The Petrophysical Evaluation and Depositional Environment of Harrison 1 Well Using Core Data and Wireline Logs

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Abstract

A comprehensive petrophysical evaluation is essential to optimise development and production in complex environments in different prolific regions including West Africa. In this study petrophysical parameters in the Harrison 1 well, central Niger Delta were carefully evaluated using cores and wireline logs zones of hydrocarbon saturation were deduced using a combination of conventional logs including Gamma ray, Resistivity (Schlumberger's platform Express-Array induction tool (PEX-AIH) and Neutron/density combination log.

Cored interval ranged from 11915ftah to 12005ftah within which several analyses were carried out to deduce lithofacies, environment of deposition and prospective reservoirs for hydrocarbon. Reservoirs are located between 11933-11952ftah, 11960-11965ftah, 11975 -12005ftah. These reservoirs have excellent porosity values (though permeability decreased with depth because of increased clay content), low water saturation percentage (≤ 20%), high hydrocarbon saturation (≥80%), favourable values of ROS and MOS.

The depositional model comprises a prograding shoreface deposit which passes upward into stacks of channel deposits characterised by features typical of estuarine setting. Studies of Hydrocarbon fill using cores from Harrison 1 well under UV-light reflected recognisable fluorescing unit between 11956-12005ftah stratigraphic interval and a non-fluorescing unit between 11915 – 11955ftah meaning these intervals contains oil and gas , however gas -oil ratio of 45:55 affirms the gas prone nature of the reservoirs within the interval of study.

Keywords: Conventional logs, hydrocarbon saturation, reservoir, ROS, MOS, UV-light, water saturation.

1.0 INTRODUCTION

In the Niger Delta, Petroleum is produced in sandstone and unconsolidated sands of the Agbada Formation. This formation is characterised by alternating sandstones and shales with rock units varying in thickness from 30m (100ft) to 4600m (15,000ft) (Short and Stauble, 1967). The sandstones in this Formation are the main hydrocarbon reservoirs with shale providing lateral and vertical seals. Hence, the physical properties of reservoir rocks found in this Formation are often dependent on the fluids in the pores so that the variations can be used to discriminate between the types, as well as the quantities of the fluid in the pores (Beck, 1981).

A 3D geological reservoir model of Harrison 1 field was built by Okkerman (1995) based on well and seismic data and he interpreted the sands as deposition of a prograding shoreface and barrier Island system.

Eneyok (1997) carried out a detailed sedimentological core description of the sands in one of the wells and defined thirteen lithofacies. He interpreted the sedimentary succession to represent a prograding wave dominated shoreface to transgressive estuarine deposits.

The present research is focused on the petrophysical evaluation of Harrison 1 well using core data and wireline log. This involved the sedimentological description of cores and interpretation of wireline logs from Harrison 1 well. The interpreted parameters include porosity, permeability, shale volume, Formation water resistivity, fluid saturation. The core samples also revealed the lithology and textures which were sampled at regular intervals (±5 meters). The cores aided in the identification of hydrocarbon bearing horizons. Also brought to fore were the effects of diagenetic processes such as cementation and the geological succession of the well.

Lithofacies characterization is believed to be a very effective tool to systematically evaluate the well since it has been recognised that excellent porosity/permeability relationship can be obtained once the conventional core data are grouped according to their rock types (Guo et al ,2005).

The various wireline logs used were Gamma ray, Resistivity, Neutron/Density combination. The petrophysical parameter determined using the logs were permeability, porosity, shale volume, Formation water resistivity, fluid saturation. The project is aimed at carrying out a detailed interpretation of the logs and also identifying fractures and over-pressured zones, as well as reservoir evaluation using geophysical tools for prospect. Fig. 1 shows the map of the studied area.

2.0 GEOLOGIC SETTING

The Harrison 1 Well is located within longitude $6^{0}18^{0}0^{1}$E and latitude $4^{0}57^{1}0^{1}$N of the central Niger Delta, which is a prolific oil and gas province with an area covering 80,000sq km.

The Niger Delta is one of the world's largest deltas located in the gulf of guinea on the west coast of central Africa extending 300km from apex to mouth. The coarsening upward regressive association of tertiary sediments present in the Niger Delta is about 12km thick (Whiteman 1982)

The Niger Delta is composed of three stratigraphic units which are the Akata Formation (Basal unit) composed of marine shales with some sandstone beds, thought to be continental slope channel fills and turbidites. Overlying this is the parallic clastics of the Agbada Formation (4,000 – 10,000m) which consist of interbedded sandstones and shales. Topmost is the continental sands (Benin Formation) comprising of gravel and sands. It's thickest in the central area where there is a maximum subsidence of the Basement.

3.0 METHODOLOGY

Coring/core analysis:

Rock characterisation serves as an integral component in Formation evaluation. Rock based measurements offer the most tangible and direct means of determining critical reservoir parameters. The need to extract more data from the subsurface has led to an enormous increase in research directed towards understanding the physical and chemical properties of reservoir rocks.

Rock characterisation has benefitted from recent advances in laboratory methodology, computerisation, instrumentation and technologies borrowed from other industries.

The goal of coring and core analysis is to reduce uncertainty in reservoir evaluation by providing data representative of the reservoir at in-situ conditions.

In this work, the cores were taken conventionally using fibreglass coring assembly. The coring assembly is made up of a steel outer barrel and s fibreglass inner barrel. After coring , the fibreglass inner core were retrieved, marked and sawed into 3 feet lengths. These were subsequently capped and placed in wood storage. The core description was done in the laboratory for the studied depth (11915 to 12005 ftah).

4.0 Geologic core description

This description was done based on the lithofacies. Lithofacies could be defined as the body of sediment or rock with specific lithological and organic characteristics (e.g. Grain size, sorting, sedimentary structures) which were impacted by a particular set of energy conditions within an environment of deposition. Lithofacies constitute the smallest building blocks used in reservoir geology. The uniform physical characteristics of a particular lithofacies type (e.g. Wavy-laminated, fine grained, well sorted sand) mean that the possess uniform reservoir properties. Although lithofacies can always be distinguished in cores, they cannot always be distinguished on logs because the resolution of logs does not allow subtle differences between some lithofacies types, or thin lithofacies intervals to be detected.

5.0 QUANTITATIVE INTERPRETATION OF WELL LOGS

The quantitative interpretation involves the use of mathematical models and relations which give identical value of the log responses to the Formation parameters. Log readings were taken at intervals (±5m) and the various measurements taken from the corresponding logs are the bulk density $P_{b,}$ Neutron density Øn, true resistivity $R_{t,}$ Gamma ray, density of Shale $P_{sh.}$

The following relations are universally used in the estimation of reservoir sands parameters.

6.0 POROSITY

Porosity can be determined using any of the porosity logs including density, neutron and sonic. Meanwhile, porosity estimate from neutron –density combination gives better result than the porosity estimate derived from the neutron log alone.

The following relations are universally used in the estimation of reservoir sands parameters.

6.1 Porosity:

The porosity values at sampled intervals were estimated using readings of the density log and neutron log according to the relationship.

Porosity from the density log uncorrected for clay (Φ_d):-

$$\Phi d = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{f1}}$$

Where ρ_{ma} = density of matrix (2.65/cm3)

Pf1 = fluid density (1.0g/cm3)

The cross plot is Neutron – Density porosity (uncorrected for clay) where Φdn is the neutron porosity value.

$$\Phi_{N\text{–}D} = \sqrt{\Phi^2_d + \Phi^2_n)}$$

7.0 Water / Hydrocarbon saturation:

The water saturation for both hydrocarbon and non-hydrocarbon bearing sands can also be evaluated from logs. Resistivity curves provide a reliable measure of the water saturation of a reservoir rock.

Normally, the resistivity (R) measured in a formation is directly proportional to the fluid (water) resistivity (R_w) and are inversely proportional to the product of the water saturation (S_w) and the Formation porosity (Φ).

In order to calculate the saturation of the fluid content of the reservoir sands, the formation water resistivity, Rw, is first calculated using this expression:

$$R_w = \frac{R_o}{F}$$

Where F = formation factor ($\frac{0.62\ldots}{\Phi^{2.15}}$ for sandstone)

Archie's equation can be re-arranged to give us the water saturation S_w:

Since a pore space contains water and/or hydrocarbon, with the calculated water saturation (S_w) the fractional pore space remaining is being occupied by the hydrocarbon. The hydrocarbon (oil and gas) saturation (S_h) is usually calculated from the relation.

$S_h = (1-S_w)$

Bulk volume water (BVW):

This parameter is determined by the product of the formation porosity and the water of saturation.

$BVW = \Phi \text{ X } S_w$

Invaded zone analysis:

In this zone, the microspherically focused log MFSL equivalent (i.e SLT 10, 20 inches) were used to determine resistivity.

Water saturation in the invaded zone (S_{xo}):

$$Sxo = \sqrt{\frac{F.R_{mf}}{R_{xo}}}$$

Where F = formation factor

R_{mf} = resistivity of 100% mud filtration (0.89)

R_{xo} = resistivity read from MFSL log

8.0 Residual Oil Saturation (ROS)

This is expressed as

$ROS = 1 – S_{xo}$

This equation gives the saturation in the unmoved or residual hydrocarbons of the invaded zone.

9.0 Moveable Oil Saturation (MOS):

This compares the S_w and S_{xo} in a hydrocarbon zone. It is expressed as

$MOS = s_{xo} – S_w$

And the moveable index = $\frac{s_w}{S_{xo}}$

10.0 Sand / Shale Analysis:

The amount of clay in a reservoir affects its porosity, permeability and predictability. The sand / shale analysis was done to ascertain the volume of clay in the reservoir.

Volume of clay (Vcl)

For unconsolidated sands we have

$$V_{cl} = 0.83\,[2^{(3.7 \text{ x } IGR)}\_I]$$

Where $I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$

IGR = Gamma ray index

GR_{log} = Gamma ray value at chosen interval
GR_{max} = Maximum Gamma (100% Shale)
GR_{min} = Minimum Gamma ray (0% Shale)

11.0 Clay correction:

11.1 Density log porosity: For corrected density log porosity (Φ_{dc}) we have

$$\Phi_{dc} = \Phi_d - (V_{cl} \times \Phi_{dis})$$

Where Φ_d = Uncorrected density log porosity

Φ_{dis} = Density log reading for Shale

Neutron Log Porosity: To correct for clay we have
$$\Phi_{nc} = \Phi_n - (V_{cl} \times \Phi_{nhs})$$

Density log reading for Shale

Where Φ_{nc} = corrected neutron log porosity
Φ_n = uncorrected neutron log porosity
Φ_{nhs} = uncorrected neutron log reading of shale.

Effective porosity for has, Φ_e

$$\Phi_e \text{ (gas)} = \sqrt{\frac{\Phi_{dc}^{2} + \Phi^{2}_{nc}}{2}}$$

Effective porosity for Oil
$$\Phi_e \text{ (oil)} = \frac{\Phi_{dc} + \Phi_{nc}}{2}$$

Effective water Saturation (S_{we})

This is given as
$$S_{we} = \frac{1}{\Phi d} \left[\frac{R_w}{R_t} + \left(\frac{0.25 \times V_{cl}}{2}\right)^2 - \frac{0.25V_{cl}}{2}\right]$$ for uncorrected sands.

Bulk volume of water for corrected Clay:
The expression gives us the bulk volume of water for clay.

$$BVW = \Phi_e \times Sw$$

Shaliness Factor (q):

$$q = \frac{(\Phi_{N-D} \times \Phi_e)}{\Phi_{N-D}}$$

12.0 PERMEABILITY

Permeability is of great importance in reservoir modelling but its estimation often poses a significant challenge to reservoir characterisation and simulation. It is not directly related to porosity alone. An improved predictive relationship may be obtained when an additional independent variable such as shale indication is included. Figs. 3, 4 and 5 shows permeability/porosity relationship models for the studied intervals.

13.0 RESULTS AND DISCUSSION

Interpretation of the log responses delineated several reservoirs bordered by shaly seal rocks. (Fig . 5). The neutron/density log also shows two fluid phases (oil and gas).

Different lithofacies were established from the cores between 11915ftah to 12005ftah which to a large extent coincides with lithologic log signatures from the gamma ray logs. Log shapes indicate deposit of deltaic progradation and river flood plains between 11927 and 11941. On the other hand, the serrated bell shaped gamma ray curve between 11943 and 11957 increasing clay content with minor interruption of clay beds accounting for the serration. This is indicative of point bars, alluvial or distributor channel sands in the delta plain environment.

The fluvial channel units are gradationally overlain by channel heterolithic units and overlain by tidal channel units. Most of the sediments are tidal bundles deposited during a neap tidal cycle comprising sand units transported by ebb or flow tide. From the analysis carried out on wireline and core from the well, observations reveal that between 11933 and 11973 ftah has a good porosity value but that does not justify it as Hydrocarbon bearing interval.

Another observation within this interval is a gradual decrease in shale content with depth, which of course indicates clean sand with depth.

Porosity and permeability alternates (i.e. increases and decreases with depth, however the porosity and permeability distribution models indicate that the well has the most viable reservoir with respect to porosity and permeability values at between 11933 to 11973m. This could be considered as a prospective zone for perforation at well completion.

A seal is formed for efficient hydrocarbon accumulation and is marked by 0.7911 clay volume at depth 11,915 while at 12005 the clay volume is 0.1155.

Based on recognised fluorescence, the reservoir sands with the studied interval fall under two categories;

1. Fluorescing ,,Unit : (11956-12005) : fluorescence occurs as bright yellow colours which were continuous and occurred as patches in some cases.
2. Non-fluorescing unit : (11915-11955) This interval also appear dark except for resin invaded zones. The non-fluorescence in this unit is interpreted to be due to gas presence as indicated by the resistivity log. The hydrocarbon column shows a gas: oil ratio of 45:55 affirming the gas prone nature of the reservoir sand within the interval of study.

14.0 CONCLUSION

Depositional model carried out reveals that the sedimentary succession comprises a prograding shoreface deposit which passes upward into stacks of channel deposits characterized by features typical of estuarine setting. This interpretation has further strengthened by the abundance of *Ophiomorpha, skilithos-Arenicolites trace fossil association in coarse sandstone.* Moreso, there are diagnostic tidal structures such as herringbone cross-bedding, sigmoidal cross bedding re-activation surfaces, wavy beddings, mud drapes and flaser bedding.

Also, supportive of the above model is the absence of strong generated structures such as hummocky cross stratification.

So based on succession of sediments, a transgressive estuarine setting cutting through underlying shoreface deposits is interpreted to be the depositional setting for the deposition of Harrison 1 well reservoir sands.

In conclusion, this research work illustrates how invaluable a porosity- permeability relationship is to reservoir characterisation and in making right decision on perforation intervals during completions. A collective use of cores and wireline logs has proven to be a veritable tool in resolving geological and petrophysical problems.

REFERENCES

ALLEN, J.R.L., 1965. Late Quaternary Niger Delta and adjacent areas sedimentary environs and Lithofacies. American Association of Petroleum Geologists, Bulletin Vol. 49 pg 547-600.

Archie, G.E 1950. An Introduction to Petrophysics of reservoir rock, Bulletin. American Association Petroleum Geologists, 34, pg 943

Anderson, B.G. and M.L. Droser (1998). Ichnofabrics and geometric configurations of Ophiomorpha within a sequences stratigraphic framework: an example from the Upper Cretaceous US Western Interior Sedimentology, Vol. 45, No 2,p. 379-397.

Bromley, R.G. (1996). Trace fossils: Blackwell Science Publishers, Glasgow.

Dewan, J.T. 1983. Modern Openhole log Interpretation. Penwell Publishing Company Tulsa, Okhlahoma,1-130.
Dresser, Atlas, 1982. Well logging and interpretation Techniques Dresser Industries Inc. Texas p. 16 – 22.
Etu-Efeotor, J.O; 1997. Fundamentals of Petroleum Geology, Paragraphies Publishers, Nigeria P. 30-130.
Eneyok G.P. (1997). Reservoir geological interpretation of Gbaran. Core rept. 95.05 PESE.
Guo, G., Diaz, M.A., Paz, F., Smalley, J. and Waninger, E.A (2005), Rock typing as an Effective tool for Permeability and Water Saturation Modelling, Proceedings of SPE Annual Technical Conference,
Texas, U.S.A, October 9-12.1-15.
Hppt://sww.war. SPDC (1997). Modeling estuarine environment deposits in the Tertiary Niger Delta. P 1-24.
John, H.D. (end) Sedimentary environments: Process, fancies, and Stratigraphy (3rdedition). Blackwell Science Publishers, Glasgow.
Okkerman J. and Amthor J. (1995): Influence of early diagenesis on reservoir on quality of Rotliegende Sandstones, northern Netherlands, AAPG Bulletin V.82, no. 12 P.2246-2265.
Rein son, G.E. (199). Transgressive Barrier Island /Estuarine Systems In: Walker, R.G. and N.P. James (eds) Facies Model (2nd edition) Geological Association of Canada. Salman Bloc, Robert H. Lander, and Linda Bonnel (2002):
Schlumberger, 1989. Log Interpretation Principles / Applications Schlumberger Wireline and testing, Sugarland, Texas page 2.1-7.5.
Short, K.C. and Stauble, A 1967. Outline Geology of Niger Delta Bulletin. American Association of petroleum Geologists, 51, pg 761-776.
Skopec R.A. (1992). Recent Advances in Rock Characterization in: coring /core analysis. Oryx Energy Company, Dallas, Texas. P270-281.
Williams, H., B.I. Jev and A. Paaradekam (1991). Reservoir geological modeling of The E-sands complex Cawthorne Channel Field.
Whiteman, A., 1982. Nigeria- its Petroleum Geology, resources and potential.
Graham and Trotman, London. Vol. 1, pg, 394.

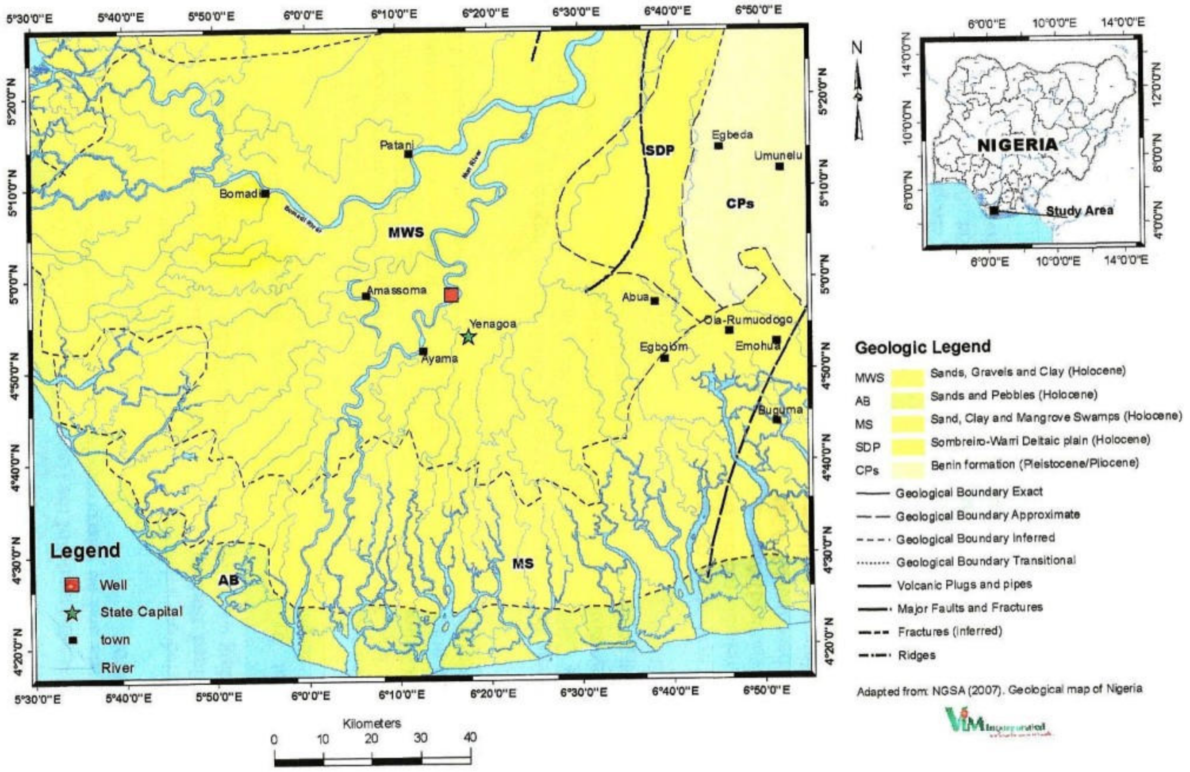
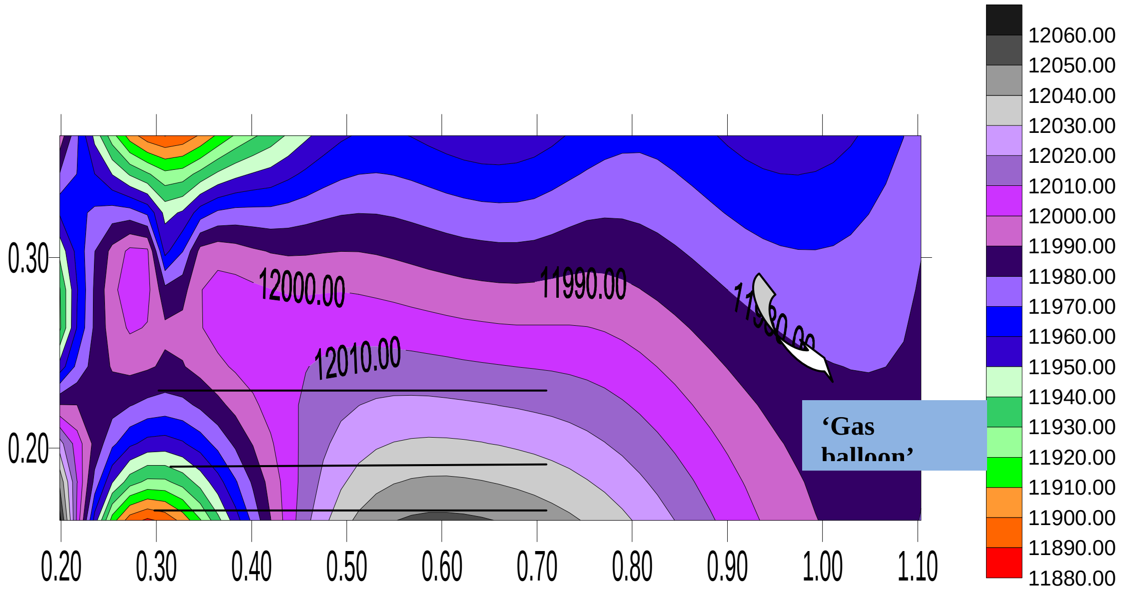


Fig. 1. Geologic Map of Studied Area (Harrison 1 well)



‘Gas balloon’

Fig. 2 DIMENSIONAL REPRESENTATION OF PERMEABILITY (X), POROSITY (Y) WITH DEPTH (Z)

(Data plotted with Surfer 3.2 software)

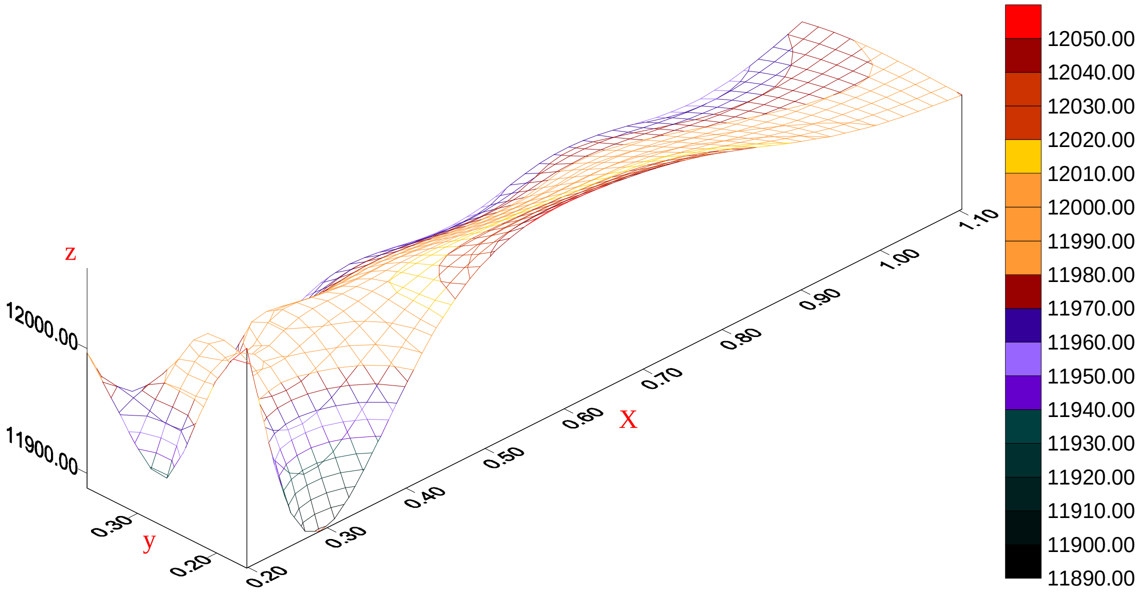


Fig.3 Three Dimensional Representation Of Permeability (X) ,Porosity (Y) With Depth (Z)

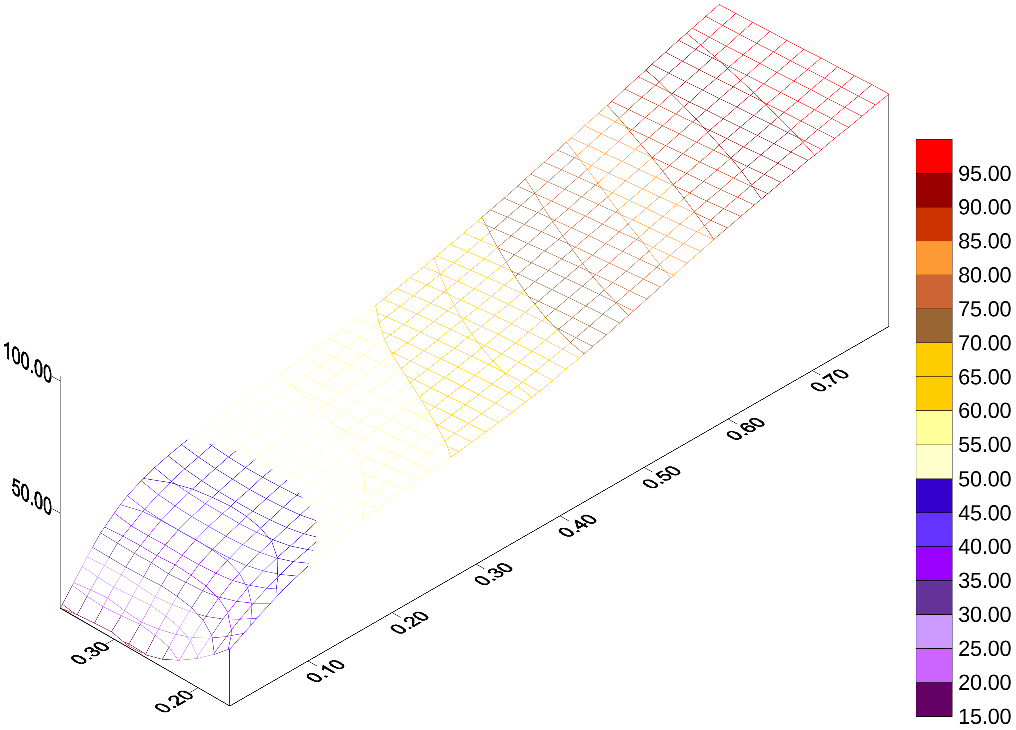


Fig. 4 Three dimensional representation of volume of clay (x) and porosity (y) and gamma ray (Z)

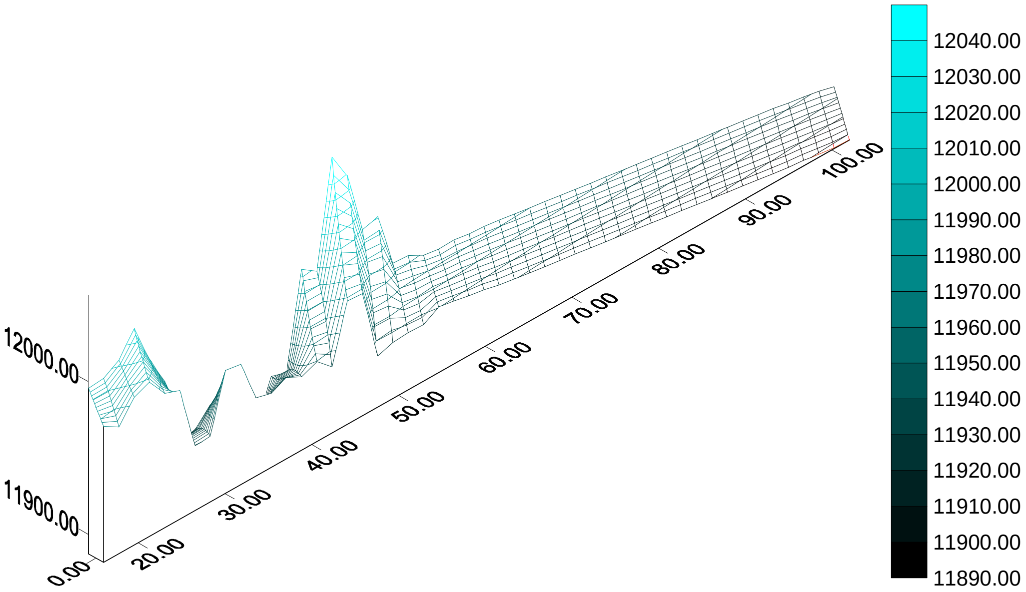


Fig. 5: Three Dimensional Representation of Volume of Clay (X), Gamma ray (y) with Depth (Z)

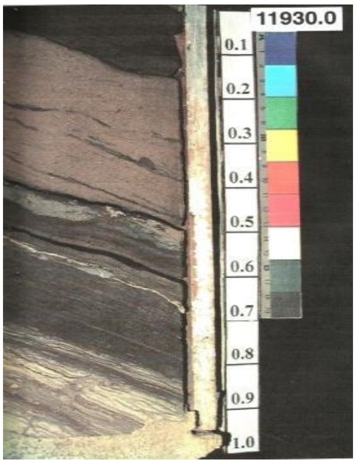


Fig. 6: lithofacies Sxc_Medium Cross bedded Sandstone

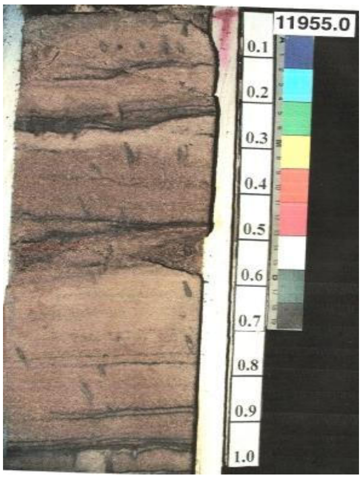


Fig.7: Lithofacies Sxm_Medium grained Cross bedded Sandstone

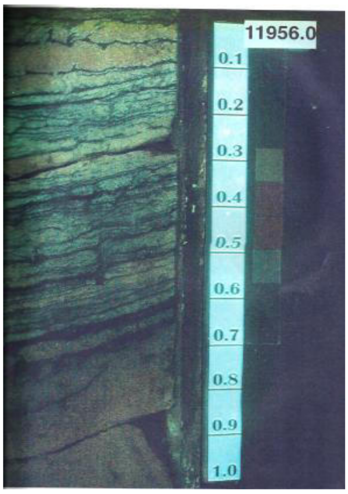


Fig.8: Core photo of Gas/oil contact at depth 11956 ftah

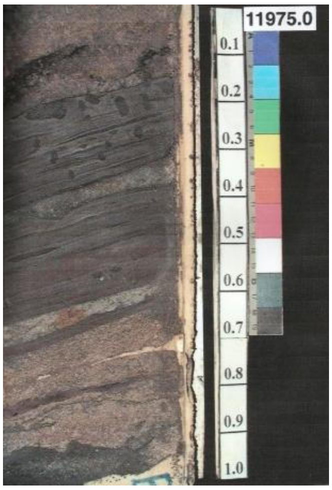


Fig. 9: lithofacies Swm_wavy to flaser bedded sandy heterolithic (bioturbated at the top)

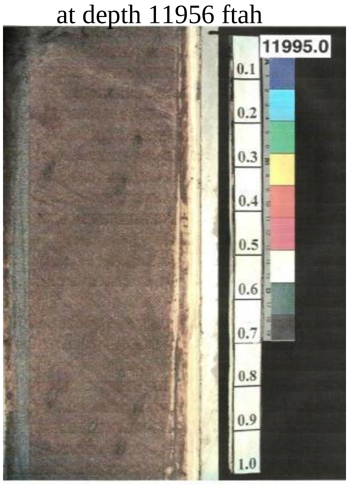


Fig. 10 : Lithofacies Sb_bioturbated sandstone

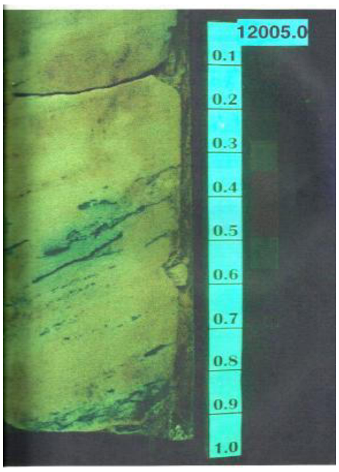


Fig. 11: Core photo of depth 12005 showing presence of oil based on fluorescence

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