ANALYSIS OF THE HYDROCARBON MATURATION WINDOWS OF THE AMAZON BASIN

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Abstract

The Amazonas Basin is a 500.000 km² intracratonic basin in northern Brazil. The ~6000-m lithologic section encloses mainly Paleozoic sedimentary rocks intruded by Triassic–Jurassic diabase dikes and sills, and subsequently buried by Cretaceous–Tertiary rocks. Geochemical and geologic data point to the Upper Devonian marine black shales from Barreirinha Formation as the main hydrocarbon source rocks.

In this work, data from 6 selected wells were used to evaluate the generation of oil in the basin, using the Temis software for delimiting the windows of oil and gas generation; compare the results obtained in Temis with the reflectance index of vitrinite data available in the literature of the wells; compare the results with seismic and gravimetric and magnetometric maps. The integration of the basin modeling with geologic and geochemical data suggests that the Barreirinha Formation source rock started to generate petroleum during the Late Carboniferous.

The main phase of petroleum generation and expulsion occurred from Late Carboniferous to Permian time and was completed by the Early Triassic. Any later tectonic event remobilized those hydrocarbons previously trapped.

Probably because of the long distances of both vertical and horizontal migration, it is believed that an important amount of the expelled hydrocarbon was dispersed along migration pathways. A significant part could also have been remobilized and lost during Cretaceous uplift of the basin margins.

Introduction

In this paper a study of the Amazon basin, as a Paleozoic basin has a long evolutionary history marked by significant disagreements and with a relatively shallow sedimentary wedge compared to Brazilian Cretaceous, is controversial about the burial fill for generating hydrocarbons.

Occur in the basin basic volcanic rocks intrusive (dikes and sills) and extrusive associated with magmatic events Triassic and Early Cretaceous, which represent an important aspect of its thermal evolution.

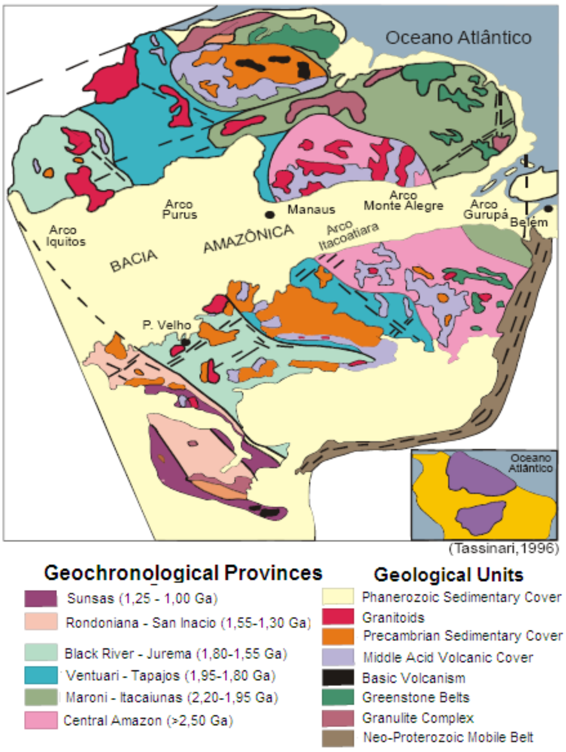

***Figure 1** – Geological map of the Amazon Basin*. Source: Modified from Tassiana (1996).

The thermal effect of these intrusions would be responsible for heat addition required for maturation of organic matter and consequent potential for oil generation.

Several authors have evaluated the thermal effect that the basic igneous intrusions produce in Brazilian Paleozoic basins (Rodrgues, 1995 Alves & Rodrgues 1985 Bender, 2001). As suggested by Thomas Filho *et al.* (2007), whereas these basins good occurring hydrocarbon source rocks in the Devonian and Permian, one can predict that amounts of oil may have been generated by the action of igneous intrusive bodies. Based on this assertion, this paper proposes a study that can contribute to the reconstruction of the thermal history of the basin from the modeling of the thermal variables associated with magmatism and burial history.

Geology

The Amazon basin is classified as an intracratonic Paleozoic basin, with total area of approximately 500.000 km², where the location map is shown in Figure 1.

The tectonic and stratigraphic point of view, according to Cunha *et. al* (1994), the Amazon Basin can be divided into four main depositional sequences:

First Sequence (Neo Late Ordovician to Early Devonian-): Group Trombetas - Composed by Autas Mirim formations, Nhamundá, Pitinga and Manacapuru;

Second Sequence (Eo-Devonian to Carboniferous): Urupadi Groups Curuá - Compounds by Formations Maecuru, Ererê, Curiri, Oriximiná and Faro;

Third Sequence (Carboniferous to Neo Permian): Tapajós Group - Formations Monte Alegre, Itaituba, Nova Olinda and Andirá;

Fourth Sequence (Cretaceous to Tertiary): Formations Alter do Chão, Solimões and Uçá.

In addition to the sedimentary sequences, the Amazon Basin has intense magmatism (basic and ultrabasic) Juro - Triassic age. This magmatism is easily identified by the presence of a lot of diabase dikes and sills in the sedimentary section. These sequence present key role in the maturation process of organic matter, as we see in the schematic section (Figure 2), provided by the National Agency of Petroleum, Natural Gas and Biofuels - ANP (Gonzaga, 2000), which cuts the Basin since the Arc Purus (SW) to the Arc of Gurupá (NE)

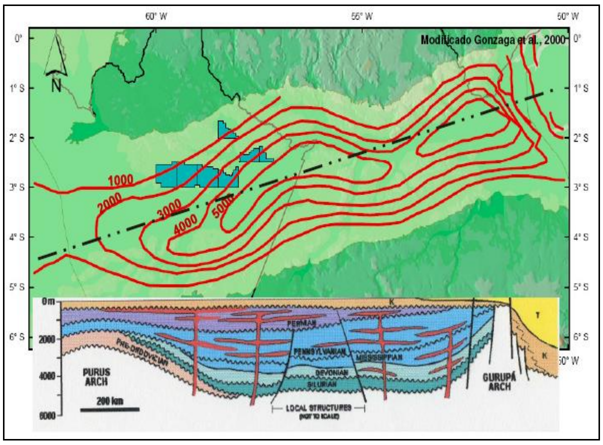

Figure 2 *- geological section of the Amazon Basin.*

Source Rocks

According to Rodrigues (1973), the geochemical analysis of the entire sedimentary sequence of Amazon basin lets you classify the Devonian shales of Barreirinha Formation as most important hydrocarbon generator. Are radioactive shales of black color, ranging from 30m to 160m thickness in depocenter and occur throughout the Amazon Basin.

Gonzaga et al. (2000) conducted an evaluation of the petroleum generating potential (S2),based on abundant geochemical data from wells (testimonies and outcrop cuts), which include a total of 3948 results for total organic carbon (TOC) analysis pyrolysis 1986, 180 results of stable carbon isotopes, 280 analyzes of organic petrography, 59 analyzes Gas chromatographic (GC) and gas chromatographic analysis - mass spectrometry (MEGCs).

The TOC data indicate that Pitinga, Barreirinha and Curiri formations are the only units with significant potential generator (Figure 2.8 and 2.9).

Maturation

According Gonzaga *et al.* (2000), the integration of optical parameters (color index spore, vitrinite reflectance and fluorescence), chemical (Tmax) and molecular (Reason isomerization steranes) allowed an assessment of the thermal evolution of the generators basins.

Also according to the author, along the northern and southern flanks and on the west platform, where the Barreirinha formation is shallow (1500 m depth), the maturity is low (<0.65% Ro). In the central trough, the maturity of source rock reaches 1% Ro, around 4000 m depth. A high degree of maturity (Ro> 1.4%) was achieved only because of the effect of warming caused by dikes and sills of Diabase (Figure 2).

Method

The density and distribution of pits with information about the temperature in the Amazon basin is reduced compared to the basin which is approximately 500 square kilometers, but were distributed into 6 well studied area of exploration interest in the basin (Figure 3).

The work was performed based on temperature data measured by electrical profiling and training tests in wells drilled by Petrobras. The wells used provided it is considered that the static temperature of the formation, ie, temperatures electrical profiling that were corrected by LA CHENBRUCH method of forming and testing. When all the wells had 3 or more temperature data.

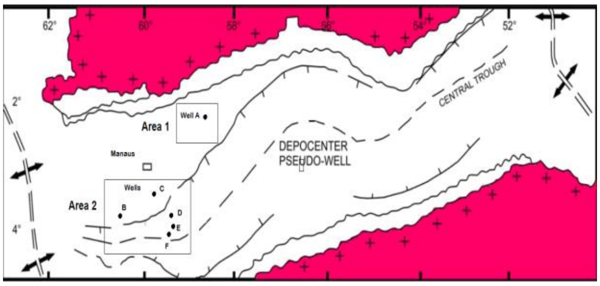

Figure 3 *– Map showing locations of wells in the basin.*

The surface temperature was considered that the reference adopted for work in geothermal, or 80 ° F or 26.7 ° C. The choice of reliable temperature values was performed according to a coherence analysis. At first was made an identification and rejection of outliers through the temperature Geotermogramas x Depth, which had been built for each well individually. The following were built two graphs that encompassed all wells relating Temperature Gradient Geothermal and x Depth x Depth. Were considered doubtful values showed large discrepancies unrelated to average values.

The next step was intended for study of geological sections and building closer models of reality, which supported the thermal effect due to intrusion. 6-well data were correlated; the well data were georeferenced and integrated in Temis, a conventional software for modeling petroleum systems that was developed by the French Petroleum Institute (IFP). From Temis graphs generated we extracted the information used in the study.

The final step, once known the thermal structure refers to the determination of kerogen maturation rates and consecutive determination of generating windows oil and gas. In this paper, the modeling of the thermal maturity was based on the model Easy% Ro developed by Sweeney & Burnham (1990).

Thermal Modeling

For this step 6 wells were used divided into two areas as shown in the basin Figure 3. The 1st area and the **A** well where there is gas condensate exploration and 2nd area are other wells where there is a gas exploration in **B** well and oil in the **C** well. From wells requested to ANP and information from other public wells present in literature were extracted values necessary for inputs in software. For the tests were used wells **A** (Pioneer), **B** (Exploratory), **C** (exploratory), **D** (stratigraphic), **E** (exploratory) and **F** (Stratigraphic),

The first models were generated graphics to analyze the thermal effect of instructions organic material in the source rock. In this work, we used the program Temis2D (IFP) for reproduction of the thermal history and maturity of source rocks.

In the thermal simulation performed with Temis2D the modules was used unpacking and heat. The decompression module allows to simulate the geometric evolution section of each cell that represents the sediment layer. Considers that the change of pore space in the course of sedimentation and burial can be described by the laws of normal, invariable compression in geological time. The thermal module calculates the distribution temperatures along the section 2D of the cells representing the sedimentary basin, considering the geometric evolution previously provided by the decompression module and the heat flux variations in the system. Thus was obtained due to the thermal effect occurrence of intrusion.

For the reconstruction of the thermal history in sedimentary basins, it is necessary the boundary conditions of the thermal model. For the simulation with Temis2D, about igneous intrusions, these conditions involved an estimated surface temperature of 22 ° C for the time of the intrusion. The basal heat flow considered was 50 mW / m2, as proposed by Pollack *et al.* (1993) as approximate value for Paleozoic basins. The effect additional heat starts from T (time) = 178 million years, when the intrusion occurred basic rocks

The information of the requested data and data available in the literature allowed infer igneous intrusions of large areas. As a result, the models are generated strongly influenced by thermal effects provided by the heat emanated by these rocks. The intrusions are present in the basal portion of the basin, intermediate and higher portion. It can be seen in the wells **A**, **B** and **C**, occur several superimposed hearths, thermal effects become significant, reaching from the contact to twice the thickness of the intrusion.

Results

Nowadays the Easy %Ro model proposed by Sweeney & Burnham (1990) is the most accepted method in basin analysis to %Ro calculation. In this method, equations are integrated chemical kinetics over time and temperature values being applicable in range vitrinite reflectance (% Ro) from 0.3 to 4.5% and heating rates from conditions laboratory ºC / week, geological, ° C / million years. The method consists of quantifying degree of maturation of the organic matter from parallel reactions of chemical kinetics, based on mass balances obtained from the results of experimental pyrolysis. Its use is permitted in combination with any type of thermal history. Kinetic-based models distributed reactivity in which the reactions are performed in the dependent rates temperature and the amount of reagent available, are widely used.

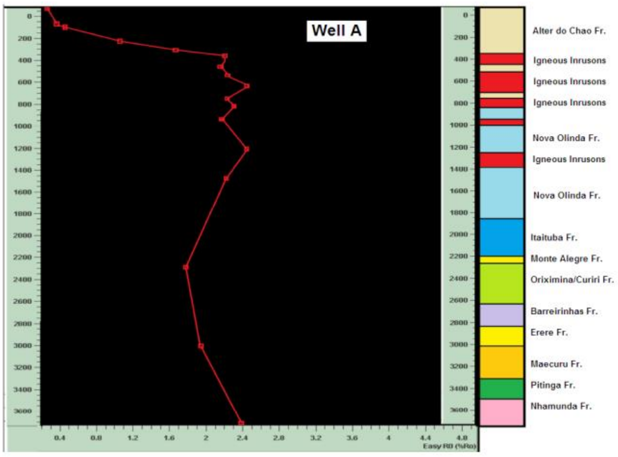

Figure 4.1 *- Two-dimensional thermal modeling evaluating the effect of igneous intrusions in the well* ***A****. Performance of the Temis2D.*

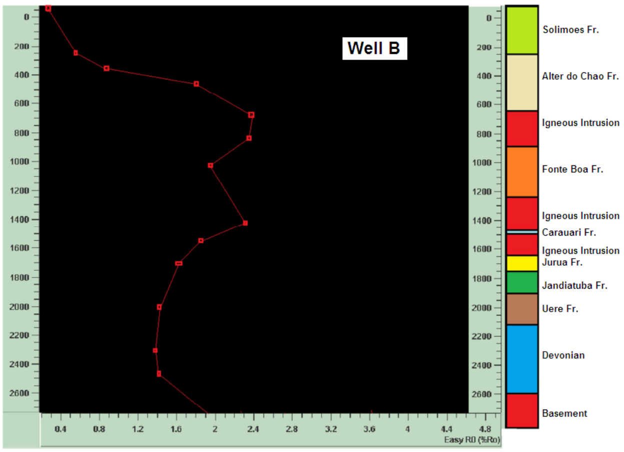

Figure 4.2 *- Two-dimensional thermal modeling evaluating the effect of igneous intrusions in the well* ***B****. Performance of the Temis2D.*

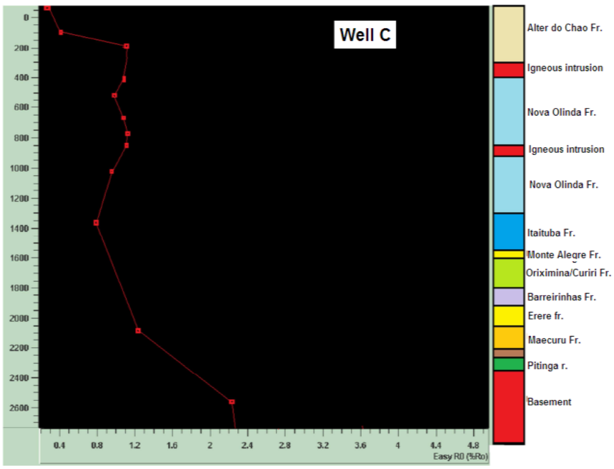

***Figure 4.3** - Two-dimensional thermal modeling evaluating the effect of igneous intrusions in the well **C**. Performance of the Temis2D.*

Figures 4.1 to 4.3 shows the variation curves of Easy %Ro index in depth. Indexes can reach values greater than 4% as they approach the intrusions igneous. The %Ro index records the thermal maturation stages of sedimentary rocks. The presented seismic sections collaborate with models generated compared.

The model for the well **C** the % Ro index was between 0.65 and 1.0% in the rock which generates and refers to the oil generation window, the models for the wells **A** and **B** the %Ro index was between the values from 1.3 to 1.8% in the source rock which in the gas of the window interval. In the intervals of intrusions values of the %Ro index are higher. Figure 5 shows the values of the %Ro index to 5 wells close to the areas of study. The values are consistent with the values observed in models of wells A, B and C.

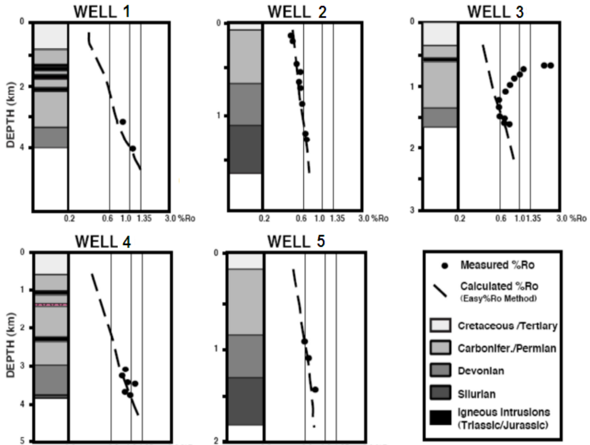

***Figure 5** – Reflectance Vitrinite graphics (% Ro) x depth to 5 wells in the Amazon Basin, may be observed the effects of the intrusion on high values. Modified GONZAGA (2000)*

Integration of Seismic and Potential Field Data (Gravity and Magnetics).

In this section we made an integration of geophysical data, we put a seismic line with welllogs and grav map to see the relationship between information extracted from each one. Also we plotted some mag and grav maps to see the biggest igneous intrusions in the basin as we can see in the figures 7.1 to 7.2.

Were plotted on the seismic line 254 some logs (Gamma, SP and resistivity) of the Well **A** and a gravity anomaly map to evaluate the consistency of the result shown in Figures 4 gas generation window for the well **A**. This line was acquired in 1980, through the well **A** and an interpretation published by Petrobras (Mendonça *et al*., 2004).

This allowed a better interpretation of the results obtained in Section 2D. Note that, due to stored characteristics of each method, including differences in scales, the similarities are clear. Both depict layers tabular without significant deformation and igneous intrusions in matching points (Figures 6.1 to 6.3). We can infer that the section has good approximation to reality; it is therefore suitable for obtaining the sections to be used in the thermal model Amazon basin.

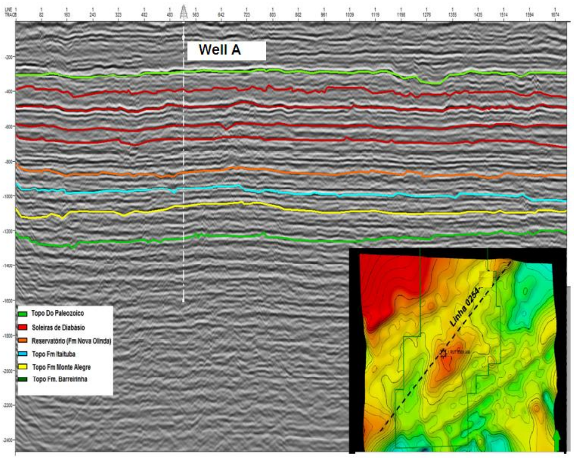

***Figure 6.1** – Comparison Seismic Line 254 , well **A** and gravity anomaly map.*

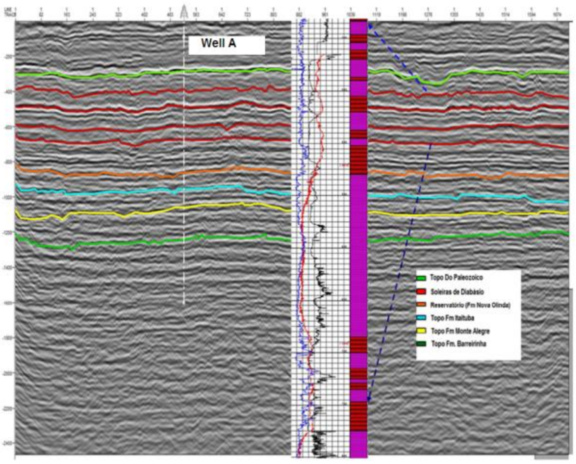

***Figure 6.2** – Comparison between Seismic Line 254 and Logs (Gamma, SP and resistivity) of well **A** in the position of volcanic intrusions.*

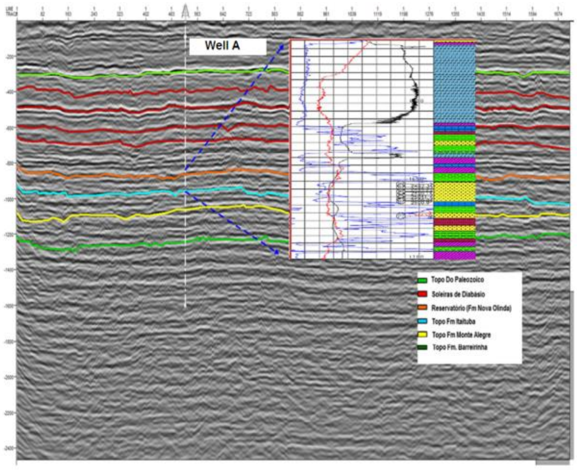

Figure 6.3 *– Comparison between Seismic Line 254 and Logs (Gamma, SP and resistivity) of well* ***A*** *in the position of reservoir.*

The gravity anomaly map of the basin (Figure 7.1) shows the integration with the main tectonic features of the Amazon basin. It is noted that the axis of the bowl is represented by gravimetric high. in correspondence to the gravimetric interpretation, indicating the possible continuities geological and geophysical structures of the exposed basement in the Amazon Basin.

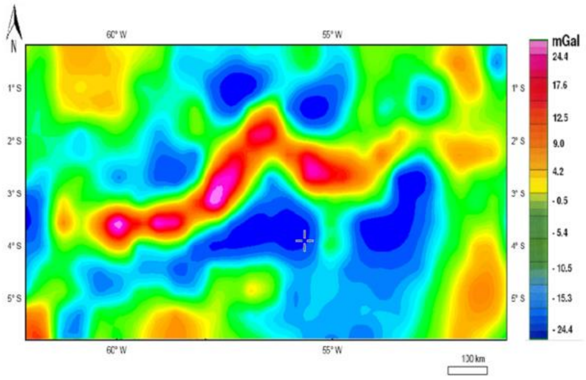

Figure 7.1 *– Gravity Anomaly GRACE map showing the main feature of the Amazon basin. Source: Software database Geosoft Oasis Montaj version 7.2.*

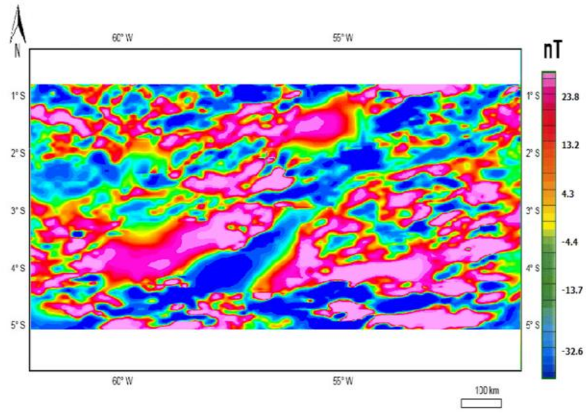

Figure 7.2 *– Magnetic Anomaly RTP Map showing the main feature of the Amazon basin.Source: Software database Geosoft Oasis Montaj version 7.2.*

The residual magnetic map RTP denotes correspond to the main areas and geological features of the Amazon basin area, and clearly show the hinge lines and the depocenter of the basin (Wanderley Filho, 1991).

Conclusions

The models have shown that basement heat flow was not enough for the thermal maturation of the basin. However, the sum of the basal heat flow with the flow from intrusions is responsible for its thermal maturation. These two sources are directly related to the generation of hydrocarbons confirmed by there existing petroleum systems.

The simulations with the models allowed the verification of the thermal effect of intrusion into sections, the thermal history was obtained from thermal maturation logs of the Easy %Ro model, and the identification of gas/oil windows.

The Easy %Ro values obtained show that the intrusion favored generation hydrocarbon basin. Indicates a potential exploration of regions not yet explored for both cases gas and oil.

The influence of the thermal effect of igneous intrusions on thermal maturation of the Amazon Basin appears to be crucial for the generation of hydrocarbons in some areas of the basin, validating the unconventional such systems.

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