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Computation of Water Saturation in Low Resistivity Low Contrast Reservoirs Using Rxo/Rt vs SP Log Overlay Technique.

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Abstract:

The biggest challenge for petro-physicists is identification of Oil water Contact (OWC) and computation of water saturation in Low Resistivity Low Contrast (LRLC) hydrocarbon reservoirs. Presence of varying amount of grain coating clays in fresh water environment, conducting minerals and laminations of shale within the reservoirs are the main reasons for lowering resistivity.

Tipam sandstone reservoirs deposited in fresh water environment are typical examples of LRLC reservoirs in Assam & Assam Arakan basin of India. In some of the pay sands of Changmaigaon and Charali field the problem is to such an extent that resistivity in hydrocarbon bearing zone is even lesser than the water bearing zone. The sedimentological studies reveal the presence of authigenic smectite clay, coating sand grains with honey comb morphology. It is well established fact that in fresh water environments, the majority of electrical current is concentrated through clay coated grain surfaces, making resistivity log measurement less sensitive towards hydrocarbons present in pore spaces.

The present study has evolved an effective methodology for identification of Oil Water Contact and computation of water saturation in LRLC reservoirs. The technique involves quantification of water saturation (S_w) through an overlay of ratio of shallow and deep resistivity with SP log. In this technique a synthetic SP curve is generated from ratio of deep and shallow resistivity logs and an overlay is made with the recorded SP log. The two SP curves show crossover in hydrocarbon bearing zone and overlap in water bearing zone. In the hydrocarbon zone, water saturation is computed from difference in both SP logs after applying a suitable scaling factor and a published relationship. This technique is particularly helpful in formations with complex lithologies and uncertain formation water salinity as it does not require the knowledge of porosity, formation factor and formation water resistivity (Rw). The technique gives satisfactorily good results in wells drilled with good salinity contrast between mud filtrate and formation water and moderate invasion.

The technique has been successfully applied in many wells of Changmaigaon & Charali fields and the computed results match well with the production data. The basin vide application of the technique will result into reserve accretion, gain in oil production and enhancement of confidence in exploitation of Low resistivity Low contrast reservoirs.

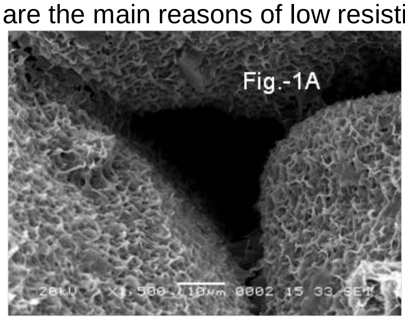
Introduction :

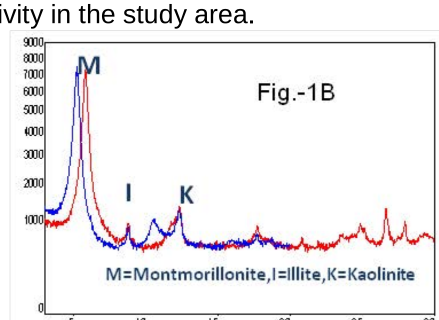
The Assam & Assam Arakan basin is situated in the north-eastern part of India and has an arial extent of around 40,000 sq. Km. Geographically, the area is bounded in the northwest by the eastern Himalayas, in the southeast by the Naga Hills,in the northeast by the Mishmi Hills, and in the southwest by the Mikir Massif and Shillong Plateau. The study area covers Charali and Changmaigaon fields of this basin. These fields are known producers of hydrocarbons from multi- layered reservoirs in Tipams and Barails. The Charali field is one of the oldest oil fields of Upper Assam with BMS (Barail Main Sand), BCS, TS-5A, TS-4 & TS-2 as the main reservoirs. The Changmaigaon Field is also very old field of Upper Assam with TS-4 & TS-5,as the main producers.

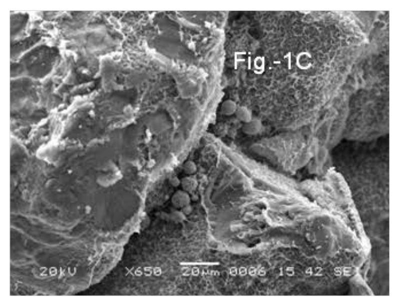
Low resistivity hydrocarbon bearing reservoirs have always been a challenge for log analysts across the globe and Tipam formations of Miocene age in Assam are typical examples. The problem in some of the reservoirs such as TS-5A sand in Changmaigaon/Charali fields, is to the extent that resistivity of oil bearing zone is even lesser than that in water zone. Well-C, has produced oil @ 25m3/d with 0.5% water cut from top 4m of TS-5A sand having resistivity 6-7 ohm m, whereas the resistivity in water section below is 7-8 ohm-m (Plate-2).The present study has evolved an effective methodology for identification of Oil Water Contact and computation of water saturation in LRLC reservoirs. The technique involves quantification of water saturation (S_w) through an overlay of ratio of shallow and deep resistivity with SP log. In this technique a synthetic SP curve is generated from ratio of deep and shallow resistivity logs and an overlay is made with the recorded SP log. The two SP curves show crossover in hydrocarbon bearing zone and overlap in water bearing zone. In the hydrocarbon zone, water saturation is computed from difference in both SP logs after applying a suitable scaling factor and a published relationship. The technique has been successfully applied in two wells of Changmaigaon & Charali fields and the computed results match well with the production data. In Well-A, the computed water saturation (Sw) using Rxo/Rt vs.SP log overlay technique shows decrease of 40-50 % in water saturation as compared to water saturation computed with conventional multi-mineral model. The basin vide application of the technique will result into reserve accretion, gain in oil production and enhancement of confidence in exploitation of Low resistivity Low contrast reservoirs.

Reasons for Low resistivity:

Thin section petrography, XRD and SEM studies carried out on core samples of area under study revealed that , authigenic montmorillonite is the major clay mineral coating sand grains(Fig.-1A & 1B). In fresh water bearing reservoirs major part of the electric current is concentrated through the clay coatings and limits current through bulk pores containing hydrocarbons. Hence, resistivity log becomes less sensitive to the presence of hydrocarbons. Conducting & magnetic heavy minerals (pyrite, iron oxides and ferruginous cement), varying from 2-25%, found in studied samples, provide continuous conduction paths to electrical currents and hence further adds to the low or reverse resistivity contrast(Fig.-1C). Magnetic heavy minerals in cores of study area were also measured through magnetic separator after applying quartz correction. Rock fragments of conducting nature have also been reported in core studies. It can be concluded that mineralogical complexities like authigenic clay coatings, conducting heavy minerals and rock fragments, as depicted from geological core studies are the main reasons of low resistivity in the study area.







Identification of LRLC H.C. layers from Overlay of Rxo/Rt and SP logs:

Identification of oil water contact in wells drilled with low salinity NaCl based muds and logged with induction resistivity tools has been attempted with the help of an overlay of ratio of Shallow (Rxo) and Deep Resistivity (Rt) with SP log. It has been observed that Pseudo-static SP (PSP) of water bearing shaly sands is related to Rxo/Rt ratio in a similar way as Static SP (SSP) of clean water sands is related to Rmf/Rw ratio. The SP and Rxo/Rt curves are plotted in the same track using suitable scales. The two curves track each other in water bearing section and show separation in hydrocarbon zone. In this way OWC can be identified on the overlay. Similar separation may be observed against shales, which is discarded witn the help of other conventional logs.

In the example Well-B, Rxo/Rt vs SP overlay indicates OWC at 2742m in TS-5A sand in which there is hardly any resistivity contrast between oil and water leg. Another H.C. bearing layer in the interval 2755-2761m is also identified which produced clean oil @ 12m3/d on testing, proving the efficacy of the present technique.

Mathematical Formulation of the technique for Computation of Water Saturation:

It has been observed that pseudo Static SP (PSP) of water bearing shaly sands is related to Rxo/Rt ratio in a similar way as static SP (SSP) of clean water sands is related to Rmf/Rw ratio. In the present technique a synthetic SP curve is generated from ratio of deep and shallow resistivity logs. Therefore PSP of a shaly sand can be written in the following form:

$$\mathbf{PSP = - K * \log R_{xo}/R_t \text{ --------------------- } (1)}$$

Where K is the same temperature dependent constant as in the relation for clean sands. In case of water bearing shaly sands,Rxo and Rw used in relation (1) above can be given by

$$\mathbf{R_{xo} = F^* R_{mf} \ \& \ R_t = R_o = F^* R_w}$$

Putting these values in =n. (1),

$$\mathbf{PSP = -K * \log R_{mf}/R_w \text{ ------------------------- } (2)}$$

For hydrocarbon bearing shaly sands,

$$\mathbf{R_t = F^* R_w / S_w^{n^*}}$$

Therefore, $\mathbf{R_w = R_t * S_w^{n^*} / F^* \text{ --------------------------- } (3)}$

And similarly for flushed zone,

$$\mathbf{R_{mf} = R_{xo} * (S_{xo})^{n^*} / F^* \text{ ------------------------}(4)}$$

Substututing Rw & Rmf from (3) & (4) into (2) gives,

$$\mathbf{PSP = -K * \log R_{xo}/R_t - K * \log (S_{xo}/S_w)^{n^*} \text{ ----------------------}(5)}$$

For Water bearing zones, Sxo = Sw and the =n (5) will reduce to = n(1)
For hydrocarbon zones, Sxo > Sw , the second term is having some negative value depending upon water saturation of virgin and filtrate saturation in flushed zone.

Now PSP is log measured SP and the first term on R.H.S. of equation (5) is SP computed using resistivity ratio. As suggested by Zaki Bassioni (Bassiouni, 1994), difference ΔSP can be used to compute Sw as below.

$$\mathbf{(SP)_{Log} = (SP)_{Ratio} - K * \log (S_{xo}/S_w)^{n^*}}$$

$$\mathbf{\Delta SP = (SP)_{Ratio} - (SP)_{Log} = - n^* K * \log (S_w/S_{xo}) \text{ ------------}(6)}$$

For moderate invasion, substituting, $\mathbf{S_{xo} = (S_w)^{0.2}}$, =(6), will reduce to

$$\mathbf{\Delta SP = (SP)_{Ratio} - (SP)_{Log} = - 0.8 * n^* K * \log (S_w)}$$

Now Sw can be computed as, $\mathbf{S_w = 10 \ (- \Delta SP/0.8 * n^* K)}$

Discussion of Results:

The Rxo/Rt vs SP overlay technique as described above, integrated with conventional logs, has been used for petrophysical evaluation of key wells of Changmaigaon and Charali fields. The results of example wells, one each from these fields are described below and presented in Plates-1 & 2 along with conventional and CMR log data.

WELL-A : This well was drilled in 2000 and HRI-SP-GR logs were recorded.This example demonstrates applicability of Rxo/Rt vs SP overlay technique for identification of OWC in TS-5A sand and identification of a new sand layer.Deep resistivity plotted in track-3, in the top oil producing portion of TS-5A is 5-9Ωm., whereas below OWC it varies from 10-11Ωm. Paralog along with NMR T2 spectrum and overlay is presented in Plate-1. The section from 2858–2889m depicts good separation on Rxo/Rt ratio and SP overlay and is interpreted as hydrocarbon bearing with OWC at 2889m.NMR response plotted in track-5(Plate-1), in the interval 2889-2905 with consistently high amplitude peaks towards right side of the T2 spectrum also confirms the OWC at 2889.During testing,the interval 2872.5-2875m produced oil @33.25m3/d and gas @510m3/d with 5% W/C.Another H.C bearing sand is also identified in this well in the interval 2907-2911m as indicated by good Rxo/Rt vs. SP overlay,moderate GR,N-D logs and this sand is producing oil @12m3/d and gas @ 29719 m3/d with 0.1% W/C in Well-B(Fig.-2).

ELAN processing has been carried out with five mineral model comprising of Quartz, Feldspar, Clay, Rock Fragments and heavy iron mineral.Water saturation has been recomputed using Rxo/Rt vs. SP overlay technique as shown in track-9.ELAN processed SW and effective porosity are presented in Track-10. Combined application of Elan processing and Sw from the above technique has successfully resulted into realistic evaluation of low resistivity low contrast TS-5A sand. Water saturation of 40-60 % is computed in the hydrocarbon bearing zone.

WELL-C: This well was drilled in 1986 and DIL-LL3-SP logs were recorded. This well is a typical example of LRLC and demonstrates the usefulness of the technique to identify OWC in TS-5A sand. In this well, resistivity logs in track-3(Plate-2) show reverse contrast in TS-5A sand.This sand is very difficult to interpret as upper oil bearing portion of this sand is having lesser resistivity(6-7Ωm) than water bearing one(7-8Ωm).During initial testing, interval 2677.5-2681.5m produced oil @ 25m3/d with 0.5% water cut.

Elan processing has been carried out with four mineral model comprising of Quartz,Clay,Pyrite and rock fragments.Water saturation has been computed using Rxo/Rt vs.SP overlay technique and shown in track-6(Plate-2).Combined application of Elan processing and S_w from the above technique has successfully resulted into realistic evaluation of low resistivity low contrast TS-5A sand. Water saturation of 40-60 % is computed in the interval 2678-2690m.

Conclusions:

1. The main reason for reverse resistivity contrast between oil and water bearing zones in TS-5A is presence of grain coating authigenic clays, metamorphic rock fragments and conducting minerals coupled with fresh water environment.
2. Rxo/Rt vs SP overlay technique has been successful for identification of OWC in low resistivity low contrast reservoirs.
3. A new sand layer within TS-5A having maximum thickness up to 12 m in Changmaigaon field has been identified from Rxo/Rt vs SP overlay technique.

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Acknowledgments:

The authors are indebted to Shri Anil Sood, GGM-HOI-GEOPIC, Dehradun, India for providing the technical input and guidance for writing this paper. Thanks are due to Shri AK Tandon Head-INTEG, GEOPIC, Dehradun, India for providing all kind of support for this work. We thank ONGC management for giving permission to submit this paper in Geo-India 2015, 3rd South Asian Geosciences conference and exhibition.

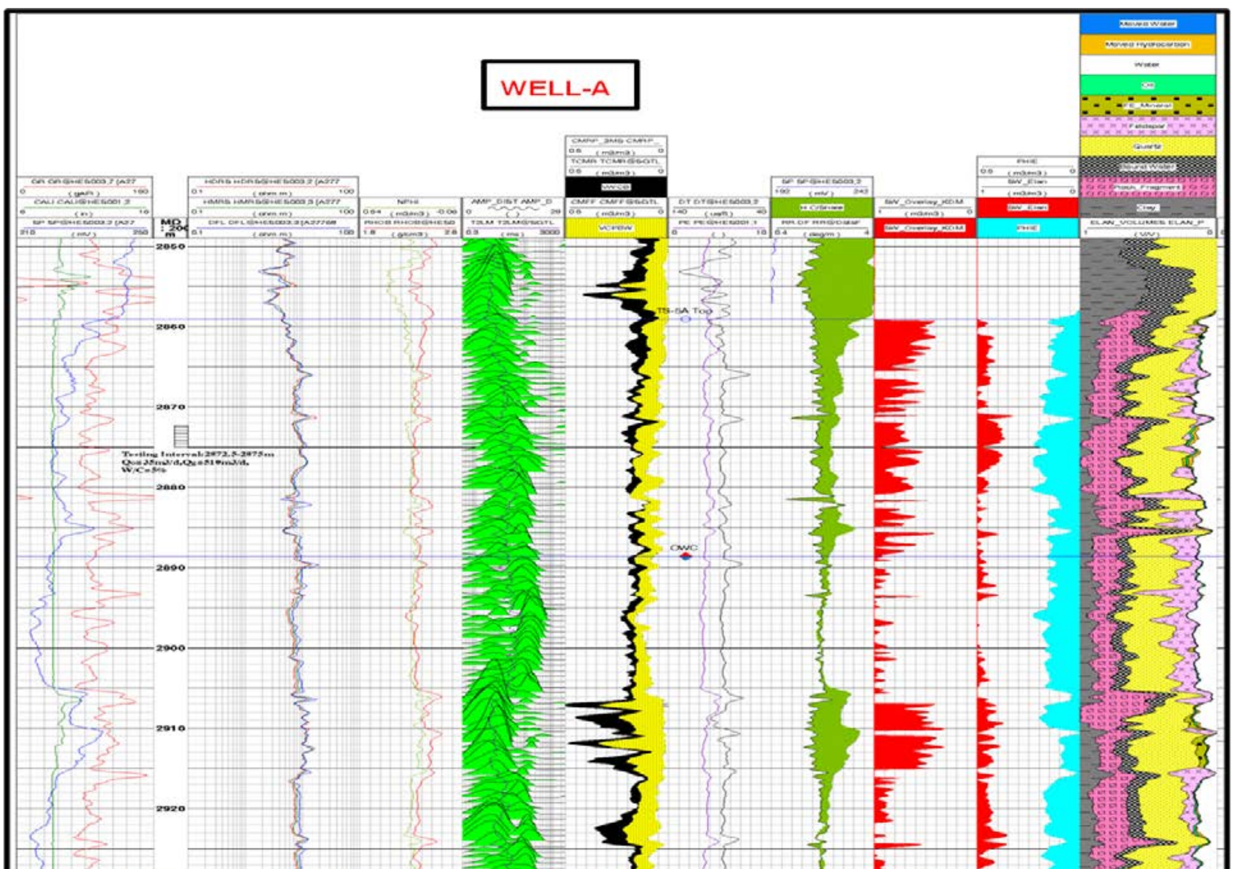

Plate-1: Paralog display of Well-A alongwith NMR T2 spectrum and overlay, Formation TS-5A,Interval 2872.5-2875m produced oil @ 33.25m3/D & gas @510m3/d with 5% W/C during initial testing.Water saturation computed from Rxo/Rt vs SP overlay indicates OWC at 2889m. New Sand in the interval 2905.5-2916 m is clearly identifiable from overlay.

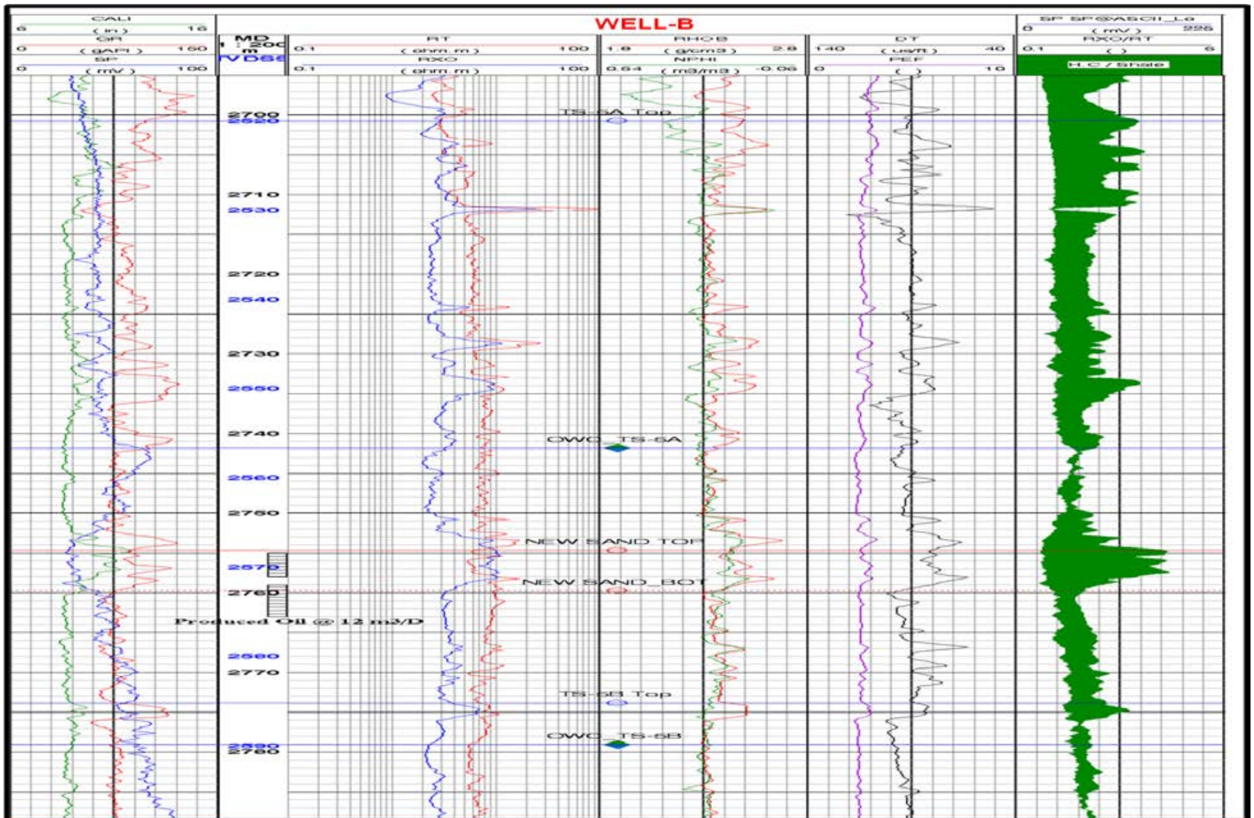

Fig.-2 :Conventional logs and RXO/RT Vs. SP overlay showing OWC at 2742m

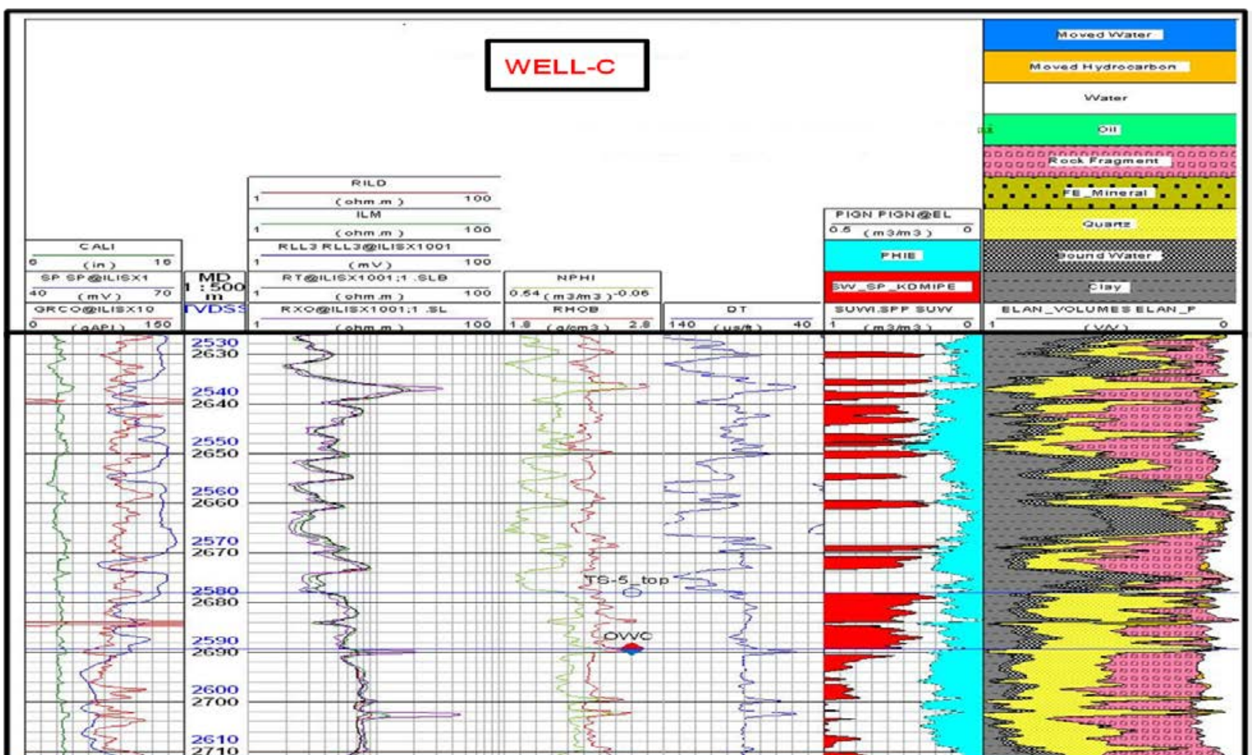

Plate-2: Paralog display of Well-C, Formation TS-5A,Interval 2677.5-2681.5m has produced oil @ 25m3/D with 0.1% W/C during initial testing.There is hardly any resistivity contrast between oil and water legs. Water saturation computed from Rxo/Rt vs SP overlay indicates OWC at 2690m.