



Application of Statistical Method for Identification of Basalt derivative Hydrocarbon Reservoirs in Olpad Formation - Tarapur south area, Cambay Basin, India.

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Keywords

Resistivity of water, Water saturation, Stastical parameter $P^{1/2}$, Basalt derivatives.

Summary

An accurate value of formation water resistivity (R_w) is essential in calculating formation fluid saturation from conventional well logs. It becomes difficult to get accurate fluid saturation where R_w value is not readily available and where the water saturation in the formation is poor due to lack of clean water bearing zones. The difficulty of obtaining clean water-bearing zones is further accentuated by complexity of reservoir lithology. Normally, in identifying reservoirs from conventional logs, natural/spectral gamma ray is taken into consideration. But due to secondary mineralization where radioactive concentration is much pronounced (i.e. weathered basement) delineating reservoir rock becomes a matter of concern. In this scenario statistical method ($P^{1/2}$) is very much useful in calculating water saturation (S_w) and hydrocarbon Saturation (S_{hc}).

Using statistical method ($P^{1/2}$) a pay zone was identified in Olpad Formation consisting of basaltic derivatives and other complex lithology and also where the conventional methods are misleading due to uncertainty in resistivity of water. The identified zone was tested conventionally with tubing-conveyed perforation and the zone flowed oil @60 bbls/day from a five-meter-perforation interval and other well tested based on the conventional results and observed result is no influx. This methodology may provide a fresh lease of life to hundreds of dwindling wells in Cambay basin where identifying oil bearing zones (in the absence of proper R_w value) in Olpad Formation had remained subjective until now.

Introduction

The Cambay basin, which is one of the major oil bearing sedimentary basins of India, is situated in the western margin of Indian subcontinent between $21^{\circ}N$ & $24^{\circ}30'N$ latitudes and $71^{\circ}30'E$ & $73^{\circ}45'E$ longitudes. The basin runs in NNE-SSW direction from the mouth of Gulf of Cambay in the form of a graben up to $21^{\circ}45'N$ latitude and thereafter takes a turn in NNW-SSE direction towards the main land.

The basin is bounded by Kutch rift basin in the north and Narmada rift basin in the south.

Based on structural styles, such as fault pattern, symmetry, size and orientation of depressions, the basin is split into the following six tectonic blocks (Chowdhary, L.R., 2004) 1) Patan-Tharad block, 2) Ahmadabad-Mehsana block, 3) Cambay-Tarapur block, 4) Broach-Jambusar block, 5) Narmada block and 6) Surat block (Chowdhary, 2004) as shown in (Fig-1).

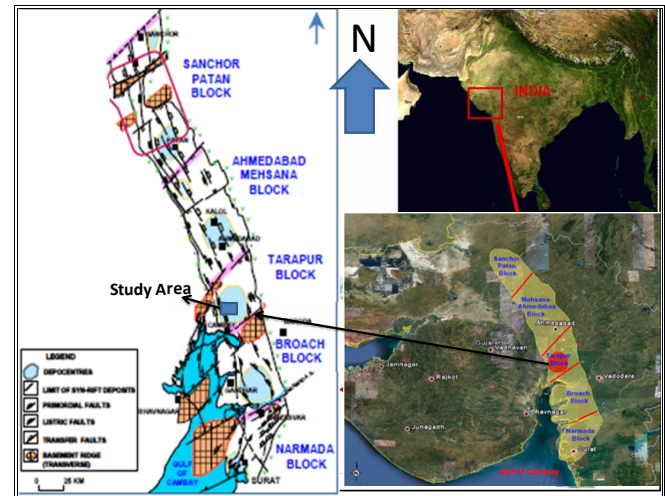


Fig-1: Study Area Location and Tectonic Block Map of Cambay Basin.

The study area falls within Tarapur exploration block in which regional litho-facies analysis indicates the development of clastic reservoirs in Paleocene, Middle Eocene, Late Eocene, Oligocene and Miocene levels. The Deccan Trap, which forms the technical basement for the Cenozoic sediments, was subjected to intense weathering at places. During the course of tectonic readjustments, several fractures and minor fissures were developed over the flanks of many paleohighs. These fractured and weathered zones which are eventually reworked to form sediments are known as trap derivatives or Olpad Formation.

Due to continental rifting of Deccan Trap a series of horst and graben structures has been evolved. The grabens are filled with rift fill sediments consisting of Olpad sediments and subsequently overlain by Cambay shale which was deposited as a result of marine transgression during Late Palaeocene and Early Eocene. Cambay Shale which forms the main source rock of the basin is at places juxtaposed to the Olpad Formation in this horst and graben tectonic set up. Deccan trap of Late Cretaceous unconformably overlies Pre-Cambrian Basement. The lowest Tertiary sedimentary unit, termed as Olpad Formation by Chowdhary (2004), directly overlies Deccan Trap basalts. It is composed of volcanic conglomerates, sandstones, silts, ashy claystones and clays, exclusively derived from underlying basalts. The succession exhibits variegated colours ranging from light gray to reddish brown or even flaming red. In conglomerates, the Deccan Trap fragments occur as pebbles, gravel, sand and silt with no selective sorting except locally. The matrix is clayey and chloritic in nature. Diagenesis is often pronounced at places.

The well under discussion is located towards southern part of Tarapur area which is a leased exploration block awarded by hydrocarbon authority of India. This well is drilled to prove/test the hydrocarbon potential of Deccan Trap or Trap derivatives (Olpad Formation).

The study well has encountered complex lithology consisting in olpad formation mainly clay stone, sand stone, chert, basalt and fine volcanic rock fragments, trap wash (Fig-2). Various minerals such as quartz, feldspar, chlorite, calcite, barite and zeolite are reported in this formation. The above described complex lithological assemblage has affected the cleanliness of the formation to a great extent. This paper mainly focuses on the successful estimation of water saturation and Oil saturation in this complex weathered basaltic derivative reservoir in Olpad Formation where formation water resistivity is not properly established.

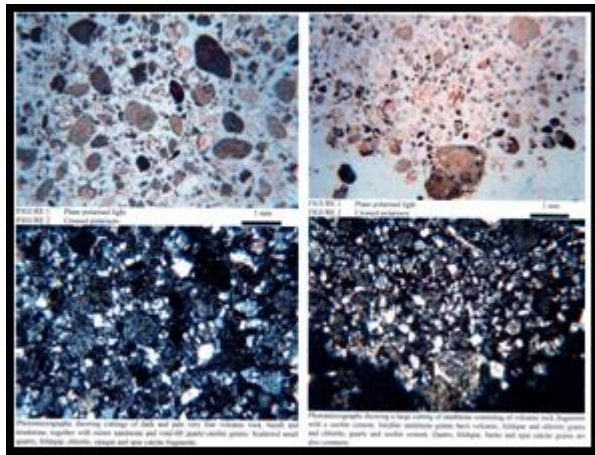


Fig- 2: Photomicrographs showing complex lithology of Trap wash, mudstone , basalt, quartz and zeolite grains in Olpad formation in Study Area.

Methodology

The interpretation technique followed in identifying pay zones is discussed as below:

P^{1/2} Determination

Cumulative Frequency VS P^{1/2}

Estimation of Water Saturation

Estimation of Oil Saturation

Identification of Pay zones

P^{1/2} determination

Hydrocarbon zones can be detected in a fractured reservoir by means of a parameter P, which is a function of formation resistivity and porosity tool response. It provides a reliable means of distinguishing the hydrocarbon-bearing zones. This parameter was investigated by Porter et al (1969), Aguilera (1974) and Alfred (2002).

$$P = Rt (\Delta t \log - \Delta t_m)^m \text{-----Eqn 1}$$

$$P^{1/2} = \bar{\sigma} Rt (\Delta t \log - \Delta t_m)^m \text{----- Eqn 2}$$

Where,

P^{1/2} = statistical parameter with an approximated normal distribution for 100- percent water saturation zones.

Rt = true formation resistivity (ohm-m)

Δt log = response of the sonic log (μsec/ft)

Δt_m = response of the sonic log in matrix (μsec/ft)

This well is drilled up to 2940m MD. Presented below (Fig.3) is the zone of interest for which conventional logs are obtained through wireline logging in Olpad Formation. This interval represents weathered Trap and Trap derivatives which are inferred from logs such as GR, LLD (Deep Resistivity), MSFL, and PE.

Application of Statistical Method for Identification of Complex Basaltic derivative Hydrocarbon reservoirs in Olpad Formation

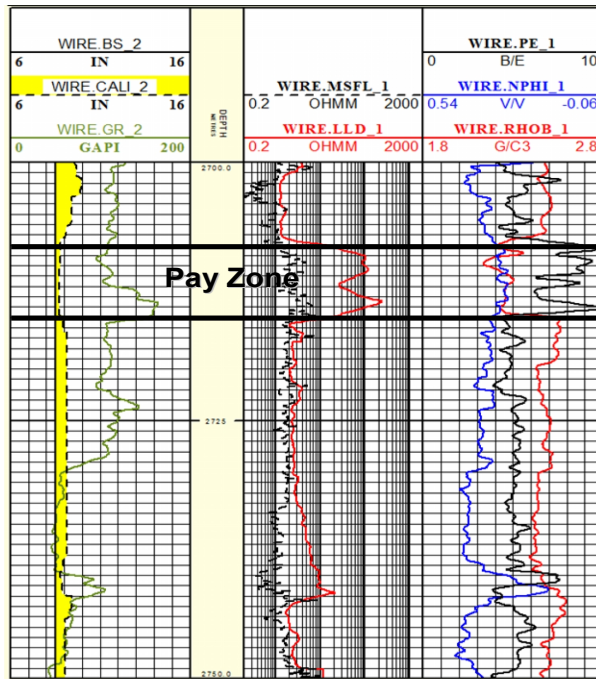


Fig -3: Pay zone (2709-2714.9m) in Olpad section case study well

In this study digital data of resistivity and sonic logs in the interval of 2600-2750m MD have been considered. Thereafter, $P^{1/2}$ values are calculated using Eqn. 1 & 2 and min & max values of $P^{1/2}$ are noted. In this interpretation, cementation factor (m) of 2.15 and sonic matrix delta transit time (Delta T matrix) value of 55.5 (i.e. for sand stone) were used as a convention for Olpad formation. $P^{1/2}$, thus calculated, is tabulated in the table below (limited table due to space limit) (Table-1).

Depth (m MD)	Delta T Log (μ sec/ft)	LLD (meter)	Delta T Matrix (μ sec/ft)	Delta T Log-Delta T Mat (μ sec/ft)	(Delta Log-Delta Mat) ^m	(Delta Log-Delta Matrix) ^m Rt	$P^{1/2}$	Range
2741.3	61.9022	10.7555	55.5	6.4022	54.15117189	582.4229293	24.13344	20-30
2741.2	62.7012	9.6641	55.5	7.2012	69.73013027	673.8789519	25.95918	20-30
2741.4	62.2796	12.6532	55.5	6.7796	61.24755448	774.9775564	27.83842	20-30
2741.1	64.1765	8.8989	55.5	8.6765	104.0976266	926.3543695	30.43607	30-40
2741	65.5772	8.6351	55.5	10.0772	143.6086957	1240.075448	35.2147	30-40
2741.5	63.8254	15.9624	55.5	8.3254	95.25131579	1520.439603	38.99281	30-40
2740.9	66.5682	8.9607	55.5	11.0682	175.6974855	1574.372458	39.67836	30-40
2740.8	67.1766	9.3573	55.5	11.6766	197.1198076	1844.509175	42.94775	40-50
2699.8	75.8013	2.8762	55.5	20.3013	647.4053371	1862.067231	43.15168	40-50
2699.7	76.661	2.6467	55.5	21.161	707.7873599	1873.300805	43.28165	40-50
2740.7	67.5836	9.7672	55.5	12.0836	212.1886414	2072.488898	45.5246	40-50
2699.6	78.7817	2.4629	55.5	23.2817	869.1236761	2140.564702	46.26624	40-50
2740.6	67.9189	10.1057	55.5	12.4189	225.0498509	2274.286279	47.68948	40-50
2740.5	68.1852	9.9391	55.5	12.6852	235.5533232	2341.188034	48.38582	40-50
2740.4	68.3679	9.7822	55.5	12.8679	242.9078254	2376.172929	48.746	40-50
2740.3	68.5699	9.492	55.5	13.0699	251.1801811	2384.202279	48.82829	40-50
2699.9	76.8832	3.3008	55.5	21.3832	723.8628705	2389.326563	48.88074	40-50
2699.5	81.6511	2.2362	55.5	26.1511	1115.843832	2495.249977	49.95248	40-50
2740.2	69.0788	9.2224	55.5	13.5788	272.6791881	2514.756544	50.14735	50-60
2676.4	93.8817	1.0927	55.5	38.3817	2546.05068	2782.069578	52.74533	50-60
2676.3	95.9058	1.0087	55.5	40.4058	2843.504868	2868.243361	53.55598	50-60
2699.4	84.7394	2.0604	55.5	29.2394	1418.509281	2922.696522	54.06197	50-60
2740.1	70.3388	9.0474	55.5	14.8388	329.9950155	2985.596903	54.64062	50-60
2676.5	94.4431	1.1491	55.5	38.9431	2626.791593	3018.446219	54.94039	50-60
2741.6	65.7958	20.5967	55.5	10.2958	150.3900868	3097.5395	55.65554	50-60
2676.6	94.9161	1.1778	55.5	39.4161	2695.8663	3175.191328	56.34884	50-60
2707.3	89.844	1.6365	55.5	34.344	2004.838447	3280.918119	57.2793	50-60
2700	79.3144	3.5967	55.5	23.8144	912.4419303	3281.779891	57.28682	50-60
2707.4	88.2235	1.8182	55.5	32.7235	1806.959666	3285.414065	57.31853	50-60
2707.2	91.6037	1.4803	55.5	36.1037	2232.215813	3304.349068	57.48347	50-60
2699.3	87.9894	1.9433	55.5	32.4894	1779.281388	3457.67752	58.80202	50-60
2715.8	86.4445	2.1618	55.5	30.9445	1602.339209	3463.936903	58.85522	50-60
2707.1	93.4941	1.4191	55.5	37.9941	2491.091886	3535.108495	59.45678	50-60

Table-1: $P^{1/2}$ determination in the Case Study Well.

$P^{1/2}$ Vs Cumulative Frequency X-plots

In this step, cumulative frequency (CumFQ) was calculated from $P^{1/2}$ sample frequency. Then a cross plot is plotted between $P^{1/2}$ and cumulative frequency (Fig-4). From the cross plot, $P^{1/2}$ mean of water bearing zone and $P^{1/2}$ hydrocarbon point for hydrocarbon zone were identified. In this cross plot it is necessary to consider the water bearing zones as a single distribution (Table-2).

Range	Frequency	Relative Freq	Cum FQ	P ^{1/2}
20-30	3	0.00198544	0.00198544	25
30-40	4	0.002647253	0.004632694	35
40-50	11	0.007279947	0.011912641	45
50-60	16	0.010589014	0.022501655	55
60-70	71	0.046988749	0.069490404	65
70-80	177	0.117140966	0.18663137	75
80-90	212	0.140304434	0.326935804	85
90-100	205	0.135671741	0.462607545	95
100-110	239	0.158173395	0.62078094	105
110-120	179	0.118464593	0.739245533	115
120-130	98	0.06485771	0.804103243	125
130-140	80	0.052945069	0.857048312	135
140-150	62	0.041032429	0.898080741	145
150-160	66	0.043679682	0.941760424	155
160-170	12	0.00794176	0.949702184	165
170-180	4	0.002647253	0.952349437	175
180-190	5	0.003309067	0.955658504	185
190-200	4	0.002647253	0.958305758	195
200-210	4	0.002647253	0.960953011	205
210-220	1	0.000661813	0.961614825	215
220-230	6	0.00397088	0.965585705	225
230-240	3	0.00198544	0.967571145	235
240-250	2	0.001323627	0.968894772	245
250-260	2	0.001323627	0.970218398	255
260-270	2	0.001323627	0.971542025	265
270-280	2	0.001323627	0.972865652	275
280-290	1	0.000661813	0.973527465	285
290-300	3	0.00198544	0.975512905	295

Table-2: Cumulative Frequencies from P1/2

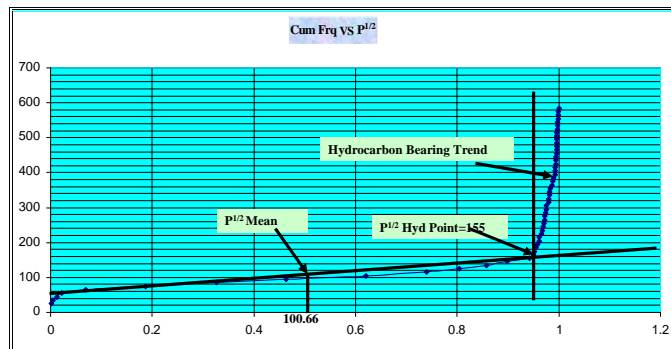


Fig-4: Cumulative Frequency(X-axis) Vs P^{1/2} (Y-axis) cross plots for the Case Study Well

Estimation of water saturation

From P^{1/2} hydrocarbon point we collected every value and incorporated following principles to find resistivity index (RI) and water saturation (Sw). Here we have used saturation exponent (n) as 2 (Porter et al, 1969 and Aguilera, 1974).

Resistivity Index (I_r) = P_{Hyd} / P_{Mean}Eqn 3

Water Saturation = (I_r)^{-1/n} Eqn 4

Using equations 3 & 4, water saturation was calculated for the whole interval. Based on water saturation values, hydrocarbon saturation was obtained and the zone of interest was identified in the interval between 2709 and 2714.9m MD (Table-3).

Depth	P ^{1/2}	P ^{1/2} mean	P Hyd	P mean	I _r	Sw	So
2709.1	226.5318	100.6	51316.64	10120.36	5.070634	0.444088	0.555912
2709.2	296.3047	100.6	87796.47	10120.36	8.675232	0.339515	0.660485
2709.3	383.521	100.6	147088.3	10120.36	14.5339	0.262306	0.737694
2709.4	420.3249	100.6	176673	10120.36	17.45719	0.239339	0.760661
2709.5	412.2474	100.6	169947.9	10120.36	16.79267	0.244028	0.755972
2709.6	378.9966	100.6	143638.5	10120.36	14.19302	0.265438	0.734562
2709.7	365.4271	100.6	133536.9	10120.36	13.19488	0.275294	0.724706
2709.8	362.034	100.6	131068.6	10120.36	12.95098	0.277874	0.722126
2709.9	365.6289	100.6	133684.5	10120.36	13.20946	0.275142	0.724858
2710	371.2081	100.6	137795.5	10120.36	13.61567	0.271007	0.728993
2710.1	381.4312	100.6	145489.8	10120.36	14.37595	0.263743	0.736257
2710.2	390.1612	100.6	152225.8	10120.36	15.04154	0.257842	0.742158
2710.3	391.3772	100.6	153176.1	10120.36	15.13544	0.257041	0.742959
2710.4	382.929	100.6	146634.6	10120.36	14.48907	0.262712	0.737288
2710.5	374.3457	100.6	140134.7	10120.36	13.84681	0.268736	0.731264
2710.6	363.2932	100.6	131982	10120.36	13.04123	0.276911	0.723089
2710.7	350.0803	100.6	122556.2	10120.36	12.10987	0.287363	0.712637
2710.8	337.9351	100.6	114200.1	10120.36	11.28419	0.29769	0.70231
2710.9	328.1721	100.6	107696.9	10120.36	10.64161	0.306546	0.693454
2711	319.4538	100.6	102050.7	10120.36	10.08371	0.314913	0.685087
2711.1	317.7983	100.6	100995.8	10120.36	9.979464	0.316553	0.683447
2711.2	317.3767	100.6	100728	10120.36	9.953002	0.316974	0.683026
2711.3	313.0934	100.6	98027.48	10120.36	9.686165	0.32131	0.67869

Table-3: Water and oil saturation values of identified pay zone in the Case Study Well.

Fig-5 is a pictorial presentation of depth v/s hydrocarbon saturation. In the present study Sw cut-off of 0.6 is used to delineate hydrocarbon bearing zones from water bearing zones with calibration of nearby wells testing data.

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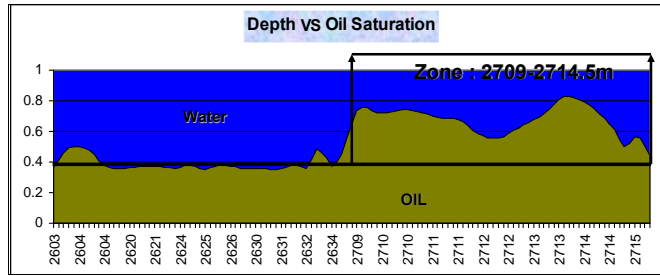


Fig- 5: Depth Vs Statistical Method derived Oil Saturation in Case study well.

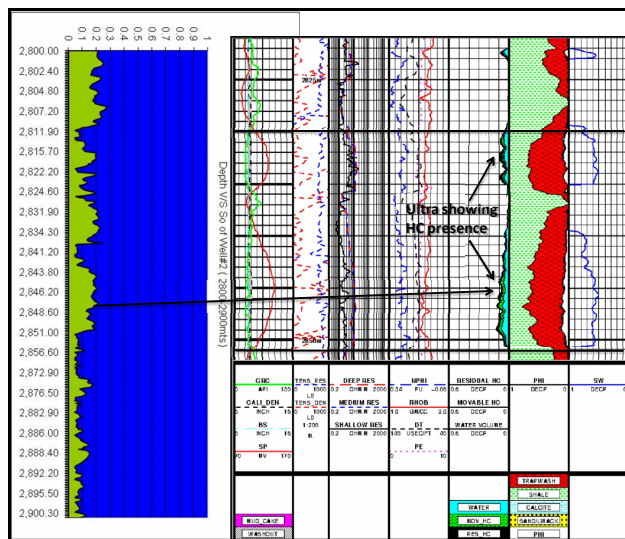


Fig- 6: Log interpretation Ultra saturation results shows HC presence above zone (2844-2850m) and Statistical Method derived Oil Saturation is not showing any saturation >40% in nearby well and the zone tested based on ultra results observed no influx.

The Result

Prior to the methodology described here, most of the conventional quantitative hydrocarbon saturation evaluations for Olpad Formation remained subjective till the zone of interest was flow tested. Applying this technique, where R_w is not properly established, oil bearing zone in Olpad Formation was successfully established. Success was demonstrated in flow test that produced oil @60 bbls /day from a five-meter-perforation interval.

In other nearby wells also clearly demarked the producible zone and non producible zones where, conventional methods clearly

indicating hydrocarbon due to problem with obtaining accurate R_w value in complex lithology fig-6.

This approach allowed the zone of interest to be perforated and flow tested which otherwise would have been left out since petrophysically similar logs in Olpad formation many a times are misleading as lithological signatures.

Conclusions

Hydrocarbon zones can be detected effectively using the statistical method (parameter P1/2) where the identification of clean water bearing zone are difficult like Olpad formation in Cambay Basin.

The interpretation model is very effective in formations whose formation water resistivity R_w is either not available or difficult to obtain in wildcat wells.

The approach validates a novel, fit-for-purpose technique for determining hydrocarbon saturation evaluation in the absence of formation water resistivity (R_w). Having tested this methodology for Olpad Formation in Cambay basin, it has opened up a new vision for many marginalised on-land blocks/fields in the basin.

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