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Correct Shale Volume Estimation and Clay Typing Identification in Shaly Sand Reservoirs: Case Study of Zarga Formation, Keyi oil field, Block-6, Sudan.

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ABSTRACT-The presence of potassium (K) in Zarag formations effects the total gamma measurement and there for causes an overestimation of the shale volume estimation. We introduce a powerful technique that combine the gamma ray and photo electric factor log (PEF) in order to overcome this challenge.
The clay type identification is essential step to calculate an accurate effective porosity and water saturation models.
As preliminary analysis steps, first density neutron cross plot investigated to verify the lithology, second spectral core logs achieved for potassium identification, thirdly a new technique applied to correct the gamma ray from the potassium effects, and finally X-ray diffraction (XRD) and multi minerals cross plots utilized to identify the formation minerals components.
The reasonable shale volume estimation provided by corrected gamma ray (CGR0) method with average of 27% and density- neutron technique with average of 20%.
The dominant clay type is Kaolinite with average volume of 39%, and considerable amount of Chlorite with average volume of 18%.
The Quartz and K-Feldspar excited in the matrix with average volume of 22% and 21% respectively.

Keywords: *Shale volume and minerals estimation for shaly sand reservoirs.*

المستخلص- تركز هذه الورقة في تقليل تاثير معدن البوتاسيوم علي الجاما(Gamma ray log)المقروؤ من تسجيلات الابار (well logging) بغرض معرفة وتقييم الحجم الحقيقي للطين وتحديدالمحتوي المعدني (Multi minerals)المكون للطبقات الطينيه المستهدفة في بئري (KEYI-4 & KEYI-11)، ويتم انجاز هذا العمل باستخدام معلومات التسجيل الطيفي للباب (Spectral Core Gamma) وتحليل عينات اللباب (Core analysis) بواسطة تقنية XRD ,لتفسير معطيات التسجيلات المذكوره للابار، هناك كثير من التحديات التي تواجه الجيوفيزيائي في هذا الحقل في حساب القيمة الحقيقية لحجم للطفل (Clay content) في نطاقات محدده، ومن ضمن هذه التحديات كيفية تقليل الأثر المحدث علي قياسات تقنية جاما (gamma ray) مع وجود معدن اليوتاسيوم في النطاق المحدد، و ماهو النموذج أو الطريقة الأفضل لحساب الحجم الحقيقي للطفل (shale volume) ومدي التمييز بين انوع الطفل (Clay type) وطرق تحديد المعادن، كخطوات اساسيه للتحليل و التفسير، اولا استخدام طريقه الكثافة و النيوترون (Density-neutron cross plot) للتحقق من الخصائص الصخرية (Lithology identification) ، ثانيا استخدام طريقه التسجلات الطيفية لصخور الباب (spectral core gamma) لتحديد تركيز البوتاسيوم، وثالثاستخدام تقنية جديدة لتصحيح أشعة جاما من تاثير البوتاسيو(corrected gamma ray) ، وأخيراستخدام حيود الأشعة السينية (XRD) لتحديد مكونات المعادن، تم تحديد المحتوي الطيني المناسب لصخور المكمن بعد تصحيح (gamma ray)عن طريقة (CGR0) ،ونسبه المحتوي الطيني الكلي بمعدل27٪، وباستخدام تقنية النيوترون (density-neutron)المحتوي الطيني الكلي بنسبه 20٪، نوع المعدن الطيني السائد هو الكولنيت (Kaolinite)بمتوسط حجم 39٪، وكمية معتبره من الكلوريت (Chlorite) بمتوسط حجم18٪. ومعادن الكوارتز(Quartz) والفلسبار (K-Feldspar)متواجده في ارضيه صخور المكمن بمتوسط حجم 22٪ و 21٪ على التوالي.

INTRODUCTION

Introduction

The study area is a part of Muglad rift basin. It is a part of trend of Cretaceous sedimentary basin of apparent rift origin related to the global phenomenon of plate tectonics. The Field is located within Block 6 Fig. (1). Keyi field area is 126 sq.km wide within the Western escarpment, Fula Sub-basin of a thick sequence of Tertiary and Cretaceous sediments has been penetrated in exploration well Keyi-1 in the study area.

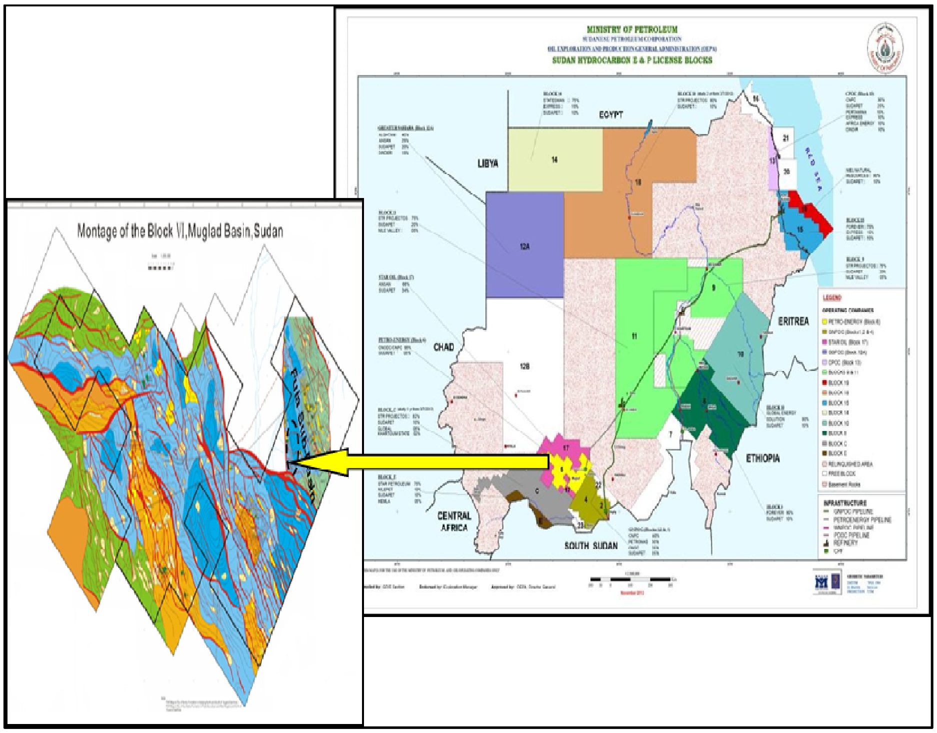

Fig.1: Location Map of Keyi-Oil Field in Fula Sub-Basin, Block-6 of Sudan.

Stratigraphic and Geological Fram Work

Stratigraphic sections of the Muglad Basin published by (Schull, 1988), (McHargue et al, 1992) and (Kaska, 1989). Three continental sedimentary depositional cycles are defined by three rifting episodes which occurred in the Early Cretaceous (140-90 Ma), Late Cretaceous and Lower Tertiary (90-60), and the tertiary to recent respectively (Fig .2) (A.Y. Mohamed et al, 2002).

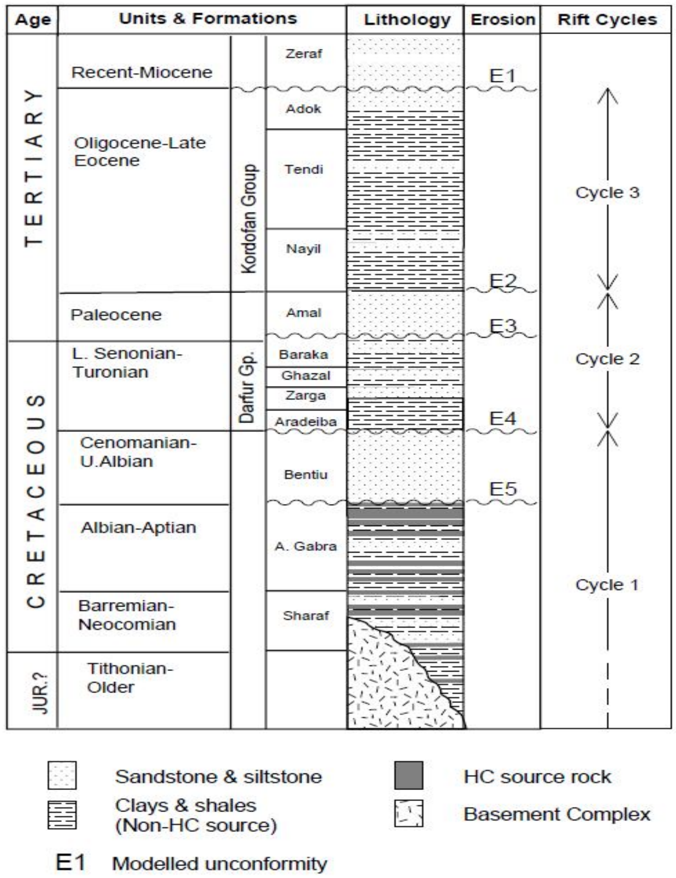

Fig.2: Summary stratigraphic column of the interior Sudan basins with generalized lithologies showing formation ages (Mohamed et al, 1999).

Objectives

The ultimate goal of this paper is to eliminate the effect of potassium from gamma ray log measurement and estimation accurate shale content in the reservoirs, another aim to identify different clays mineral for Zarag sub layers of the wells (Keyi-4 & Keyi-11), utilizing spectral core data, X-ray diffraction analysis (XRD) and well logging interpretation.

The Data

The available conventional well logs include; the gamma ray log (GR), density and neutron porosity logs, resistivity logs and Photo Electric Factor (PEF) log, and the gamma ray log used as a clay indicator.

Spectral logs analysis performed in order to identify the concentration of the radioactive minerals thorium (TH) and potassium (K) in the formation, also X-ray diffraction (XRD) core analysis investigated to verify the clay type in the formation.

ElanPlus of Techlog software utilized, in order to calculate accurate shale content and discriminate between the clay types based on the logs responses.

The Probleum Description

The presence of potassium concentration in the studied layer at depth (1571.0-1586.0m) of well Keyi-11 in Zarag Formation showing relatively high gamma ray at the bottom (105 API), while density ,neutron and resistivity logs were not consistence with gamma ray, high gamma ray overestimate the shale contents up to (60%) in this interval (Fig.3). It is necessary to remove the potassium concentration from the total gamma ray measurement.

Layers 2, with interval (1689.5m-1721.3m) and layer 3, with interval (1721.9-1729.6m) of well Keyi-11. Layer 2, with interval (1685.5m-

1711.8), and Layer3, with interval (1719.3-1726.2m) of Keyi-4, were studied to evaluate the shale volumes in Zarag formation.

Estimating the rock's shale volume linearly from the gamma ray log still remains the first preferred approach to become with a preliminary shaliness indicator. The procedure is easy and straightforward, and might give reasonable results for some zones. However, quite often the linear IGR shalines indicator yields an over-estimation of rock's shale volume (especially for shallow, young reservoirs), producing an overall pessimistic scenario of the reservoir quality. An empirical formulations has been

eveloped in this paper to correct and reduce the rock's shale volume (VSH), instead of direct functions of IGR, that is VSH = f (IGR) as in equation-1.

$$VSH = \frac{GRL - GRclean}{GRshale - GRclean} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

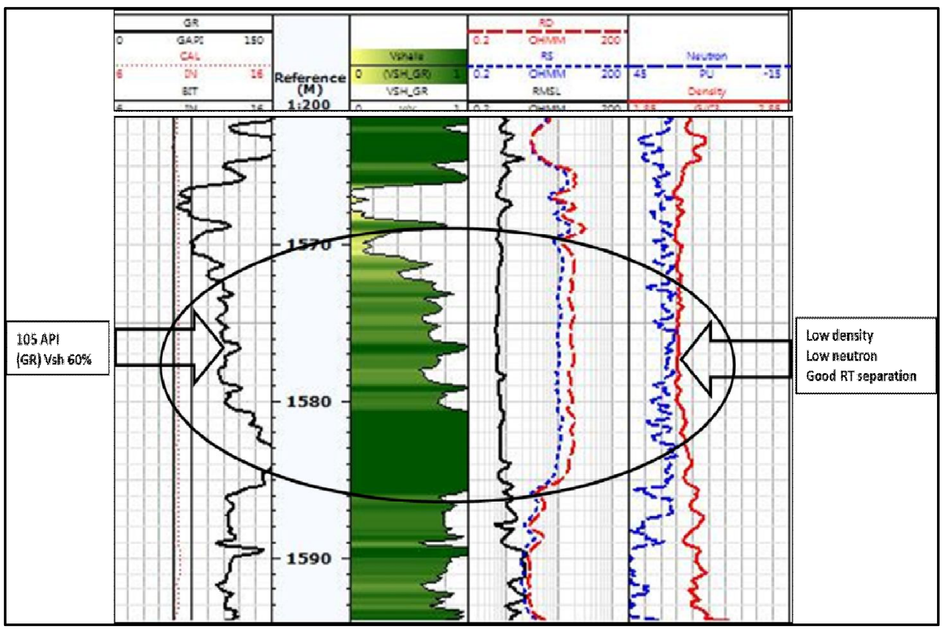

Fig.3: Log plots displayed relatively high gamma ray measurement at the bottom of the target layer at depth (1571.0-1586.0m) with high shale volume about (60%) as direct function of gamma ray index (IGR).

ANALYTICAL APPROACH

Density-Neutron for Lithology/Shale Volume Identification

The zones from the well log has been selected for analysis, a scatter cross plot can be made by plotting the density porosity on the y-axis and neutron porosity on the x-axis, and initially a few parameters must be set, and by default a few values are already in place. The matrix density (ρma), fluid density (ρf), and gas correction values should be set early to facilitate the analysis. Matrix density is the density for the primary mineral being analyzed, and this is set to Quartz (sandstone): ρma = 2.65 g/cm3, after investigated with cross plot (Fig.4).

Fluid density (ρf) will be the density of the formation water in the reservoir. Normally for evaluation of shaly-sand reservoir the shale endpoint parallel to dolomite line and perpendicular to the dolomite line to sandstone line the shaleness decrease (Fig.4).

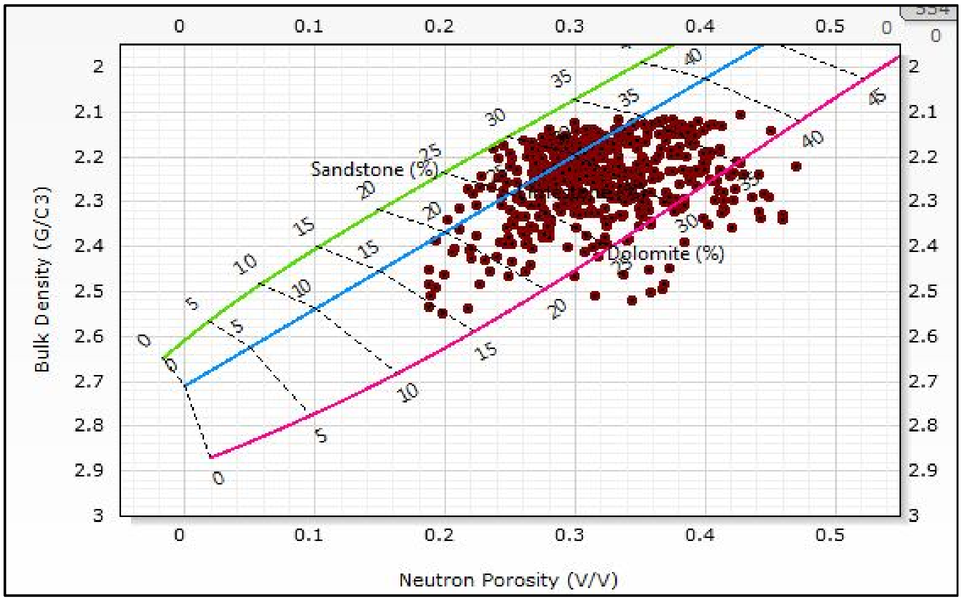

Fig 4: Bulk density and neutron porosity cross plot for lithology and clay content identification.

Analysis

A thorium-potassium methodology using a core or gamma ray spectral log is available for determining the predominant clay (Rodolfo, 2010).

In order to verify the presence of the thorium concentration in the matrix, Spectral logs (Potassium,Thorium,Uranium concentrations) were investigated and plotted in Fig (5), and cross plot based on core data of thorium vs potassium showing low (Th/K) ratio almost equal to zero as in Fig.(6).

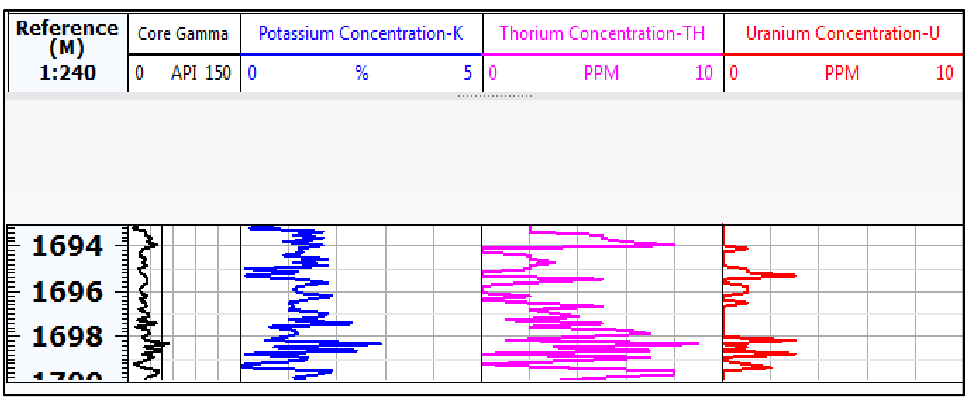

Fig.5: Spectral logs analysis showing the concentration of K-potassium in the core sample of the well KEYI-11.

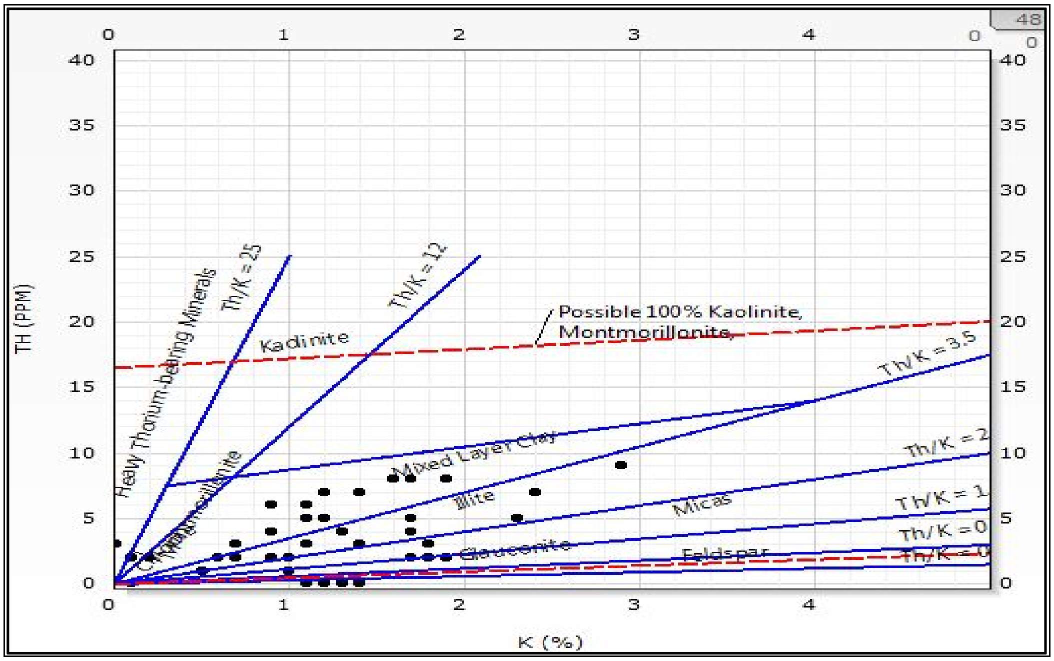

Fig 6: Thorium and Potassium cross plot showing low (Th/k) ratio.

Clay Mineral Identification by XRD Core Analysis

The study of the clay minerals has been investigated by X-ray diffraction (XRD) technique, and six clay rich samples from the studied intervals have been analyzed with the XRD technique. Four clay mineral species were identified from the size fraction less than 2 micron using the procedures of (Chamley, 1989).

A quantitative estimation of the clay mineral clay type obtained as in (Fig.7), (Table.1) and (Table.2).

Table 1: The XRD analyzed sample of well Keyi-4, showing the percentages of the clay minerals in Zarag formation

Sample Depth (m)	Clay Minerals %				
	Kaolinite	Smectite	Illite	Chlorite	Illite/ smectite
1695.45	68.9	0.1	0.6	30.4	0.04
1689.55	58.8	0.04	0.2	40.9	0.01
1511.55	58.1	0.06	0	41.6	0.47
1510.55	71.9	0.4	0	27.6	0.11

Table 2: The XRD analyzed sample of well Keyi-11, showing the percentages of the clay minerals in Zarag formation.

Sample Depth (m)	Clay Minerals %				
	Kaolinite	Smectite	Illite	Chlorite	Smectite/illite
1695.3	99.23	0.23	0.34	0.12	0.08
1698.6	84.91	0.27	0.24	14.53	0.05

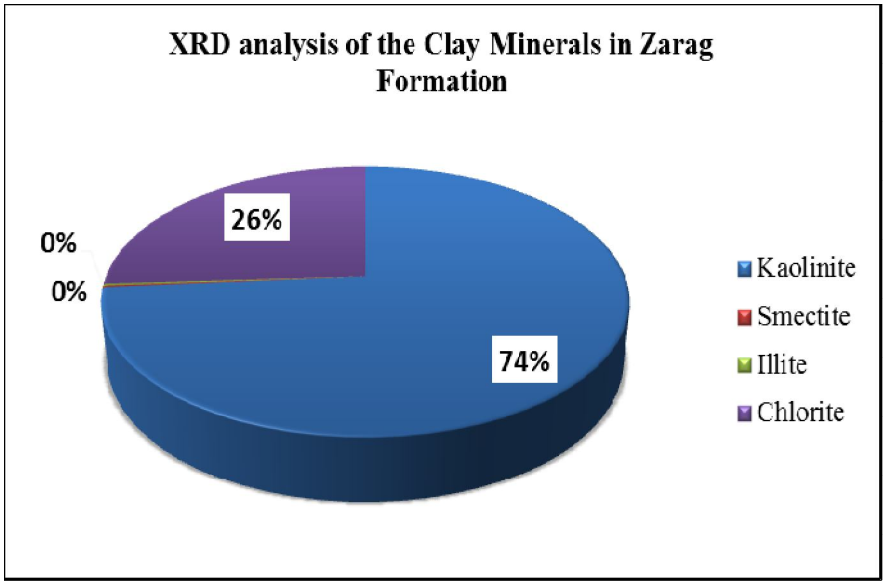

Fig 7: Showing the percentage of the clay minerals in ZaragFormation, based on core data of keyi-4 and Keyi-11.

METHODOLOGY

It is common to use the standard gamma ray log (SGR) or total contribution from all three elements-uranium (U), potassium (K), thorium (Th)-as an indicator of the clay content. The presence of highly radioactive black organic material and/or natural fracture in the formation results in a big difference from X-ray diffraction data.This causes an overestimate of shale volume and therefore affects the original oil in place (OOIP) andreserves.A novel methodology that combines normal distribution and normalization to predict correct gamma ray from SGR and deep resistivity, Rt, and across correlation technique applied to validate the methodology, and the model corrected gamma ray (CGR) matches the actual CGR very well.
Next, element capture spectroscopy (ECS) logs used to quantify the actual caly volume (Vsh).Then computing techniques to develop a shale volume model using CGR and Rt as independent variables and Vsh from ECS as the dependent variable (Rodolfo, 2010).
This paper used density-neutron, sonic, resistivity, and thorium (TH), potassium (K) andcore data, as main source for shale volume estimation.
In general two methods adopted for shale volume estimation, first the linear method, and the second is multi mineral method based on clay minerals identification.
In order to study and verify some information regarding lithology, shale volume and clay minerals, different techniques investigated, and can be summarized as following:

Photoelectric Factor (PE) and Gamma Ray Logs Method

Photoelectric factor (PE) and gamma ray logs can be combined into a powerful tool to eliminate the effect of radioactive minerals concentration. Photoelectric factor log has linear relation with gamma ray to some extend and less affected with radioactive mineral. Multi wells cross plot of target zones was generated and plotted GR against PEF and region, with upper and lower limit of lithology was identified (sand-shale end points), then linear equation was developed to correct for gamma ray (CGR) as in figure (8) and equation (2).

GR=57.6*PE-57.4………………..……. (2)

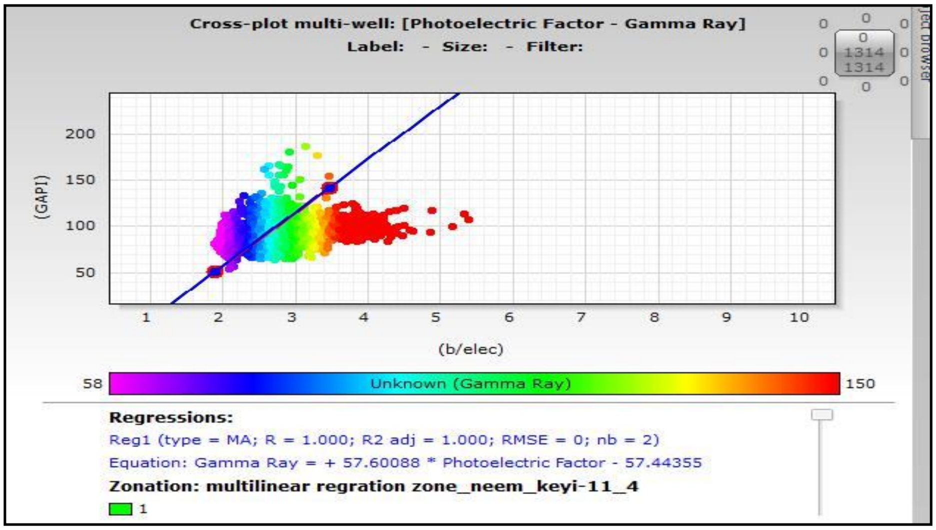

Fig 8: The relation between photoelectric factor and gamma ray, to develop a new method (CGR0) to eliminate the effect of the potassium concentration from gamma ray log.

Multi Minerals Method

Multi wells cross plot generated and the responses of Quartz, Feldspar, Kaolinite and Chlorite were realized, the clay end points were identified and the dry weight per cent of the clay minerals components estimated (Fig.9).

The wet-clay point or (end point) represents the response on density and neutron measurements due to water associated with clay under the prevailing thermodynamic conditions (Aaron D. Kurtz, 2013).

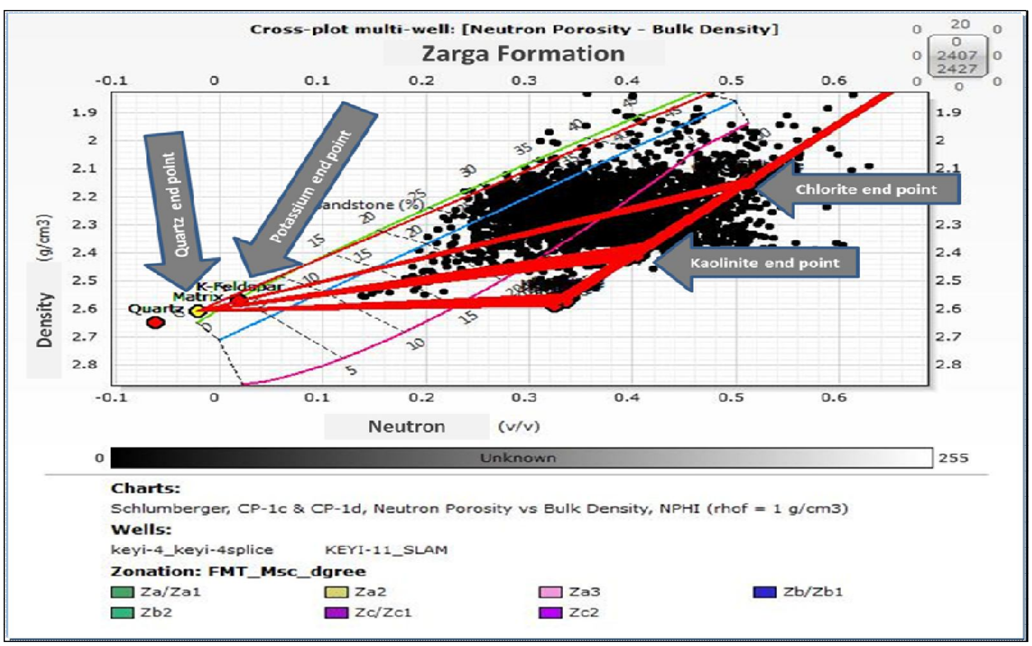

Fig 9: Multi wells cross plot for multi mineral identification.

THE INTERPRETATION RESULTS

The Shale Volume Results of Well Logs

This concept of gamma ray correction (CGR0) was applied to wells (KEYI-4 & KEYI-11) that has spectral core gamma ray and confirmed the effects of potassium on original gamma ray, then the gamma ray correction (CGR0) was done and the result of new method (CGR0) showed clear difference in shale volume estimation from 60% to 29% in some intervals (1571.0-1586.0m) (Fig.10),and slightly acceptable differences ranged from 5.0 % to 8.0 % in the studied layers 2 and 3 as in (Fig11).

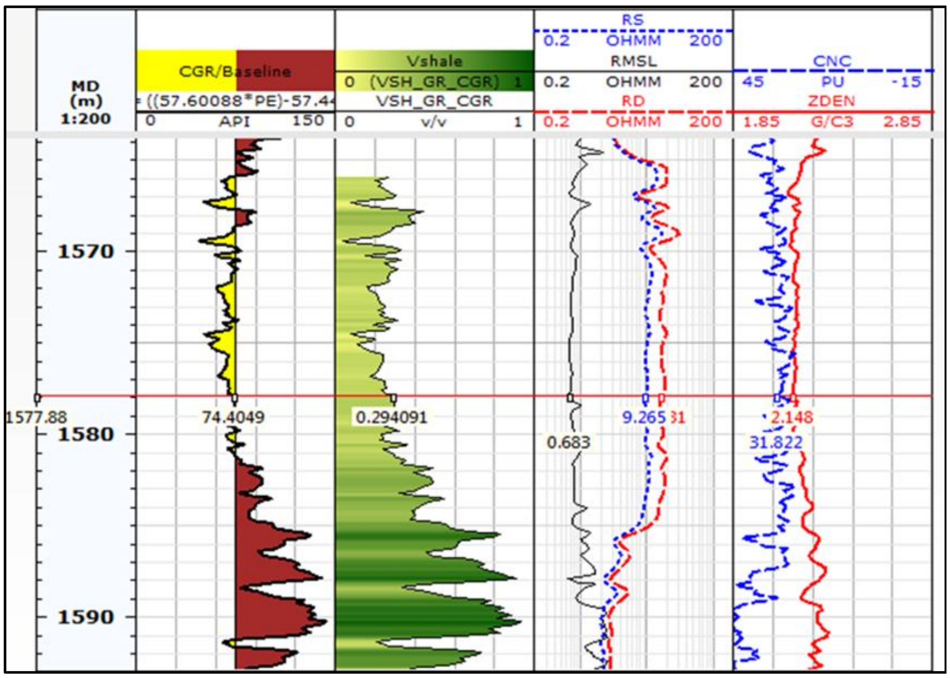

Fig 10: Shale volume estimation after gamma ray corrected from potassium effect, using equation-2, and calculates reasonable shale content about 29% of well Keyi-11.

The below histogram illustrate the differences between the shale volume estimated by the gamma ray before the correction, and shale volume by gamma ray after the correction (CGR0) applied equation-2 of layer 2 and 3 of Zarga formation (Fig.11).

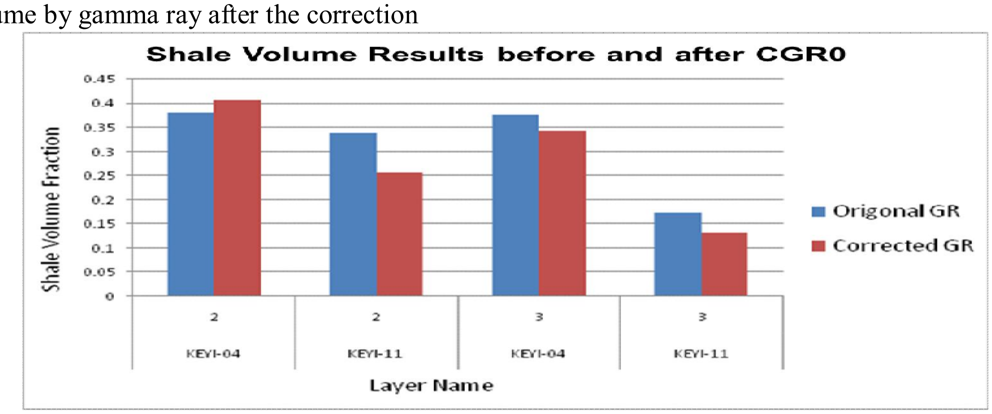

Fig.11: The difference in shale volumes between gamma ray before and after the correction.

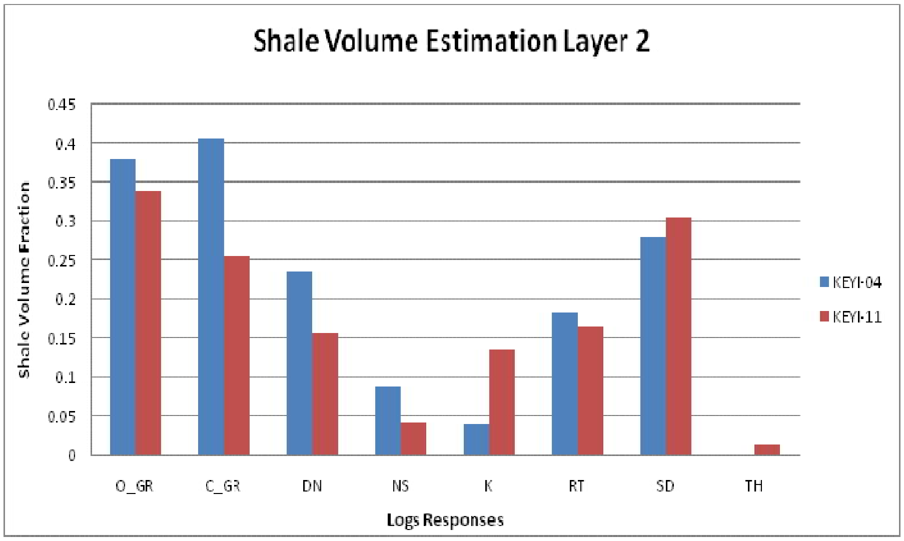

Fig.12: Shale content estimation base on gamma ray (O_GR), Spectral core gamma (TH,K), corrected gamma ray from Potassium concentration(CGR0), density, neutron(DN), resistivity(RT),neutron–sonic(NS) logs measurements in layer 2.

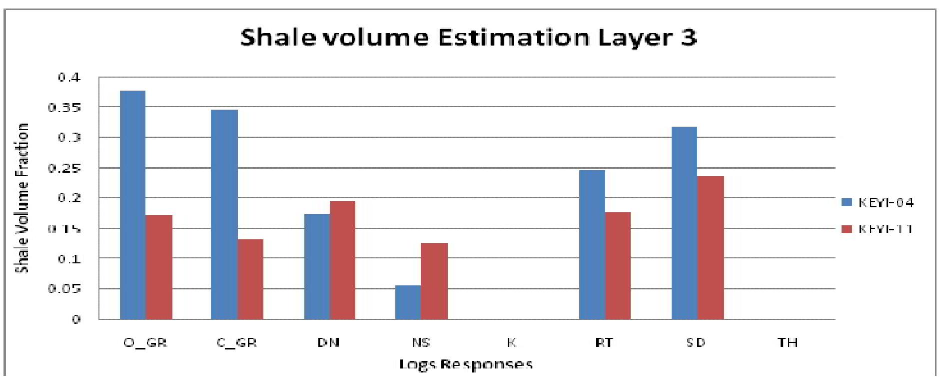

Fig.13:Shale content estimation base on gamma ray (O_GR), Spectral core gamma (TH,K), corrected gamma ray from Potassium concentration(CGR0), density, neutron(DN), resistivity(RT),neutron–sonic(NS) logs measurements in layer 3.

The Shale Volume Results of Multi Minerals Method

In the target reservoirs of Zarga formation there are two different clay minerals have been recognized, Kaolinite as dominate with average volume about 38%,and considerable amount of Chlorite with 17% as average of clay content (Fig.14) (Table-3).

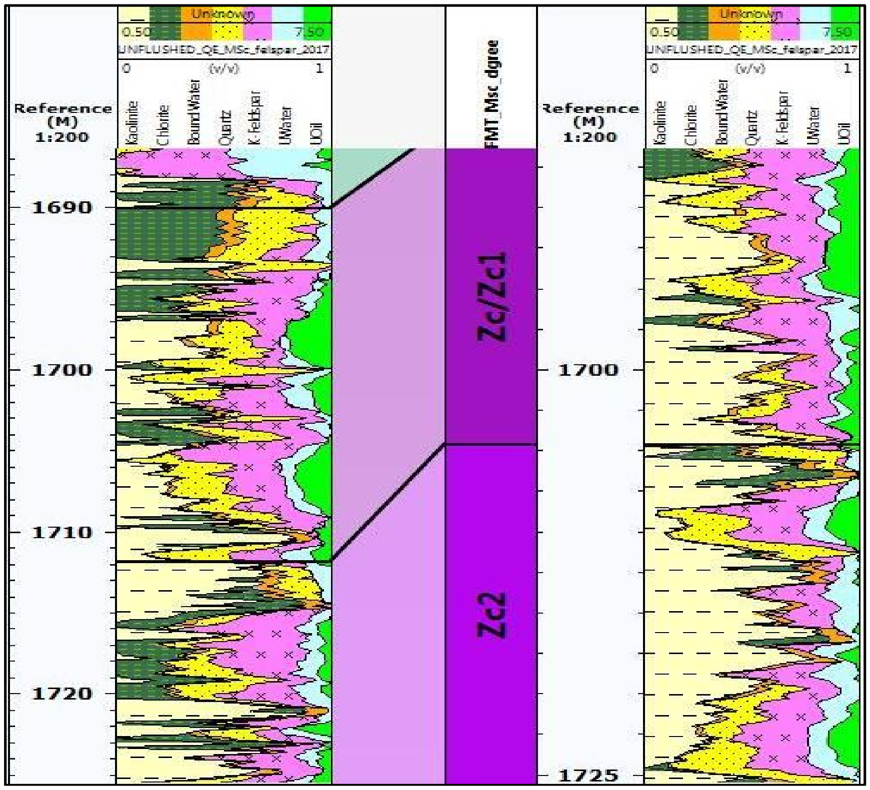

Fig.14: Multi minerals and clay type interpretation results.

Table-3: The Clay Type Identification based on Multi Mineral of Core analysis and Logging Interpretation

Well	Formation	Sub layers	Top	Bottom	Gross	Av_Chlorite Volume Fraction	Av_Kaolinite Volume Fraction	Av_Quartz Volume Fraction	Av_Potassium Concentration
			m	m	m	v/v	v/v	v/v	v/v
Keyi-11	Zarga	Za/Za1	1605.8	1623.1	17.3	0.157	0.297	0.371	0.175
		Za2	1623.1	1635.8	12.7	0.06	0.341	0.467	0.131
		Za3	1635.8	1649.3	13.5	0.11	0.284	0.428	0.178
		Zb/Zb1	1649.3	1675.2	25.9	0.146	0.451	0.279	0.124
		Zb2	1675.2	1690	14.8	0.089	0.27	0.365	0.277
		Zc/Zc1	1690.0	1711.8	21.8	0.277	0.256	0.182	0.286
		Zc2	1711.8	1729.5	17.7	0.218	0.38	0.168	0.235
keyi-4		Za/Za1	1603.5	1617.6	14.1	0.152	0.59	0.091	0.167
		Za2	1617.6	1630.7	13.1	0.222	0.461	0.113	0.204
		Za3	1630.7	1644	13.3	0.182	0.247	0.382	0.189
		Zb/Zb1	1644.0	1661.7	17.7	0.226	0.357	0.096	0.321
		Zb2	1661.7	1685	23.3	0.257	0.553	0.074	0.115
		Zc/Zc1	1685.0	1704.6	19.6	0.175	0.428	0.059	0.338
		Zc2	1704.6	1726	21.4	0.174	0.524	0.058	0.245

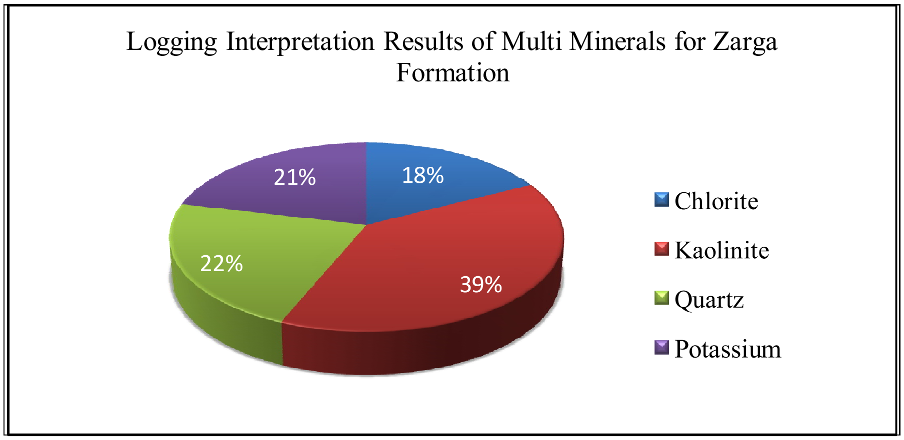

Fig.15: Logging Interpretation Results of Multi Minerals of Keyi-4 and Keyi-11 Zarag Formation.

RESULTS AND DISCUSSION

The spectral core gamma indicates the presence of potassium, accordingly to demonstrate the validity of gamma ray correction method (CGR0), the log response of the corrected gamma ray consist with density-neutron and resistivity log response, moreover reasonable shale volumes estimated.

The shale content estimated from corrected gamma ray, density-neutron, resistivity and spectral core gamma logs showed wide range of shale content from (6.0% to 38.0%) as average in layer 2, and (9% to 36%) as average in layer 3 as in (Fig.12) and (Fig.13).

The shale volume estimation linearly from the gamma ray overestimated (maximum) the Vsh more that 15% compared to density, neutron (minimum) method.

The clay minerals verified by X-ray diffraction (XRD) analysis and the logging interpretation results dominated by kaolinite volume (39%), quart volume (22%) and considerable amount of potassium and chlorite 12%, 18% respectively (Fig.15).

CONCLUSIONS

The challenge facing shale volume estimation and clay type identification have been evaluated from spectral core logs, XRD analysis, and introducedthe new technique(CGR0).

The combination between Photo Electric Factor (PEF) and measured gamma ray, considered as powerful technique (CGR0) to overcome the radioactive effects from gamma ray.The presence of the potassium concentration verified by spectral core gamma.

Density-neutron method, estimate the minimum shale volume in the reservoirs, and the linear gamma ray method provide the maximum shale volume.

There is a clear reservoir characterization made by introducing multi minerals interpretation models.

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