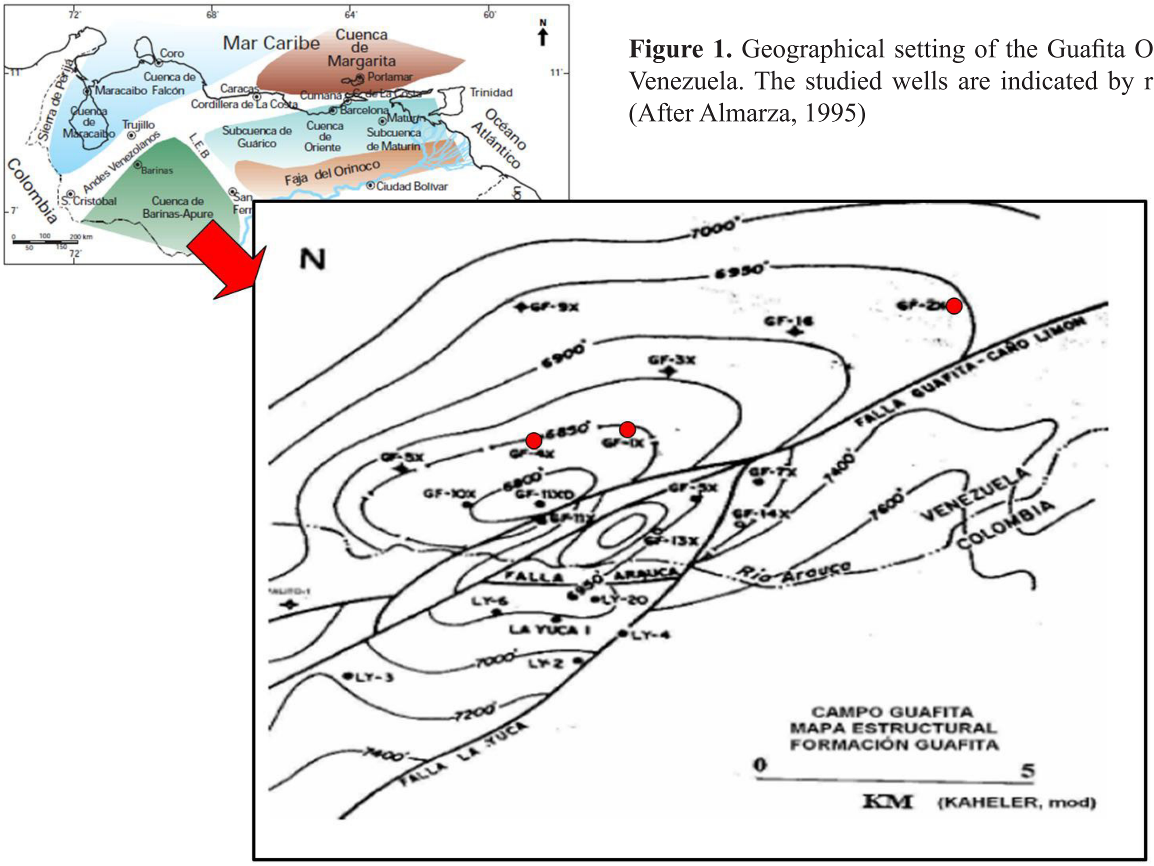


Figure 1. Geographical setting of the Guafita Oil Field, Venezuela. The studied wells are indicated by red dots. (After Almarza, 1995)

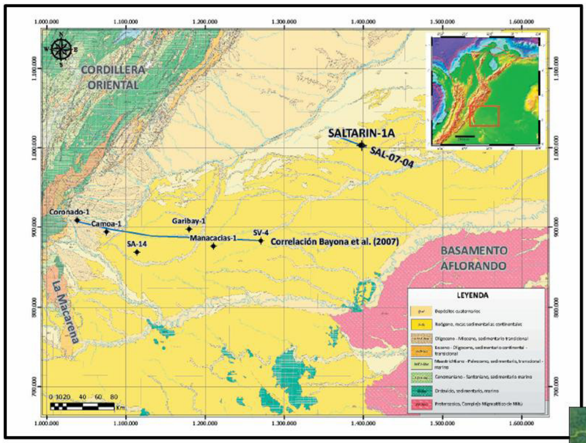
Saltarín 1A are from the Upper Carbonera Formation that includes a lower sandstone unit accumulated in a fluvial system, a middle mudstone unit accumulated in a lacustrine system and an upper sandstone unit that records sedimentation in a fluvial-deltaic system. Overlying the Carbonera formation is the León formation, a muddy sequence of sediments that accumulated in a freshwater lacustrine system. The youngest unit is the Guayabo formation (Bayona *et al.*, 2008).

Decomposition of IRM curves

To quantify the main magnetic mineralogies, the IRM curves of the samples analyzed have been decomposed using the Direct Signal Analysis (DSA) method proposed by Aldana *et al.* (2011). To apply the DSA method to the IRM data, the experimental curve is described by the sum on N elementary curves, each one modeled according to the expression proposed by Robertson and France (1994). Hence, the experimental curve is approximated by the superposition of N of these elementary IRM curves as:

$$IRM(B):\sum_{i=1}^{N}\frac{Mrm_i}{DP_i(2\pi)}\int_{-\infty}^{\infty}\exp\left[-\left(\frac{\left(\log_{10}(B)-\log_{10}(B_{1/2i})\right)^2}{2(DP_i)^2}\right)\right]d(\log_{10}(B))$$

In the equation above, *Mrmi* represents the contribution of each elementary curve to the experimental IRM. Initially, all the bins contribute equally to the IRM curve. The method adjusts this contribution. The computer program, based on the Levenberg-Marquardt algorithm, returns a spectral histogram of $\log_{10}B_{1/2i}$, whose heights are the adjusted contributions, *Mrmi*, of each elementary process or bin to the experimental curve (fig. 3). From this histogram, the number of magnetic phases that are present in the sample and the width and mean coercivity ($\log_{10}B_{1/2}$) values of each main component can be directly obtained. The areas under each Gaussian envelope of the main magnetic phases identified in the spectral histograms are proportional to the relative amounts of these phases in the sample.



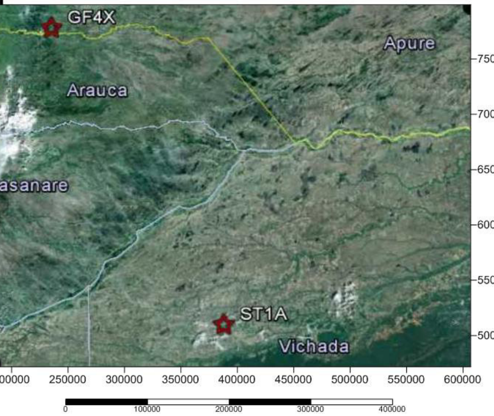


Figure 2. Geographical setting of the stratigraphic well Saltarin 1A, Colombia Foreland basin. The relative position of well GF-4X (Guafita) is also indicated.

Results and Discussion

The bar plots of Figures 4 and 5 show the vertical variation of the magnetic mineral concentration for wells GF-1X and Saltarín 1A, after applying the DSA method. At each well, the mineral magnetic concentration of every level has been normalized to that level with larger area (*i.e*. mineral proportion). The MS logs are also presented. The relative normalization of the areas along the well indicates, as expected, major magnetite proportion at the anomalous MS levels. Nevertheless, between both wells, clear differences in the magnetic composition of the Anomalous A levels can be observed. No Fe-Sulfides were identified at the A levels of GF-1X, GF-2X or GF-4X (see fig. 6); nevertheless, the A level of Saltarín 1A shows traces of sulfurs. Costanzo-Alvarez *et al.* (2012) reported magnetic framboids with sulfur content at the A levels of this well. The difference in the magnetic phases at these levels points out to distinct authigenesis mechanisms associated with hydrocarbon migration. According to Díaz *et al.* (2006), in Guafita's oil wells a hydrocarbon-mediated transfer of electrons from the organic matter to primigenic iron oxides (*i.e.* hematite)

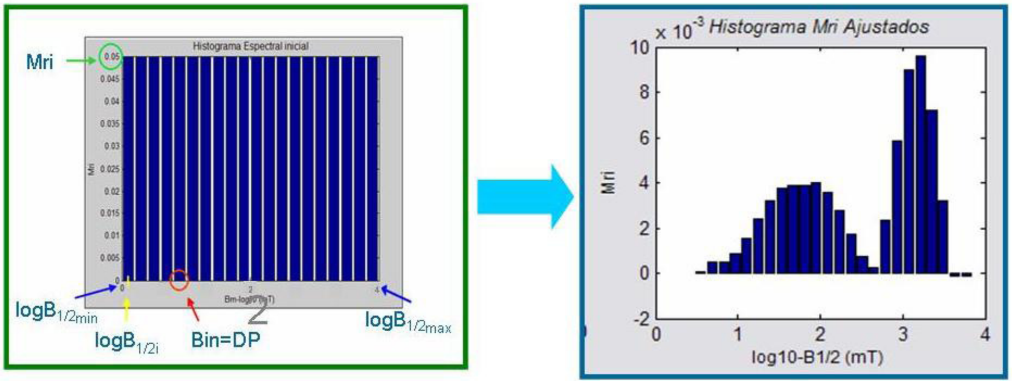


Figure 3. Sketch of the DSA decomposition of IRM curves.

must have occurred at shallow depth levels, producing magnetite. This process defines a zone where the appropriate reducing conditions for diagenesis of the earliest Fe-oxides have been achieved. On the other hand, Costanzo-Alvarez *et al.* (2012) argued that a higher concentration of H_2S in the crude oils of the Colombian Llanos foreland basin might account for the formation of secondary Fe-sulfides in Saltarín 1A. The hematite identified in these levels could be an earlier magnetic phase. Initially, hydrocarbon leakage would form pyrite framboids (McCabe *et al.* 1987; Machel 1995). Partial replacement of magnetite, in these pyrite framboids, would be the result of a late alteration event that gave rise to the formation of the observed framboids formed mainly by magnetite, with low traces of sulfurs (Suk *et al.* 1990).

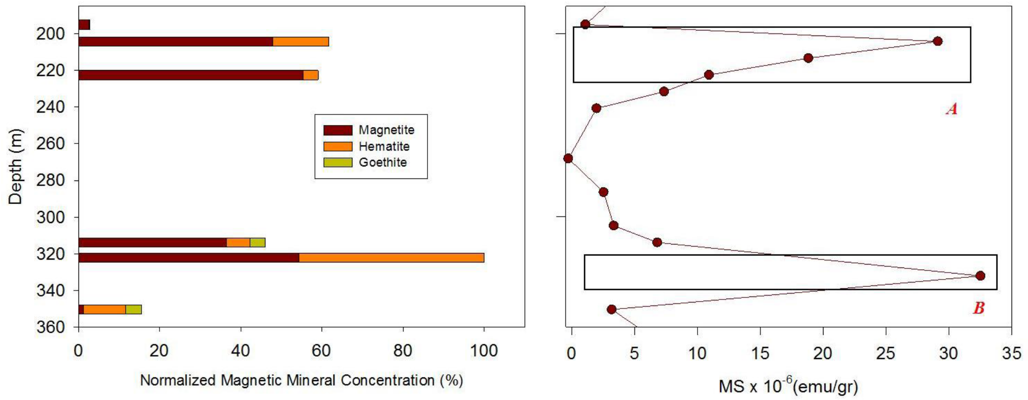


Figure 4. GF-1X: Normalized bar plot of relative mineral concentration obtained according to the DSA. The MS log is also presented.

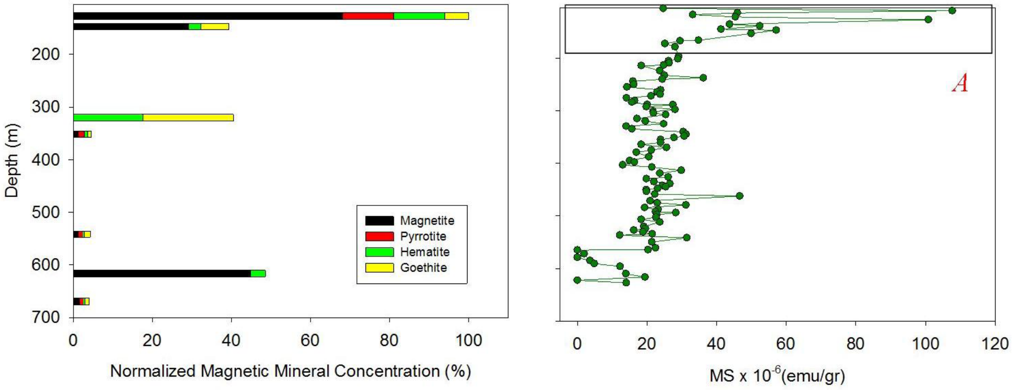


Figure 5. Saltarín 1A: Normalized bar plot of relative mineral concentration obtained according to the DSA. The MS log is also presented.

Figure 6 shows the bar plots of relative mineral magnetic concentration for all the studied wells. In this case, the level concentration is not normalized. Levels 198.12 m and 320 m of GF-4x and Saltarín 1A, respectively, are characterized by the solely presence of goethite and hematite (see fig. 6). An equivalent level with the mainly presence of these two minerals is also observed at GF-1X (322 m). According to Da Silva *et al.* (2010), this level at Saltarín 1A could be associated with a palaeoenvironmental change from oxidized palaeosols to alluvial plains accumulated in reducing conditions, and with a thoroughly documented global regression that occurred at the Serravallian stage (Vail *et al.* 1977). The coexistence of both hematite and goethite could be additional evidence of a pedoclimatic change or for a late alteration of hematite to goethite, related to the variation of the weathering conditions (*i.e.* from warmer and drier to cooler and moister environments) (Costanzo-Alvarez *et al.* 2012). On the other hand, during the late Miocene-Pleistocene, shaly-sandy sediments of fluvio-deltaic provenance (Parángula and Río Yuca Formations) were deposited discordantly in the Barinas-Apure basin after the Andean uplift. Warmer weather conditions have been

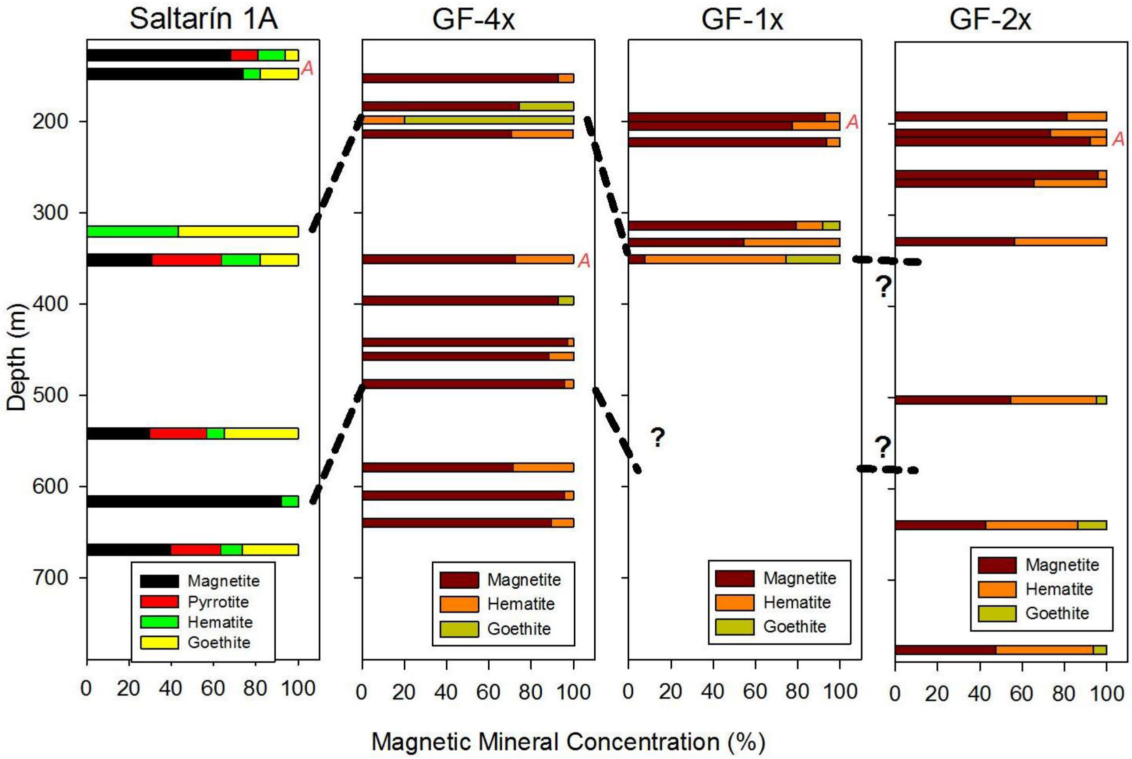


Figure 6. Bar plots showing the relative concentration of the main magnetic mineralogies observed at all the studied wells according to the DSA.

indicated for this basin during the Miocene. Hence, as these levels at Saltarín-1A, GF-1X and GF-4x were sedimented during the Miocene, it is possible that they were exposed and experienced warmer conditions and later they have been preserved. At GF-2X this hematite-goethite level is not clearly observed, probably due to the lack of samples associated to this event.

At Saltarin 1A, the level 616.48 m shows a relative higher concentration of hematite and magnetite. We have extrapolated the distance between levels 320 and 616.48 at this well to GF-4X, measuring it from the hematite-goethite level of this last well. As can be observed, level 616.48 m of Saltarin 1A can be correlated with level 487.66 m of GF-4X. Both non-anomalous levels present the same relative proportion of hematite and magnetite (see fig. 6).

Conclusions

Bar plots showing the vertical variation of the magnetic mineral concentration along the studied wells (shallow depth levels, up to 1200 m.) have been obtained applying the DSA decomposition to the IRM curves measured at these wells. The bar plots show clear differences in the magnetic composition between the Colombian and Venezuelan wells at those levels related with hydrocarbon migration. This quantification gave more information regarding the difference between the authigenic hydrocarbon related processes that could take place at them. A level with the major presence of hematite and goethite has been identified in almost all the studied wells. This level could be associated to a global regression. A late alteration of hematite to goethite, related to the variation of the weathering conditions at both basins during the Miocene, could explain this magnetic mineral assemblage. Hence, these results suggest that this kind of quantification could serve as an additional "stratigraphic" marker.

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