Estimation of Reservoir Properties from Well Log Analyses: A Case Study from Schuppen Belt Area

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Abstract

Assam Arakan is one of the prolific basins in context of hydrocarbon deposits. From the dawn of petroleum exploration in India, hydrocarbons have been discovered from several reservoirs of Eocene to Mio-Pliocene age. Recently hydrocarbons have been discovered from sandstone reservoirs within Girujan Formation from an area in Schuppen Belt. The present petrophysical study was carried out using basic well log data of three wells on an anticlinal structure with the region of Schuppen belt. A number of reservoir properties were estimated for the sandstone units of Girujan Formation. Apart from neutron-density crossplot, various types of logs (gamma ray, resistivity, neutron porosity and density) were used to scrutinize the nature of lithology. Pickett plot study has indicated a relative increase in Formation water salinity with depth. Moreover, multi-mineral probabilistic models were prepared through ELAN (Elemental Log Analysis) for quantitative estimation of petrophysical properties like shale volume (V_{sh}), effective porosity (φ_e), effective water saturation (S_{we}) and hydrocarbon saturation (S_{hc}) of reservoirs. Within the Girujan clay unit, a number of intercalated sand units were identified based on well log data. The sand intercalations show variable thickness and this parameter has been found to correspond with the shale-content. For several clean sands (V_{sh}<45 %) identified from the area, show presence of hydrocarbons (gas). Overall, most of the hydrocarbon-bearing sands show a wide range of effective porosity (i.e. 8-14%). For such reservoir units, the hydrocarbon saturation varies between 30 to 50 percent.

Introduction

Assam-Arakan represents a geologically complex petroliferous basin in NE India (Fig. 1). This complexity can be attributed to multiple phases of crustal deformation. This widespread tectonic deformation is believed to be closely linked with a number of phases of hydrocarbon generation (Kent and Dasgupta, 2004). In the Assam-Arakan basin, Mio-Pliocene sediments are dominated by clay-rich unit called Girujan clay formation. In a number of oil fields, this clay-rich unit (Girujan Formation) acts as a cap rock on hydrocarbon-bearing Tipam sandstone reservoir strata. However, in some of the oil-producing regions - like Kharsang and Kumchai fields, sand units within Girujan clays have been reported to be of reservoir quality (Basin Information Dockets, DGH). Recently, in the study area located in the Schuppen Belt province of the Assam-Arakan Fold Belt (study area is shown in Fig. 1), gas has been discovered from such sandstone units (within Girujan Formation). In this context, present study aimed for petrophysical characterization of reservoir sand units within Girujan Formation in the study area of Assam-Arakan basin. In this study, wireline logs were utilized for the purpose, which provide key information on subsurface reservoir rocks. The petrophysical studies were carried out using basic well log data for a total of three wells located on anticlinal structure (Fig. 2).

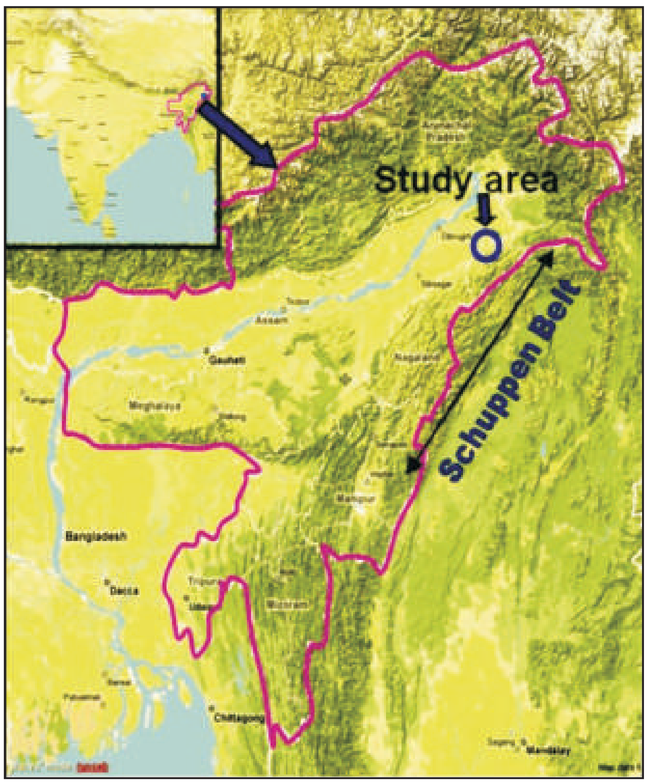

Fig. 1: Map showing the location of Schuppen belt in Assam-Arakan region

Geological Settings

During the northward movement of Indian plate from middle to Late Cretaceous, the Assam-Arakan basin experienced extensional tectonic activity. This resulted in formation of a number of horst-graben structures within the basin. These structures favoured the accumulation of fluvio-marine sediments for a long geologic time (Paleocene to upper Eocene). The carbonate and shale-dominated middle to upper Eocene sediments were overlain by coarse-grained clastic sediments of Oligo-Miocene age. This wide span of sediments accumulation in the basin was followed by compressive tectonism during late Miocene and Pliocene (Sahoo and Gogoi, 2011). In the Upper Assam shelf region, such a tectonic environment led to development of multiply-thrusted crustal zone known as Schuppen belt. This 20 to 35 km wide zone extends for a length of approximately 200 km and is bounded by Disang thrust as innermost edge and Naga thrust as foreland edge. Among a number of thrusts between Naga and Disang thrust, the anticlinal structure lies between Kumsai thrust in north and Margherita thrust in south (HOEC Internal Reports, 2008 to 2015). The present study concentrates on this anticlinal structure in terms of petrophysical characterization of sand units within Girujan clays (Fig. 2).

Petroleum System

In the Upper Assam shelf region, the Tipam sandstone and sand units within Barail and Girujan Formations act as reservoir rocks. On the other hand, within the shelf region the Kopili shale and Barail coal/shale units are considered as source rocks. For a widespread region within the shelf region, Girujan clay is the cap rock for the Tipam sandstone. For the sandstone units inter-bedded within Girujan Formation, the clay- and shale-dominated units act as intra-formational cap rock.

The hydrocarbon entrapment seems to have a litho-structural control, with truncation of anticlinally-folded sand units against faults (HOEC Internal Reports, 2008 to 2015).

Well log analyses

In this study, for a total of three wells (Well A, B, C which are about 0.5 to 2.0 km apart at the sub-surface and the depth of the sand units is varying from 600m to >2500m) basic wireline log data (gamma ray, resistivity, acoustic, neutron porosity, caliper and spontaneous potential log) were used. Gamma ray log response, neutron porosity and bulk density were utilized for lithological identification. Volume of clay was also estimated using well logs. Another key reservoir parameter, that is, Formation water resistivity (R_w) was estimated from Pickett plot, as the testing results did not provide information on water salinity. For quantitative interpretation of well log and determination of reservoir parameters like total porosity, effective porosity, effective water saturation and hydrocarbon saturation, ELAN models were prepared throughout the Girujan Formation using Schlumberger Techlog software.

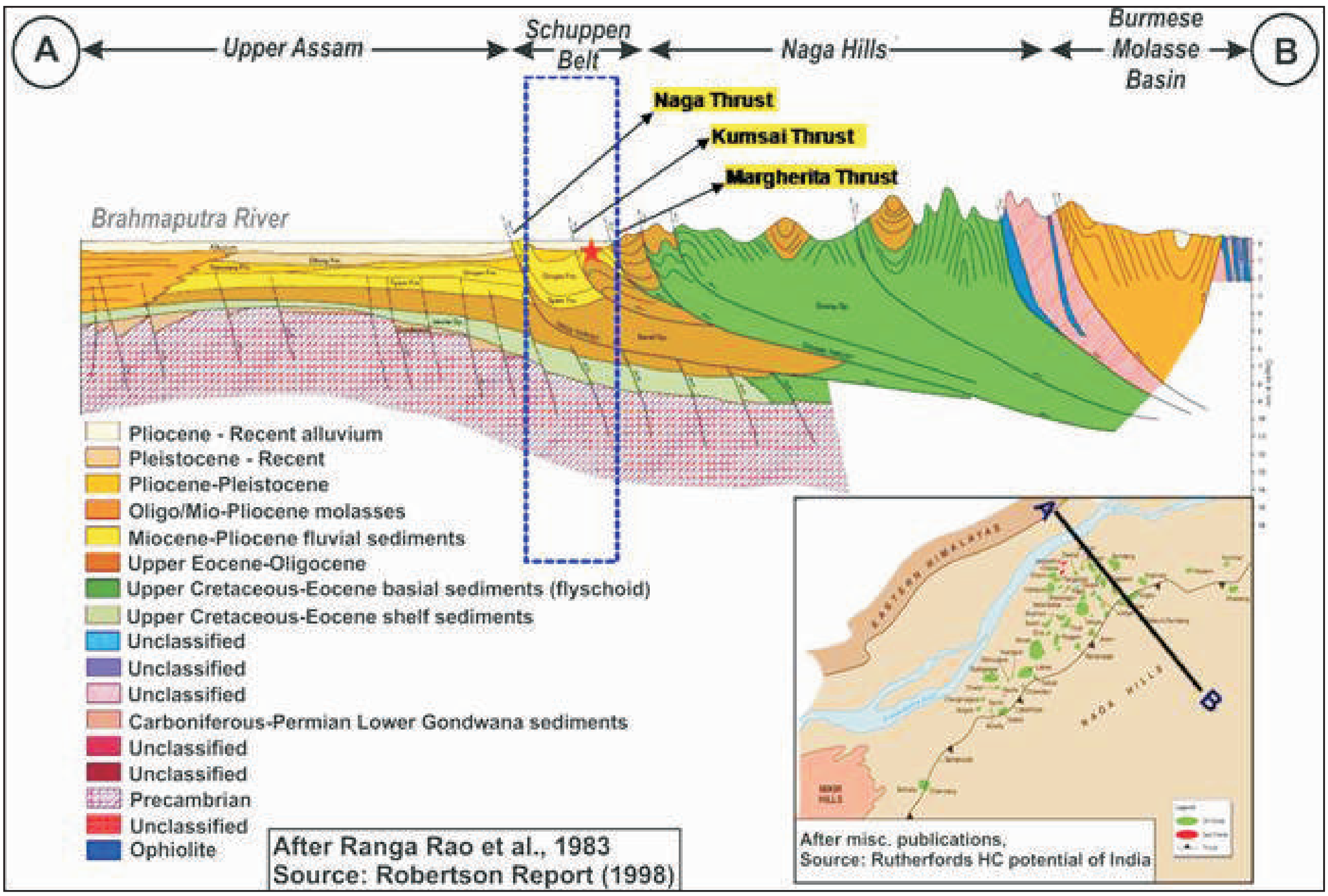

Fig. 2: Geological cross-section showing the extent of various litho-structural domains in Assam-Arakan region (Modified after Ranga Rao et al., 1983)

Lithology Identification

Based on gamma ray log signature, various lithological sequences were identified comprising mainly of sand and shale units. The fundamental principle to distinguish between sand and shale units is based on the gamma ray counts. As the naturally occurring radioactive elements (Thorium, Potassium and Uranium) tend to be associated with shale, this results in higher gamma ray count for shale units as against that for sand comprising unit(s) which have relatively clean matrix minerals (e.g. sand). Within Girujan Formation several sand units were identified intercalated within clay units. Among them some sand units (thickness varies from 10m to maximum 65m) are clay poor i.e. clean, while few are thicker (75m to 100m) and are dirty i.e. clay rich. Except some, often the identified sand units poorly correlate across all the three wells. In order to efficiently distinguish between sand, silt and shale units in each of the well, neutron porosity vs. bulk density cross plots were also studied. In this study, neutron porosity and bulk density values were plotted along the abscissa and ordinate respectively (Fig. 3). As shown in Fig. 3, the shale units with high neutron porosity and high density values lie in the right side of the crossplot. In contrast to this, the clean sand units have lower values of neutron porosity and density and thus lie in the left side of the plot. As evident from Fig. 3, the crossplot shows the presence of a sand-shale mixed lithology in all the three wells.

Estimation of Formation water resistivity

The Formation water resistivity (R_w) is one of the key reservoir parameters, which can be determined directly from salinity of water sample collected during Formation testing. In absence of salinity data, the Rw can be estimated through a set of equations and methods. The Pickett plot, which is a graphical representation of Archies equation, can be used for estimation of R_w. In Pickett plot, the resistivity values (X-axis) are plotted against porosity values (Y axis) on logarithmic scales. The equation used in Pickett plot is,

$$\text{Log}(\varphi) = (1/m)\log(R_t)\ \ n\log(S_w) + \log(a.R_w)$$

where φ = porosity, R_t = true resistivity of Formation S_w = water saturation, R_w = Formation water resistivity, a= tortuosity, m= cementation exponent, and n=saturation exponent. The R_w was estimated assuming values of 1, 2 and 2 for the parameters a, m and n respectively. The calculated Rw values are 0.93 and 0.43 for respective Formation temperatures at shallower and deeper depths (Figs. 4, 5). It must be noted that the deduced Rw values may have limited error due to influence of mud on log reading.

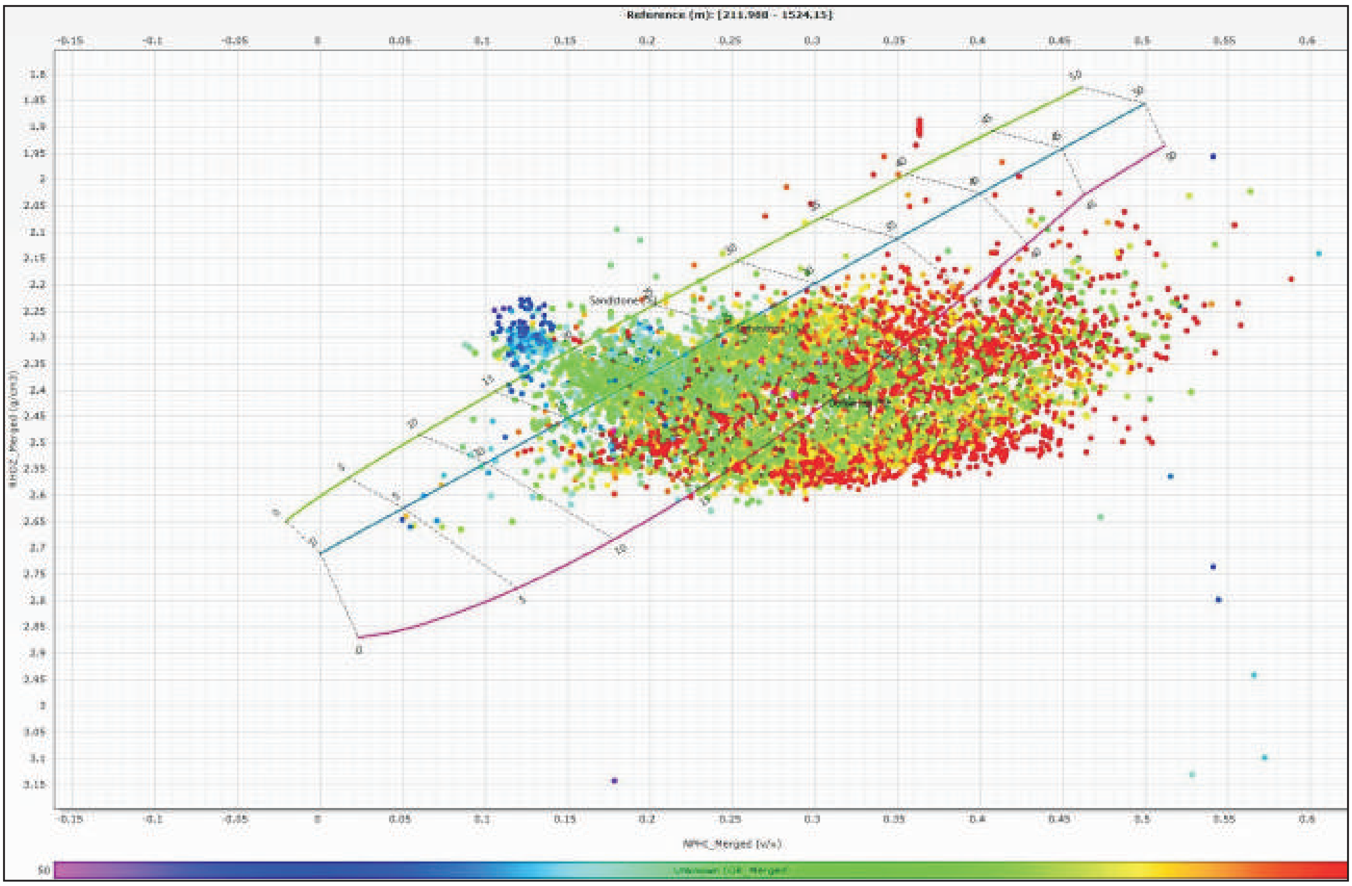

Fig. 3: NPHI-RHOB crossplot for the well A with GR as third axis showing sand and shale distribution

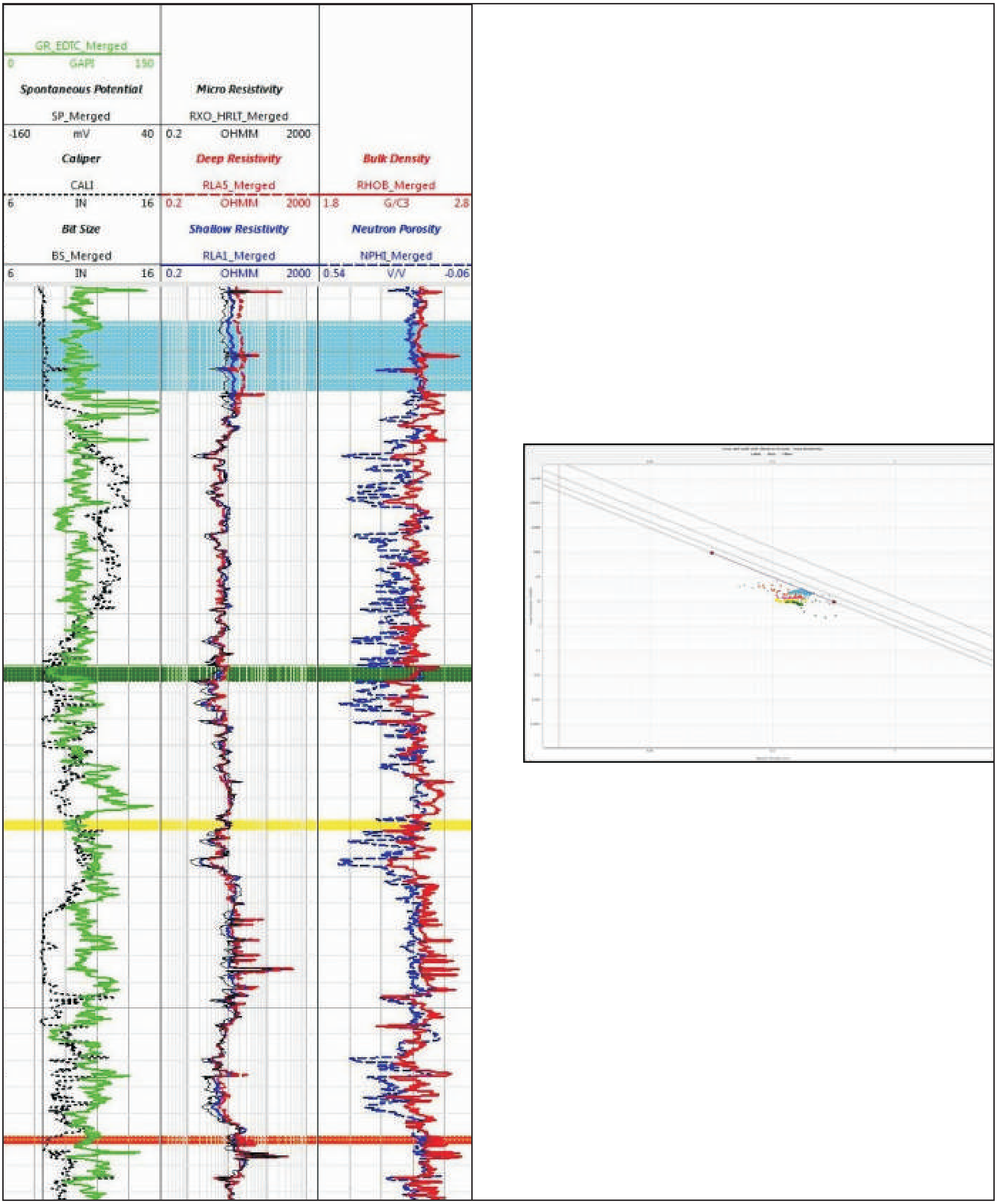

Fig. 4: Estimated R_w (0.93 ohm-m) at formation temperature calculated from water bearing sands of well C through Pickett plot. Different colours in the graph correspond to different zones indicated in the log.

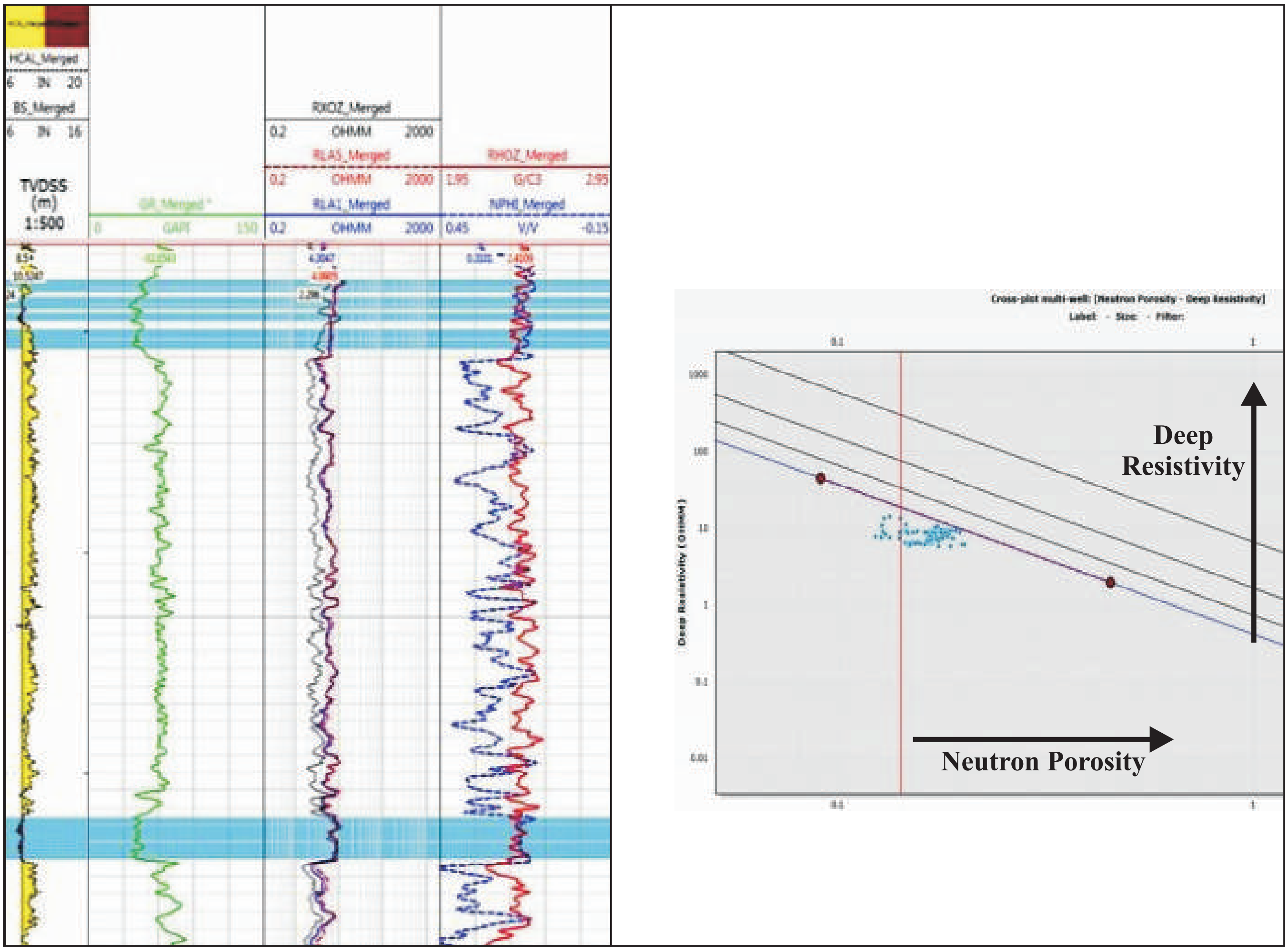

Fig. 5: Estimated R_w (0.43 ohm-m) at formation temperature calculated from water bearing sands of well C through Pickett plot. Different colours in the graph correspond different zones indicate in the log.

Determination of other petrophysical parameters

Quantitative log analyses were carried out in detail to determine petrophysical parameters like total porosity (φ_t), effective porosity (φ_e), volume of clay (V_{sh}), effective water saturation (Sw_e) and hydrocarbon saturation of sand units of Girujan Formation. For quantitative log interpretation, Quanti Elan method of Schlumberger Techlog software was used for preparation of probabilistic multi-mineral model with simultaneous solver. Quantitative formation evaluation through ELANplus applications (Schlumberger Techlog Software) were carried out by optimizing simultaneous equations. ELAN model is prepared by solving inverse problem in which log measurements or tool and response parameters are used together in response equations to compute volumetric result for formation components. The relationship is shown in the triangular diagram (Fig. 6), where t represents tool vector (i.e. all logging instrument data and synthetic curves), v is the volume vector (i.e. the volumes of Formation component) and R is the response matrix containing parameter values corresponding to tool reading.

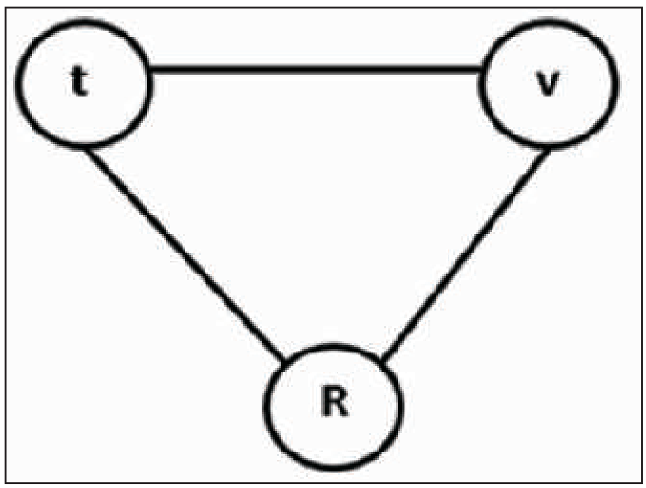

Fig. 6: Petrophysical model used by ELAN plus application (redrawn from manual of Schlumberger Techlog software)

In this study, for all the three wells, ELAN models were prepared for reservoirs to evaluate Girujan Formation, based on log response and cross-plot study. The ELAN reservoir model was prepared using quartz as matrix and clay in addition to two fluids that are gas and water. The gamma ray, bulk density, shallow resistivity, deep resistivity and neutron porosity logs were used for volumetric computation of formation component. Hydrocarbon saturation, water saturation, total porosity and effective porosity were computed from ELAN processing. Considering the presence of shale within the formation, hydrocarbon saturation was computed using Indonesian saturation equation (Poupon, and Leveaux, 1971). The equation can be written as:

$$1/\sqrt{(R_t)} = [\{(V_{clay})^d/\sqrt{(R_t)}\} + \{\phi\, m^{/2}/\sqrt{(a.R_w)}\}] * (S^w)^{n/2}$$

where R_t = true resistivity, V_{clay} = clay content, $d = 1 - (V_{clay}/2)$,

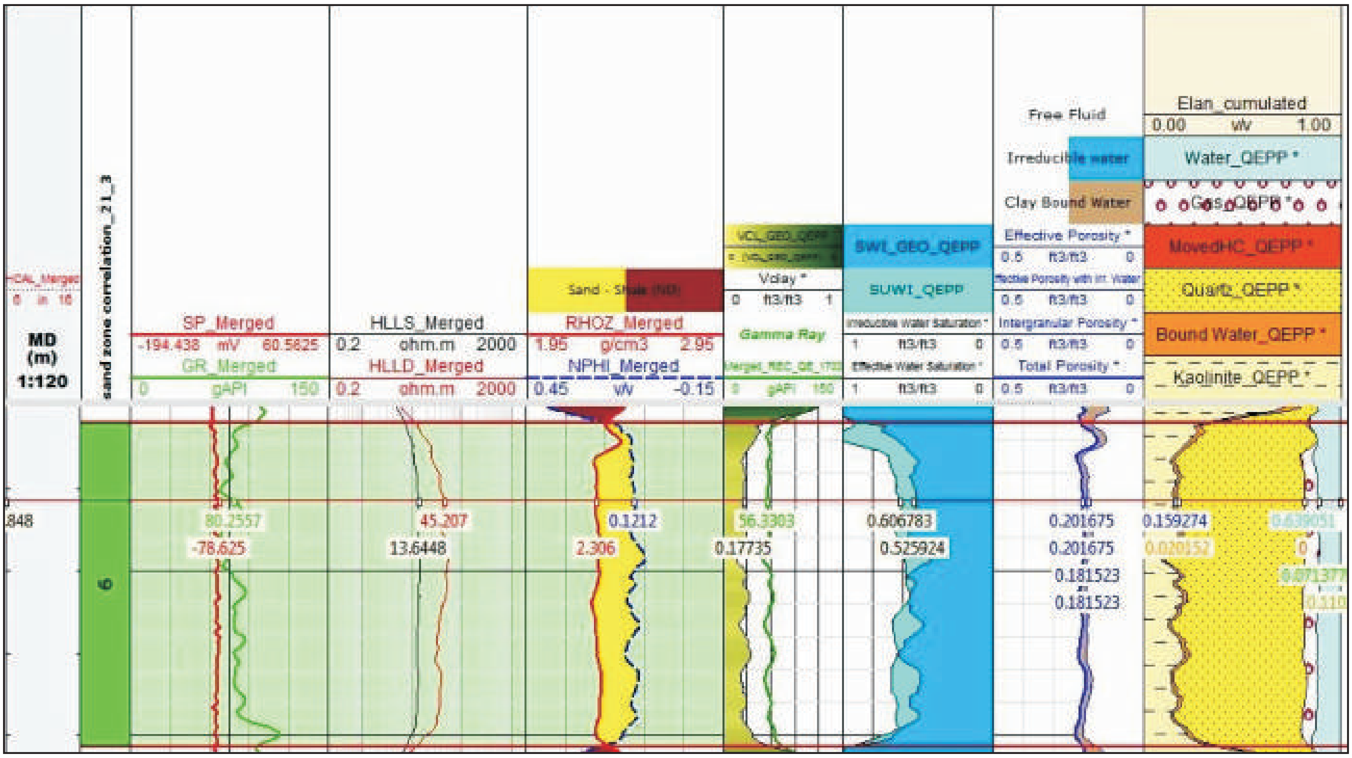

Fig. 7: Diagram showing the results of Quanti Elan output for sand-6 of Well A

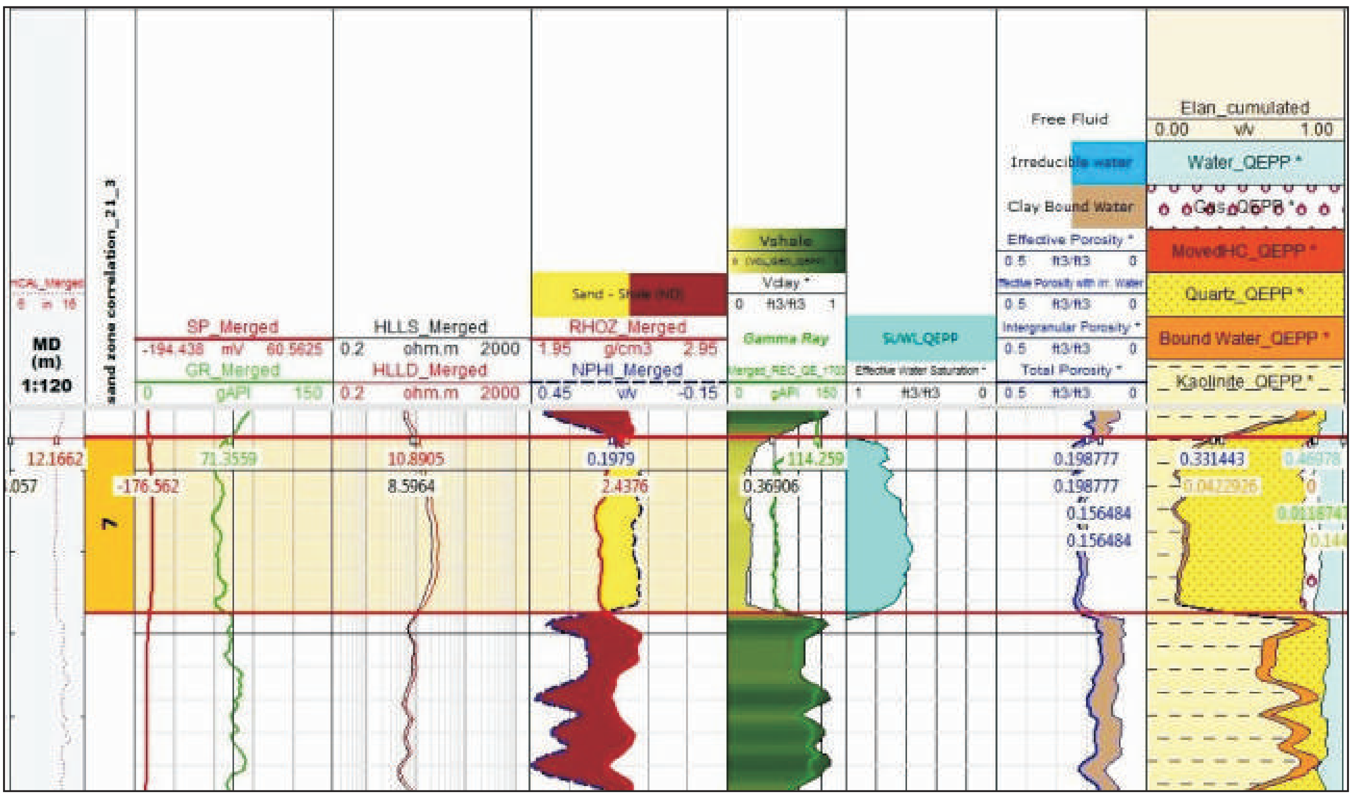

Fig. 8: Diagram showing the results of Quanti Elan output for sand-7 of Well A

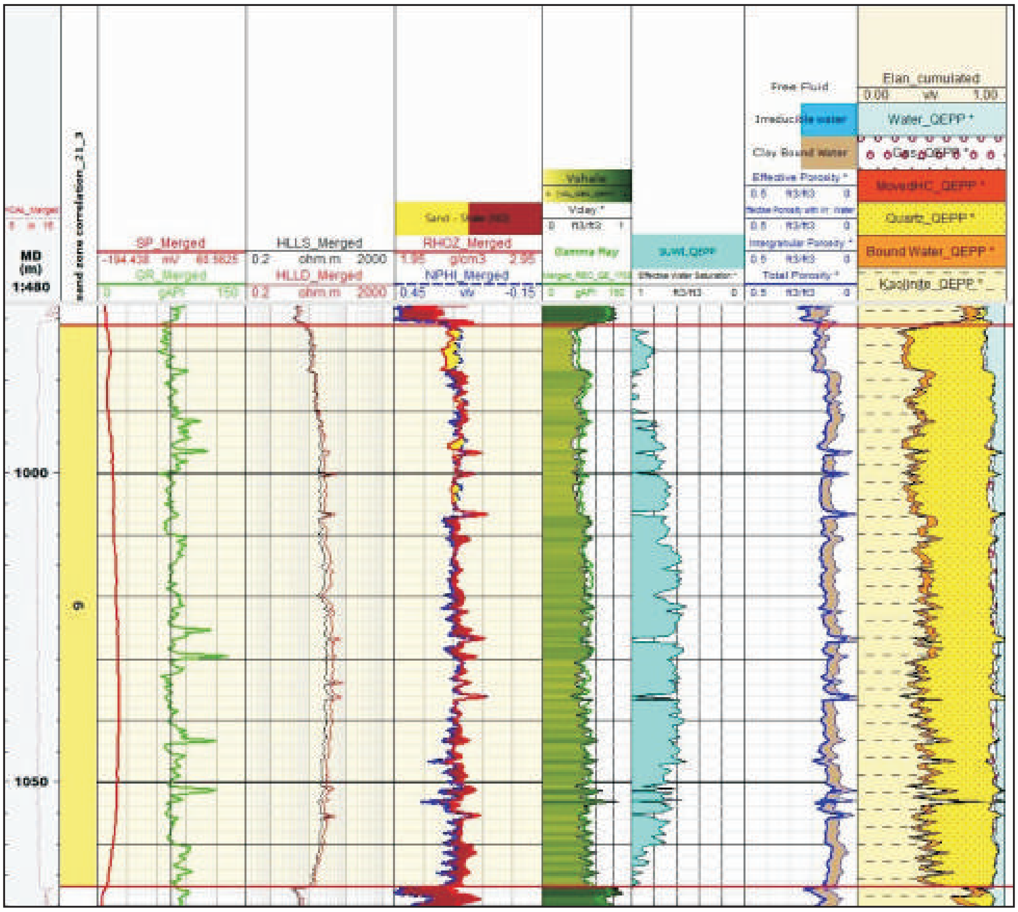

Fig. 9: Diagram showing the results of Quanti Elan output for sand-9 of Well A

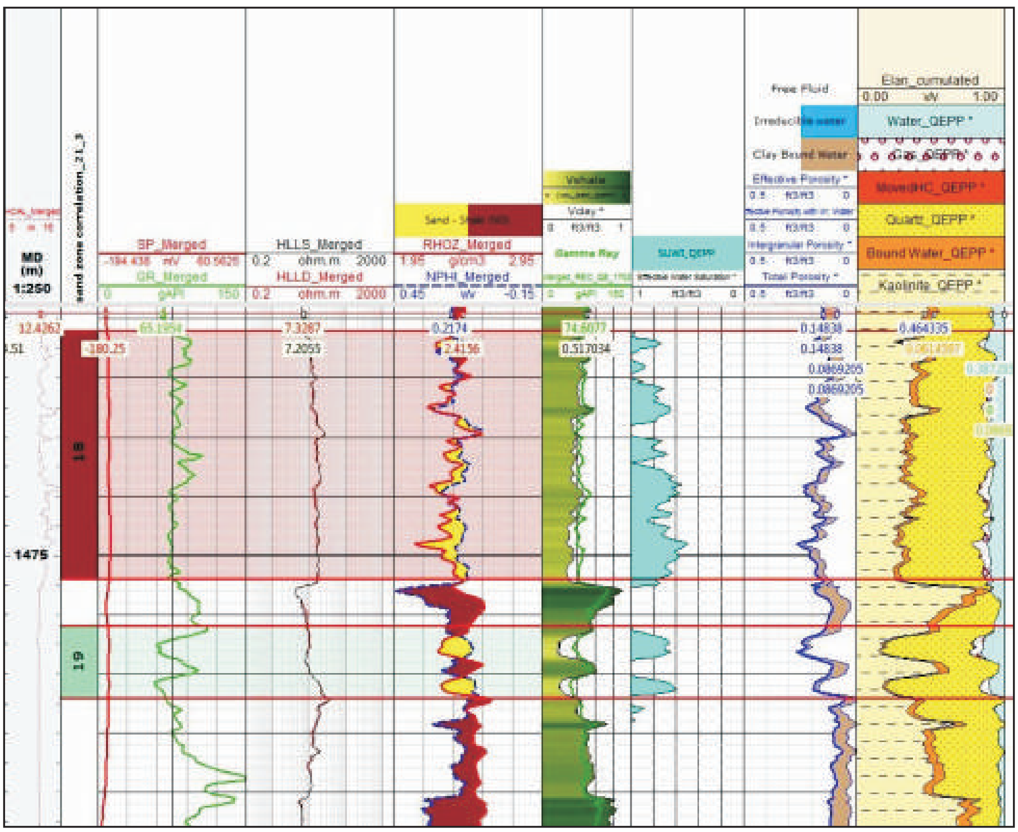

Fig. 10: Diagram showing the results of Quanti Elan output for sand-18, -19 of Well A

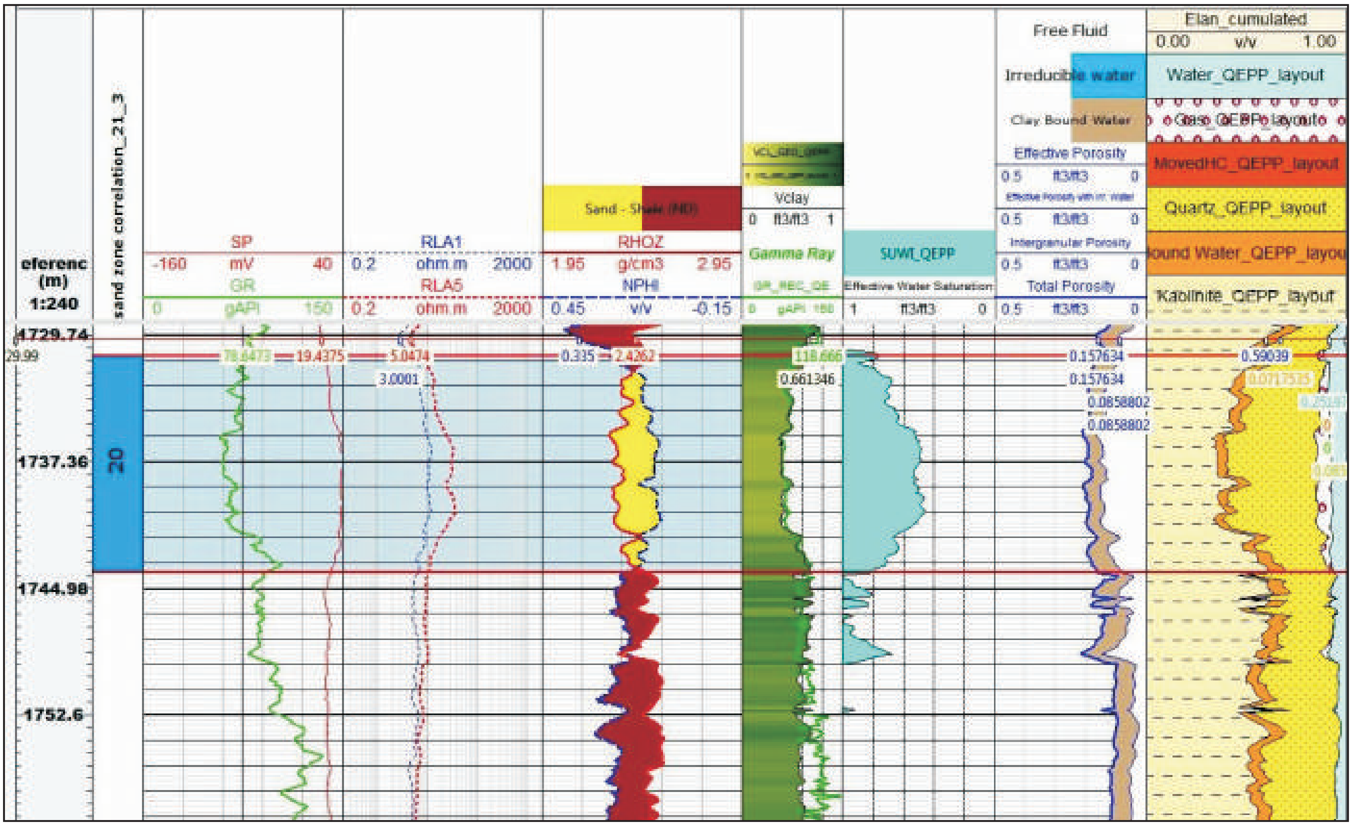

Fig. 11: Diagram showing the results of Quanti Elan output for sand-20 of Well B

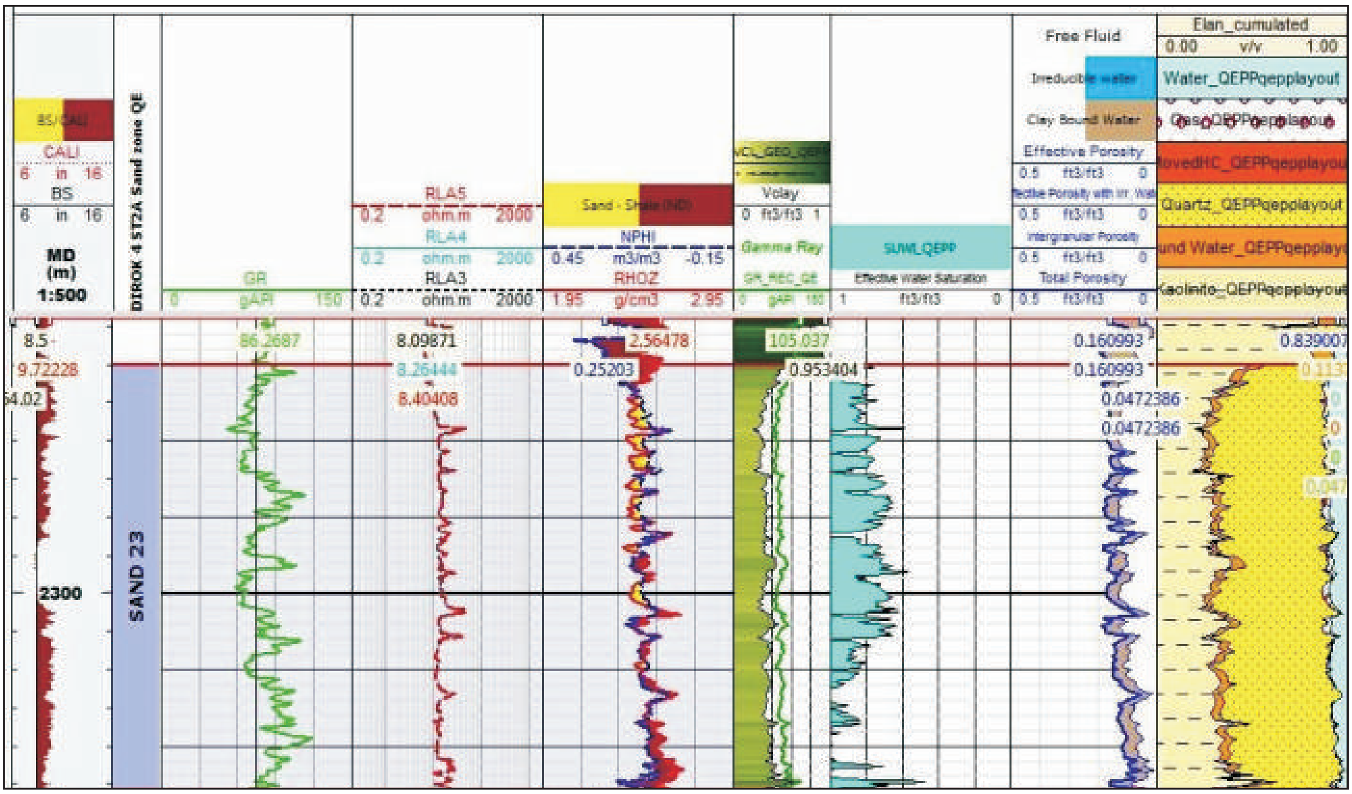

Fig. 12: Diagram showing the results of Quanti Elan output for sand-23 of Well C

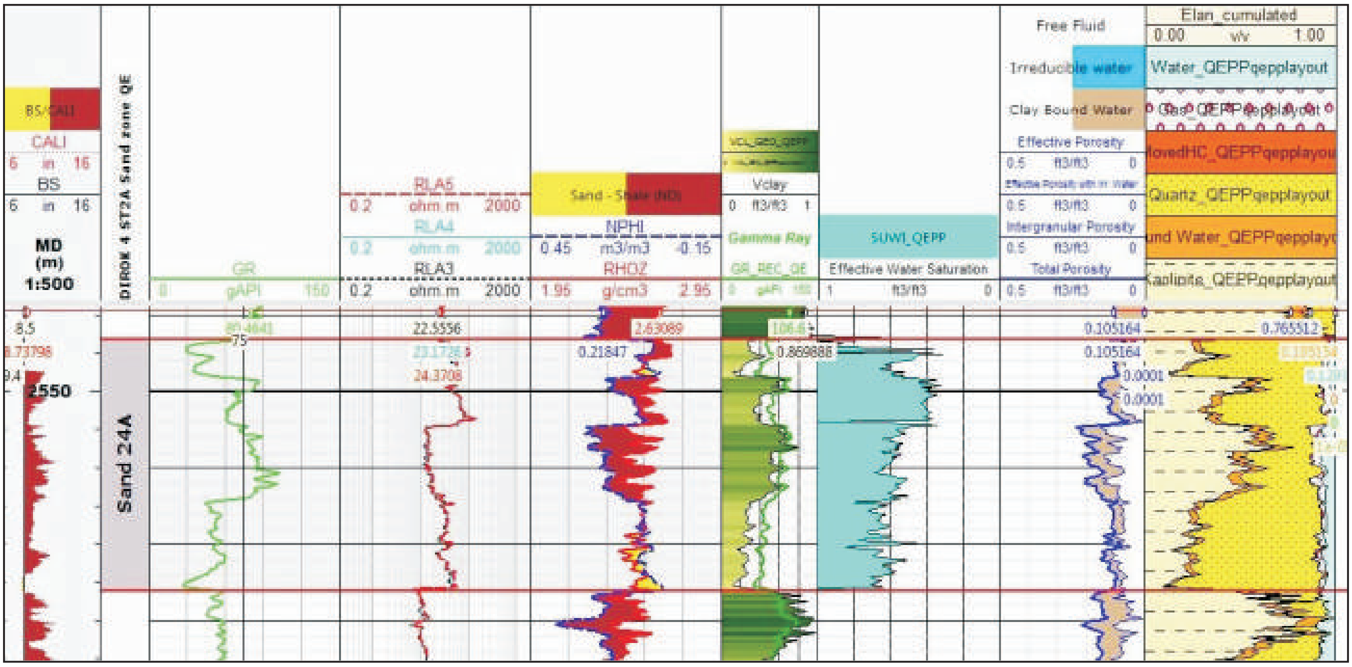

Fig. 13: Diagram showing the results of Quanti Elan output for sand-24A of Well C

a = tortuosity, m = cementation exponent, and n = saturation exponent.

In the absence of core data, the value of a, m, n have been assumed as 1, 2, 2 respectively.

Other shale models were prepared to minimize the effect of shale and false hydrocarbon response in logs due to bad condition of borehole. Thus, these two models, the reservoir model and shale model were combined to deduce the final output model. The output of ELAN models for several representative zones are shown in Figs. 7 - 13. The details of the petrophysical parameters are given in Table 1.

Discussion and Conclusion

This petrophysical study enabled us to estimate a number of reservoir properties, like effective porosity, shale volume (V_{sh}), effective water saturation etc. Well data was acquired for the Girujan Formation comprising sand-shale intercalations. A total of 19 sand units were identified. Among them, some of the sand units are of clean nature ($V_{sh} < 45$ %) with thickness varying from 10 to 40 m. However, the relatively clay-rich sand units of dirty nature ($V_{sh} > 45$ %) show a wider range of thickness (76-100 m). Interestingly, except few, most of the sand units correlate poorly across all the three wells, which conform to their erratic nature, (Basin Information Dockets, DGH). Based on log response some of the sand units could be correlated across all the three wells. On the other hand, correlation of rest of the sand units across the well remains ambiguous. The two sand units (sand 9 and sand 10), which could be convincingly correlated across the three wells also exhibit the presence of water, based on testing in well-C. Apart from this, rest of the sand units in all the wells have gas shows. Among them, some of the units were tested during drilling. This testing process has confirmed variable gas flows for these sand units.

The estimated effective porosity values show a bit wider range, although most of the values overlap in the range of 8 to 14 %. For the same tested units, effective hydrocarbon saturation mostly ranges from 30 to 50 % and notably extends up to even 63 %. Based on the limited results in the present study, estimated petrophysical parameters (Table 1) in addition to near-consistent gas shows for the sand units could be an indication of possible hydrocarbon potential of sand units within Girujan clays.

However, it is very important to note that the hydrocarbon prospects of such sand units warrants further detailed studies with ECS (Elemental capture spectroscopy) logs, NMR (Nuclear Magnetic Resonance) logs or core data.

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