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EFFECTS OF CLAY ON RESISTIVITY INDEX THIN BED: CASE STUDY FROM WESTERN NIGER DELTA

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ABSTRACT

Certain clays produce micro-porosities that retain a relatively thick water layer and enhance the path for conductivity of electric currents through capillary forces. Saturation exponent (n) in clay-rich fields is less than the value of 2, usually assumed in well-logging. Accurately determined clay-corrected saturation exponent ("n") and resistivity index are needed for better reserve estimation.

A clay inclusion study of saturation-resistivity relationships from thin and laminated beds is carried out in the laboratory. Saturation exponents (n) are measured on a number of core samples from several wells in a Niger Delta field Cation exchange capacity (CEC) technique is used to detect clay in the rocks CEC values are in the ranges of 0.0278 and 0.0078 for the interval 5456-5574ft and 0.0025 – 0.0166 for 8600 to 8695ft. A correlation of the resistivity index and saturation indicates deviations, from 'normal', caused by the effect of clay minerals such as kaolinite, montmorillonite and smectite. Clay presence produces a curve towards low saturation point. The average field "n" is 1.83 and acceptable CEC tolerance in heterogeneous formations is within a depth of 0.2ft. The larger the CEC, the greater the suppression of downhole resistivity and active clays such as montmorillonites have greater influence on log response than kaolinite.

Key words: Resistivity, saturation, clay.

INTRODUCTION

A long-standing problem in thin suture zones or seams containing concentrations of clays or other insoluble rock constituents is determining to what extent they affect reservoir permeability. This work aims at addressing the problem as it affects the Niger Delta. Reliable measurement of saturation is important in accurate reserve estimation (Appah and Onumaegbu, 1996). Resistivity index is used to assess the prospects of a formation. The lithology of the Niger Delta is mainly sands with substantial shale laminations (Ajoku, 1998). The fields are highly heterogeneous and characterized by thinly bedded reservoirs. Cores were therefore obtained from a large interval (5456-86957ft). Formations with low resistivity values have often been improperly evaluated, while some intervals are entirely overlooked. The effect of clay becomes more significant as the formation water salinity decreases, when the kaolinite is susceptible to salinity shock (Lynn and Nasr-El-Din, 1999). The assumption is that only sodium chloride salt is present in the formation water. This is standard as in the explanation of ionic movement causing potential difference along the membrane or bed boundary. The effect of clay on rock resistivity depends on the amount, type and distribution (Amaefule and Keelan, 1987). Resistivity index is a function of water saturation and pore geometry. Clay creates microporosities and it is highly conductive even at low water saturation.

RESERVOIR GEOLOGY

Cores were obtained from a large onshore reservoir in Nigeria, with an areal extent of over 5,000 acres. The oil field (Fig.1) was discovered in 1958 and it is fully developed

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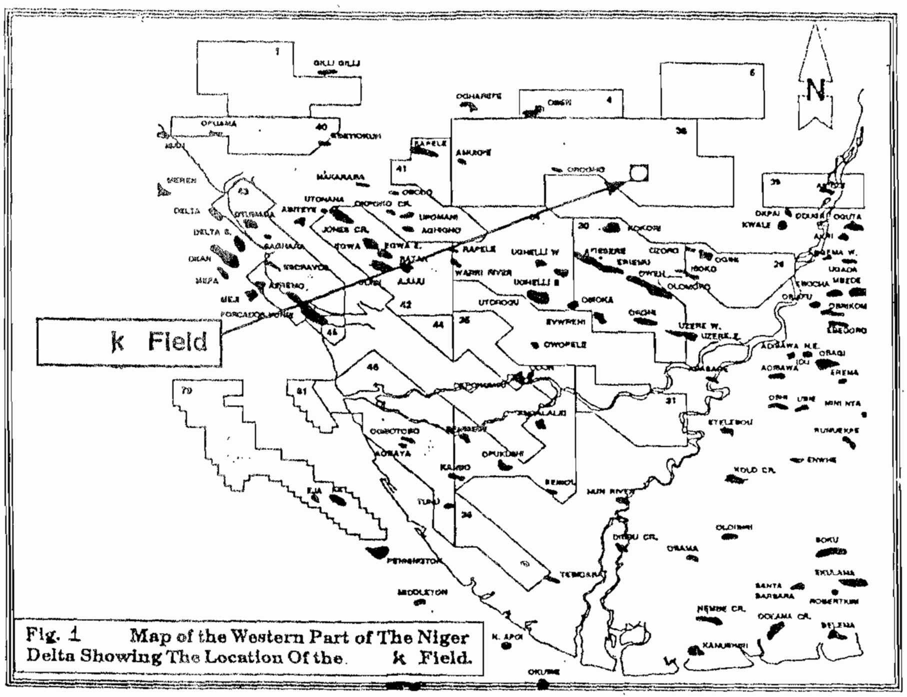

Fig. 1 Map of the Western Part of The Niger Delta Showing The Location Of the k Field.

with a total of 52 wells drilled. There are five main reservoirs: E1.0, E1.3, E2.0, E3.0 and the H1.0. The H1.0 (Fig.2) is thicker in the north (well – 43; 116ft) and becomes thinner to the south (well – 49; 76ft) and to the east (well-37; 59ft). Deductions on the lithofacies type and variations are based on electric log motif and core sampling.

The sand is interpreted to represent a complete sedimentary cycle consisting essentially of upper/middle shoreface sands with a few channel cuts laid down during a period of slow delta advance. It commences with a well developed marine shale underlying the unit and grades through a lower shoreface laminated silt, fine sand and clayey basal part, into a predominantly sandy and well developed upper shoreface sequence. Six units have been identified in the reservoir sand within the field. The units consist of fine to very fine grained well sorted sands, with thin (often a millimeter thick) silt and clay laminations becoming more dominant in the basal units. Generally, they display a funnel shaped log motif, typical of upper shoreface deposits.

Kaolinites, mixed layer illite/smectite are the main clay types generally seen in this reservoir. The kaolinites are mainly authigenic, while the mixed layer clays occur in detrital and authigenic forms. In addition, the very fine-grained portions of H1.0, contains some percentage of iron-bearing siderites, chlorite and sometimes in laminae associated wi detrital clays. Sand quality deteriorates in south easternly direction with the intercalatin shale becoming thicker suggesting sedimer transport from a north-western direction.

Production (3000 stb/d) began in 197 achieved a peak rate of some 14,000 stb/d 1999 and anticipated to decline by 2003 some 2000 stb/d, because of reserv characteristics and poor production polic Following a revamp of its surface facilities, field rejuvenation is currently proposed.

PRE-TEST HANDLING

Cores from the field are highly unconsolidate laminated and friable. The cores were froze in dry ice before slabbing parallel to th bedding planes, They were then plugge perpendicular to these planes. Plugs, unifor in lithology, were 1.49-1.5 ins. in diameter an 3.0-3.2 ins. long as measured with digit calipers. The electrode spacing greater tha 1.5 times the diameter, used fo heterogeneous cores, was maintained an liquid nitrogen was the lubricant to maintai core samples conductivity.

Plugs were cleaned in a standard reflu Soxhlet Extractor filled with toluene an heated to a spill point (111°C). The solver

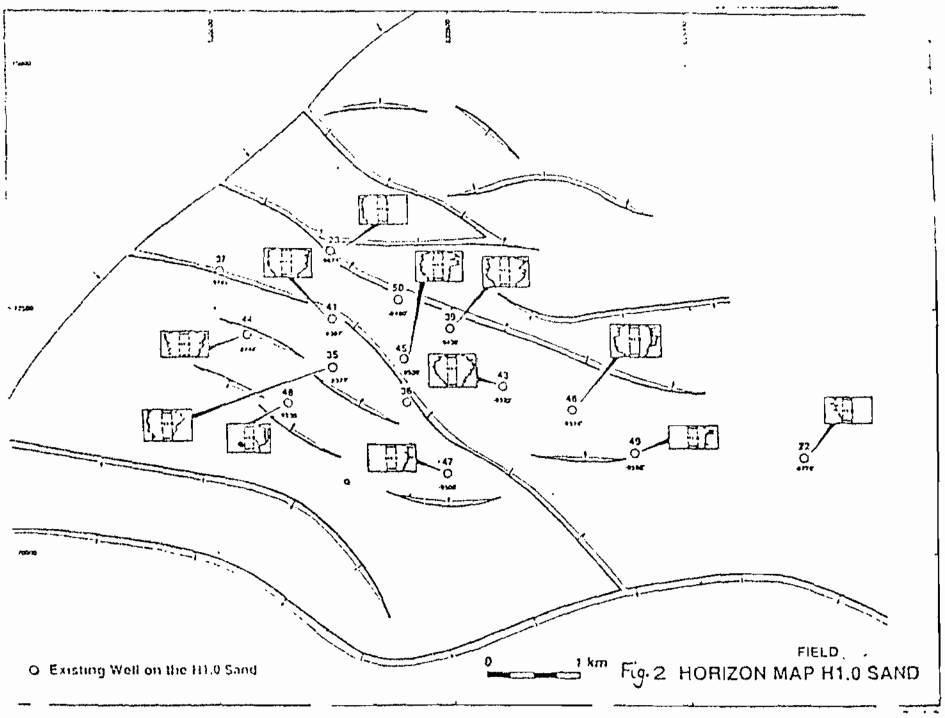

Fig. 2 HORIZON MAP H1.0 SAND

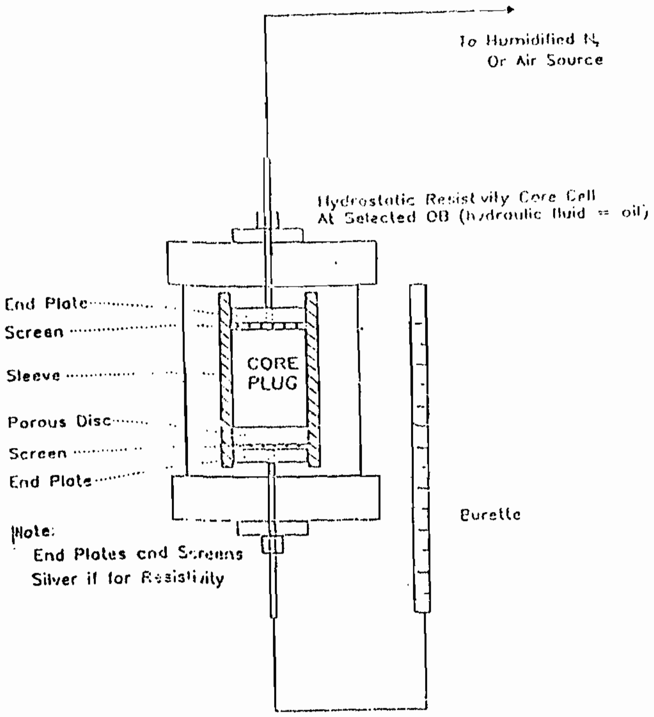

Fig. 3:

Equipment configuration for nesistivity at constant overburden configuration

was refluxed and sample cleaned by solvent imbibition, diffusion and drainage. The oil-cleaned samples were confirmed under ultra-violet light (UVL), since oil fluoresces in the presence of UVL. The core samples were aired to evaporate toluene and methanol used to leach out salt precipitate. The test for complete leaching is when core plugs do not form white precipiation with 10% silver nitrate solution. Plugs were vacuum dried in an oven at 140°F and –15 psi to preserve samples physical features.

For routine petrophysical analysis, a helium Boyle's law porosimeter in a quartz transducer was used to determine the grain volume. The plug was loaded into a hydrostatic core holder, to determine the pore volume. The air-permeability was measured by steady state method of the flow rate using a timed bubble meter.

RESISTIVITY INDEX MEASUREMENTS

Procedures

Ten samples from two Niger Delta reservoirs were used to measure resistivity indices of clayey sands. Clean, dry core samples were loaded into a saturation chamber and pressure-saturated using 20,000 and 11,050 ppm synthetic brine. The samples were brine-soaked for at least seven days prior to loading in the apparatus. Overburden pressures of 2600 and 3500 psig to simulate reservoir

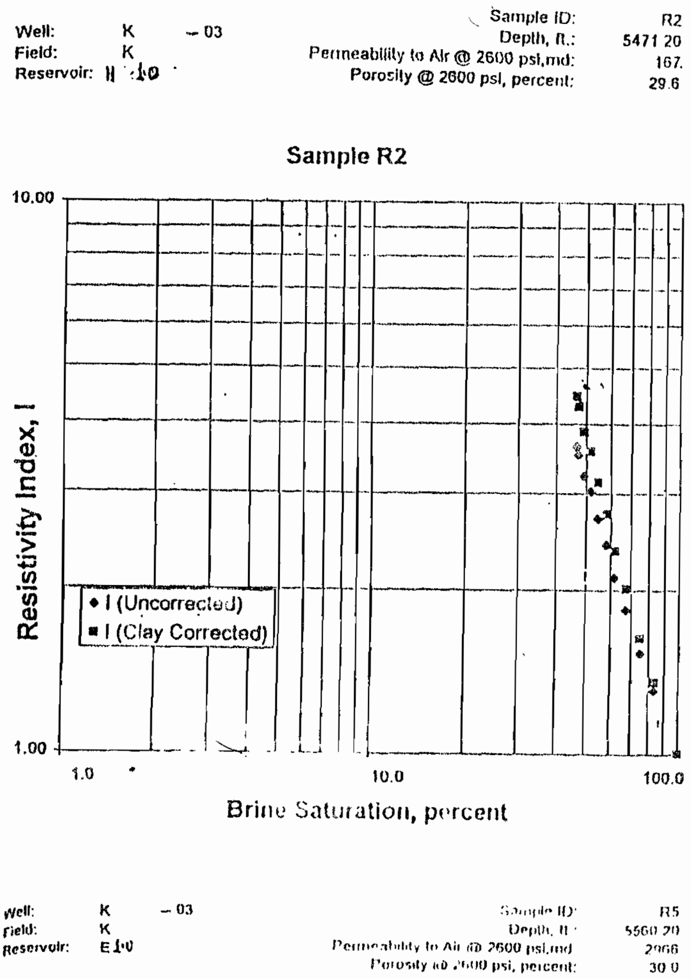

Fig 4: RESISTIVITY INDEX Vs. SATURATION

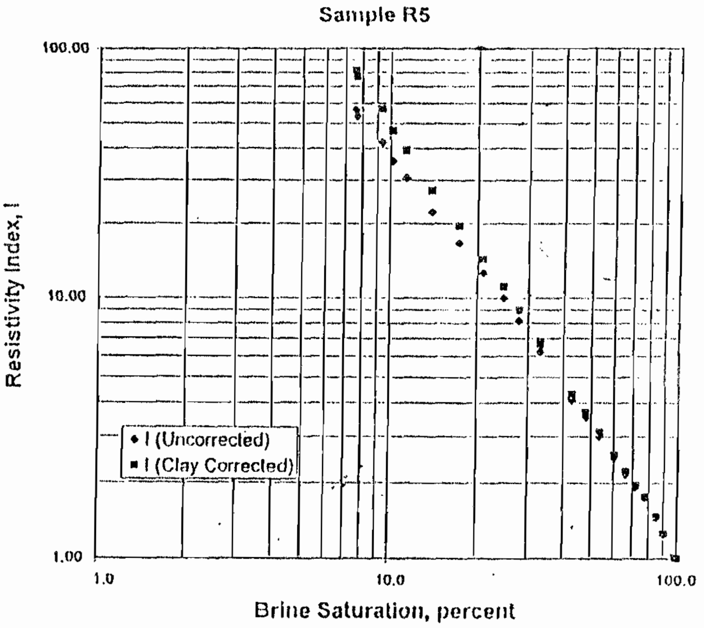

Fig.5 RESISTIVITY INDEX Vs. SATURATION

stress were exerted on the resistivity core holder equipped with thermocouple (Fig.3). The internal thermocouple measured core plug temperature and indicated thermal stability. Typically, about 10 to 20 pore volumes of the brine are injected through the samples at a low rate to prevent fines migration and to completely fill the system with brine.

Each sample was desaturated to irreducible water saturation, using humidified nitrogen as the displacing phase. The displaced fluid volumes were measured daily and brine saturations (S_w) calculated:

$$S_w = \left[\left(\frac{W_2 - W_1}{\rho}\right)\right] / V_p \qquad (1)$$

Where,

W_2 - weight after desaturation point
W_1 - Grain weight
ρ - Density of saturant
V_p - Pore volume at stress

Sample resistivity, determined with a 4 electrode device (Fig. 3) at each of the decreasing water saturations, was normalized at 77°F. Resistivity index (I) values at each saturation were calculated (Eq. 2) and plotted against S_w (Diederix, 1982):

$$I = \frac{R_t}{R_0} = \frac{1}{S^n} \qquad (2)$$

Where, R_t – total resistivity and R_o – rock resistivity. Conventional method for determining residual oil saturation indirectly, Dean-Stark and leaching with methanol (Wardlaw and Mckellar, 1999), was used and samples permeability to air determined at 2600 and 3500 psig simulated reservoir stresses.

Saturation exponent (n) was obtained from a log-log plot of I and S_w (Eq. 2). The effect of clay on I was corrected by incorporating cation exchange capacities (CEC) of the sample. Trimmed ends from each clean and dry sample were crushed to pass through a 60 mesh screen. About 3g of the sample was added to deionised water, kept overnight at 110°C, mixed with 3.2g of $BaCl_2$ and methanol (25cc.) added. The resultant slurry was titrated with 1N magnesium sulphate. Resistivity index corrected for clay effect (I*) is given as (Seale and Irving, 1988):

$$I^* = S_w^{-n} = \frac{I(1+R_w BQ_v/S_w)}{(1+R_w BQ)} \qquad (3)$$

Table 1: CLAY CORRECTION DATA

TEST TEMPERATURE: 77°F

Vell: K .03
ield: K
Reservoir: E .02 1 0

Saturant: Brine (20,000ppm)
B, ml/meq-ohm-m: 3436

SAMPLE ID	DEPTH FEET	CATION EXCHANGE CAPACITY meq/g	CONFINING STRESS	POROSIOTY %	Qv meq/cc
R1	5456.30	0.0278	2600	31.4	0.1630
R2	5471.20	0.378	2600	29.6	0.2384
R3	5480.30	0.0255	2600	29.4	0.1650
R4	5553.10	0.0248	2600	28.9	0.1600
R5	5560.20	0.0060	2600	30.0	0.0370
R6	5574.20	0.0078	2600	34.4	0.0391

Table 2: CLAY CORRECTION DATA

TEST TEMPERATURE: 77°F

Vell: K D7 (D)
ield: K
eservior: E 1.0-01

Saturant: Brine (11,050 ppm)
B, ml/meg-ohm: 3.01

SAMPLE ID	DEPTH FEET	CATION EXCHANGE CAPACITY meq/g	CONFINING STRESS	POROSIOTY %	Qv meq/cc
R7	8600.10	0.0278	2500	27.1	0.0180
R8	8650.35	0.378	2500	25.6	0.0580
R9	8680.00	0.0255	2500	28.3	0.0303
R10	8695.00	0.0248	2500	26.0	0.1261

able 3: ELECTRODE RESISTIVITY INDEX
Test Temperature 77°F

ell K -03
ield: K
eservoir: E -2 H1.0

Sample ID: R1
Depth, ft: 5456.30
Permeability to Air @ 2600 psi, md: 194
POROSITY @ 2600 PSI, PERCENT: 31.4

		2600 psi Confining Stress			
Brine Saturation, Percent P.V.	Resistivity Rt, Ohm-m	Resistivity Index, I	Resistivity Index I*	Saturation Exponent n	Saturation Exponent n*
100.0	2.485	1.00	1.00	1.81	1.98
95.2	2.719	1.09	1.10		
87.6	3.203	1.29	1.31		
78.9	3.856	1.55	1.61		
73.1	4.573	2.16	1.94		
67.4	5.362	1.84	2.31		
62..5	6.169	2.48	2.69		
60..9	6.397	2.57	2.81		
57..5	7.203	2.90	3.20		
54..2	7.865	3.17	3.55		
51 4	8.728	3.51	3.98		
46.4	9.929	4.00	4.65		
41.7	11.74	4.72	5.66		
39.9	12.76	5.14	6.23		
33.9	13.33	5.37	6.56		
38.2	13.40	5.39	6.63		
37.9	13.58	5.46	6.73		

Vhere, R_W – formation water resistivity, B- obility index of the absorbed cations on the ay surfaces, and Q_v depends on CEC uhasz, 1979):

$$Q_v = \frac{CEC(1-\phi)\rho_{ma}}{(100\phi)} \qquad (4)$$

here, ϕ - porosity, ρ_{ma} – rock matrix density. EC is converted, with knowledge of rock orosity and grain density, into Q_v which ccounts for the total utility of the clay.

RESULTS

Clay correction data for reservoirs H1.0 and E1.0 are given in Tables 1 and 2 CEC values are in the ranges of 0.0278 and 0.0078 (Table 1) and 0.0025 and 0.0166 (Table 2) for depths of 5456-5574 ft and 8600-8695 ft, respectively. Q_v values are from 0.1630 to 0.0391 (Table 1) and 0.0180-0.126 (Table 2) for the corresponding depths. Corrected and uncorrected resistivity indices for core samples with clay are presented in Table 3. Resistivity indices I and I* plotted against saturation are shown in Fig. 4. The differences between the uncorrected and corrected data become remarkable as sample saturation reduces. This trend is explained by the fact that clay effect on resistivity index is more pronounced at low brine saturations. The presence of clay in the samples produces a curve towards the low saturation points, while for clay-effect corrected saturation it is a straight line

Dispersed clay and relatively fresh water suppress resistivity in both water saturated and hydrocarbon bearing zones. The suppression is related to the clay activity, which in turn is reflected in the laboratory determinable cation exchange capacity (CEC).

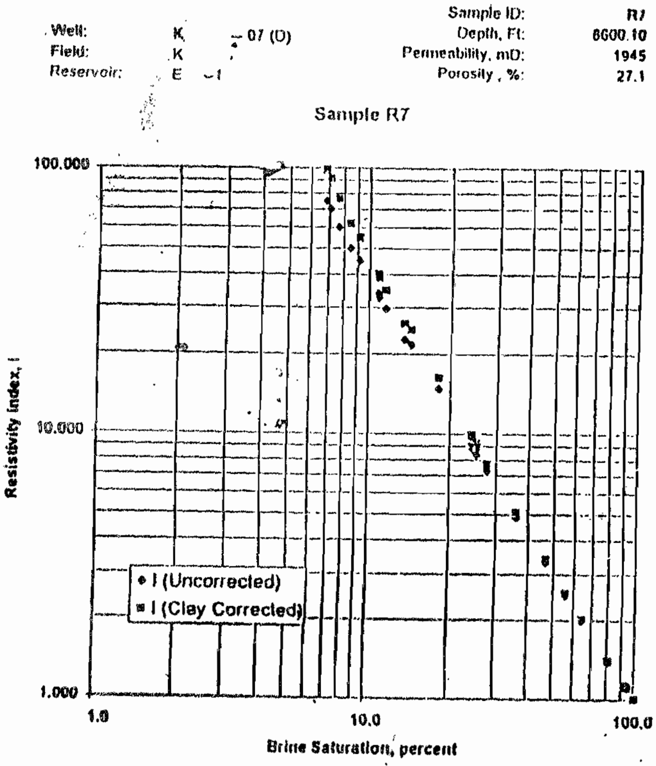

Fig. 6 RESISTIVITY INDEX Vs. SATURATION

Table 4: ELECTRODE RESISTIVITY INDEX
Test Temperature 77°F

Well: K -07 (D)
Field: K
Reservoir: E1.0-1 -2 H1.0

Sample ID: R10
Depth, ft: 8695.00
Permeability mD: 983
POROSITY %: 26.0

3500 psi Confining Stress					
Brine Saturation, Percent	Resistivity Rt, Ohm-m	Resistivity Index, I	Resistivity Index I*	Saturation Exponent n	Saturation Exponent n*
100.0	5.214	1.00	1.000	1.70	1.98
96.5	5.510	1.06	1.062		
91.5	6.093	1.17	1.182		
87.9	6.583	1.26	1.284		
83.8	7.231	1.39	1.419		
65.4	10.90	2.09	2.225		
61.6	11.99	2.30	2.472		
58.4	13.10	2.51	2.728		
47.6	17.42	3.34	3.785		
44.7	19.19	3.68	4.232		
41.0	21.53	4.13	4.845		
34.1	29.81	5.72	7.053		
33.7	30.30	5.81	7.195		
29.[illegible]	38.28	7.34	9.486		
24.5	51.45	9.87	13.518		
22.5	59.50	11.41	16.161		
21.8	63.07	12.10	17.348		
21.1	66.93	12.84	18.620		
19.0	85.14	16.33	24.736		
17.9	93.83	18.00	27.931		
16.8	110.1	21.12	33.785		
15.9	123.7	23.72	38.830		
15.5	130.5	25.03	41.473		
14.7	146.1	28.02	47.591		
14.4	155.8	29.88	51.800		
[illegible]	165.7	31.78	56.083		

The larger the CEC, the greater the suppression of the downhole resistivity as shown by samples R2 and R10 in Fig.4 and Table 4, respectively. The least resistivity reductions were noticed from samples R5 (Fig.5) and R7 (Fig.6) with the smallest values of CEC. Small quantities of an active clay (large CEC), such as montmorillonites, have greater influence on log response than kaolinite.

CONCLUSIONS

1. The Saturation exponent could vary widely from the usually accepted value of 2.0. In the present work it was 1.81 for E1.0 reservoir and 1.70 for H.10 reservoir.
2. Cation exchange capacity (CEC) and grain density determinations are necessary for all routine core analyses, to account for clay effects. This is particularly important for slightly saline formation water and active clays.
3. Laboratory electrical properties serve as base data but require corrections to obtain the appropriate saturation exponent, n*. It is 1.98 in this study.
4. CEC, like other reservoir parameters, is depth dependent; hence for heterogeneous core samples the tolerance is ± 0.2 ft. The greater the depth, the smaller the value.

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