Petroleum Res. J. Vol. 13 (2001); P. 65-74, 11 Figs.

Mineralogical Identification and Depositional Environment Estimation of Lower Nubian Sandstone Formation Using Wire-line Logs Analysis

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التعرف عن المعادن واستنباط بيئة الترسيب بالجزء السفلي من تكوين الحجر الرملي النوبي باستعمال تحليل تسجيلات الآبار

محمد البرغوث

تم تحليل العينات اللبية المتوفرة من صخور المكمن النفطي العلوي بالجزء السفلي من تكوين الحجر النوبي بالبئر 82-001 الذي تم حفره بتراكيب 00 الواقعة بالجزء الجنوبي الشرقي من حوض سرت من حيث عمليات الترسيب والوصف البتروغرافي ونواتج النشأة المتأخرة، كما تمت مقارنة التحاليل المتوفرة بالنتائج التي تم الحصول عليها من تفسيرات السرود، وأمكن التعرف على المحتوى المعدني (خاصة الطينية منها) وتقييم بيئة الترسيب من خلال تحليل تسجيلات السرود وتدعيم ذلك بالمعلومات البتروغرافية والنشأة المتأخرة.

يوضح الفحص البتروغرافي أن الرمل ناضج من حيث المحتوى المعدني والنسيج وأن عمليات النشأة الكيميائية المتأخرة قد أدت إلى نمو موضعي لعدة مواد لاحمة كالمرو والكاولين مع كميات ضئيلة من معادن الآلايت والكلورايت. يتميز الرمل الناعم والرمل الغريني بقراءات عالية لتسجيلات سرود النيوترون والكثافة وتسجيلات منخفضة لتسجيلات السرود الصوتية ومنخفضة ومتوسطة للسرود الجيمية. أما الرمل الخشن والمتوسط الحبيبات، فهو على العكس من ذلك بالإضافة إلى أنه يعطي تسجيلات منخفضة لسرود الجاما. ويعزي هذا التباين في القراءات إلى وجود معادن المرو والكاولينايت بالنوع الثاني من الصخور، واحتواء المجموعة الأولى من الصخور على معادن تتكون من كربونات الحديد والبيرايت. وقد تم التأكد من هذه الخواص باستعمال الرسومات البيانية ROMA مقابل UMA. كما أكدت الرسومات البيانية لمعامل الامتصاص الكهروضوئي ضد القيمة اللوغاريثمية لعناصر الثوريوم على البوتاسيوم (Th/K) أو البوتاسيوم أن الكاولينايت هو أكثر معادن الطين شيوعاً. وتوضح عدة رسومات بيانية أخرى ناتجة عن تحليلات السرود أن الحجر الرملي الغني بعنصر الثوريوم والشحيح في عنصر البوتاسيوم مع تواجد لعنصر اليورانيوم أحياناً يعتبر مؤشراً لترسيب هذا الجزء من التكوين في بيئة قارية نهرية. أما وجود تركيزات أكثر قيمة لعنصر البوتاسيوم في حجر الطين (النوبي الأوسط) فإنه يعطي دلالة أن هذا الأخير قد ترسب في بيئة البحيرات.

Abstract: *Available cores cut in the upper pool of Lower Nubian Sandstone Formation of OO1/82 well drilled in OO structure, located in the southeast Sirt Basin, are analyzed according to their sedimentology, petrography and diagenetic products. The analyses are correlated with the results obtained from wire-line log interpretation. Analysis of these logs on the basis of different cross plots results, with the support of petrographic and diagenetic investigation, allows analysis of the mineralogical composition, particularly clay*

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minerals, and estimation of the depositional environment. Petrography examination shows that the sands are mineralogically and texturally mature. Diagenetic processes resulted in different cements such as authigenic quartz overgrowth, authigenic kaolinite with subordinate minor amounts of illite and chlorite. High readings of neutron and density logs plus low sonic and fair to medium gamma-ray reading characterize the very fine to silty sandstone while the opposite, with low gamma-ray readings, is true for medium to coarse sands. These values reflect quartz/kaolinite composition of the latter and presence of iron carbonates (e.g. siderite and/or ankerite) and pyrite in the former. These characteristics are confirmed by cross plots of ROMA (matrix density) versus UMA (absorption photoelectric cross section of matrix). Plotting of PEF (photoelectrical absorption index) against log Th/K and/or K confirm kaolinite as the most common clay mineral. Various cross plots obtained from analysis of spectral gamma-ray logs show that the sandstone are characterized by abundant thorium, minor amounts of potassium and locally uranium, interpreted as indicating fluvial continental environment. Higher amounts of potassium and uranium in the middle shale define a lacustrine environment.

INTRODUCTION

Classically core and/or cuttings are considered to be the most important well data source for lithology and sedimentary structure identifications, and hence depositional environment interpretation. However, a number of difficulties that are experienced in drilling operations such as lost circulation, and stuck drilling pipes can some times result in non-recovery of some cuttings. This can obviously complicate geological interpretations. Moreover, the time consuming and hence high cost of coring limits its general application resulting in a shortage of accurate identification of lithology and reservoir characteristics. On the other hand, wire-line log tools usually display a continuous survey of different lithology characteristics penetrated in the drilled well. Analysis of the different log curves generated, can provide valuable information about potential reservoir rocks and their characteristics, such as porosity and the nature of fluids present (Rider, 1986; Hurst, 1990; Doveton, 1994). Lithology and/or mineral identification, and correlation between drilled wells according to their log curve responses, are additional valuable information streams which can be obtained from logs analysis (Doveton, 1994; Schlumberger, 1989). Furthermore, estimation of depositional environments by applying different log technique analysis, has been documented during the recent decades (Rider, 1991; Selly, 1976, 1985; Schlumberger, 1989).

Aim of the Study

The upper pool of Lower Nubian Sandstone Formation, represented by the OO1/82 well, is the main subject of this study since it has long continuously cored section, and different wire-line logs are available. Hence, a valuable and accurate study expected to be achieved. Some other wells, surrounding the above mentioned well, such as OO2, OO3, OO4 and OO5, are included in this particular study as different logs types are available as well.

The aim of the study is to estimate the depositional environment and identification of the mineral composition types (especially clay minerals), which are distributed in the Lower Nubian Sandstone Formation represented by some wells drilled within OO structure. This is very important in the petroleum industry because knowledge of the relationship between clay content, types, texture, and water saturation enhances reservoir evaluation (Figs. 1, 2).

Methods of the Study

- The cored sections in the OO1/82 well were studied sedimentologically and petrographically in order to identify the lithofacies and their mineralogical contents. These results are compared with the different log responses, such as curves shape of the gamma ray logs and their relations of sediments grain size
- Analysis of the mineral composition of the formation according to the different logs responses such as density logs (LDL, LDT), neutron logs (CNL), sonic logs (DT). The analysis was compared with data obtained from the accurate mineral compositional analysis of the core section, determined from different application of petrographic techniques

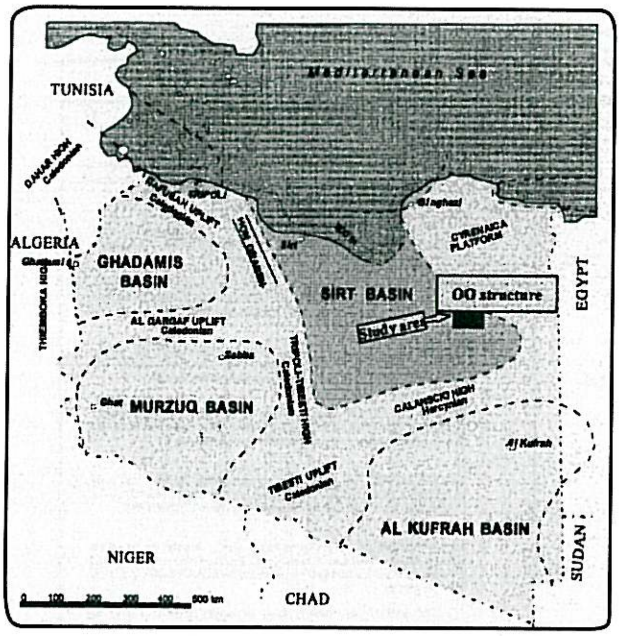

Fig. 1. Location map

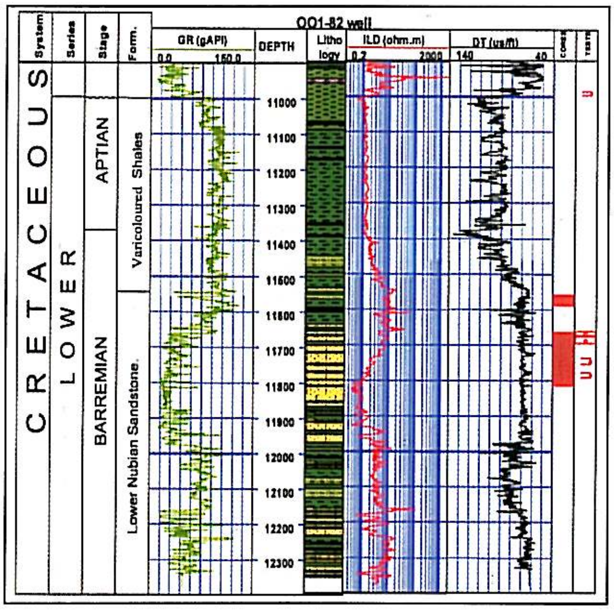

Fig. 2. Lithostratigraphic column defining LNSST and varicoloured shale, included the core interval and logs curves of OO1-82

- Analysis of the natural spectral gamma ray logs according to their natural radioactive elements (Th, K, U), which are available from some wells drilled within OO structure, and using different types of cross plots of these data for mineral identification and depositional environment estimation.

RESULTS OF THE STUDY

Lithofacies Analysis From Rock Samples

The upper pool of Lower Nubian Sandstone Formation, as represented in the OO1/82, well can be subdivided, according to hand specimen rock observation and petrographic analysis, into two main lithofacies as follows:

Fine to Very Fine-graind and Silty Sandstone

This type of lithofacies is characterized by very fine to fine quartz grains, moderately sorted and strongly indurated in most parts. It is occasionally characterized by moderate amounts of altered carbonaceous materials, presence of considerable percentage of pyrite in the form of cubes and/or poikilotopic cements and iron carbonates (ankerite and/or siderite). Low angle to horizontal laminations is the common structures identified.

These deposits could be represent overbank facies deposited under low energy conditions (Figs. 3, 4).

Medium to Coarse-grained Sandstone

This lithofacies is considered as the common sediment texture characterizing the OO1/82 well samples. It consists of moderately sorted, medium to coarse quartz grains, commonly characterized by sharp and/or erosinal surfaces containing mud-clasts conglomerates, and some times upward fining grain size profiles. Sedimentary structures presented as medium to small-scale cross laminations as well as gently dipping cross bedding. The multiple upward-fining units and the sedimentary structures, noted above, suggest that this lithofacies was deposited in channel environment under high-energy conditions (Figs. 3, 4).

Lithofacies and Mineralogy From Different Logs Responses

As Schlumberger (1989) reported, combination of different logs, such as NGS, neutron, density, and sonic logs can permit acceptable mineral identification, particularly within those formations characterized by less complex mixtures. Accurate mineralogical analysis was made on some

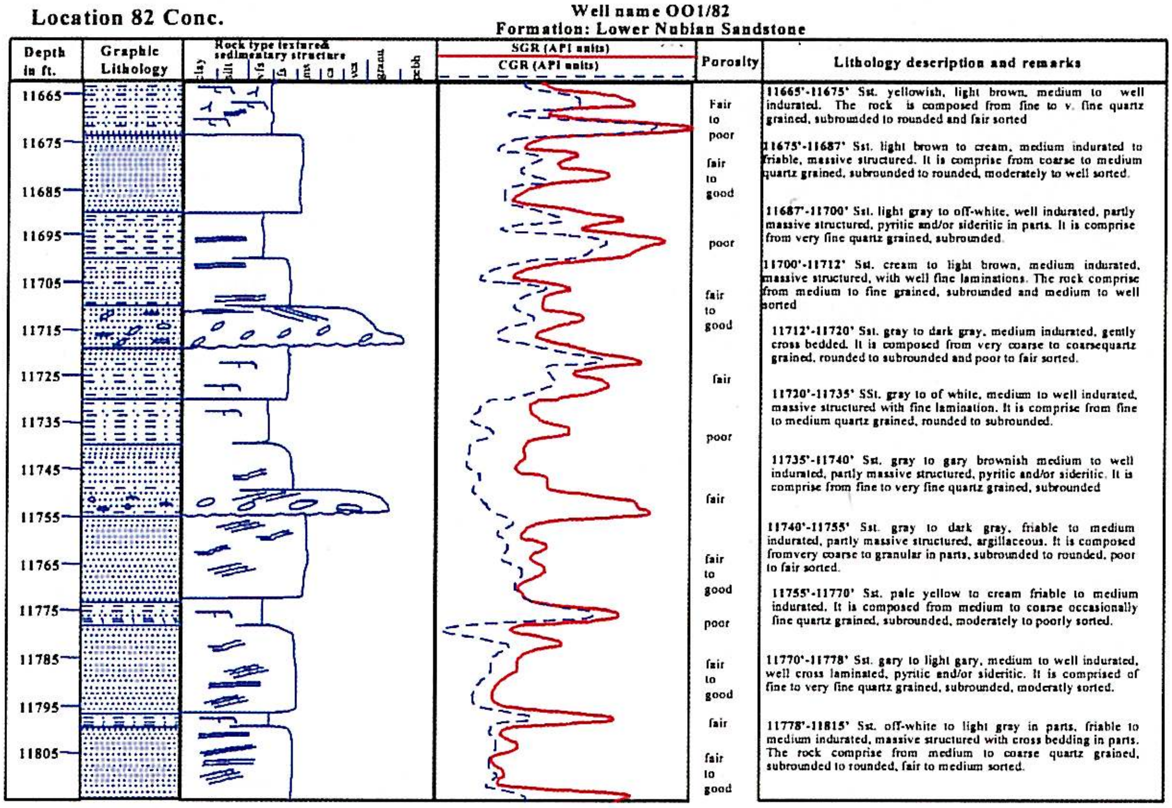

Fig. 3. Lithology and sedimentary structures of the OO1-82 core section (XX665'-XX815').

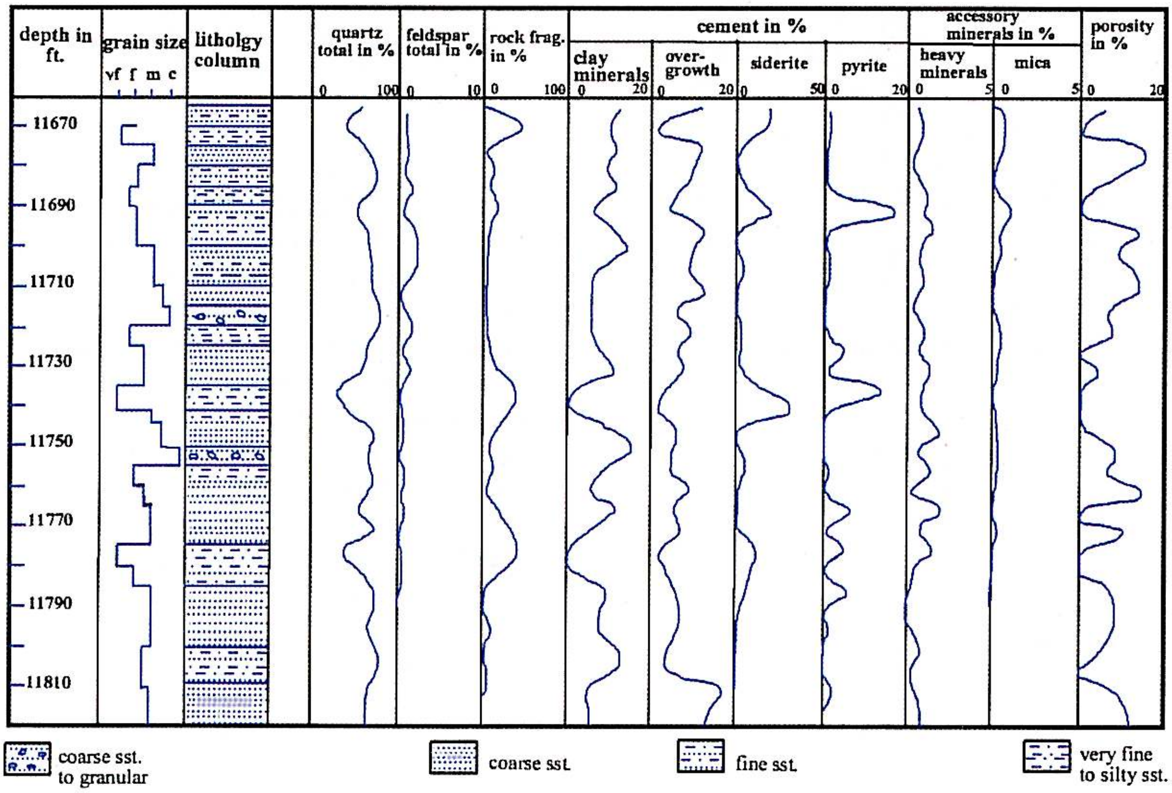

Fig. 4. Mineral distribution in percentage of the core section (XX665'-XX815') OO1-82 represented the upper pool of LNSS.

interesting samples selected from the core section and carefully correlated with the log responses. XRF was also used to identify the characteristics and to quantify the different minerals representing this lithology. Correlation of log curves with core samples in the OO1/82 well supported the subdivision into the two main lithofacies identified earlier. Distinct log responses of the different log curves define the two lithofacies. The characteristics of log responses related to the two identified lithofacies could be explained as follows:

Lithofacies one shows squashed quartz grains, and abundant matrix and cements possibly comprising detrital clays, so considerable percentage of bound water is present and hence a higher hydrogen index that is reflected by quite high readings in neutron curves in front of these lithofacies. Sonic logs on the other hand show quite low reading (about 58 us/ft. Density log is usually expected to give higher readings in front of very fine to shaly sandstone (Hurst, 1987; Rider, 1986). This is recognized in this lithofacies with higher bulk density pecks (approximately 2.65-2.70 gm./cc). These values do not, however, record shale lithology but result from the concentration of iron carbonates and/or pyrite, which are present and confirmed from petrography and chemical (XRF) analyses (Figs. 5, 6).

Log responses of lithofacies two, which is characterized by medium to coarse-grained sandstone, are mostly significant in that the neutron log responses show quite low readings compared with the values in lithofacies one. This might be explained by the presence of authigenic kaolinite filling part of the pore space and hence causing low fluids content (fair to poor hydrogen atoms). The hydrogen content within fine sand to shale lithology is higher than in medium to coarse-grained sediments (Hurst, 1987). Sonic logs, on the other hand, displays higher values compared with lithofacies one (about 70 us/ft.). Density log display lower values compared with lithofacies one. This can be explained logically as due to the abundance of quartz framework grains and authigenic kaolinite, which partially fills the pore space (Average grain density of quartz and kaolinite, documented in literature, ranges from 2.60-2.68 gm/cm3). Moreover, the minor amounts of iron carbonates and /or rarity of pyrite possibly control the low readings of density logs in this lithofacies (Figs. 5, 6).

LDT AND NGS LOGS EVALUATION

The log data in this analysis are derived from the two logs curves, the natural gamma-ray spectrometry (NGS), which is measuring Th, K, U, radioactive minerals and from the lithodensity log (LDT), which records the bulk density of a formation (apparent density) and photoelectrical absorption index (PEF). It records the absorption of low-energy gamma ray by the formation in units of barns per electron, and is commonly scaled on a range from 0 to 10 barns per electron on its log curves (Schlumberger, 1989; see log curves in Fig. 5).

Accuracy of NGS Data

Before accepting the NGS data, examination of their accuracy must be made (Hurst, 1990). Precision of the NGS log data is assessed by comparing the main runs of logs, displaying thorium, potassium and uranium data, with the repeat run section. The values of the NGS logs are obtained directly from the recorded curves (Schlumberger, 1989). To expand examination of the accuracy of analysis as a mineralogical indicator and as a parameter for deposition environment interpretations, some other wells (OO2, OO3, OO4, OO5) surrounding the OO1/82 well are included in this study. However, lack of core samples from these wells limits the study to log analysis only, but with the core section of OO1/82 well as reference. According to the data, which are derived from the study wells, fair to good correlations were achieved referring to 1:1 line. A few of points, however, are positioned quite a way from the main trend. These ambiguous values could be attributed to wireline stretching during logging operations. Also, the emission of natural radioactivity is random in any examined formation, therefore, many case studies show that measuring radioactivity of minerals within the same formation, over different times, often gives slightly different readings (Hurst, 1990).

Analysis of LDT and NGS Logs

Clay minerals identification according to the photoelectrical index is a function of their content

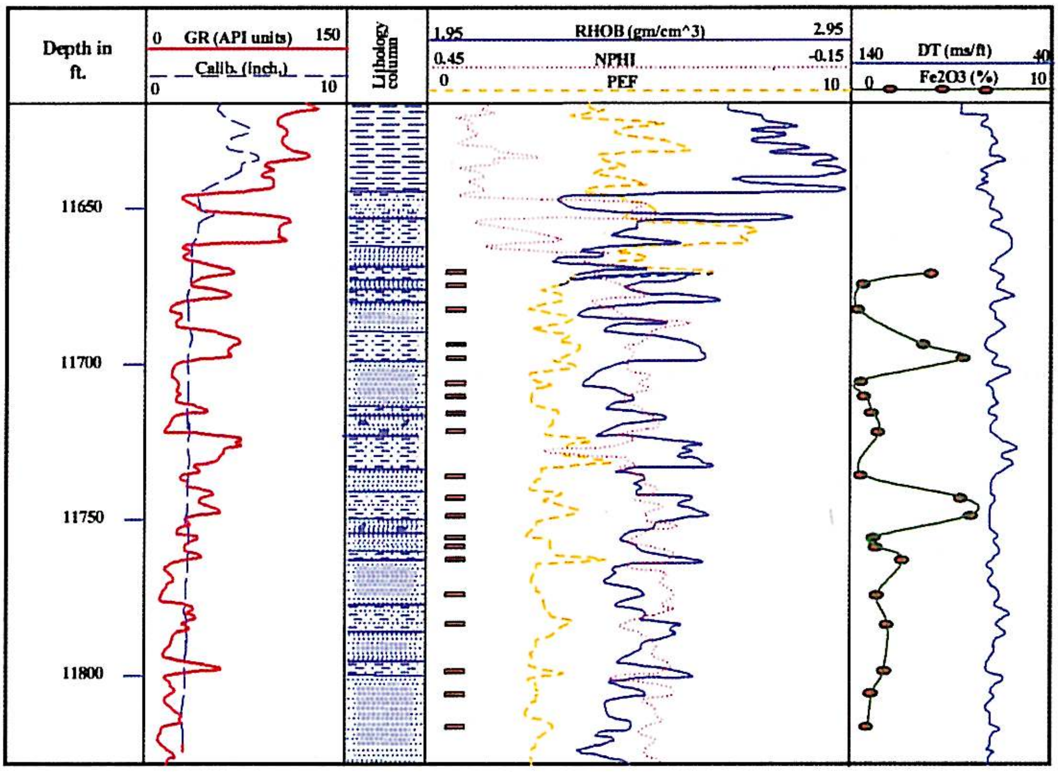

Fig. 5. Variation of different log curves (OO1-82 well) according to mineralogical and fluid composition. Note the positions of the selected thin sections related to log curves.

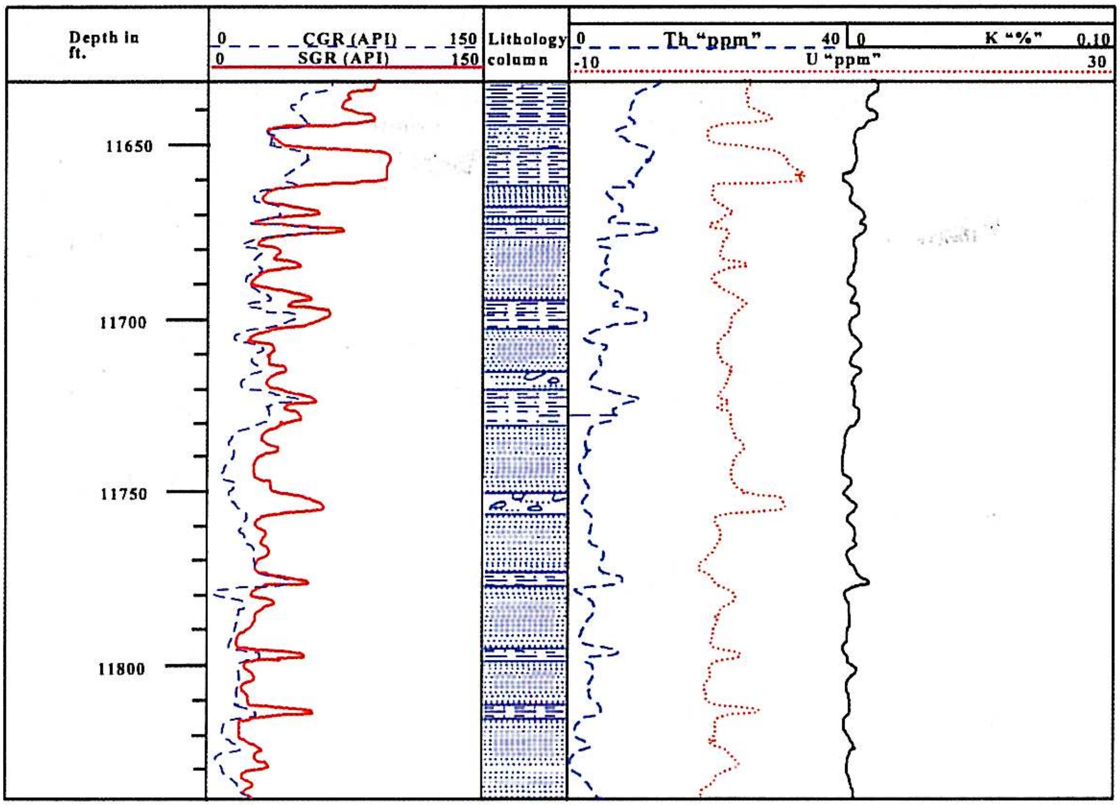

Fig. 6. Distribution of the radioactive elements (Th, K, U) within the OO1-82 well, Upper Pool of LNSS.

of iron, in which clays characterized by free iron (e.g. kaolinite) often have values similar to quartz. Preveraro and Russel (1984), Shlumberger (1989) and Doveton (1994) have discussed clarifications of these raw data, which are obtained from the above-mentioned logs. They propose that cross plots of these parameters can help in the identification of mineral composition. By identification of the data from different logs analysis (NGS, LDT logs), cross plot methods are made for minerals descriptions which are represented by known selected points and/or clusters on the cross plots (Preveraro and Russell, 1984; Schlumberger, 1989 charts).

Cross plot of ROMA versus UMA is used to separate lighter minerals such as pure quartz and kaolinite from heavier ones, which often contain iron concentrations, for instance, iron carbonates and/or pyrite. In this cross plot, the clean zones, which are characterized by medium to coarse quartz sand grains and authigenic kaolinite cements, appear to be concentrated in the left side of the cross plot confirming quartz and/or kaolinite minerals. The intervals characterized by fine to very fine-grained, display very high values of UMA, which are attributed to the presence of iron carbonates and/or pyrite (UMA>20). Minor scattered points represent mica, mixed clay, and heavy minerals (Fig. 7).

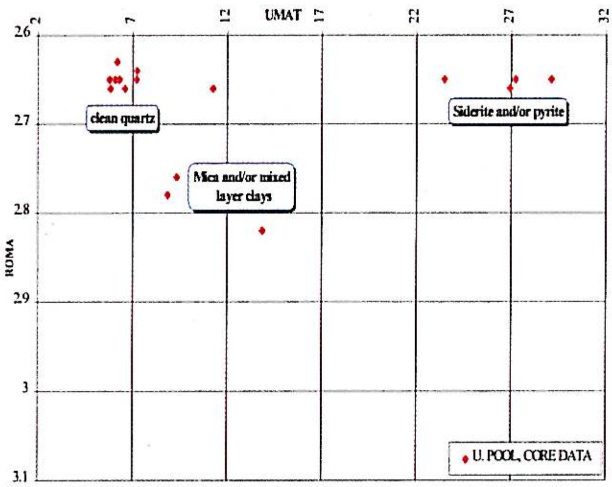

Fig. 7. Apparent matrix volumetric cross section versus apparent matrix density defining the distribution of the main minerals within the OO1-82 core section.

PEF data versus log Th/K and/or K cross plots are on the other hand, used to identify clay minerals types. Comparison of the cross plot data with the results obtained from petrographic studies show that reliable results can be obtained and clearly confirm the abundance of kaolinite, which is the most common clay minerals of the upper reservoir of the Lower Nubian Sandstone Formation (Figs. 8, 9)

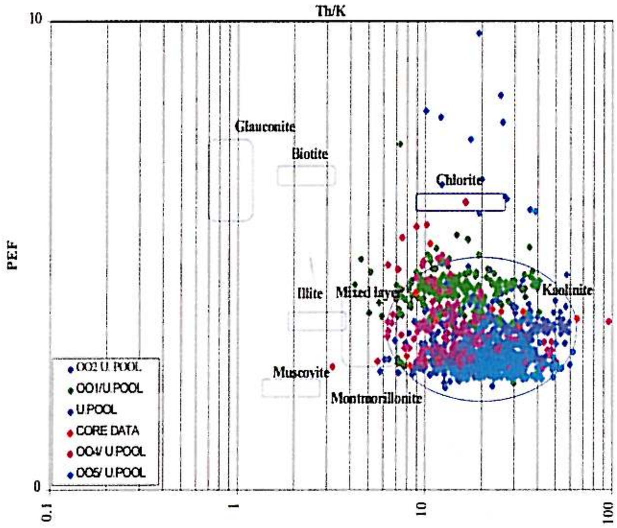

Fig. 8. Cross plot of Th/K ratio versus PEF (barn/electron) for identification the main minerals represented the upper pool of LNSS - OO1-82 wells

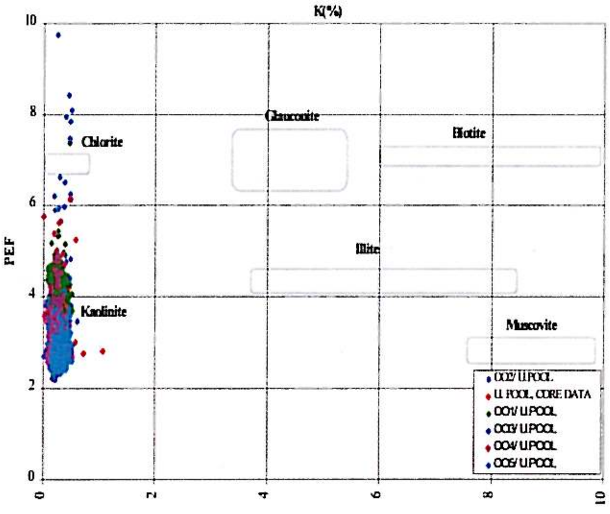

Fig. 9. Cross plot of potassium (K) versus photoelectric cross section (PEF) for identification of clay minerals within OO1-82 wells.

Spectral Gamma-ray Analysis

Introduction of natural spectral gamma-ray logs (NGS) has provided valuable information in geological studies, dealing with reservoir evaluation (Schlumberger, 1989). For instance, identification of clay minerals within drilled oil well is considered important in the petroleum industry because knowledge of the relationship between clay contents, types, texture, and water saturation enhances reservoir evaluation (Hurst, 1987). Spectral gamma-ray log was run in OO1/82 well as is shown in figure 6. Interpretation of these logs on the basis of different cross plots results, with the support of petrographic and diagenetic analysis, allows analysis of the mineralogical composition, particularly clay minerals, and estimation of the depositional environment of the Lower Nubian Sandstone Formation. Three members represent this formation; the lower member comprising interbedded sandstone and shale intervals. The middle shale member, separating the two sandstones. The upper member, comprising the major sandstone intervals. This possibly forms the bulk of the reservoir rocks (Figs. 2, 3). Most of the radioactive sources in this case study are obtained from thorium and, locally, uranium, where as potassium shows a minor but constant amount through the whole of the upper sandstone member. The middle shale member, however, accommodates fair amounts of potassium. Support for these observations are confirmed in petrographic analysis on the available rock samples of the OO1/82 well, which show rare, or almost absent potassium feldspar, traces of mica, and absence or poor amounts of illites (Fig. 4). Data of thorium, potassium, and uranium were identified from analysis of spectral gamma-ray logs in OO2, OO3, OO4, and OO5 wells, and plotted on the same cross plots of the OO1/82 well to identify any data variations related to the mineralogical compositions.

Potassium-thorium cross plot

This plot was introduced by Quirein *et al.,* (1982) for recognition of different clay minerals types and also for identification of the accessory radioactive materials responsible for the quite high gamma ray reading in front of clean formation (e.g. sandstone reservoir). This is usually attributed to potassium feldspars, mica such as muscovite and, in some parts, to concentrations of accessory minerals (heavy minerals) such as rutiles, and zircon.

Application of this technique on Lower Nubian Sandstone presented by OO wells of concession 82 clearly separate the main minerals. It can be seen that the majority of plots are concentrated along the kaolinite track. In contrast the middle shale section plots are mostly a mixture of illite and kaolinite with subordinate amounts of smectite and/or mixed layer clays (Figs. 10a, 10b). As mentioned earlier, confirmation of these results has been obtained from petrography, and diagenetic analysis.

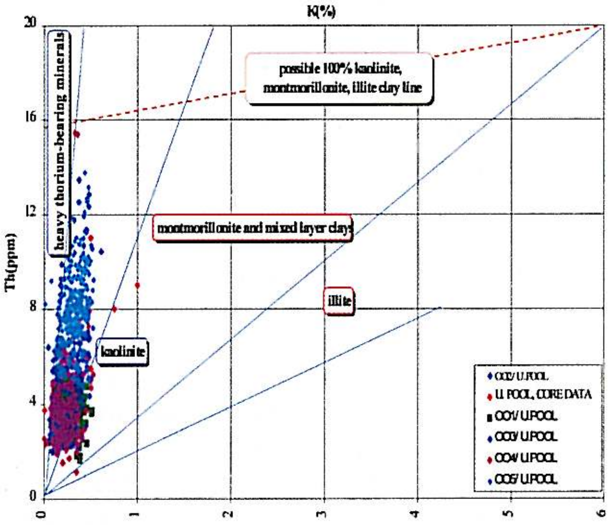

Fig. 10a. Distribution of clay minerals concentration within the upper pool of LNSS. - OO1-82 wells

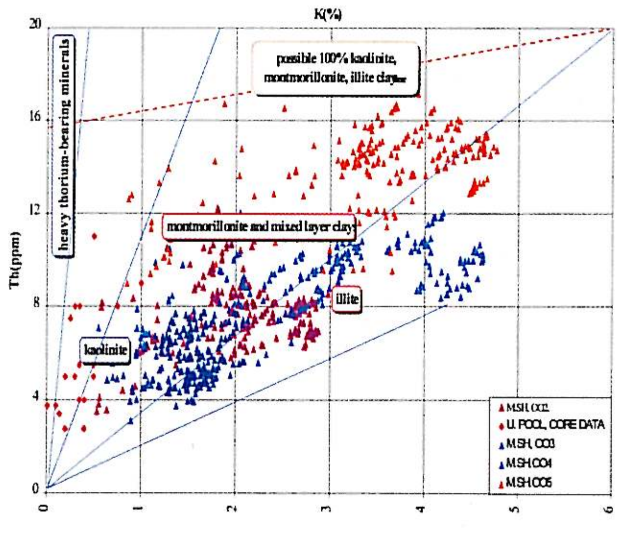

Fig. 10b. Distribution of clay minerals concentration within the middle shale of LNSS. - OO1-82 wells.

Thorium- uranium cross plot

Thorium, potassium and uranium are documented as helpful indicators for environment identification and hence, natural gamma ray spectral logs (NGS) can be used for environment analysis (Adams and Weaver, 1958; Doveton, 1994). The suggested basis recommended for differentiating between marine sediments and continental ones is that the marine are characterized by a low Th/U ratio (reducing conditions) and vice-versa for continental sediments (oxidizing conditions). Clay minerals concentrations can also assist in distinguishing marine, transitional, and non-marine environments. This analysis in general shows that non-marine deposits commonly contain kaolinite as the abundant clay minerals, whereas illite is greater within marine sediments (Harron, 1986; Doveton, 1994; Lonnie, 1982). Application of this approach to the upper reservoir and the middle shale of Lower Nubian Sandstone, involved cross plots of Th/K versus Th/U. The plots show that most of the data related to the upper reservoir fall in the zone defining kaolinite and heavy thorium bearing minerals (Th/K >10) and (Th/U>2). A combination of the abundance of kaolinite and Th/U ratio is higher than two has been interpreted in as a very strong indicator of terrestrial depositional environment (Doveton, 1994). A few points are positioned along the area characterized by Th/U<2, these attributed to intervals characterized by presence of considerable amounts of uranium as recognized from NGS log analysis (Figs 3, 6). Explanation to these anomalous readings is that these intervals accommodate amounts of organic matter, which are attractive sites for uranium concentration (Doveton, 1994; Rider, 1986). The middle shale cross plot are mostly characterized by Th/K ratio range from 2.5-7.5 defining that this section accommodates considerable amounts of illites and/or mixed layer clays displaying characteristics of lacustrine type (Figs. 11a, 11b).

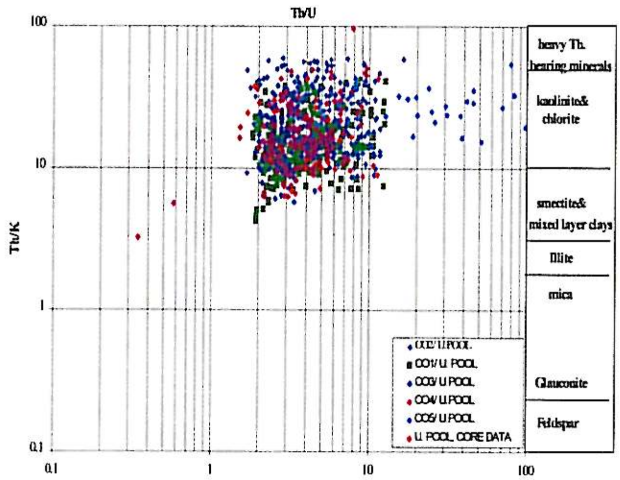

Fig. 11a Concentration of clay minerals within the upper reservoir of LNSS. Formation - AA/82 wells

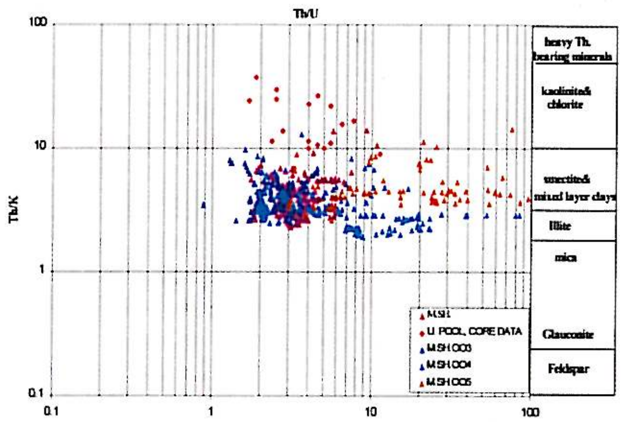

Fig. 11b Concentration of clay minerals within the middle shale of LNSS. Formation - AA/82 wells

CONCLUSIONS

Accurate interpretation of the mineralogy is obtained from application of cross plots of different data derived from log curves analysis. These are achieved and/or confirmed by careful selection of the same zones from the cores available and by analysis of some rock samples obtained from the core section of OO1/82 well sedimentologically, petrographically, and geochemically. The core section has been classified generally into two lithofacies; lithofacies one characterized by fair amounts of iron carbonates and/or pyrite minerals; lithofacies two shows clean quartz sand grains, and partially cemented by authigenic kaolinite. Moreover, the section documented intensive diagenetic processes in which most of the potassium feldspar and labile rock fragments containing muscovite were dissolved and replaced by authigenic clay minerals.

The dominant clay minerals characterizing the upper pool of the Lower Nubian Sandstone Formation is kaolinite with minor amounts of illites and chlorite. In contrast, illites and/or mixed layer clays characterize the middle shale. As a result, the gamma-ray values indicate quite low to fair API units within the whole sandstone section, except those intervals characterized by abundance of detrital clays and/or which accommodate amounts of iron carbonates and pyrite.

The different cross plots of thorium versus potassium and (log Th/K) against (PEF) are shown to be reliable means of estimating mineral types in the Lower Nubian Sandstone of the OO structure. This was achieved by recognition of abundance of kaolinite clay minerals, which is considered as a signature for the non-marine environment. Moreover, Th/K versus Th/U cross plots; on the other hand, show oxidizing conditions by displaying minor amounts of uranium.

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