8th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2010"

P-62

Clay-typing, Depositional Environment and Framing a Petrophysical Model for Formation Evaluation in Vashista Field, Krishna - Godavari Basin-a Case Study

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Summary

An attempt has been made to identify Clay Mineralogy, to determine depositional environment and to frame a petro physical model using open hole well logs,namely NGS (Natural Gamma Ray Spectroscopy), ECS (Elemental Capture Spectroscopy), Litho Density and Neutron logs, recorded in Vashista, an offshore upcoming exploratory field in Krishna - Godavari Basin.Three exploratory wellsX1, X2(gas bearing) and X3(dry well) are drilled in this field.In the present study, a detailed analysis has been carried on open hole well log data.Reservoir sands are mostly channel sands as evident from log motifs. A number of cross plots with various combinations (Ex.KvsPef, Si (vs) Al etc.,) are generated forthese wells.These cross plots shown at Serial No. 1 to 9 are nearly identical for two gas bearing wells, whereas a little deviation in the distribution of data points for the 3rd well, which went dry probably due to absence of lateral seal. Smectite-Mixed layer clay mineralogy isevident from the cross plots. NGS ratio cross plot (Sl.No. 9) infers that the depositional environment is of neutral to non marine with most of the data havingTh/U ratio in the range of 4 to 30.This cross plotalso indicates that the clay mineralogy in the formation under study is of Smectite-Mixed layer type. These results are inagreement with that of laboratory studies carried out in nearby G1 Field. A Petrophysical model comprising Quartz as rock matrix, Smectite, Illite and Clay1 (representing Mixed layers properties) as Clay and Gas & Water as reservoir fluids is framed and adopted in the multimineral model that works based on Error Optimization technique. The reservoir parameters in detail are computed using this multi-mineral model for allthree wellsand are presented(Sl.No.10).The reservoir summation was done using outputs generated separately for twogas wells.The zone-wise estimated reservoir parameters namely, Net Pay thickness (He), Effective Porosity(Phie) and Water Saturation (Sw) are also corroborating with the production testing resultsfor the two gas bearing wells X1 and X2.The well X3is found to be water bearing and hence noproduction testing is done.Thus, the Petrophysical model framed in the present study isreasonable for this field and hence can be adopted for appraisal / development drilling.

Introduction

Formation evaluation plays a significant role in the exploration and exploitation of hydrocarbons. In exploration, it involves volumetric estimation of reservoir parameters such as Net Pay (He), Effective porosity (Phie) and Water saturation (Sw)which are key inputs for estimation of in - placehydrocarbons.In exploitation front, it is related to porosity, permeability, formation /aquifer pressure are the key parameters that affect the production profile. Permeability is often controlled by very low levels of clay minerals present in pore space. Specific knowledge of clay minerals present in the reservoir sands is essential for framing the suitable Petro-physical model for formation evaluation.Almost all the log measurements are affected by clay minerals present in the formation and hence all the logs have some potential to determine clay mineralogy. It is well established that Gamma Ray log measures the total radio activity of formation is one of the most commonly used clay indicators[1]in the formation evaluation. Natural Gamma Spectroscopy tool measures individual fractions of radio active elements Uranium, Thorium and Potassium and also their ratios as function of depth. Various cross plots with different combinations (Ex. K (vs)Th, Pef(vs)Th/K) of these parameters along with Litho-Density and Neutron indicate the probable presence of clay minerals present in the formation to some extent. In addition to this, Elemental Capture Spectroscopy (ECS) tool that works based on Neutron-induced capture mechanism[2]yields continuous measurement of dry weight fractions for Si,Ca,Fe,Al(computed using the dry weight fractions of other elements)Ti,Cd,S,Cl and H. These dry weight fractions when cross plotted along with NGS data with different combinations define the presence of different

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clay mineralsin a given formation like smectitie, illite, kaolinite and glauconite etc.

In this paper an attempt has been made to identify clay mineralogy, depositional environment and framing the suitable petrophysical model for estimating the optimized reservoir parameters by adopting cross plot technique using open hole well log data in VashistaField.Smectite-Mixed clay mineralogy is identified from the cross plot studies. Depositional environment is of neutral to non-marine nature with development of stackedchannel sands in these wells. Finally the framed Petrophysical model based on above studies is adopted in the detailed log data processing of the three wells namely X1,X2 and X3 and the results are discussed in the ensuing sections.

Methodology, Results & Discussion

A. Clay Mineral Identification

The well log data in three exploratory wells viz., X1, X2 and X3 inVashistaField of Krishna-Godavari Basin is considered for present studies. Suitable cross plotsare generated that depict the possible presence of clay minerals in Godavari Clay Formation. Each welldata is considered separately for generating the cross plots. A group of cross plotsgeneratedfor these wells include 1.Si (vs) Al, 2.Si (vs)Ca 3.Al (vs)Ca 4.Si (vs) Fe 5. K (vs)Th6.K (vs)Pef 7.Th/K (vs)Pef 8a.Rhoz (vs)Nphi(Clay mineral Identification) 8b. Rhoz(vs) Tnph (rock matrix)9.Th/U (vs)Th/K 10. Multi mineral processed output results and 11. Reservoir Summation output results. It may be noted that in all the cross plots generated colour distinction is given in order to highlight the shale points(red color) from the total points (blue color) covering entire Godavari Clay Formation.The two sets of cross plots for gas bearing wells are identical for each serial number of the cross plot, but found that there is little deviation in the distribution of data points in the set of cross plots generated for dry well probably due to absence of lateral seal. The presence of clay minerals like Smectite and Illite are evident in cross plots at Sl.Nos 1to 3.The cross plot at Sl.No.4 shows the presence of Illite. The cross plot at Sl.No.5 shows the dominance of mixed layered clay. The cross plot at Sl.No.6 indicate the presence of Montmorillonite. InTh/K (vs)Pef cross plot (Sl.no.7), inaddition to the dominant presence of mixed clay, Montmorillonite is also seen. In cross plot Nphi(vs)Rhoz at Sl.No.8a, most of the shale points (red color) are seen distributed between Quartz line and Montmorillonite line with some of the blue points scattered around Quartz line. Another cross plot TNPH (vs)Rhoz at Sl.No.8b shows most of the matrix points (red color) corresponding to sandstone line. The cross plot at Sl.No.9 ieTh/U (vs)Th/K infers that the main clay mineralogy in this GodavariClayFormation is Smectite-Mixed layered Clays. Higher values of Thorium-Potassium ratio (Th/K) probably reflect the increased presence of Smectite as a significant component. This finding is also corroborated by laboratory studies[3] in nearby G1 field.

B. Depositional Environment

Geologically, the hydrocarbon bearing sands in Vashista Field belongs to Godavari Clay Formation of Pliocene age. Lithologically, it is represented by a thick clay section interbedded with thin sands.These reservoir sands are deposited eitherby submarine channels or fans.Log motifs depict fining upward nature. Sonic log (SlNo.10) against these sands read 140-160us/ft which indicates that these sands are unconsolidated. This finding corroborates with the laboratory studies as well. These sands are compositionally quartz rich "wackes" unconsolidated with variable amounts of feldspar, fine micaand glauconiteetc.

Thorium-Uranium ratio cross plot has generated for these wells to understand the depositional environment. Thorium-Uranium ratios in these sedimentary rocks[4]range less than 0.02 to more than 21. Ratios in many oxidized continental deposits read more than 7 whereas most marine deposits have ratios less than 7. Thus, Thorium to Uranium ratio varies with sedimentary processing and depositional environment. In Th/U (vs)Th/K cross plot at Sl.No.9 most of the points (red and blue color) read Th/U ratios more than 7 indicating that the depositional environment is of neutral to non-marine nature.It is inferred from this study that Godavari ClayFormation is deposited in oxic/neutral environment as Th/U ratio varies between 4 and 30.

Petro physical Model

On the strength of geologic evidences and above cross plot studies, a Petro physical (Multi-mineral) model has been framed comprising Quartz as rock matrix, Smectite, Illite and Clay1 (representing Mixed Layer properties) as Clay and Gas & Water as reservoir fluids. Log response equations of Density, Neutron, Gamma Ray, Resistivity, Total CMR porosity and Photoelectric factor (Pef) are considered. Open hole log data of these wells X1,X2 and X3 is corrected for depth discrepancies before subjecting the data to detailed bore hole environmental corrections. Detailed log data processing was carried out taking the borehole corrected data as input. Computed reservoir parameters are optimized by comparing the reconstructed data with the measured data. Error minimization technique between reconstructed and measured logs is adopted and the processed results are optimized by varying model parameters. The optimized results are presented in the form of parameter log for well X1 at Sl.No.10. Neither shale/porosity cut offs nor any impositions are made to the processed results presented in the parameter log. Input log responses of GR,SP,RHOB,TNPH,TCMR and PEF are sufficiently good to consider in this multi-mineral model analysis. Good positive SP development is noticed against the sands. Water saturation, Clay Minerals and Fluid volumes are presented in tracks 4 & 5. The presence ofstacked channel sands along with moved hydrocarbon and gas are evident.In production testing in well X1Object-I (intervals 2053-2048, 2042-2032, 2030-2028.5m 2022.5-2018m and 2010-2007m) has flowed 7,80,222 M^3/day of gas through 6mm choke.Layer-wise reservoir parameters estimated are presented in Reservoir summation output. Computed Effective Porosities and Water saturations are in the range of 12-17% and 34-52% respectively and thus corroborating with the testing results.

Computer processed output resultsfor well X2 using the above adopted multi-mineral model are presented along with input logs at Sl.No10. It can be inferred from this figure that the reservoir sands developed in this well are complicated by the presence of capillary bound water (shaded in orange color), clay bound water (T2 Spectra of CMR data) and alternations of thin layers of sands and shales (FMI dynamic and static images). The average resistivity in the interval 2084-2098m which is part of Object-1a is around 1.5ohm.m, which is very low when compared with normally observed hydrocarbon resistivity. High capillary bound (irreducible) water is a frequent cause of low resistivity in many hydrocarbon bearing shaly sand reservoirs that exhibit water free production[5]. Log responses of SP and GR are not as good as in well X1 and hence these response equations are not considered in the formation evaluation ofwell X2. The presence of gas is evident in the processed output results.On production testing of the object-1a covering intervals 2098.5-2095m, 2093-2089m, 2088-2084m and object-1b 2079-2071m, the well flowed 3,28,591 M^3/D of gas through 24/64" choke. Layer-wise computed effective porosities and Water saturations are presented in Reservoir Summation output. The estimated Effective Porosities and Water Saturations are in the range of 7-12% and 41-48 % respectively. These computed effective porosities are relatively low compared to those of well X1. It is evident from the results of well X2 that CMR free fluid porosity also reads low values as those of estimated/computed and thus justifying accuracy of Computed Effective Porosities.

The same multi-mineral model for two wells X1 and X2 is adopted for the third well X3. All the log response equations as chosen for well X1 are considered in the processing of well X3. The detailed processed output results along with input logs are presented at Sl.No.10. All the sands are well developed as in the other wells but are found water bearing due to absence of lateral seal. The Effective Porosities and Water saturations are in the range of 15-20% and 90-100%.

Conclusions

The study of Vashista Field inKrishna-GodavariBasin indicates that well logslike NGS, ECS, Litho-Density and Neutron are a suitable combination for identifying the clay mineralaogy, rock matrix and framing thePetrophysical model.The petrophysical modelenvisaged comprises Quartz as rock matrix, Smectite,Illite and Clay1(representing Mixed clay properties) as Clay and Gas & Water as reservoir fluids gave results that are in agreement with production data for both gas and water bearing well. Therefore, this model can be adopted in this field for appraisal / development drilling.

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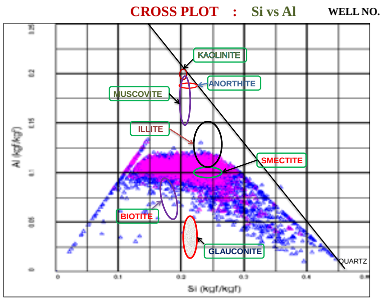
Acknowledgements

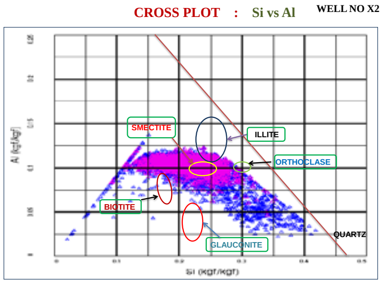
The author expresses deep sense of gratitude to Director (Exploration), ONGC Ltd, New Delhi for permission to present this paper in SPG-2010 atHyderabad, India.

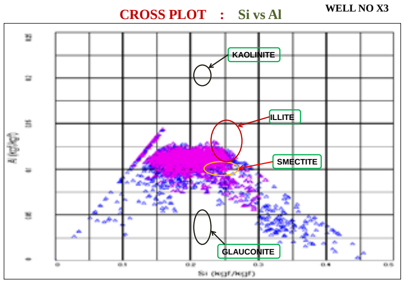
CROSSPLOTS DEPICTING CLAY MINERALOGY AND ROCK MATRIX

Sl. No.	X1	X2	X3

1







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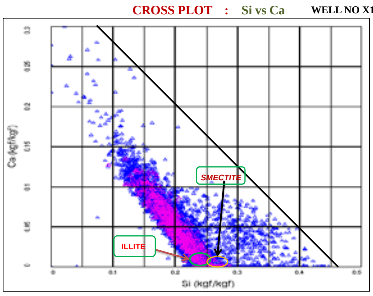

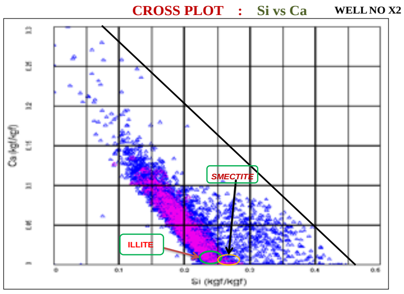

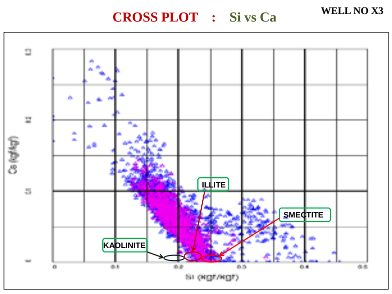

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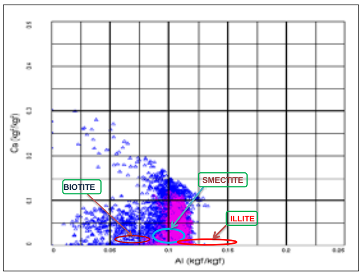

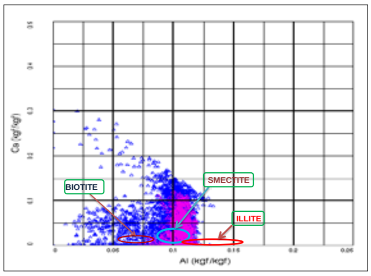

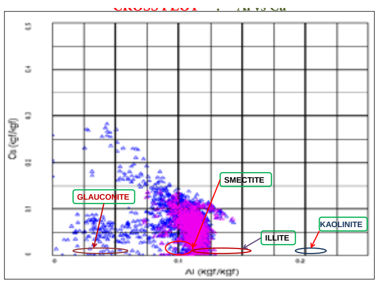

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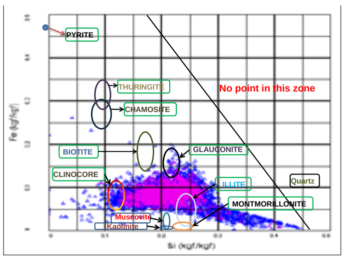

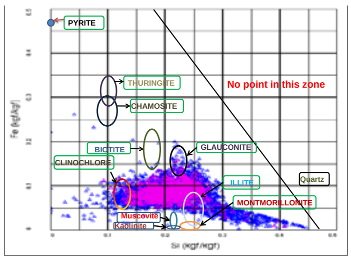

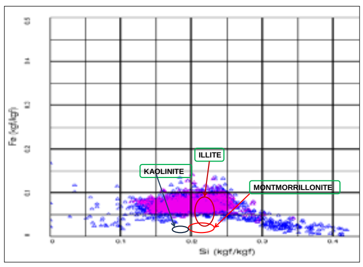

Petro Physical Model

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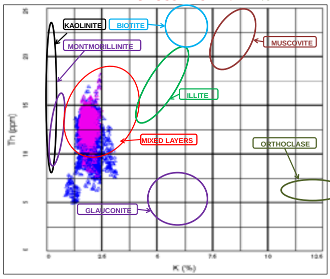
Sl. No. **X1** **X2** **X3**

5

CROSS PLOT : K vs Th WELL NO X1



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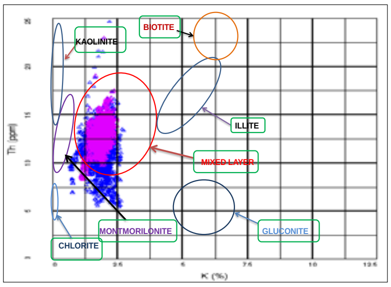

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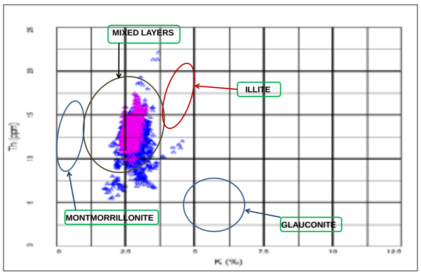
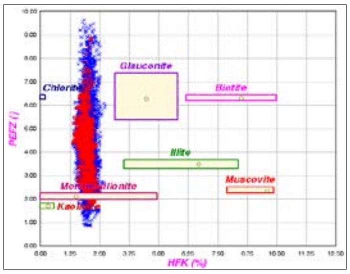


6

CROSS PLOT : K vs Pef WELL NO X1



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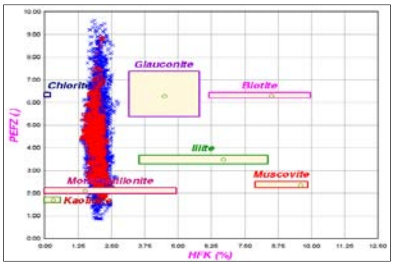
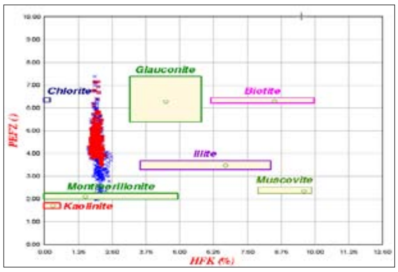
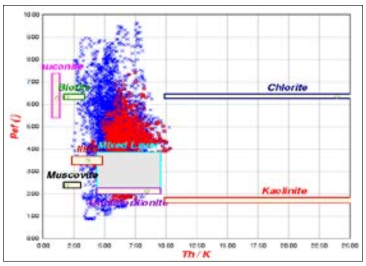


CROSS PLOT : K vs Pef WELL NO X3



7

CROSS PLOT : Th/K vs Pef WELL NO X1



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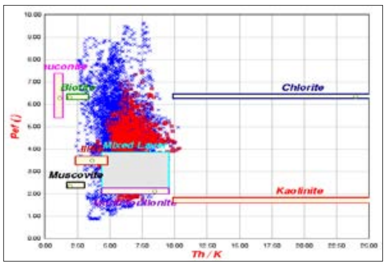

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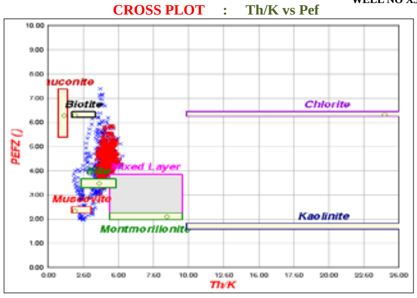
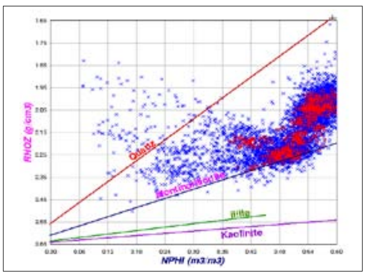


8a

CROSS PLOT – NPHI vs RHOZ WELL NO X1



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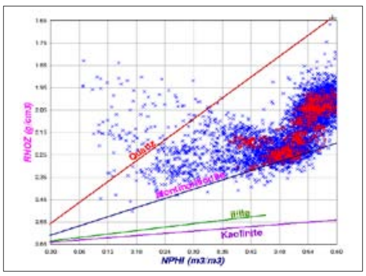

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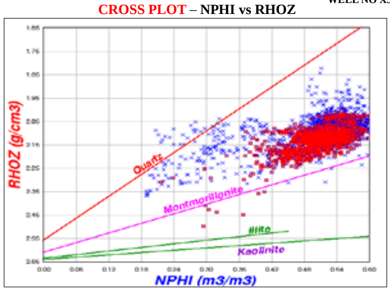

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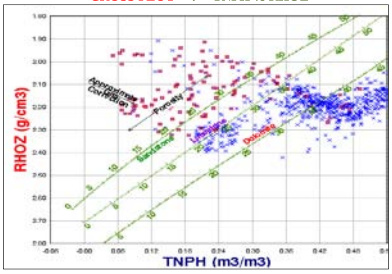
CROSSPLOTS DEPICTING CLAY MINERALOGY AND ROCK MATRIX

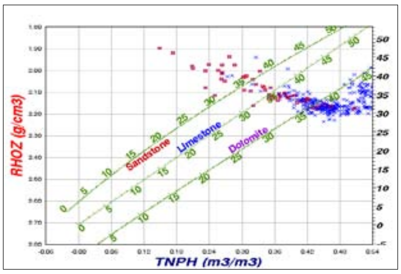
Sl. No.	X1	X2	X3

8b

CROSS PLOT : TNPH vs RHOZ WELL NO X1



WELL NO X2
CROSS PLOT : TNPH vs RHOZ



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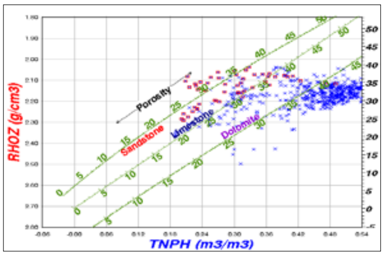
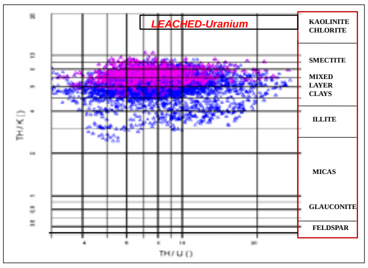
CROSS PLOT : TNPH vs RHOZ



9

NGS RATIO PLOT – Th/U vs Th/K WELL NO X1



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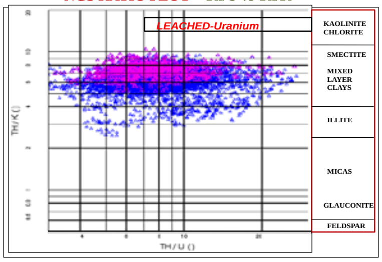
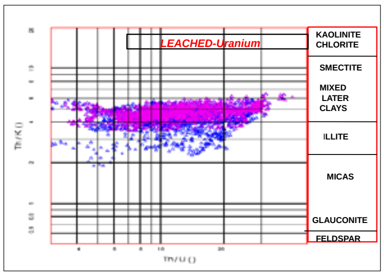
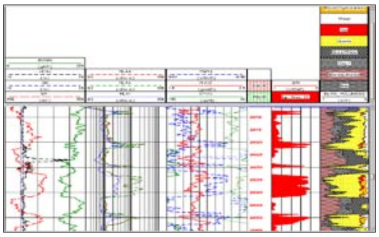


NGS RATIO PLOT – Th/U vs Th/K WELL NO X3



10

WELL NO X1
FORMATION EVALUATION: INPUT LOGS-WATER SATURATION –CLAY MINERALS & FLUID VOLMUES



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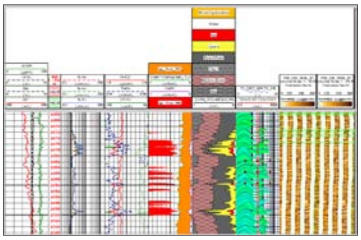

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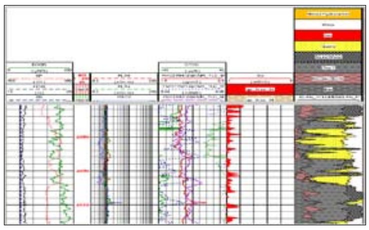

11

WELL NO X1
RESERVOIR SUMMATION OUTPUT RERSULTS

NAME	Top Depth (MD) (m)	Bottom Depth(MD) (m)	Net Pay Thickness (m) He	Net Pay Porosity (m3/m3) Phie	Net Pay Water Saturation (m3/m3) Sw
Zone 1	2006	2010	1.6	0.121	0.51
Zone 2	2019	2023	2.6	0.18	0.47
Zone 3	2027	2031	1.0	0.125	0.52
Zone 4	2031.5	2042.5	8.7	0.171	0.34
Zone 5	2047	2055	4.0	0.161	0.46

WELL NO X2
RESERVOIR SUMMATION OUTPUT RERSULTS

NAME	Top Depth (MD) (m)	Bottom Depth(MD) (m)	Net Pay Thickness (m) He	Net Pay Porosity (m3/m3) Phie	Net Pay Water Saturation (m3/m3) Sw
Zone 1	2071	2080	5.0	0.121	0.41
Zone 2	2083	2088.5	1.8	0.074	0.48
Zone 3	2089	2094	1.2	0.089	0.47
Zone 4	2094	2100	3.2	0.111	0.42

No Pay sand developed in this well
All sands developed in this well are water Bearing

Si--→Silicon Ca--→Calcium Al--→Aluminium Fe--→ Ferrous K-→Potassium

Th-→ Thorium U-→Uranium Th/U—Ratio of Th and U Th/k-→ Ratio Th and K

Pef-→ Photo Electric Factor Rhoz-→ Density TNPH-→ Thermal Neutron Porosity