APPLICATION OF CHEMOSTRATIGRAPHY IN THE STUDY OF CARBONATE RESERVOIRS OF THE CAMPOS BASIN

Gilberto Athayde Albertão[1], Pedro Paes de Carvalho[2], Marcelo Blauth[3], Alexandre Dutra Sayd[4], Ratcliffe, K.T.[5]
[1] Petrobras UN-BC/ST/CER Av. Elias Agostinho 665, Macaé/RJ (albertao@petrobras.com.br)
[2] Halliburton/Sperry Drilling Services Av. Prefeito Aristeu Ferreira da Silva 1000 – Macaé/RJ (pedro.paes@halliburton.com)
[3] Petrobras E&P-ENGP/RR/CER Av. Chile 65, Rio de Janeiro (blauth@petrobras.com.br)
[4] Petrobras UN-BC/ATP-S/RES Av. Elias Agostinho 665, Macaé/RJ (sayd@petrobras.com.br)
5 Chemostrat Inc., 6700 Portwest Drive, Houston, Texas, 77024, USA

Key-word: chemostratigraphy, carbonate reservoirs, Siri Member, Campos Basin

INTRODUCTION

The Siri Member of the Emborê Formation is comprised of rocks deposited in the carbonate platform of the Campos Basin Tertiary. As of the 70's the occurrence of oil in these reservoirs was already known, evidenced by the drilling of wells, especially in the south area of the basin. The initial data informed of the existence of a very heavy and viscous oil, in a basically unknown reservoir, considering the non representative sampling of the same, since, in its shallow occurrence (approximately 1000m deep with water depth below 100m) the reservoir was considered, in general, of little interest, only 'crossed' on the way to deeper objectives. Around the mid-90's, a formation test carried out in the Campos Basin demonstrated the potential of commercial production of this reservoir, despite the oil conditions.

However, only after the implementation of a systematic program, aiming at the commercial development of heavy oil accumulations initiated in 2001 by Petrobras, was a study proposal presented aiming at assessing the Siri reservoirs, in the Badejo field area (Fig. 1). The main attracting factors resided in the existing production facilities as well as in the small water depth and, particularly, in the initially estimated volume. The proposal was approved and a preliminary assessment project was proposed, aiming at the drilling of a horizontal well with the objective of adequately characterizing the oil, as well as assess the production potential of the reservoir.

From the geological point of view, there was a sequential development of the work stages. Pre-existing information of logging studies, core sample data and old 2D and 3D seismic data were used. With the seismic and well data a preliminary work plan was prepared, re-estimating the hydrocarbon volumes. This information also subsidized the preliminary project proposal for the exploration of the Siri reservoir. Additionally, a study to estimate the value of the information was carried out, confirming the feasibility of drilling a well for the Acquisition of Reservoir Data (ARD). The ARD would be comprised of a pair: pilot-well, to assure the support of data, and horizontal well, to effectively implement the production well.

Parallel to this, thanks to the new 3D seismic acquisition in the ring fence areas of the Campos Basin, it was possible to obtain good quality data for the seismic reinterpretation of the area. Furthermore, the re-description of flume samples from the main wells in the area was performed, as well as of the existing core sample, with the objective of supporting the geological interpretation. The main result, through the logging, rock and seismic data, was the conception of a more consistent geological model, which indicated the presence of almost N-S oriented algal banks, at the edge of the carbonate platform, in principle with good reservoir conditions in its upper portion.

GEOCHEMISTRY

The first attempts to carry out a detailed stratigraph ic analysis which would allow a more adequate zoning of the reservoir failed due to the lack of definition provided by traditional tools, specially the electric logging and biostratigraphy. The opportunity then arose to carry out a study using inorganic geochemical analysis to perform the chemical stratigraphy (chemostratigraphy). Moreover, the availability of a tool to perform the chemical analysis *in situ* was identified:LaserStrat®. This tool performs the chemical analysis in the drilling bore, with the objective of using the geochemical data for the determination of the horizontal well's geo-direction, i.e., as a support to control the forward direction of the well in its horizontal segment.

In the initial chemical stratigraphy study, 321 flume samples were analyzed, collected from 3 wells in the Badejo field, selected, selected to serve as a basis for the geochemical correlation. These samples included approximately 70m of carbonate shale from the Ubatuba Formation, and approximately 300m of basaltic limestone from the Emborê Formation/Siri Member. All these samples were analyzed in a laboratory, based on high resolution analytical technique (ICP-OES – *inductively coupled plasma optical emission spectrometry*), when it was possible to determine 24 elements, amongst the major ones, rare traces and soil. The spectral variation of the elements allowed the definition of 4 major geochemical "packages" that were subdivided into a total of 15 geochemical units (table 1 and Figure 2). The definition of these chemical zones was carried out not only by the behavior of the chemical elements but also due to ratios between some of them.

Geo-chemically speaking, the Ubatuba Formation (identified by the P4 chemostratigraphy package) can be clearly differentiated from the limestones of the Emborê Formation (P1-P3 Packages). The carbonate shales of the Ubatuba Formation have high concentrations of elements associated to debris components, particularly clays (Si, Al, Fe, K, Ti and Zr), presenting however, low quantities of Ca (10%-15% CaO). The limestones of the Emborê Formation, on the other hand, have a high content of CaO (circa 50%) and are generally poor in terms of Si, Al, Fe, K, Ti and Zr.

The most important, from the point of view of the detailing desired for the reservoir zoning, was the obtainment of the sub-zoning. Within the Ubatuba Formation (P4 Package) in all three wells, three chemostratigraphic units (P4-U1 to P4-U3) were acknowledged, based on Ca, Si, K, Al variations and on the Si/Al, Fe/K and Ca/Fe ratios. Approximately 10m above the Emborê Formation top, the P4-U1 Unit base is marked by a strong enrichment of Ca and a reduction of Si and Al, marking the entrance in the marls that make the transition between the Emborê and Ubatuba Formations; still in the Ubatuba Formation base, we noticed a considerable phosphate enrichment. These characteristics constituted an indication for a core sampling programming to be carried out at the top of the Siri reservoir, during the drilling of the pilot-well.

Within the carbonates of the Siri Member, which constitute the reservoir target in the area of this project, the detailing obtained was even greater, with the acknowledgement of three chemostratigraphy packages (P1, P2 and P3) and internal subdivisions. These packages were acknowledge based on content variations of debris elements, such as Si, Al, Fe, K, P and Zr, and also on elements related to carbonates such as Ca, Sr, Mn and Mg. The P1 package may be subdivided in three units (P1-U1 to P1-U3), despite not having been sampled in one of the wells. The P2 package was subdivided in four units (P2-U1 to P2-U4) and was correlated in all three wells. The P3 package was subdivided in 5 units (P3-U1 to P3-U5), but the P3-U5 unit was only identified in one of the wells. Figure 2 represents one of the correlation wells with the geochemical profiles of some elements and the identification of chemical zones defined in the Siri reservoir.

This stratigraphic segmentation was fundamental to the proposition of the detailed zoning of the reservoir and served as a base to acknowledge the interval of interest that would guide the navigation of the horizontal well, as from the seismic support. On the other hand, the variations verified in the geo-chemical profiles need to be better investigated. They may be partially related, for example, with the changes observed in the carbonate facies (presence of *wackstones*, *grainstones* and *bindstones*). Furthermore, the concentration of certain elements, such as l Mg, Ca and Sr, can be related to the porosity: a proportional ratio between these elements and the estimated porosity in neutronic profiles has been eventually observed (Chemostrat, 2003). A possible use of the geochemical distribution of these elements would be the creation of a high porosity distribution model for the identification of karstic surfaces.

Based on the geochemical results, the correlation of the Siri Member detail was reassessed, based on the electric logging, and five main sediment sequences were identified, which subdivided, resulted in a total of 10 units (1a, 1b, 1c, 2a, 2b, 3, 4a, 4b, 5a, 5b, from base to top). We noticed that the geochemical zoning was very consistent with the independently proposed stratigraphic zoning.

Thus, we considered that the geo-chemical results obtained in the three wells selected to operate as control wells, support the potential use of chemical stratigraphy (main elements and traces) as a support, along with the seismic and the electric profiles, for the geo-direction of the horizontal well. Finally, we constructed a 3D geological model (Fig. 3), based on the integration of the available data (seismic, geological properties based on logging and geochemistry, conceptual sedimentological model, etc.), which, on the other hand, was used to define the navigation of the horizontal well (Albertão et al. 2003). The chemostratigraphy zoning would further be confirmed through the pilot well, drilled to subsidize the horizontal segment.

The drilling of the horizontal segment was a success not only from the drilling engineering point of view, as it perfectly respected the updated project of the geologic model (Fig. 1), but also from the navigability point of view in the segment of good reservoir conditions, as indicated in the electric logging, as well as the formation test carried out after the end of the drilling. The 3D geologic model was updated based on the new information acquired with the pilot-well and the geometry of the horizontal well was redesigned within feasible time. Geochemistry provided important subsidies for the definition of the stratigraphic scope, but despite the potential of its application in the geo-directional control, operational motives prevented its use in the horizontal segment.

REFERENCES

Chemostrat, 2003. Chemostratigraphy, Training Document. 200 p.

Albertão, G. A.; Sayd, A.D.; Blauth, M.; Rosseto, J.A.; Franco Filho, N.P.; Franco, M.P., 2004. Importância do Modelo Geológico no Geodirecionamento de Poço - O projeto Siri. Resumos do II SEDEST (Seminário de Estratigrafia). Relatório Interno da Petrobras. 3p.

TABLE and FIGURES

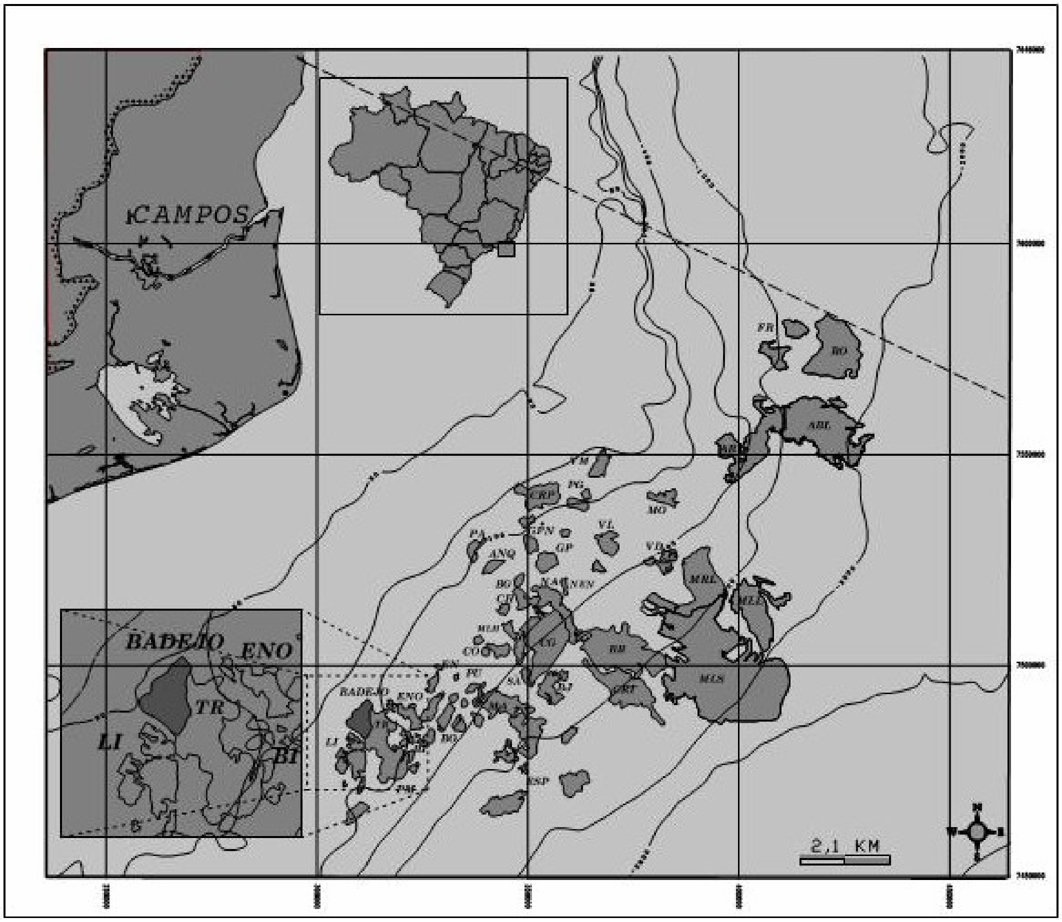

Fig. 1 – Location of the study area within the context of the Campos Basin

Table 1 – Chemostratigraphy zoning proposed for the Siri Member in the area of study.

Formation / Member	Interval	Package	Unit
Ubatuba / Tamoios	Miocene 2	P4	P4-U3
			P4-U2
			P4-U1
Emborê / Siri	Miocene 1	P3	P3-U5
			P3-U4
			P3-U3
			P3-U2
			P3-U1
	Oligocene 2	P2	P2-U4
			P2-U3
			P2-U2
			P2-U1
	Oligocene 1	P1	P1-U3
			P1-U2
			P1-U1

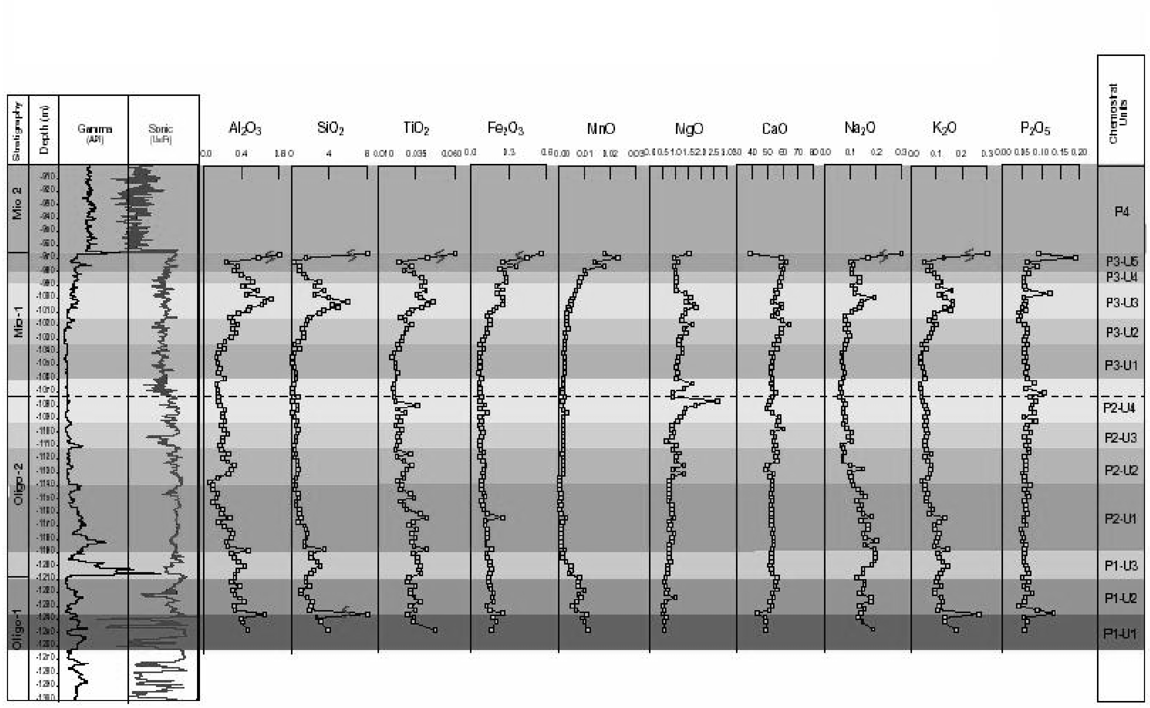

Fig. 2 – Geo-chemical profile of elements Al, Si, Ti, Fe, Mn, Mg, Ca, Na, K and P, within the Siri reservoir, in one of the correlation wells of the Badejo area. The concentration of elements is represented in relative percentage values. In the first two profile columns, on the left, there are the Gamma and Sonic Ray electric profiles. The chemostratigraphy zoning proposed was based not only in these elements, herein represented, but also in other minor elements and traces, as well as in elementary ratios, not represented in this figure.

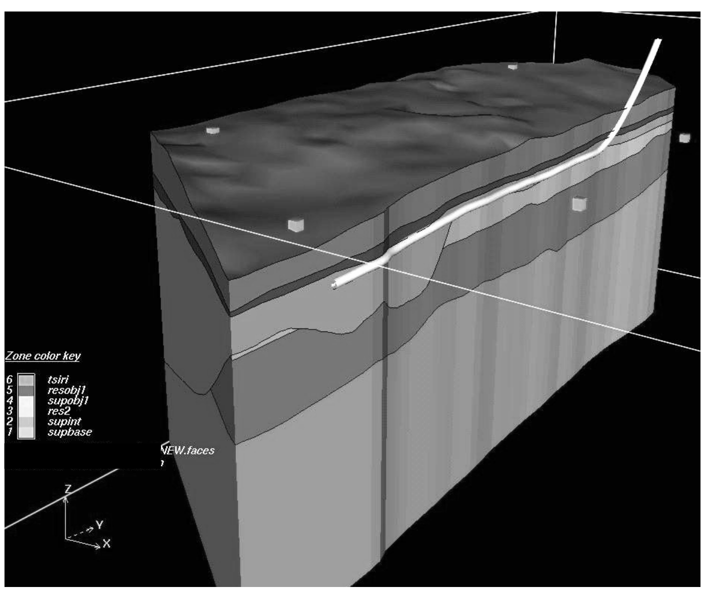

Fig. 3 – 3D representation of the geological model, restricted to the horizontal well area. The figure effectively represents the interval crossed by the horizontal well (white cylinder) and its navigation in the geological horizon 4 (supobj1), defined as the interval of interest for the production of oil. The total horizontal of the well is of 2 km. The figure presents a vertical exaggeration of 3 times. X represents the E-W direction and Y is N-S. The cubes represent control wells.