An integrated approach to volume of shale analysis: Niger Delta example, Orire Field

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An Integrated Approach to Volume of Shale Analysis: Niger Delta Example, Orire Field

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Abstract: An integrated approach for the estimation of volume of shale from a suite of logs comprising the gamma ray, neutron-density combination, resistivity, combination of different methods (total) was carried in an Old Niger Delta Field called Orire with a view to ascertaining the reservoir quality and mapping reservoir bodies for further petrophysical analysis. The volume of shale (Vsh) calculation based on naturally occurring gamma ray frequently overestimates shale volume when encounters radioactive sand as sand appears shaly. In this situation, a Vsh calculation from neutron-density data yields a more accurate shale volume but in the presence of gas or light hydrocarbon, this approach is less accurate. The deficiency in this method is now addressed by Vsh calculation from the resistivity data. To avoid overestimation or underestimation of shale volume from any of the methods, the three methods were integrated to obtain Vsh total which finds the minimum value of all the methods. This approach distinguishes properly permeable bed (sand) from non-permeable bed (shale). Also from this method, the depositional environment was easily inferred.

Key words: Gas · Sand · Gamma log · Resistivity · Hydrocarbon

INTRODUCTION

The geology of the study area falls within Agbada formation in the offshore part of Niger Delta. This formation forms the hydrocarbon-prospective sequence in the Niger delta. It is represented by an alternation of sands, silts and clays in various proportions and thicknesses, representing cyclic sequences of offlap units [1]. These paralic clastics are the truly deltaic portion of the sequence and were deposited in a number of delta-front, delta-topset and fluvio-deltaic environments. G-01 sand used for analysis in Orire field is characterized by shore face sands. The sands are deposited in high energy environment [2]. Shore face sands are divided into three: upper shore face sand, lower shore face sand and middle shore face sand. The G-01 sand predominantly fall between lower shore face and middle shore face.

Shaliness is known to affect both formation characteristics and logging tool response [3]. This has now made the volume of shale (Vsh) calculation from logs critical because of its further influence on the computation of important petrophysical properties such as porosity and water saturation [4]. It is applied to most widely used shaly sand saturation equations such as Waxman-Smit [5] and Dual-water [6] to characterize excess conductivity. There are a number of ways volume of shale is derived from log measurements, using gamma ray, spontaneous potential, neutron-density combination, resistivity and combination of different methods [7]. The most frequently used technique for deriving volume of shale in the Niger Delta, due to measurement availability, is from gamma ray and neutron density logs [4].

In this study, different volume of shale methods used in Orire field for the data analysis include; gamma ray, neutron density combination, resistivity and combination of different methods as against the conventional methods from gamma ray and neutron density logs which led to uncertainties in reserve estimate. Due to inaccurate prediction of Vsh from gamma ray log when encounters radioactive sand, less accurate estimation of Vsh from neutron-density data in the presence of gas or light hydrocarbon and effectiveness of Vsh resistivity only in the presence of gas or light hydrocarbon informed the study. Hence, to improve on the shortcomings of the three methods necessitated the development of Vsh total. This method combines all the methods with a view to finding the minimum of the three methods.

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MATERIALS AND METHODS

The volume of shale analysis was carried out using the petrophysical software called Geolog 6.5. The different volume of shale methods used in Orire field to address the uncertainties unresolved by traditional Vsh from gamma and neutron-density are; gamma ray, neutron density combination, resistivity and combination of different methods (total). The details of the methods are as follows:

Vsh from Natural Gamma Ray (Linear and Steiber Methods)

(a) Vsh linear (vsh_gr_l) = $\frac{GR - GR_{CL}}{GR_{SH} - GR_{CL}}$ (1)

The above equation expresses Vsh linearly with increase of gamma ray reading, where;

GR = Gamma ray log reading in zone of interest (API units)
GR_{CL} = Gamma ray log reading in 100% clean zone (API units)
GR_{SH} = Gamma ray log reading in 100% shale (API units)

(b) Vsh Steiber(vsh_gr_s) = $\frac{0.5 \times vsh\_gr\_l}{1.5 - vsh\_gr\_l}$ (2)

The non-linear gamma ray (Vsh Steiber) will predict less vsh than Linear method [8]. The non-linearity was used in unconsolidated rocks because they tend to be more chemically immature and may contain radioactive minerals such as feldspars that could contribute to gamma but are unrelated to shale volume.

Volume of Shale from Neutron-density Combination: (3)

Vsh neutron-density (vsh_snd_x) = $\frac{\phi_N - \phi_D}{\phi_{NSH} - \phi_{DSH}}$

ϕ = neutron porosity in the sand
ϕ= density porosity in the sand
ϕ_{NSH}= neutron porosity in adjacent shale
ϕ_{DSH}= density porosity in adjacent shale.

Volume of Shale from Resistivity:

Vsh resistivity (vsh_r) = $\frac{\log(RESD) - \log(RESD\_CLN)}{\log(RESD\_SHL) - \log(RESD\_CLN)}$ (4)

RESD = resistivity log reading from zone of interest
RESD_CLN = resistivity log reading from clean sand
RESD_SHL = resistivity log reading from shale

Volume of Shale Total (Vsh_t) I.e. Vsh from the Combination of Different Methods: The approach for deciding which of the several available shale volume results to use is to find the minimum values of the feasible results. The minimum is chosen because errors for any method tend to increase the apparent shale volume.

In Orire field, the conditional statements below were used for Vsh total estimation.

- For composite logs comprising gamma ray log, resistivity log, neutron and density logs with the presence of gas; if in the presence of gas, use minimum value betweenVsh Steiber and Vsh resistivity and if not in gas, use minimum value between Vsh neutron-density and Vsh linear.
- For composite logs comprising ray log, resistivity log, neutron and density logs without gas; the minimum value between Vsh neutron-density and Vsh linear was used.
- For composite logs comprising gamma ray log, resistivity log, with either neutron only or density only or without neutron-density log; the minimum value between Vsh Steiber and Vsh resistivity was considered.

RESULTS AND DISCUSSION

The results of the study are shown in Figures1 (a-d) and 2(a-e) respectively and are subsequently discussed as follows. The results of the different Vsh methods show that Vsh linear and Vsh Steiber (Figure 1a) did not work well where there were radioactive sands within the formation. Also, Vsh neutron-density (Figure 1b) worked well in such an environment. However, where cross plot from neutron and density logs indicate gas, gas-flag (GAS_3) was introduced. Vsh Resistivity (Figure 1c) worked well in gas environments because it compensates for the negative Vsh values from the neutron-density cross plot where gas presence affects the quantitative results from this method. Vsh-total (Figure 1d) was calculated for all the wells with a view to finding the minimum value of the feasible results.

Histograms of Vsh gamma, (Figures 2a and 2b), Vsh neutron-density (Figure 2c) and Vsh resistivity (Figure 2d) could not define depositional environment properly due to their bias for gamma, neutron-density and

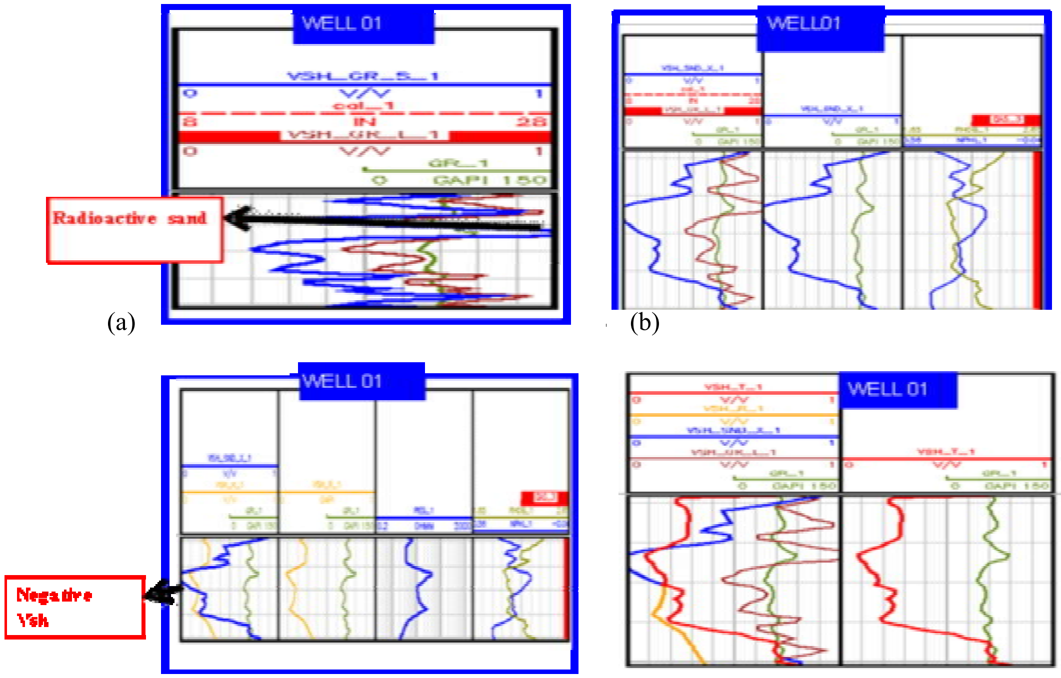

Fig. 1a-d: a. Effect of Vsh linear and Vsh steiber on G.01 sand
b. Effect of Vsh neutron - density on G.0.1 sand
c. Effect of Vsh resisitivity on G.0.1 sand
d. Effect of Vsh total on G.01 sand

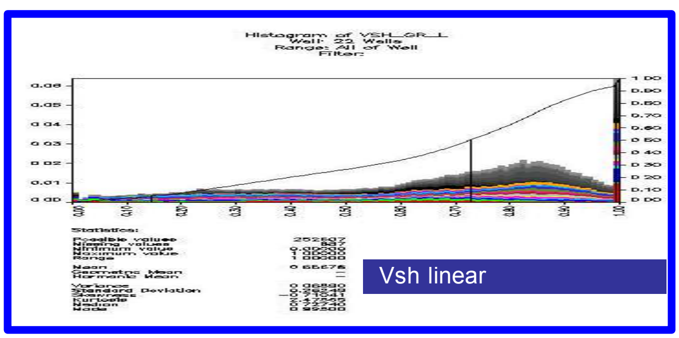

Fig. 2a: Histogram of Vsh linear

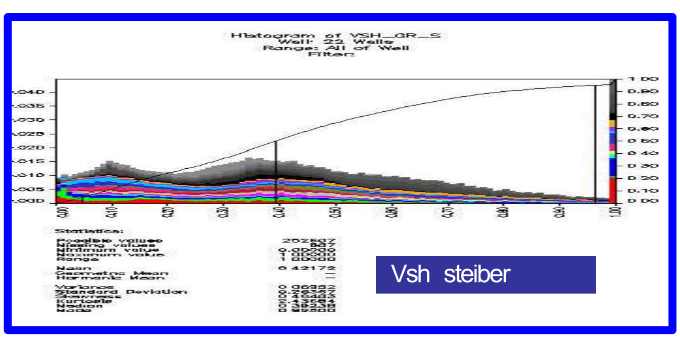

Fig. 2b: Histogram of Vsh Steiber

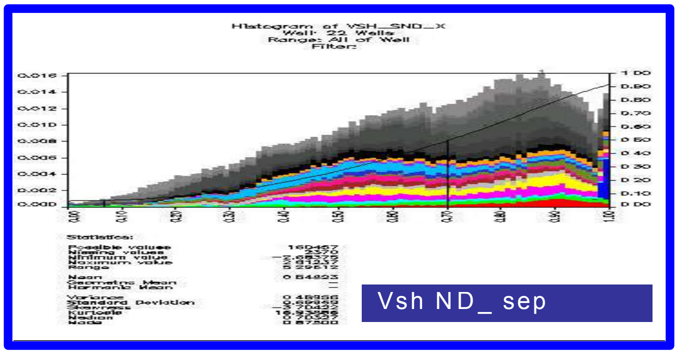

Fig. 2c: Histogram of Vsh neutron-density

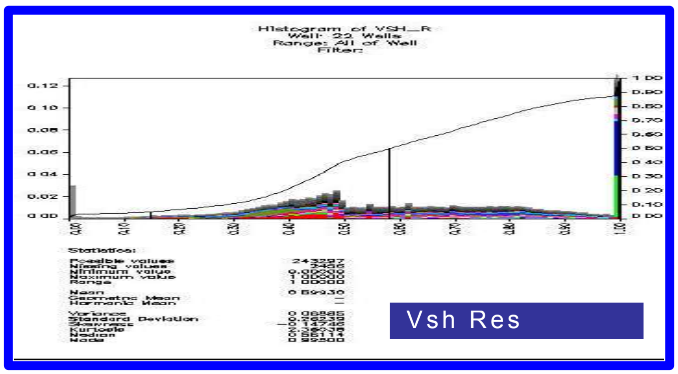

Fig. 2d: Histogram of Vsh resistivity

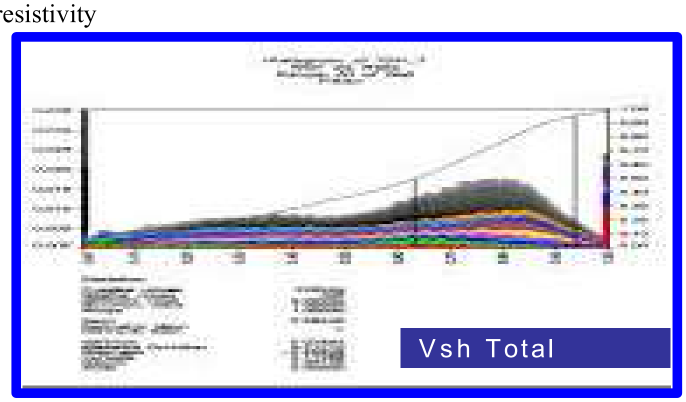

Fig. 2e: Histogram of Vsh total

resistivity data respectively. In contrast, histogram of Vsh total (Figure2e) defines it properly because it involves the combination of gamma ray, neutron-density and resistivity data. Hence, from the result, the shore sands are up to 65% while the rest 35% is shale (prodelta). The results from analysis agree with deposition environment of the study area.

Also from the histogram of Vsh total (Figure 2e), sand cut off could be inferred effectively. It was observed that the sand cut off could be determined when the Vsh total is less than 65 % (Vsh total<0.65). This cut off has been determined to know what defines sand formation. Its determination is the driving factor for all the remaining cut offs which would be used for hydrocarbon summary evaluation.

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