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Petrophysical Analysis on Radioactive Sands for Koala Field in Termit Basin, Niger

Muhammad Syafiq Zainal Malek, Lo Shyh-Zung and Abdul Ghani Md Rafek
Department of Petroleum Geosciencet, Universiti Teknologi PETRONAS (UTP),
40150 Seri Iskandar, Perak, Malaysia

Abstract: Investigations in Niger delta adjacent to Termit basin, Niger has widespread occurrence of radioactive sands. About 34-45% of producing wells contains this anomaly which is misinterpreted as shales in petrophysical analysis, specifically from Gamma Rray (GR) log. This causes potential pay zones to be overlooked unless revaluation of conventional logs is done. A four-step approach is established to define existence of radioactive sands and identifying source of radioactivity based only on conventional wireline logs. Targeted radioactive sands for the research are hydrocarbon bearing. Methods starts with identifying mudcakes in shale lithology layers detected by GR log and cross-referencing with neutron-density (NPHI-RHOB) crossover. By interpretation of NPHI-RHOB crossover and identifying high values in resistivity log, hydrocarbon zones are identified focussing specifically on shale layers with mudcake. Hydrocarbon zones detected as shales contradicts with interpretation as mudcake only sticks on porous and permeable layers specifically on sandstone not shale. To confirm interpreted radioactive sands, NPHI vs. RHOB cross plot is done to identify lithology. This is followed by radioactive source identification by evaluating spectral gamma ray to determine potential source. Lastly, thorium vs. potassium cross plot is used to identify specified minerals present which contributes to high radioactivity. Approximately 25-30 m of accumulated pay zones were found within all five wells. Methods mentioned is to re-evaluate wells in the system without any additional logging tools. The study is to facilitate the development and improve interpretative procedures that might lead to cost-effective re-completion of hidden reservoirs within the same producing system.

Key words: Reservoir characterization, radioactive sands, Termit basin, procedures, reservoirs, hidden

INTRODUCTION

Conventional interpretation based on petrophysics analysis plays an important role especially in reservoir volume calculation. Volume estimation would affect in choosing potential prospect for development. A problem related to volume estimation is misinterpretation of pay zone thickness.

The neighbouring region of Termit basin is the Niger delta which is located on the southern section of Nigeria. Several investigations were carried out from 1971-2012 which confirms that there is wide spread occurrence of radioactive sands in the Niger delta (Chudi and Simon, 2012). Amongst the wells drilled 55-70% are hydrocarbon bearing zones. Out of the producing wells, 35-45% are believed to be radioactive with thickness ranging from 3-10 m (Chudi and Simon, 2012). The mentioned literature, highlights the importance of identifying radioactive sand layers.

Radioactive sands which have potential as reservoirs are overlooked as shale using Gamma Ray (GR) logs. Presence of radioactive minerals and clays would give high radioactivity leading the GR log to detect these sands as shale. This causes many potential sandstone reservoirs to be overlooked. From the statement, two main objectives can be set. First is to define the presence of radioactive sands in well log and second is to identify the source contributing to radioactivity.

The best way to identify radioactive sands is by analysing thin sections but in the scenario where only well logs are available, a four-step approach can be used. The paper presents examples of reservoir characterization on radioactive sands from Koala field, Termit basin of Niger which includes 5 wells. It discusses the methodology using analysis of only conventional well logs.

Geological setting

Regional geology: The mesozoic plate tectonic has contributed to the development of the West and Central African Rift System (WCARS) during the opening of the Atlantic Ocean via. the benue trough and shear zones

Corresponding Author: Muhammad Syafiq Zainal Malek, Department of Petroleum Geosciencet, Universiti Teknologi PETRONAS (UTP), 40150 Seri Iskandar, Perak, Malaysia

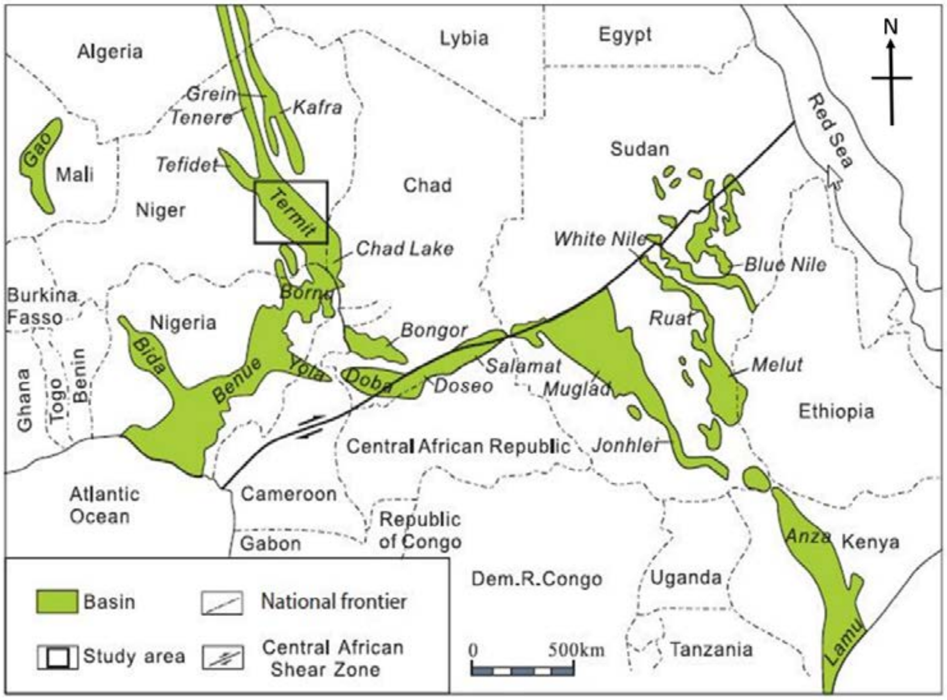

Fig. 1: Location of Termit basin and tectonic settings in the Central-Western African rift system (Liu *et al*., 2015)

cutting Cameroon (Fairhead *et al*., 2013). Accordingly, the Cretaceous-Paleogene rifts of Niger, Chad and the Central African rift (C.A.R.) resulted in large part of a geotectonic continuum of the WCARS (Fairhead *et al*., 2013; Liu *et al*., 2012). The rift extends to a length of 4000 km which starts from the Gao Trough in Mali to the Anza basin in Kenya (Cratchley *et al*., 1984). WCARS system is subdivided into two coeval Cretaceous genetically related but physically separated rift subsystems which are the West African rift Subsystem (WAS) and Central African rift Subsystem (CAS) shown in Fig. 1. The main difference between the two subsystems is that WAS is filled by thick sequences of non-marine and marine Cretaceous to Tertiary sediments, however, the CAS is filled by virtually all cretaceous continental sediments (Genik, 1993).

Termit basin: Agadem block is part of the Termit basin and koala field is in the eastern flank of the block. According to the Agadem Field Development Plan (FDP) report, hydrocarbon in Niger is in two large sedimentary basins which are Lullemeden basin in the west and the Eastern (Chad) basin in the east which covers 90% of the national territory.

Termit basin basement is Precambrian while the other components: Donga, Yogou, Madama is Upper Cretaceous, Sokor-1 and 2 of Paleogene and Neogene+Quartenary (N+Q). The lower Cretaceous thickness is approximately 5000 m and was continental coarse fan delta, underwater fan and lacustrine facies. However, Upper Cretaceous which composes of Donga and Yogou formation was of marine environment while Madama was under the continental environment (Genik, 1992, 1992). This was proven by the lithologies found. Figure 2 shows the geological profile of formations found in Termit basin.

Termit basin is individualized during early Cretaceous and belongs to the northern intracration of the Western African Rift Subsystem (WARS) (Fairhead *et al*., 2013). According to well report, it has been proven that an abundant oil-generation kitchen by drilling was discovered in seven fields surrounding the Koala field area. The oil and gas discovered have been made in the Eocene reservoirs on tilted fault blocks and uplifted horst blocks in the Agadem block, the central portion of Termit basin. Neponto Regency capitalized in Bontosunggu has wide are or 837,99 km$_2$ and divided into 113 village and 11 subdistricts. Jeneponto Regency has main commodities such as agriculture, plantation, agriculture, fishery, livestock and service sector. Main commodities of agriculture are corn, soybean, potato, banana, pineapple, sweet potato and cassava. Main commodities of fishery are fishery catch, fresh water pond culture, sea culture and brackish cultivation. Main commodities of livestock are cow, sheep, goat, buffalo and horse. Main commodity of service are culture and nature tourism.

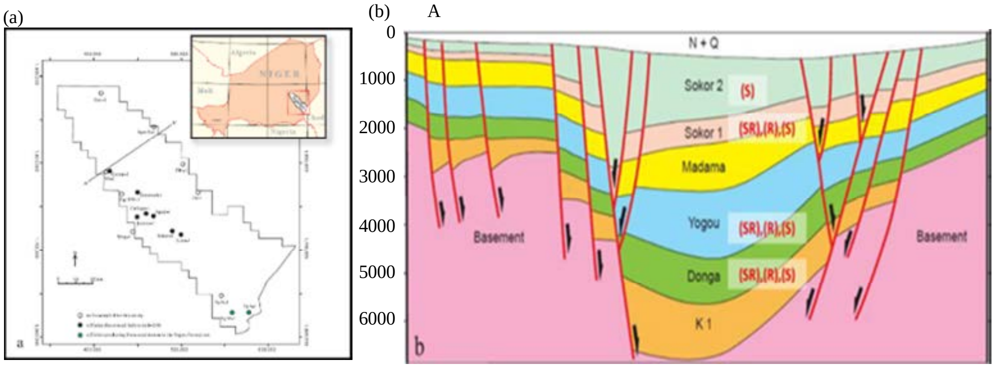

Fig. 2: a) Map of the Agadem permit area in the Termit basin, SE Niger and b) The geological profile of Termit basin (Bottom) (S = Sseal, R = Reservoir, SR = Source Rock) (Liu *et al*., 2012)

Petroleum system: Termit basin petroleum system is in the in upper Cretaceous and Paleogene (Fairhead *et al*., 2013; Genik, 1993). The formation ranges involved are Yogou to Sokor-1 and -2 systems. Eocene and Upper Cretaceous sandstones are the main reservoir intervals found in Termit basin. The main oil discoveries occur mainly in the Eocene reservoirs while the source rock and the seal are from the upper Cretaceous and the Eocene marine and lacustrine shales (Genik, 1993; Harouna and Philp, 2012).

There are two main oil groups classified in WCARS The first is derived from marine-paralic source while the second is from lacustrine source. Unique geological features are established to have 5 types which are source rocks, reservoir rocks, regional caps with controlling factors, major play types and favourable accumulation zones in passive rift basin (Fairhead *et al*., 2013). The petroleum geology of Termit Basin (Wan *et al*., 2014) are made of:

- Reservoir rock: upper member of Yogou Formation and sandstones from upper Paleogene Sokor-1 Formation (dominant)
- Source rock: principal source rock are in Yogou formation and Lacustrine mudstone in Sokor-1 formation
- Seal: regional top seal from Sokor-2 paleogene formation and intraformational mudstone seal from upper member of Yogou formation

Radioactive sands occurrences: Gamma Ray (GR) log responds based on the concentration of radioactive materials contained in the rock adjacent to the borehole. Enough energy is emitted by the rock for the GR tool to detect. The three-main usage of GR log is well correlation, lithological identification and as shaliness indicator. GR has high affinity for radioactive minerals like Thorium (Th), Uranium (Ur) and Potassium (K40) which are contained in shale and flag off as high radioactive counts in the log while sands is vice-versa. In the case of sediments originating from nearby granitic highland, sands and gravels found usually consist of high concentration zircon or maybe highly arkosic (high feldspar content) with high potassium content. From the explanation, the question that arises is whether natural GR log can be used as a sole discriminator for sand/shale or reservoir/non-reservoir and how it impacts in choosing reservoir tops or base for net pay calculation. In some cases, clean sandstone can produce high GR response if the sand contains potassium feldspar, glauconite, micas or uranium rich water which is known to be radioactive sands or hard sands. The challenge present in this case is how net sand is defined and what constitutes valid criteria for differentiating net reservoirs from non-reservoirs. Identifying radioactive sands can increase potential pay zones which is important for prospect evaluation.

The aim of research: This study conducted research based only on conventional logs with the objectives of defining existance of radioactive sandstone and identifying the source of radioactivity.

MATERIALS AND METHODS

The methodology conducted in the study area consist of Field Development Plan (FDP) report, 3D seismic data and conventional wireline logs. For this evaluation only the FDP reports and wireline logs were used. Software used was Interactive Petrophysics (IP) by LR synergy for petrophysics analysis. The following steps were carried out for the study:

Phase 1: Interpreting and analysing data of the study area based on the regional geology with petrophysics analysis and formation identification based on the stratigraphic column. Termit basin basement is Precambrian while the other components: Donga, Yogou, Madama, Sokor-1, Sokor-2 and Neogene+Quartenary (N+Q) is Lower Cretaceous. The focused formation of study is on Sokor-1 formation which has complete petroleum system.

Phase 2: Evaluation of radioactive sands based on conventional petrophysics data from the wireline logs.

M1: Comparison of gamma ray log with calliper log along with density and neutron density logs. This is to identify presence of mudcake and sections with hydrocarbon as well as determining the facies.

M2: Analysing assumed layers through neutron-density (NPHI vs. RHOB) cross plot to confirm defined layers of radioactive sands.

M3: Interpretation of source of radioactivity using spectral gamma ray (uranium, thorium and potassium). Observation on the increase of each individual spectrum indicates different causes of radioactivity.

M4: Identifying contributing minerals using potassium vs. thorium cross plots (Spectral Gamma Ray (SGR) components) to determine the specific mineral causing radioactivity in the sands.

RESULTS AND DISCUSSION

Sandstone interval identification: Interpretation of the sandstone interval was identified from three major traits which are from Gamma Ray (GR) log, resistivity log and neutron-density log. In the GR log, American Petroleum Institute gravity (API) range set for sandstone is 0-75 where 2 types of lithology were set which are clean sandstone (0-40 API) and fine sandstone (40-75 API). Siltstone was set at a range of 75-100 API while shale ranges from 100-150 API. Resistivity of the layers will indicate the potential content of the respective layers whereby high resistivity usually indicates oil or gas (hydrocarbon). In addition, the gap between deep resistivity log and shallow resistivity log will indicate the permeability of identified layers (the bigger the gap, the higher the permeability of the layer). Comparison between the Neutron density Hydrogen Index (NPHI) log as well as the density (RHOB) log indicates low values in both fields for sandstone while shale would have high values. Interpretation of sandstone interval is shown in Fig. 3.

Radioactive sandstone interval identification: M1 comparison of gamma ray log with calliper log along with density and neutron density logs. Initial interpretation of radioactive sands which are hydrocarbon bearing was seen in the three major aspects. An indicator is from gamma ray log respond where it suggests shale lithology but is seen to have presence of mudcake detected by the

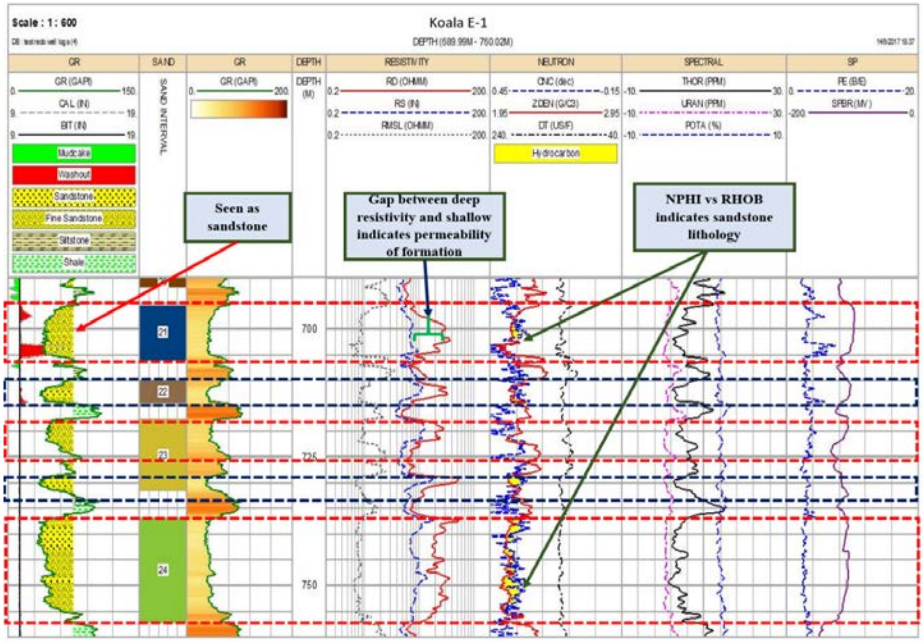

Fig. 3: Example of chosen sandstone interval based on Koala E-1 well

calliper log. Mudcake may indicate formation swell and flow (swelling of shales) into borehole or presence of porous and permeable formations which is a characteristic of sandstone.

To further confirm this analysis, observation from the crossing of NPHI log and RHOB log is used. Cross over may either be hydrocarbon presence or lithological differences of scaling effect. Besides that, NPHI and RHOB log will have low value in sandstone layers. To further confirm presence of hydrocarbon zone, the resistivity log illustrates high value together with obvious separation between shallow and deep resistivity log (high permeability). These three indicators give the first evidence for defining radioactive sands with hydrocarbon. Figure 4 shows examples of radioactive sand interpretation for two zones of Koala CE-1 well. However, zone 7 shows more promising in hydrocarbon bearing potential as the permeability is much higher than zone 6.

M2; Analysing assumed layers through neutron-density (NPHI vs. RHOB) cross plot: The neutron-density cross plot function used for the interpretation is Schlumberger Neutron-Density Raw Rhob = 1.1 mode which includes three lithology reference lines which are sandstone (quartzite) line, limestone line and also the dolomite line. From Fig. 5, the interpreted radioactive sand layers from the previous section is plotted to further confirm that it is sandstone. Plotted points that fall on the sandstone line verifies that the layers are radioactive sands and not shale. Zones where plots do not fall on the sandstone line are automatically removed as they do not fulfil the characteristics of sandstone. In addition, the referenced lithology lines do include the range of porosity for the zones, in the example it is seen that the interpreted radioactive sand zones range from 25-45% porosity.

M3; Interpretation of source of radioactivity using spectral gamma ray (Uranium, Thorium and Potassium): After conforming the radioactive sands, spectral gamma ray analysis is studied to identify the source of -1 radioactivity. Three common naturally occurring radioactive elements in rocks are uranium, potassium and thorium. Analysis of spectral gamma ray which consist of the three mentioned spectrums each has different indication of the source of radioactivity. Increase in Thorium reading as seen in Fig. 6 indicates the presence of clay minerals and/or heavy minerals, e.g., kaolinite, illite, smectite and chlorite for clays and monazite and/or zircon (found near granitic highlands in unconformities or erosional surfaces) for heavy minerals. Uranium increment is associated with phosphates and organic compounds (shales, plants, shell fragments, euxinic environments). An

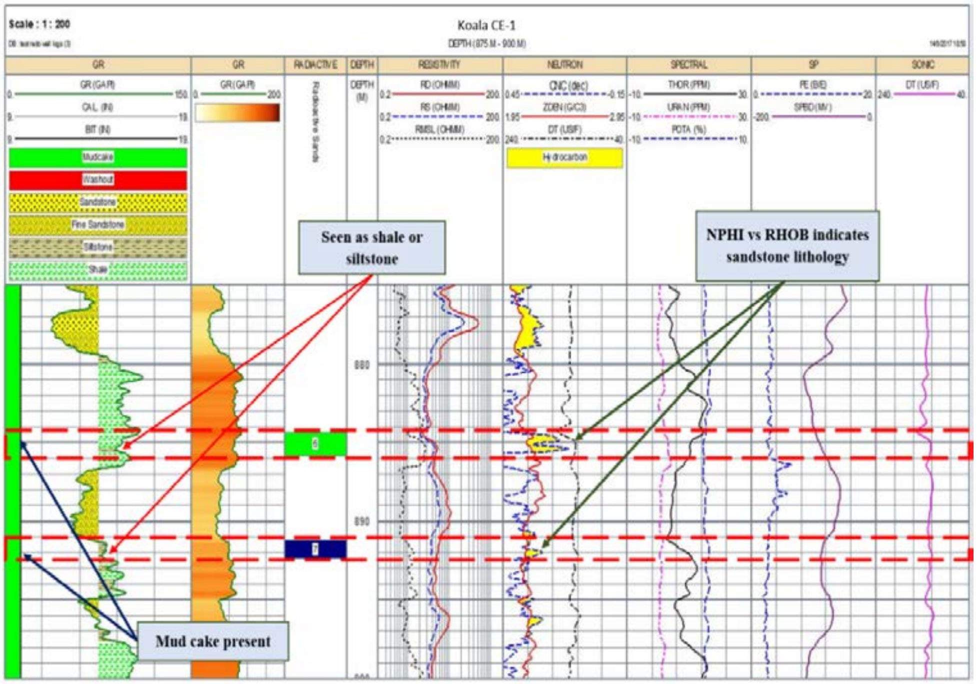

Fig. 4: Radioactive sands interpretation based on present of mudcake with comparison of gamma ray results and NPHI-RHOB crossing in Koala CE

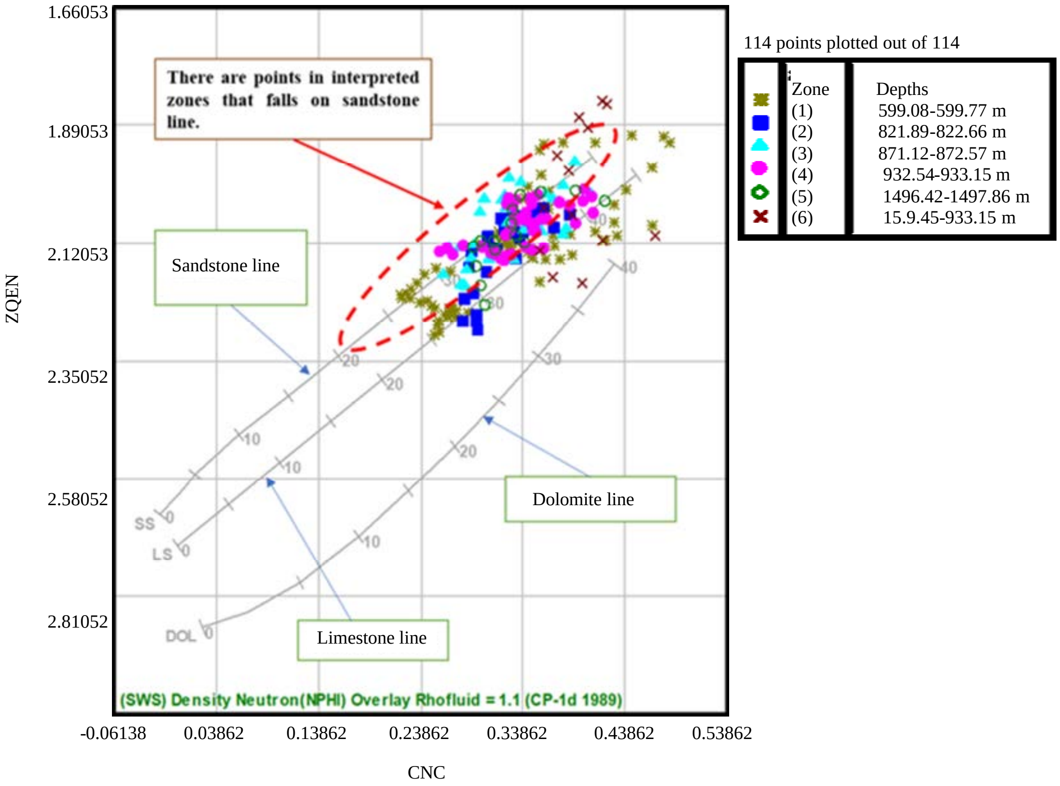

Fig. 5: NPHI vs. RHOB cross plot indicating the interpreted radioactive sands as having characteristics of sandstone

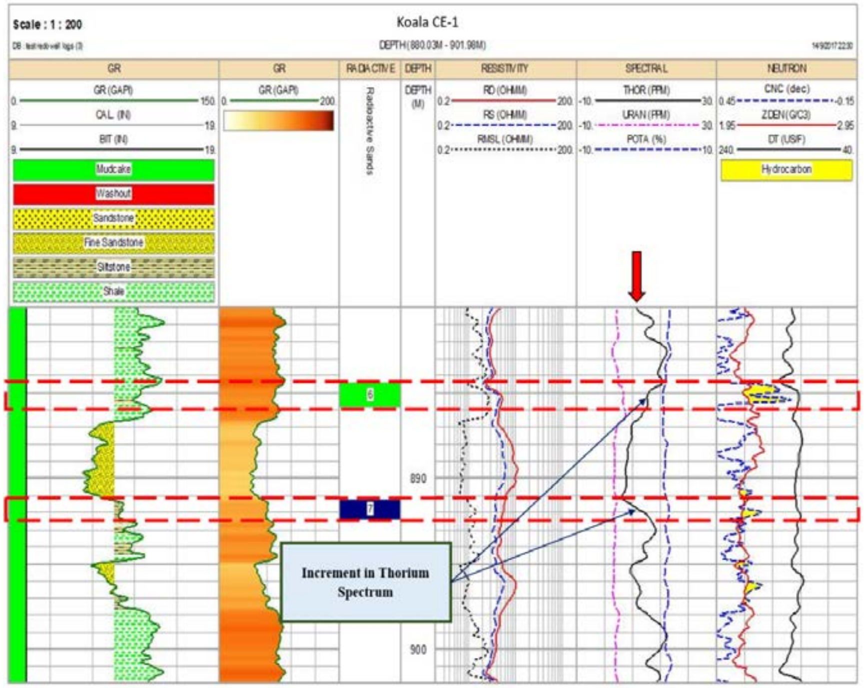

Fig. 6: Spectral gamma ray-thorium spectrum increase in interpreted radioactive sands layer 6 and 7 in Koala CE-1 well

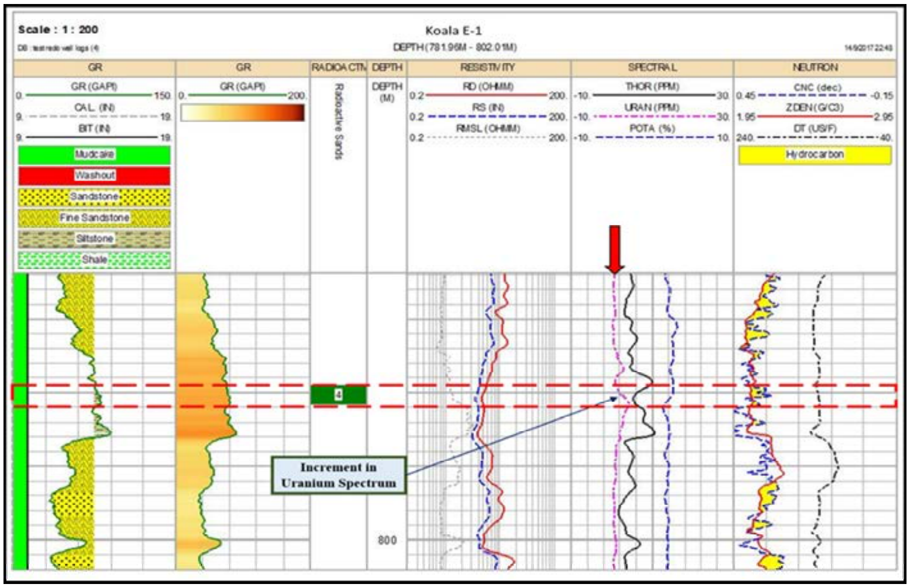

Fig. 7: Spectral gamma ray-uranium spectrum increase in interpreted radioactive sands layer 4 in Koala E-1 well

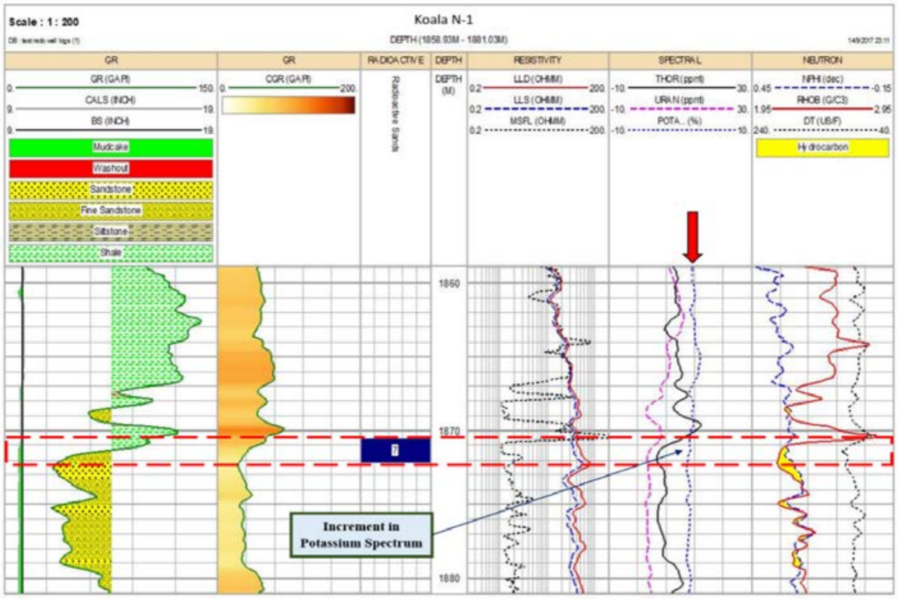

Fig. 8: Spectral gamma ray-potassium spectrum increase in interpreted radioactive sands layer 7 in Koala N-1 well

Table 1: Summarizing gamma ray spectrum and radioactive source

Spectral gamma ray	Source indicator
Thorium	Heavy minerals Clay minerals
Uranium	Organic compounds Phosphates
Potassium	Presence of mica Presence of K-feldspar

example of increment in uranium reading can be seen in Fig. 7. In addition, sometimes increase in the Uranium reading in the sandstone layer is due to water saturation where the water is washed out from the shale layer beneath the sandstone thus resulting in the presence of uranium rich water. On the other hand, increase in potassium reading in radioactive sands is due to high mica content and/or K-feldspar mineral as seen in Fig. 8. This relates to sediments originating from nearby granitic highlands. Table 1 summarizes each individual spectrum and its potential source referred from Chudi and Simon (2012).

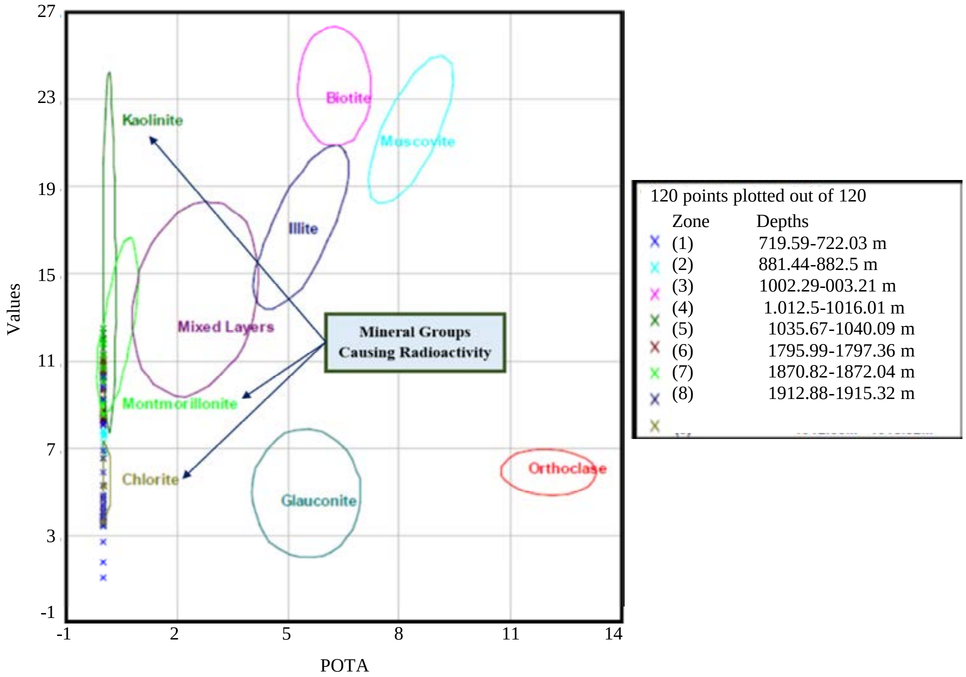

Fig. 9: Potassium vs. thorium cross plot of radioactive sand zones in Koala N-1 well indicating the presence of potential clay minerals of chlorite, montmorillonite and kaolinite

M4; Identifying contributing minerals using potassium vs. Thorium cross plots (spectral gamma ray components): The potassium vs. thorium cross plot is divided into 9 types of mineral zones. Clay minerals in the range are kaolinite, montmorillonite, chlorite, mixed layers (corrensite and rectorite), illite and muscovite. The balance three are glauconite, biotite and orthoclase. These minerals are said to have significant radioactive characteristics. Glauconite which is also known as green sand is deposited in continental shelf marine environment with slow rates of accumulation. Biotite is considered as a common phyllosilicate mineral within the mica group. Also known as “Black mica” as opposed to “White mica” (muscovite), it is found in igneous and metamorphic rocks. Orthoclase is an important tectosilicate mineral from igneous rocks. Figure 9 shows a good example of the minerals found in the interpreted radioactive sands which consist of clay minerals. From the example, the presence of kaolinite has potential in altering the wettability of the formation to the extend in some cases from oil-wet to water-wet. Mineral identification is important as it helps in choosing suitable composition for drilling mud, since, different clay minerals would affect the porosity and permeability of the reservoirs as well as wettability. Hence, highlighting the importance of identifying the type of radioactive minerals.

CONCLUSION

Radioactive sands are a major feature in petrophysics interpretation and has serious impacts to the exploration evaluation. Identification of the true net pay thickness including radioactive sands is essential for the volumetric calculation. In addition, determining the source of radioactivity gives better understanding on the depositional environment and during well development phase especially in choosing the most suitable mud and cement composition. This is because suitable mud will affect the permeability of the formation. By following the proposed methods, volumetric calculation of the reservoir and the pay zone can be achieved as well as accomplishing positive economic values of the studied area.

From the results, it can be observed that the defined radioactive sands are seen directly adjacent between interbedded sands. Thickness of the anomaly ranges from 0.5-3 m which may not be thick but coverage of area is large enough to give significant effect on volume. Source of radioactivity based on spectral components are dominated by the presence of heavy minerals seen by the subjugation of thorium spectrum. This indicates that radioactive sand interval has clay mineral present. With regards to minerals present, majority of radioactive sands consist of kaolinite, montmorillonite, mixed layers (corrensite and rectorite) and chlorite. Thus, the study highlights the geological implication on radioactive sand concept and its importance. In addition, it shows that gamma ray sole interpretation is not enough to define sand or shale sequence, especially in areas which are highly interbedded. Overlooking net pay reservoirs due to misinterpretation of radioactive sands could result in the losing of potential barrels of oil.

The mentioned methods can be used to re-evaluate the wells in the system without the need of other additional logging tools. This study illustrates employing improved interpretative procedures that lead to more cost-effective re-completion of hidden reservoirs within the same producing system.

RECOMMENDATIONS

Since, the interpretation of the radioactive sands are based on petrophysics analysis only, the interpretation is an assumption based on statistical analysis from the cross plots as well as standard conventional interpretation from wireline logs. If new wells are explored it is suggested to execute as Many Sidewall Core (SWC), Modular formation Dynamic Tester (MDT) and Formation Multi-Tester (FMT) to increase the understanding of the well. If there is core data and thin section analysis or reports, more accurate interpretation can be established. In addition, from the cross referencing of the core analysis, petrophysics data and seismic data an excellent geological model can be achieved.

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