Effect of Non-Clay Radioactive Minerals in Petrophysical Evaluation of Shaly Sand Reservoirs Having Anomalous GR Response- A Case study of Kalol field, Western Onshore Basin, India.

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Abstract:

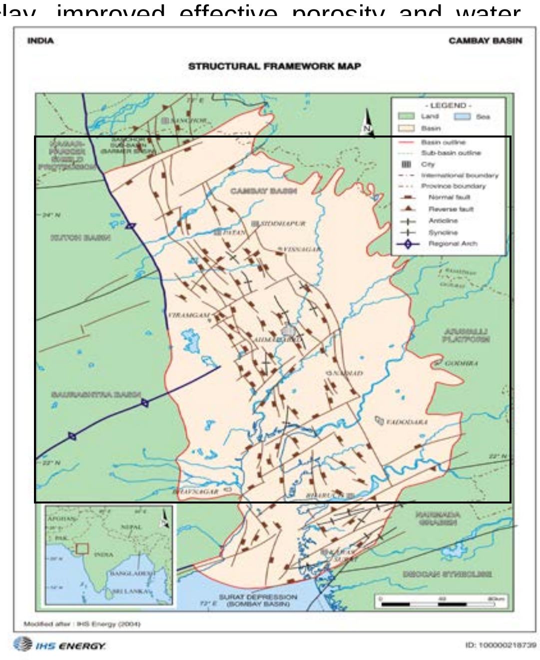
Natural Gamma Ray (GR) log has long been considered as an essential input in any petrophysical interpretation model for clay volume estimation, which is further used for computation of effective porosity and water saturation in shaly sand models. The presence of non-clay radioactive minerals such as alkali feldspars, micas, zircon, allanite, monazite etc. make sandstone reservoirs appear highly shaly which, otherwise , are clean or moderately shaly having good porosity and permeability . Such anomalous GR response have been reported in many different in many Indian and foreign basins. Multi-mineral models incorporating these non – clay radioactive minerals are essential as higher clay volume computed with simple shaly sand models will undermine the reservoir quality and hydrocarbon potential of such complex lithology reservoirs.

Anomalously high GR response has been observed against almost all pay sands in some or the other part of Kalol field. GR values upto 500 API have been encountered against reservoir layers which exhibit tracking neutron density logs and even cross over indicating these layers to be clean or moderately shaly. Good SP development has also been observed against these high layers. However, in some parts of the field, these sands have very low GR values (20-30 API) also. Natural GR spectroscopy logs recorded in selected wells indicate high Thorium concentration against sandstone/siltstone layers having high GR activity. Photo Electric Factor (PEF) log generally leads high against these highly radioactive layers, suggesting presence of heavy minerals .It is worth mentioning that other non- radioactive minerals like ilmenite, siderite, pyrite etc have also been reported in core studies. Local geological knowledge suggests that minerals such as allanite, monazite responsible for this anomalous GR response are likely to be present in the provenance.

In present study, non-clay radioactive mineral has been incorporated in the multi-mineral model for petrophysical evaluation of pay sands of Kalol Field. The processing parameters for this special mineral have been estimated from published literarture and log features against layers having anomalously high GR response. Log data processing with the present model has resulted in realistic computation of volume of clay, improved effective porosity and water saturation as compared to simple shaly sand models.

Introduction:

Kalol oil field is one of the biggest onshore oil field situated in Cambay r basin on western margin of Indian platform (Fig: 1).It is under exploitatic since 1961. The field is located around 20 km NNW of Ahmedabad city Ahmedabad – Mehsana tectonic block and the most prolific hydrocarb producer of the basin. So far, 700 nos of wells have been drilled to expl the 11 pay zones viz K-II to K-XII. The OIIP of Kalol oil field is about 1! MMTOE with a poor recovery of about 10% only.



Natural Gamma Ray (GR) log has long been considered as an essenti input in any petrophysical interpretation model for clay volume estimation, which is further used for computation of effective porosity and water saturation in shaly sand models radioactive material and give low gamma ray readings. GR log response increases with increase in the concentration of radioactive material in shale. Because shale is usually more radioactive than sand, GR log can be used to calculate volume of shale (Vshale) in porous reservoirs.This volume then be applied to the analysis of shaly sands. In some cases clean sandstones (i.e. with low shale content) might also produce a high gamma ray response if the sandstone contains feldspars, mica, or uranium rich waters or thorium rich minerals.

In this paper an example is drawn from the radioactive shaly sands of almost all the sand of Kalol field in the Cambay Basin, India. The purpose of this paper is to address the petropysical properties of the radioactive shaly sands, evaluation criteria for computing realistic Vcl(clay volume), effective porosity (Φe) and water saturation (Sw) and and a methodology to compute the clay volume (Vcl), Effective porosity (Φe) and Water Saturation (Sw) incorporating non-clay radioactive mineral in multi-min ELAN processing.

1. Effect of Non-Clay Radioactive Mineral on Wireline Logs:

The response of logging tool is a combined effect of all the minerals and their proportional volume present in the formation. The presence of non-clay radioactive minerals in hydrocarbon bearing formation measures high gamma ray log value, which in turn gives higher estimation of clay volume, thus reduced the effective porosity and water saturation drastically. This type of anomaly has been observed in many wells in different formations of Kalol field. Fig: 2(a) and 2(b) illustrates the effect of radioactive mineral on GR and other logs. Here GR shows high value while Neutron-Density & PEF shows clean sand with hydrocarbon bearing. Additionally good SP development in combination with neutron-density log also helps in the identification of this mineral. The petrophysical evaluation based on conventional method will misguide the petrophysical results therefore the approach of multi-mineral processing has been adopted to encounter the effect of the presence of these minerals that will be discussed in petrophysical analysis.

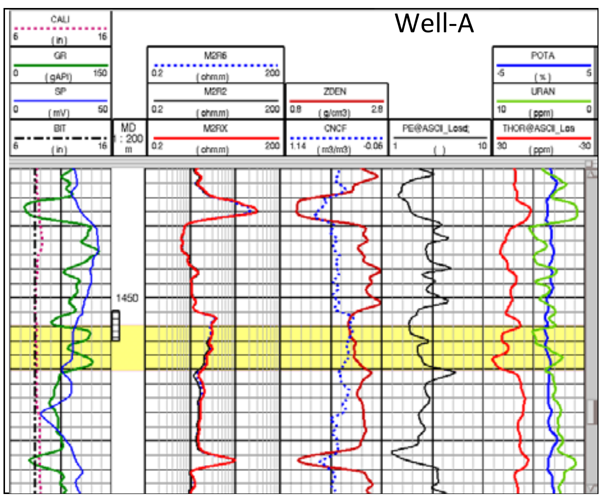


Fig 2(a) High Thorium reading across high GR response (Kalol field)

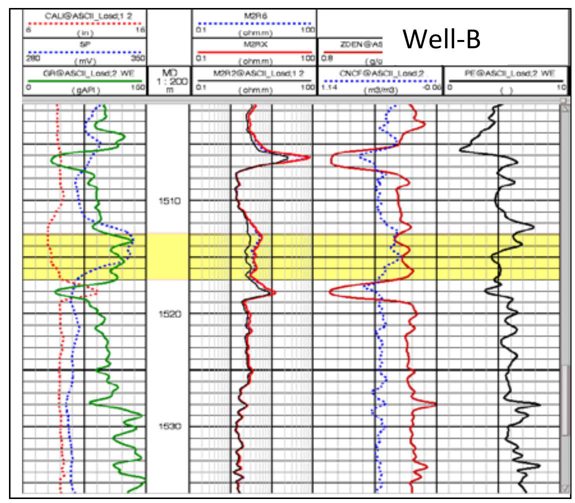


Fig 2(b) High PEF reading across high GR response (Kalol field)

2. Identification of Non-clay Radioactive Mineral in Shaly Sands:

The biggest challenge is for realistic estimation of water saturation, effective porosity and clay volume by optimizing the petrophysical model in view of the presence of this non clay radioactive mineral over the simple sand shale model. This paper will highlight the insight of the problems encounter during the model fixing and formulate the methodology to compute effective porosity, water saturation and clay volume with ELAN processing using multi-mineral approach.

Quartz, the principal constituent of the coarse grained detrital rocks shows no radioactivity. Sandstones usually show low GR values. However, if the source of the sediments are nearby granitic highlands, implying that the detrital materials from the sedimentary source have not undergone sufficient transportation and weathering, then the parent minerals like feldspar(K), micas and heavy minerals would be retained in the sedimentary rocks. In this case, the sands and gravel may be highly arkosic (high feldspar content), micaceous or may contain zircon, monazite or allanite enriched with thorium.

The best method for identification of radioactive sand is through core analysis. The wireline logs were calibrated to core studies that have been carried out in few selected wells to understand the mineralogy and other petrophysical parameters. In this section log based technique and published literature data were used to identify the non-clay radioactive sands.Cross plot technique is also a strong tool for lithology and mineral identification. Neutron -Density cross plot gives better identification of lithology while M-N plot gives about the idea of heavy mineral. The natural gamma ray spectroscopy (NGS) tool is used to identify uranium, potassium and thorium contents. The combination of NGS with photoelectric cross section or volumetric cross section can be used to determine clay mineral types within sands. In sandstone formations, the thorium is directly related to clay content. In the presence of heavy non-clay radioactive minerals potassium indication is generally low, only the thorium and uranium curves shows high incursions.

Radioactive sands belong to one of the following groups, the identification of which may be possible with the charts given in Fig: 3a & 3b

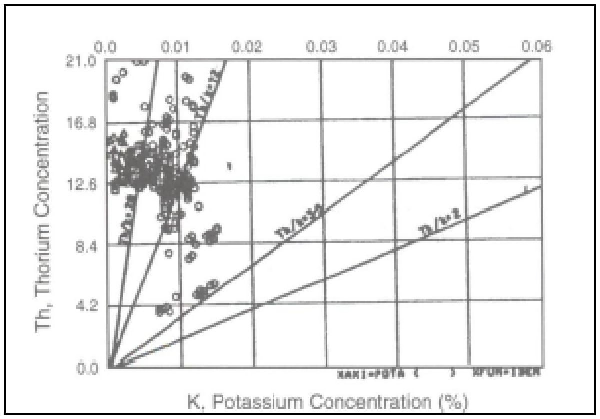


Fig 3(a). Typical Th Vs k cross plot for water bearing radioactive sand(Obuaya 1989)

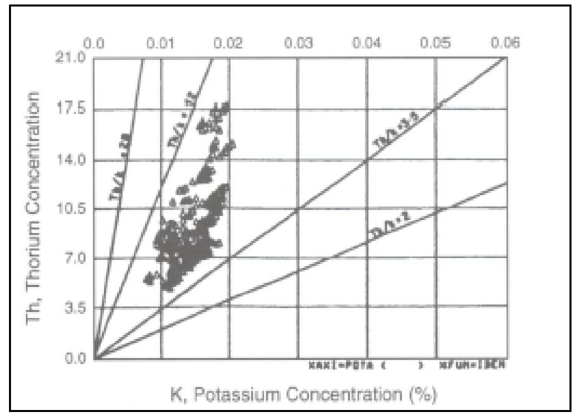


Fig 3(b). Typical Th Vs k cross plot for water bearing non-radioactive sand(Obuaya 1989)

a) Feldspatic sandstone or arkoses- these shows K-content, dependent on the percentage of feldspar is the sand. The Th/K ratio will be less than 1 x 10^{-4} due to low Th and K content.

b) Micaceous sandstone shows K content lower than that of feldspars. At the same time the Th content will be higher. The Th/K ratio will be close to 2.5 x 10^{-4}.

c) Mixed Feldspatic-micaceous sandstone or gray wackes-the Th/K ratio will be intermediate in this case.

d) Heavy minerals within sandstones are Th and U bearing, which give rise to radioactivity in clean sands or shaly sands. The K level is generally low and the Th/K ratio will therefore be high.

Fig 2(a), the well composite log where the yellow shaded interval shows the high GR reading and NGS logs show high Thorium reading and less potassium reading and Fig 4(a), the cross plot of the yellow shaded interval of same well A between Th & K shows the high Th/K ratio indicates the presence of non - clay radioactive mineral.

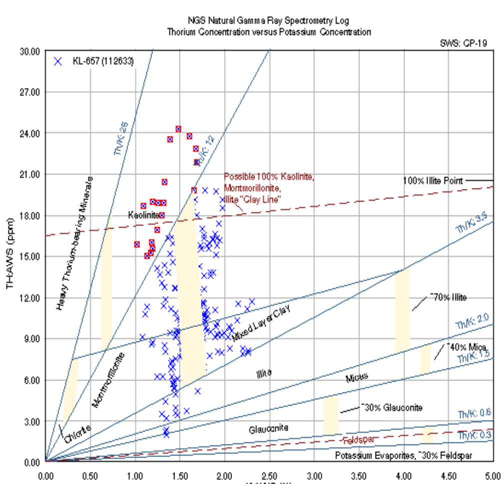


Fig 4(a): Th Vs K cross plot of well A

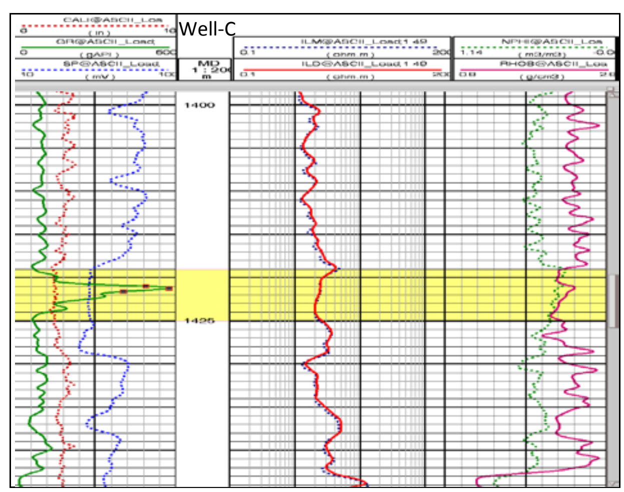


Fig 4(b): Well Composite Well-C radioactive water bearing sand.

The Potassium (K), Uranium(U) and Thorium(Th) distribution in radioactive minerals are shown in table -1(a).

Accessary Minerals	Potassium(K)%	Uranium(U)ppm	Thorium(Th)ppm
Allanite	-	30-700	500-5000
Apatite	-	5-150	20-150
Epidote	-	20-50	50-500
Monazite	-	500-3000	2,5x10-20x10
Sphene	-	100-700	100-600
Xenotime		500-3.4x10	Low
Zircon	-	300-3000	100-2500

Table – 1(a).The Potassium(K), Uranium(U) and Thorium(Th) distribution in radioactive minerals(Risø National Laboratory, DK-4000 Roskilde, Denmark, April 1987).

3. Petrophysical Evaluation:

Since natural radioactivity is not always associated with shale alone. Radioactive minerals which are rich in uranium or thorium (zircon, allanite, torite, uranite, phosphate etc) as well as uranium rich sapropelic and above all, humic organic matter can have a considerable influence on the gamma ray response and may completely mask variations in clay percentage. Natural Gamma Ray Spectroscopy logs recorded in selected wells indicate high thorium concentration against sandstone /siltstone layers having high GR activity (Fig2a). Photoelectric Factor log generally reads high against these highly radioactive layers suggesting presence of heavy mineral (Fig2b). Other non-radioactive minerals like ilmenite, siderite, pyrite etc have been reported in core studies.

Based upon the above fact wireline logs of Well-D (Fig: 5) were studied to characterize the porosity and water saturation of the reservoir. The logs were environmentally corrected and normalized. Shale volume, effective porosity and water saturation were computed using multi-min ELAN processing. Fig5(a) and Fig5(b) shows processed output of Well-C, which are the ELAN volumes output processed without and with incorporating heavy radioactive mineral in the model respectively.

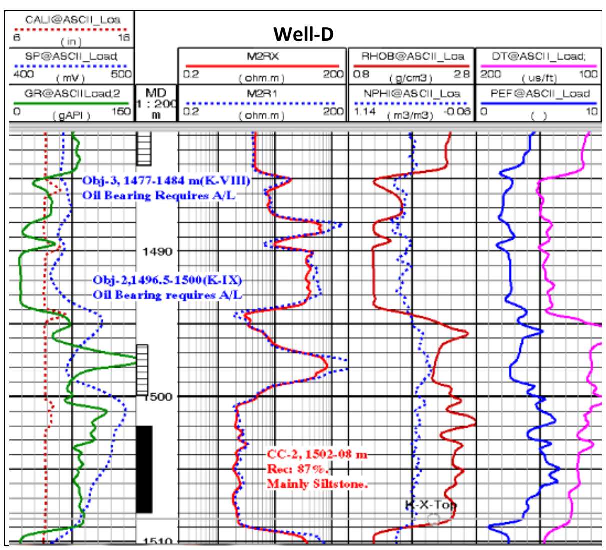


Fig 5. Well Composite of Well - D processed with multi-min ELAN module. (Kalol field)

A simple shaly sand model was fixed to compute the shale volume, effective porosity and water saturation. Fig 5(a) shows here the computed volume of water saturation (Sw), effective porosity(Φe) for the siltstone interval. Without incorporating the heavy radioactive mineral in ELAN processing the computed effective porosity (Φe) against high

Gamma Ray is 10 pu and the clay volume is 40%, whereas the maximum effective porosity (Φe) computed across low Gamma ray reading at the bottom of the reservoir is around 28%. The estimated reservoir parameters have reduced and the thickness of the pay sand also reduced in terms of effective porosity and clay volume.

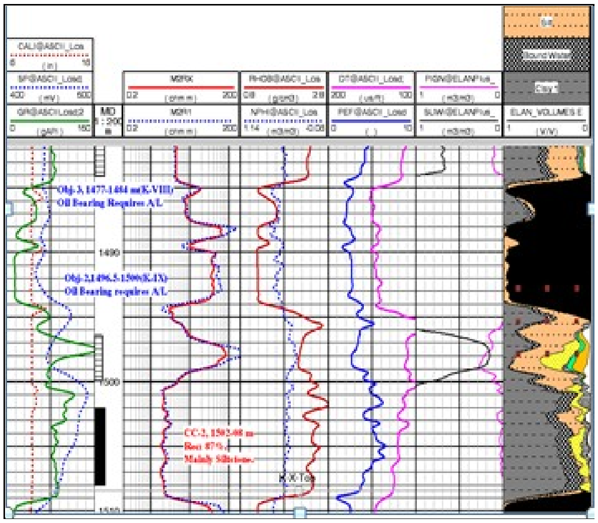


Fig 5a.ELAN volume output without incorporating radioactive Mineral in processing. (Well-D Kalol field)

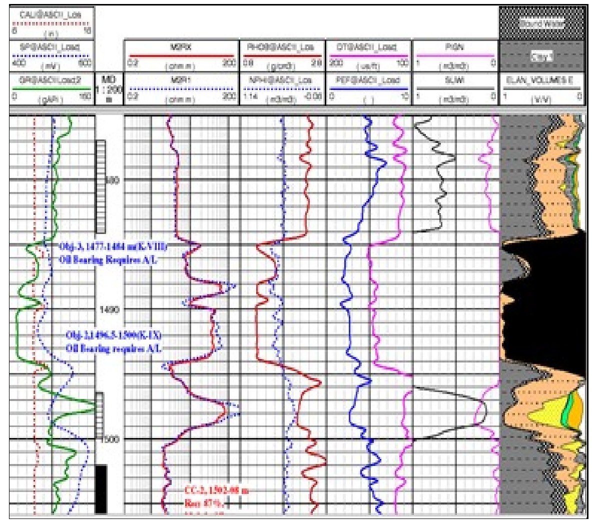


Fig 5b.ELAN volume output with incorporating radioactive mineral in processing. (Well- D Kalol field)

Fig 5(b) shows the processed output of the same Well-D. To reduce the effect of high Gamma Ray in computation of volumes a heavy radioactive mineral has taken into the petrophysical model with bulk density of 3.5 gm/cc, Neutron porosity of value 0.05, DT of value 45 µsec/ft, U of the order of 500 and Gamma Ray activity of the order of 3000gAPI.This Electron parameters are nearly equal to Allanite. Fig 5(b) shows the computed volume of water saturation (Sw), effective porosity (Φe) and clay volume (Vcl) for the same interval. It is clearly observed from the paralog Fig 4(b), the clay volume has decrease significantly upto 20%, effective porosity (Φe) increased significantly from 10 pu to 20 pu across the high GR response and 2 pu to overall reservoir interval.

The parameter of the Non-clay radioactive mineral fixed for processing is taken from published literature and data. Fig4(b) the well composite of Well:C, aids in identify the radioactive water bearing sand. Siderite is used as heavy mineral associated with this Non-clay radioactive mineral. The volume of clay computed only with simple shaly-sand model across the radioactive siltstone would show dirty reservoir with high clay content. Otherwise, it is a good reservoir.

Conclusion:

1. Computation of mineral volumes using multi-mineral process technique requires detail study of mineralogy using Core, Lab and Sedimentological reports.
2. Identification of non-lay radioactive mineral conductive and non-conductive requires detail analysis for volume estimation.
3. The fixing of processing parameters requires a complete understanding of the reservoir and geological setup of the area.
4. Maximum no of logs will certainly help to estimate the correct knowledge of reservoir parameters.
5. Realistic estimation of reservoir parameter i.e. effective porosity, water saturation, clay volume and volume of mineral will help for property modeling in reservoir model for optimum exploitation of the field and help in development planning.

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