Radiometric and Thermal Signatures of Turbidite Flows in Namorado Oil Field

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Abstract

Results of natural gamma logs in 39 deep wells have been used in estimating distributions of radioelements (Uranium, Thorium and Potassium) in the Namorado oil field of the Campos basin. The methodology adopted makes use of an optimization program, based on simplex algorithm, in inverting results of gamma and density logs for determinations of radioelements and radiogenic heat production. Successful application of the method has been verified using both synthetic and real data. Analysis of results for Namorado oil field have allowed identification of characteristic features in the vertical and lateral distributions of radioactive elements. Most of the sand and shale sequences in this oil field are characterized by low concentrations of uranium relative to those of thorium. Maps of the spatial distributions of radioelement abundances and radiogenic heat indicate the presence of belts with relative enrichments of of radioelements. These are nearly coincident with the channels of turbidity currents inferred in geologic studies.

Geothermal data available for wells in the Namorado oil field reveal concave shaped temperature distributions, considered as indicative of down flow of fluids through channels identified in seismic surveys. We conclude that the results of the present work provide evidences for radiometric and thermal signatures of turbidite flows in the Macaé formation of the Namorado oil field, in the Campos basin.

Introduction

A common characteristic feature of basins in the continental margin of Southeast Brazil is the widespread occurrence of turbidity currents. Results of deep drilling have revealed the presence of turbidite deposits at depths greater than 5000 meters (Posamentier & Walker, 2006; Mutti et al, 2009). Such deposits are formed by turbidity currents which are rapid, downhill flow of sediment water mixtures. It is believed that such currents have been set into motion when mud and sand on the continental shelf are loosened by influx of fluvial discharge, earthquakes, collapsing slopes, and other geological disturbances. Influxes of fluvial discharge are believed to be intense along the continental slopes during periods of low level sea stand. Turbidity currents are considered responsible for changes in the physical shape of the continental shelf and slope by eroding large areas, carving out underwater canyons and creating channel systems on the sea floor. Considerable advances have been made over the last few decades in understanding the geological characteristics of turbidite deposits (see for example Bouma, 1962; Mutti et al, 2003; Shanmugam, 2003).

The processes responsible for turbidity currents belong to the general class of subsurface flows in permeable media. Occurrences of headless canyons have been cited in some studies (MCHARGUE et al, 2011) as marks of turbidity currents triggered by subsurface flows. Castro (1992) reported an overview of channel systems carved out by turbidites in the area of the offshore segment of the Campos basin. Zones of fluid flows identified by Pimentel and Hamza (2014) using geothermal methods are indicated in Figure (1).

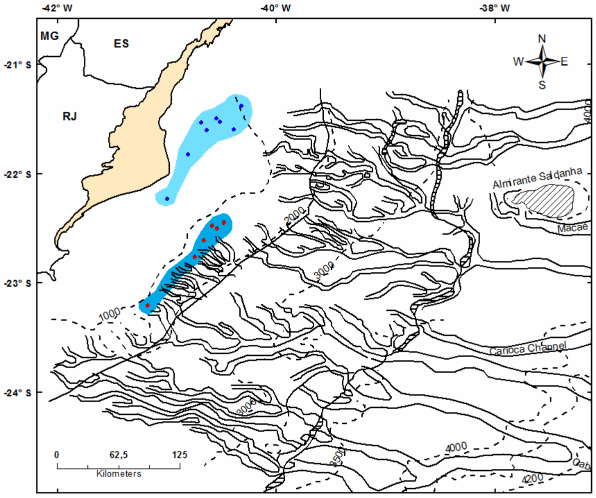

Figure 1 - The turbidite channels in Quaternary sediments (Adapted from Castro, 1992). Also indicated are sites where fluid flows have been identified by geothermal methods (Pimentel and Hamza, 2014).

Most of the oil fields are situated along a NE – SW trending belt, between the shallow and deep-water sections of the Campos basin. Seismic surveys (Augusto, 2009) coupled with analysis of core samples have allowed development of depositional models that outline the turbidity deposits in oil field areas of the Campos basin. A remarkable feature in results of these models is the presence of channel like features extending from the continental margin to the deep-water sectors of the basin. According to the model proposed by Barboza (2005), turbidity currents had its beginning in the early periods of deposition but the channels associated with currents were covered sediment depositions during later periods. This model of evolutionary sequence reproduced in Figure (2).

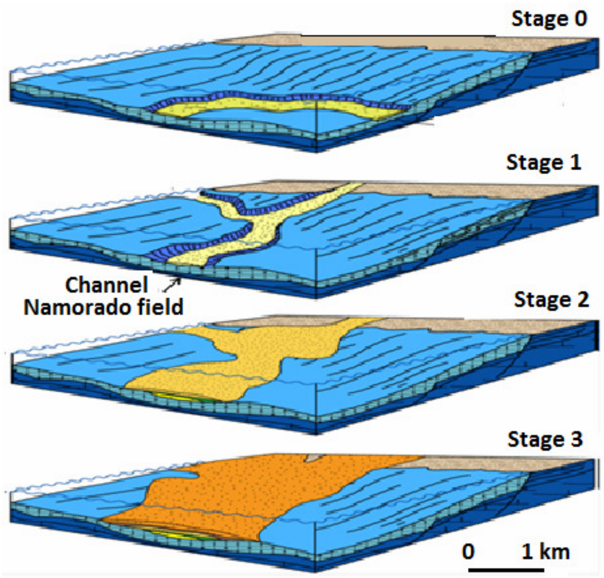

Figure 2. Model of evolutionary sequences of Turbidite in the Campos basin (adapted from Barboza, 2005).

Turbidity flows lead to characteristic features in the concentrations of natural radioactive elements (U, Th and K). Uranium is transported as dissolved species while thorium remains with heavy fractions. Potassium is associated with clay fractions.

In the present work, we report progress obtained in analysis of gamma ray logs for determining radioelement abundances and temperature logs for understanding the thermal structure of Namorado oil field and compare the results with model proposed by Barboza (2005).

Method

In the present work, use has been made of a procedure based on the simplex algorithm in determining relative abundances of radioelements from results of natural gamma logs of oil wells. The simplex is a popular method for solving problems in linear programming. It tests adjacent vertices of the feasible set (which is a polytope) in sequence so that at each new vertex the objective function improves or is unchanged. The shape of this polytope is defined by the constraints applied to the objective function. If the objective function has a minimum value on the feasible region then it has this value on (at least) one of the extreme points (Murty, 1983). There is a straightforward process to convert any linear program into one in standard form so this results in no loss of generality.

The computational procedure adopted in the present work makes use of the function "LINPROG" in MATLAB. The objective function adopted for this purpose is the relation for radiogenic heat (A):

$$A\ [\mu W / m^3] = 10^{-5}\rho(9{,}52\,C_U + 2{,}56\,C_{Th} + 3{,}48\,C_K) \qquad (3)$$

In the above equation (proposed initially by Rybach, 1986; Bucker and Rybach, 1996), C_u and C_{th} are respectively the abundances of uranium and thorium in ppm, C_k is abundance of potassium in percent and ρ is density in kg/m^3. The constraints applied to the objective function are based on the relation between intensity of radiation in gamma ray logs (GR) and concentrations of radionuclides as described in equation (3):

$$GR_{obs} = 10^{-3}\rho(6{,}57C_U + 1{,}77C_{Th} + 2{,}40C_K) + 5{,}0 \qquad (4a)$$

$$GR_{obs} \geq 0^{-3}\rho(6{,}03C_U + 1{,}62C_{Th} + 2{,}20C_K) + 0{,}8 \qquad (4b)$$

In addition, it was found necessary to adopt suitably selected values for the concentrations of radionuclides in limiting the process of optimization. In the present case, the following values selected, based on data reported by Wahl (1983) and Schlumberger (2014):

$$0{,}0 \leq C_U \leq 6{,}0\,ppm$$

$$0{,}0 \leq C_{Th} \leq 20{,}0\,ppm$$

$$0{,}0 \leq C_K \leq 15\%$$

The operational aspects of the computational procedure were verified using test runs employing both synthetic and real data (Oliveira and Martins, 2011). The results of tests with synthetic data for a hypothetic well cutting across six different rock types is presented in Figure (3). In this figure, the red color curves indicate synthetic data before optimization and the blue color curves represent results obtained after the optimization. It is clear that the computational scheme employed in optimization process has been remarkably successful in reproducing the abundance values within the limits of experimental errors.

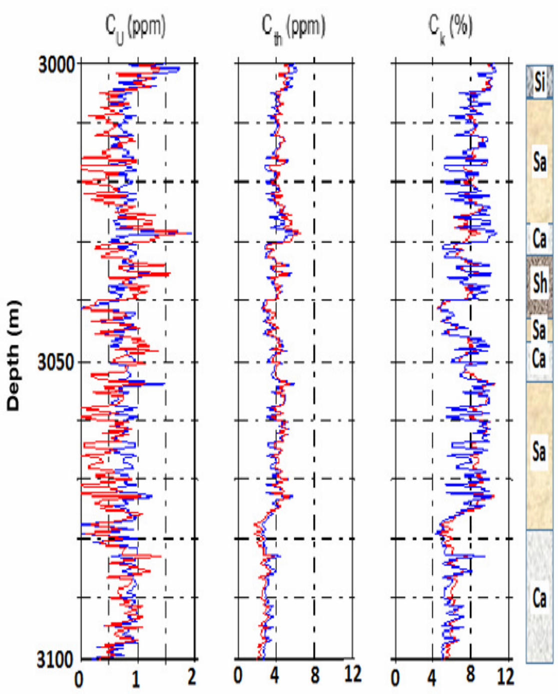

Figure 3. Results of tests with synthetic data for a hypothetical well. Red curves indicate synthetic data before optimization while blue curves represent results obtained after the optimization. The column on the right indicates the lithology (Si – Silt; Sa – sandstone; Ca – Calclutite; Sh – Shale).

Results

Comparison of the results of natural gamma ray logs with vertical distributions of radionuclides derived using the SIMPLEX method have been attempted for 39 wells in the Namorado oil field. An illustrative example of the results are presented in Figure 4, for well Na01. In this figure, the left column indicate the record of gamma ray log and the middle column the vertical variations of U, Th and K. The magenta and black colored curves in the middle column indicate distributions of thorium and uranium (abundances in ppm) respectively. The potassium abundances (in %) are indicated by the blue curve. Note that the uranium abundances (indicated as black curve in the middle column) are extremely low, compared to that of thorium.

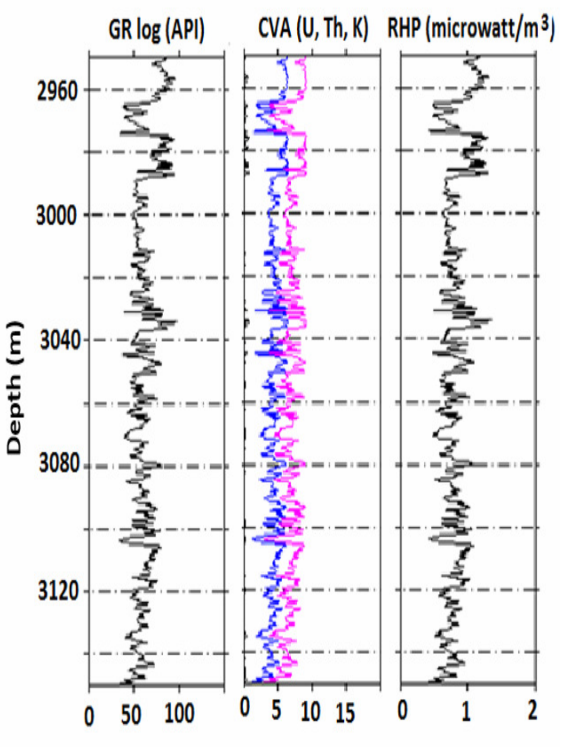

Figure 4. Comparison of natural gamma ray log and vertical distributions of radioelement abundances (U, Th and K) and radiogenic heat production (RHP) in well Na01.

The distribution of potassium follow trends that are similar to those of thorium. The lithological sequences encountered in these wells, in the range of 2971 and 2990 m depth, include mainly sandstones, siltstones, shale and marga, diamectites and layers with intercalated sequences of shale and sandstone.

A summary of the mean values of radioelement abundances is presented in Table 1, for the main rock types in the Namorado oil field. Interlaminated sequences of silt, shale and sandstone are found to have GR log values with API units in excess of 80. Conglomerates and breccia are found to have GR log values less than 50. The remaining rock types have API values in the interval of 50 to 80.

Table 1. Mean values of natural gamma ray logs (in API units) and abundances of U, Th and K.

Rock Type	GR (API)	U (ppm)	Th (ppm)	K (%)
Interlaminated silt and shale	100.2	2.5	9.8	7.3
Stratified silt and clay	99.4	1.1	9.4	6.7
Radioactive shale	99.2	0.7	9.2	6.5
Interlaminated sand. bioturbated	89.3	0.04	7.9	5.2
Shale and silt /Marga bioturbated	73.5	0.03	8.3	5.6
Marga. bioturbated	71.8	0.03	8.0	5.32
Intercalated sand and shale	58.4	0.1	6.8	4.3
Interlaminated argillaceous silt	55.2	0.2	5.9	3.5
Medium grained Sandstone	52.7	0.14	6.4	3.9
Conglomerates. breccia	29.6	0.55	2.3	0.7

Signatures of Turbidity Currents

The availability of results of the optimization process based on natural gamma ray logs provides an opportunity to examine spatial distributions of radioelement abundances. The map of Figure (5) illustrates the distribution of uranium at the depth level of 3100 meters. Note that the range of values are in the interval of 0 to 5 ppm. Most of the Namorado oil field is characterized by uranium values of less than 1 ppm. A remarkable feature in the map of Figure (5) is the presence of an approximate north – south trending narrow belt (trapezoid) where values of uranium higher than 2 ppm occur. The boundaries of this region of relatively high concentrations of uranium are indicated by black lines, which form a trapezoid. The geographic position of this trapezoid coincides with the position of channels of turbidite flows identified by Barboza (2005). Note that the belt is wider at the northern sector compared to that in the southern sector.

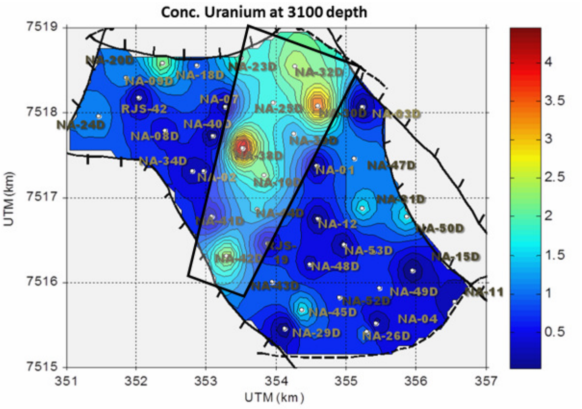

Figure 5. Map of the spatial distribution of uranium at the depth level of 3100m, in the Namorado oil field,

The maps of Figure (6) illustrate the distributions of thorium and potassium at the depth level of 3100 meters. The thorium values are in the range of 4 to 10 ppm while potassium is in the range of 2 to 8%. The northern sectors of the oil field are characterized by relatively high values relative to those in the southern parts.

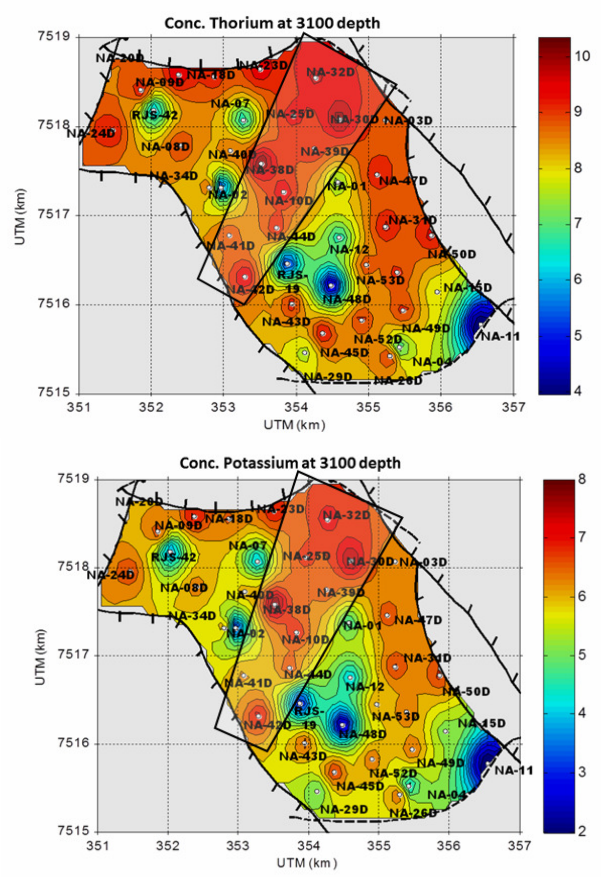

Figure 6. Maps of the spatial distribution of thorium (upper panel) and potassium (lower panel) at the depth level of 3100m, in the Namorado oil field.

Note the presence of approximate north – south trending narrow belts with relatively high values of thorium and potassium. As in the case of figure (5), black lines indicate the limits of these belts, forming trapezoids. The belts are wider at the northern sector compared to that in the southern sector. We consider these belts as indicative of channels with relative enrichment of radioelements, associated with channels of turbidity flows.

Geothermal Data

Geothermal log data are available for some of the wells considered in the present work (Bayao de Carvalho, 2014). The vertical distributions of temperatures reported in this work are indicated in Figure (7). Note the non-linear trend, typical of subsurface fluid flows. According to Pimentel and Hamza (2012; 2014), concave shaped curves in temperatures indicate of down flow of fluids. It seems reasonable to argue that fluid flows are still taking place along channels identified in seismic surveys (Figures 5 and 6).

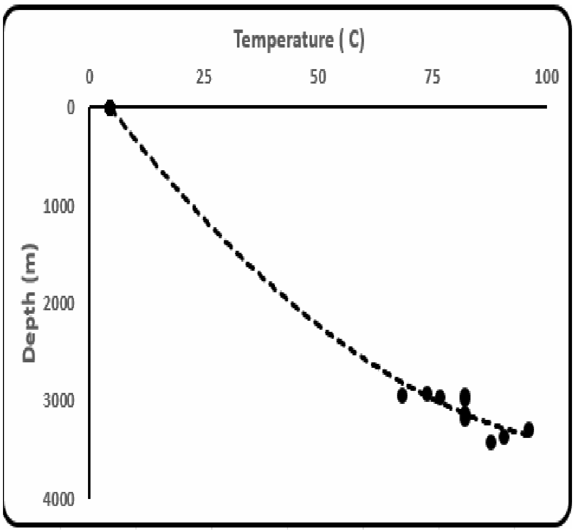

Figure 7. Vertical distribution of temperatures in the Namorado oil field, based on data reported in Bayao de Carvalho (2014).

Conclusions

According to results of the present work, most of the sand and shale sequences in Namorado oil field are characterized by relatively low concentrations of uranium. At 3100m depth, the concentrations of uranium values generally in the range of 0.5 to 5ppm. On the other hand, concentrations of thorium are found to be relatively high, with values generally in the range of 2 to 10 ppm. Potassium abundances are found to fall in the normal range of 1 to 8%.

The spatial distribution of radioelement abundances point to the presence of approximate north – south trending narrow belts of relatively high values. Such belts, with relatively high concentrations of uranium, thorium and potassium have been considered as indicative of channels associated with turbidite flows. A comparison of the ranges of the radioelement abundances inside and outside such belts is provided in Table 2. The relative enrichment of radioelement concentrations has been considered as a characteristic feature of turbidite flows.

Table 2. Ranges of values of radioelement abundances in and out of turbidite channels.

Description	**U (ppm)**	**Th (ppm)**	**K (%)**
Inside Turbidite Channel	1-5	5-10	5-8
Outside Turbidite Channel	< 1	< 4	< 4

Geothermal data available for wells in the Namorado oil field reveal concave shaped temperature distributions, considered as indicative of down flow of fluids through channels identified in seismic surveys.

We conclude that the results of the present work provide evidences for radiometric and thermal signatures of turbidite flows in the Macaé formation of the Namorado oil field, Campos basin.

Acknowledgments

The database discussed in the present work is part of public domain information available for academic research, provided by the National Agency for Petroleum (ANP) of the federal government of Brazil.

The present work was carried out as part of Ph.D. thesis Project of the first author. We thank Dr. Jorge Leonardo Martins for his guidance and collaboration in the early phases of this thesis work.

We acknowledge the research scholarship granted to the first author for her thesis work by the Coordenadoria de Aperfeiçoamento Pesquisa e Ensino Superior - CAPES.

The second author is recipient of a research scholarship granted by Conselho Nacional de Desenvolvimento Cientifico e Tecnológico – CNPq (Project No. 301865/2008-6; Produtividade de Pesquisa - PQ).

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