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UNCERTAINTY IN VOLUME OF SHALE CALCULATED FROM GAMMA RAY LOG: A COMPARATIVE STUDY BASED ON LINEAR AND NON-LINEAR MODELS

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Abstract

In this study, we evaluated volume of shale from gamma ray log based on three techniques: gamma ray index, Larionov pre-Tertiary, and Thomas-Steiber, and compared results to evaluate variability in volume of shale.

Twelve zones were recognised in the reservoir interval penetrated by B1 based on qualitative analysis of gamma ray and sonic logs. Volume of shale was calculated for the zones to build facies-constrained object models in a three-dimensional grid. The grid comprises 1306 cells and 1180 cells in the horizontal directions with cell dimensions of 5 ft by 5 ft (1.5 m by 1.5 m) and 68.5 ft (21 m) along depth.

In all the zones, gamma ray index is linear, whereas Larionov pre-Tertiary and Thomas-Steiber techniques yield deflected curves from the gamma ray index. Two-dimensional models of volume of shale show that gamma ray index technique produces overestimated volume of shale unlike Larionov pre-Tertiary and Thomas-Steiber techniques. Findings reveal that the Thomas-Steiber model with higher constant value produces significantly lower volume of shale. This variability in volume of shale reflects large contrast in volume of shale across lateral extent of channel elements that dominate the internal architecture. To reduce this uncertainty and the attendant risk of overestimation or underestimation of average net-to-gross value used in resource/reserve calculation and flow simulation, it is imperative to adopt a multi-technique approach that compares volume of shale from these techniques with volume of shale computed from spontaneous potential and combined neutron and density logs.

1. Introduction

Since its inception in 1953 (Khan, 1989), natural gamma ray measurements have become a source of information in exploration and production phases of the oil and gas industry. The log presents a plot of naturally occurring radioactivity measured in a formation, and it is one of the most popular logs that are usually deployed during formation evaluation to: (1) discriminate nonreservoir rocks such as shales and clays from reservoir rocks, principally sandstone and carbonates, (2) define beds, (3) estimate degree of shaliness of reservoir rock, (4) interpret facies, (5) identify minerals, (6) calculate volume of shale, and (7) correlate wells. Shales and clays are derived from rocks that tend to contain naturally occurring radioactive elements such as potassium, thorium, and uranium. As a result, shales and clays are more radioactive than clean sandstones and carbonates. Because quartz and calcium carbonate produce almost no radiation, identifying formations with low background radiation is key to delineating zones that have potential for accumulating hydrocarbons (Alberty, 1992).

In most geological formations, however, shale content varies from one interval to another, thus introducing uncertainty in reservoir potential of these intervals. In clean formations, shale content may be zero, whereas in heterogeneous formations, it may reach 100% (Szabó, 2011a). Variability in shale content in reservoir intervals, therefore, affects their petrophysical properties, effectively reducing porosity and permeability. Aside from these effects, shale changes a rock's electrical features and may reduce true resistivity of the formation, causing inaccurate estimation of water saturation, and hence hydrocarbon potential (Sharma and Chopra, 2018; Kumar, et al., 2022). In the literature, various methods are used to estimate volume of shale. These methods are based on single log techniques or crossplot techniques. Single log techniques utilize gamma ray, spontaneous potential, and resistivity logs, whereas crossplot techniques involve crossplots of neutron and density, and neutron and sonic logs (Rider, 2002; Asquith and Krygowski, 2004). Although normal procedures adopt the linear model to estimate volume shale from gamma ray log, this model often yields overestimation of shale volumes where non-clay radioactive minerals such as feldspar, glauconite, mica, zircon, and/or uranium are present. In an instance where muds that are rich in potassium chloride are used during drilling of a sand-rich formation, gamma ray measured from the formation may be high, erroneously implying shale. This study adopts a single log technique based on gamma ray log to estimate volume of shale, and then compares the results with corrected volume of shale calculated from nonlinear alternatives.

2. Geological setting

The well primarily investigated in this study penetrates the main channel system in the North Brae field. The field is located in UK Continental Shelf covering Blocks 16/07 and 16/08 (Figure 1), and forms part of the cluster of fields that are located in the western margins of the South Viking Graben. It is a mature gas-producing field that is composed of a turbidite reservoir system in the Upper Jurassic Brae Formation. The reservoir is over 700 m (2296.6 ft)-thick and extends over an area of 19 km^2 (7.3 mile^2). It has recoverable reserves of 207 MMbbl of condensate and 800 Bcf of dry gas in its 169 m (554.5 ft)-thick hydrocarbon column. The formation is interpreted as a sand-rich, deep-water turbidite system typified by overlapping slope-apron fans and composed of conglomerate and sandstone turbidites and sandy debrites interstratified with extensive thin-bedded turbidites and very thin-bedded, mud-rich turbidites (Omoniyi et al., 2018).

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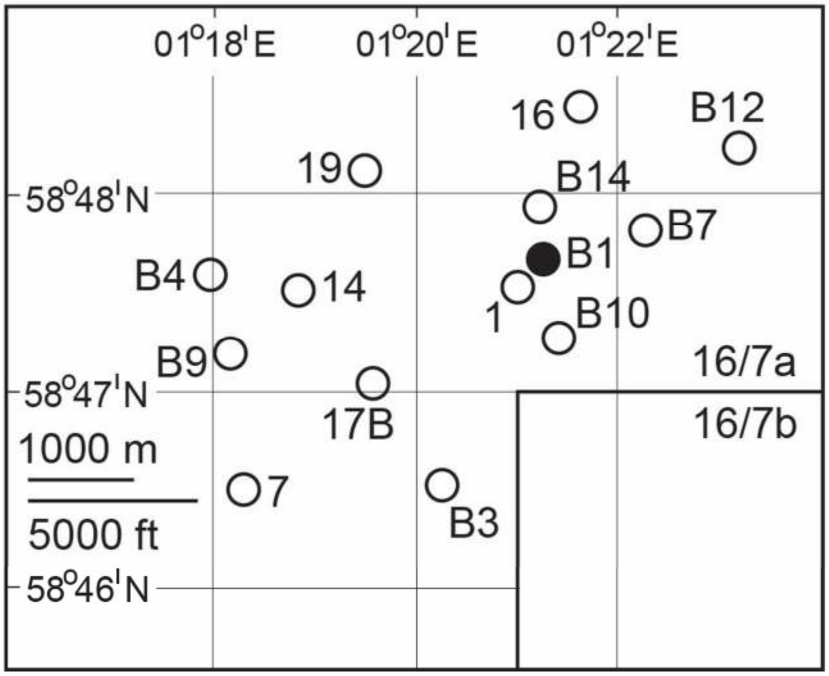


Figure 1. Map illustrating spatial distribution of wells in Block 16/07, UKCS. Well logs comprising gamma ray and sonic log from B1 provide data that are analysed in this study while B10 and B17 serve as control wells for building 3-D models of volume of shale.

3. Material and methods

3.1 Volume of shale

The data used in this study are gamma ray and sonic logs, sourced principally from B1 (Figure 2). The logs were analysed qualitatively to delineate distinct zones over a reservoir interval that extends from 12360 to 13250 ftMD (11940 to 12845 ftSS). The zones were investigated based on a quantitative approach that utilized gamma ray to calculate volume of shale (V_{sh}) for the interval. In this regard, the techniques used are: (1) gamma ray index, (2) Larionov (1969) model for pre-Tertiary rocks, and (3) Thomas-Steiber (1975) model. B10 and B17 serve as control wells for 3-D modelling of volume of shale.

3.1.1 Gamma ray index

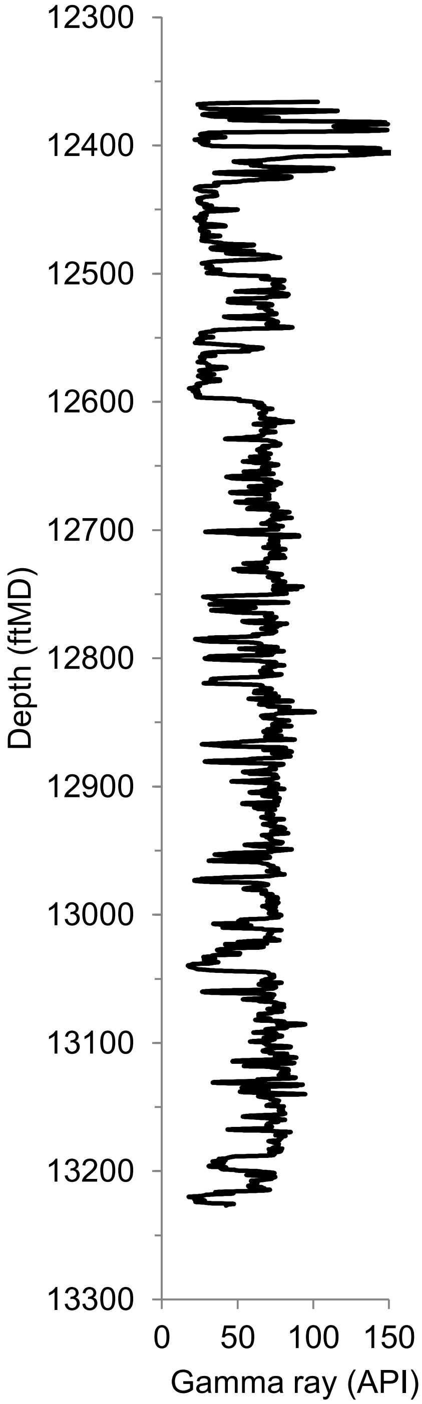
This technique assumes a linear relationship between gamma ray values and volume of shale based on the following equation:

$$I_{GR} = {GR_{log} - GR_{min}} \Big/ {GR_{max} - GR_{min}} \quad (1)$$

I_{GR} is GR index; GR_{log} is GR reading at any depth read from log; GR_{min} and GR_{max} are minimum (lower limit) and maximum (upper limit) GR values, respectively. The minimum GR and maximum GR values correspond to clean sandstone and shale, respectively.

GR index technique assumes the following conditions:

1. Shale formation is composed of all clay.
2. Any increase from clean sandstone to shale is due to an increase of clay content only.



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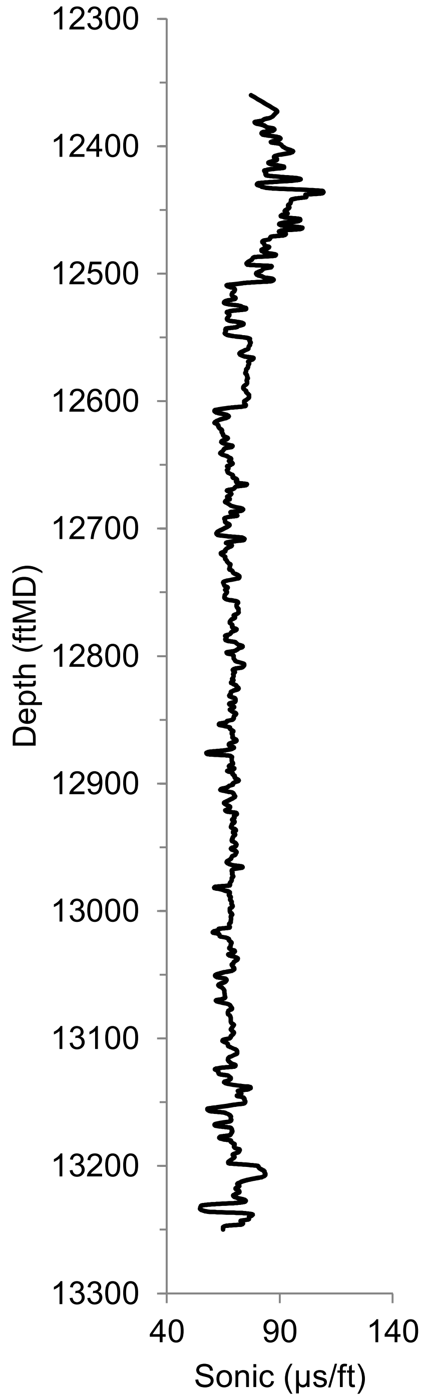

B.

Figure 2. (A) Gamma ray log (B) Sonic log for B1.

Consequently, one or more points on clean sand and shale zones must be selected to calculate the volume of shale. The failure to satisfy these assumptions in practical terms yields overestimation of the volume of shale and may be corrected using non-linear models (Asquith and Krygowski, 2004).

3.1.2 Larionov (1969) model for pre-Tertiary rocks

This is a non-linear model that addresses overestimation in volume of shale, commonly associated with gamma ray index technique. It is calculated as follows:

$$L_{pT}V_{sh}GR = 0.33 * \ [2^{(2*I_{GR})} - 1.0] \tag{2}$$

$L_{pT}V_{sh}GR$ is volume of shale based on Larionov model for pre-Tertiary formation and consolidated rocks; I_{GR} is gamma ray index.

3.1.3 Thomas-Steiber (1975) model

The Thomas-Steiber (1975) model is another non-linear alternative to gamma ray index technique for calculating volume of shale. The model is based on the following equation:

$$SV_{sh}GR = {}^{I_{GR}}\!\big/_{(a - (a-1) * I_{GR})} \tag{3}$$

$SV_{sh}GR$ is volume of shale based on Thomas-Steiber model; a is a constant that varies between 2 and 4.

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3.2 Volume of shale modelling

Modelling of volume of shale realisations utilised a three-dimensional (3-D) object model, built in Schlumberger Petrel^{TM} using parameters from a previous study (Omoniyi et al., 2018). The rationale for adopting this approach is to mimic channel element spatial distribution in 3-D to capture variability in volume of shale models generated based on gamma ray, Larionov, and Thomas-Steiber techniques. The grid comprises 1306 cells and 1180 cells in the horizontal directions. Each cell has dimensions of 5 ft by 5 ft (1.5 m by 1.5 m) along horizontal directions and 68.5 ft (21 m) along depth. The grid has a total of 20034040 cells.

4. Results and discussion

In B1, twelve zones are recognised using a combination of gamma ray and sonic logs (Figure 3). The results of volume of shale calculated based on the three methods considered are plotted for comparison (Figure 4). In these plots, gamma ray index is linear, whereas Larionov pre-Tertiary method yields a deflected curve from the gamma ray index. The Thomas-Steiber technique yields the most deviated curves in the twelve zones identified in B1. Both Larionov pre-Tertiary method and Thomas-Steiber method (a=2) display similar trends in volume of shale. The 2-D models of volume of shale generated for these results show that gamma ray index technique produces overestimated volume of shale in contrast to Larionov pre-Tertiary and Thomas-Steiber techniques with the latter producing a significantly lower volume of shale than the former (Figure 5). As observed in the Thomas-Steiber model, the higher the constant applied,the lower the volume of shale.

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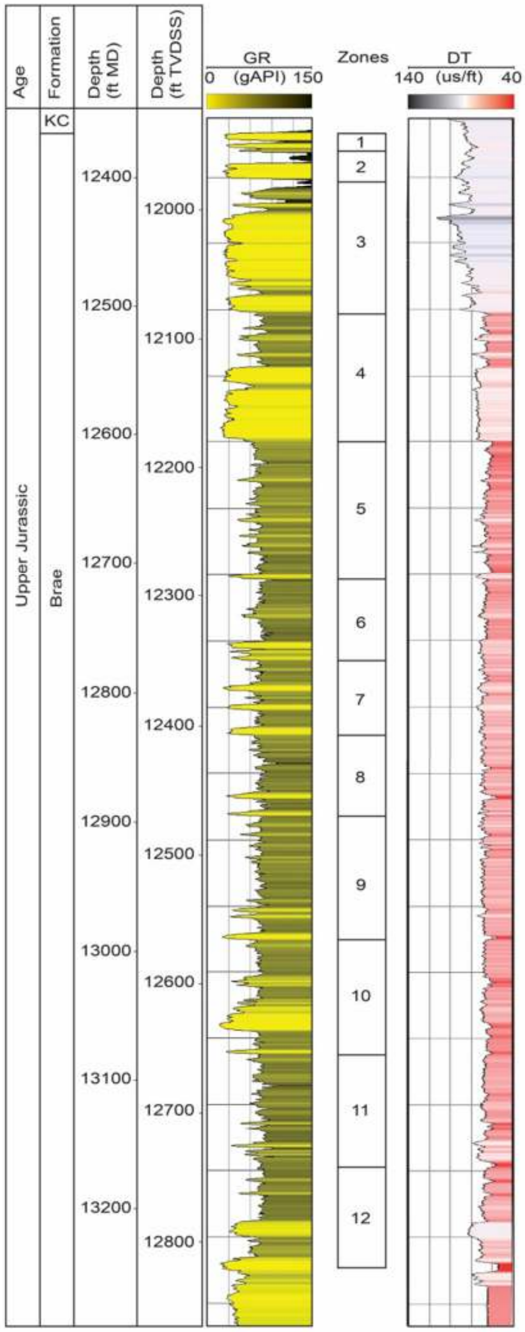

Figure 3. Zones delineated in B1 from gamma ray and sonic logs.

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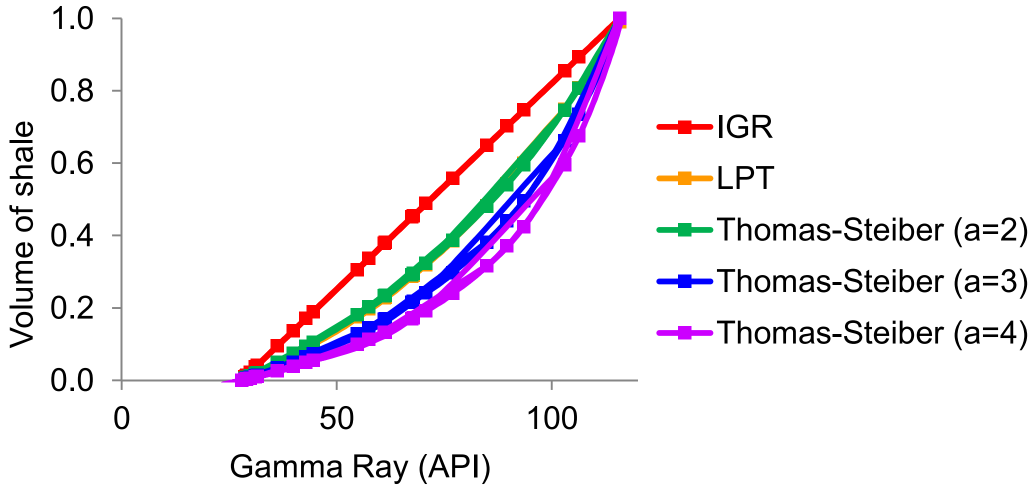
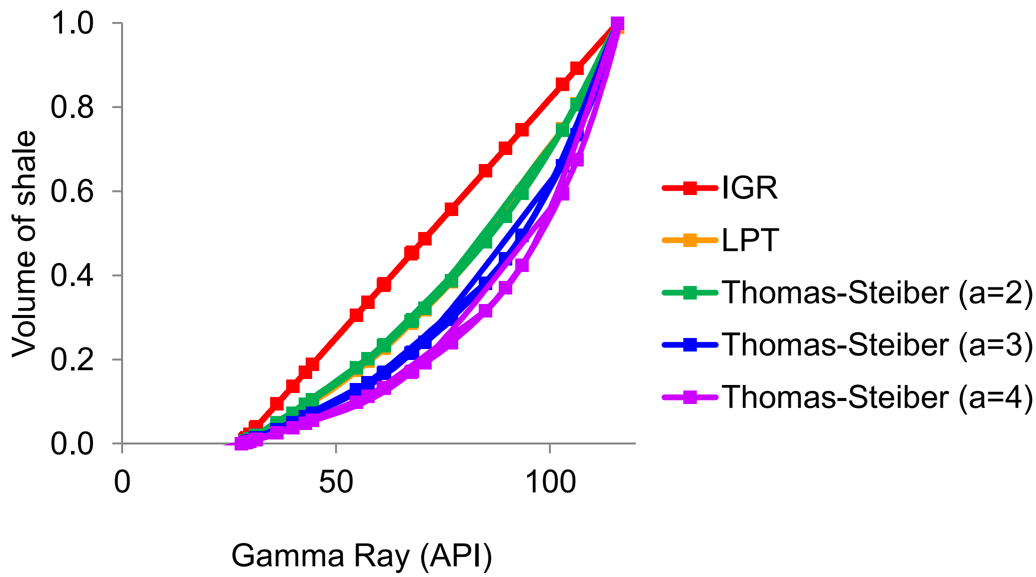


A.



B.

Figure 4. Representative plots of volume of shale calculated based on gamma ray index, Larionov pre-Tertiary, and Thomas-Steiber techniques for: (A) channel cover/margin facies, and (B) channel facies in B1.

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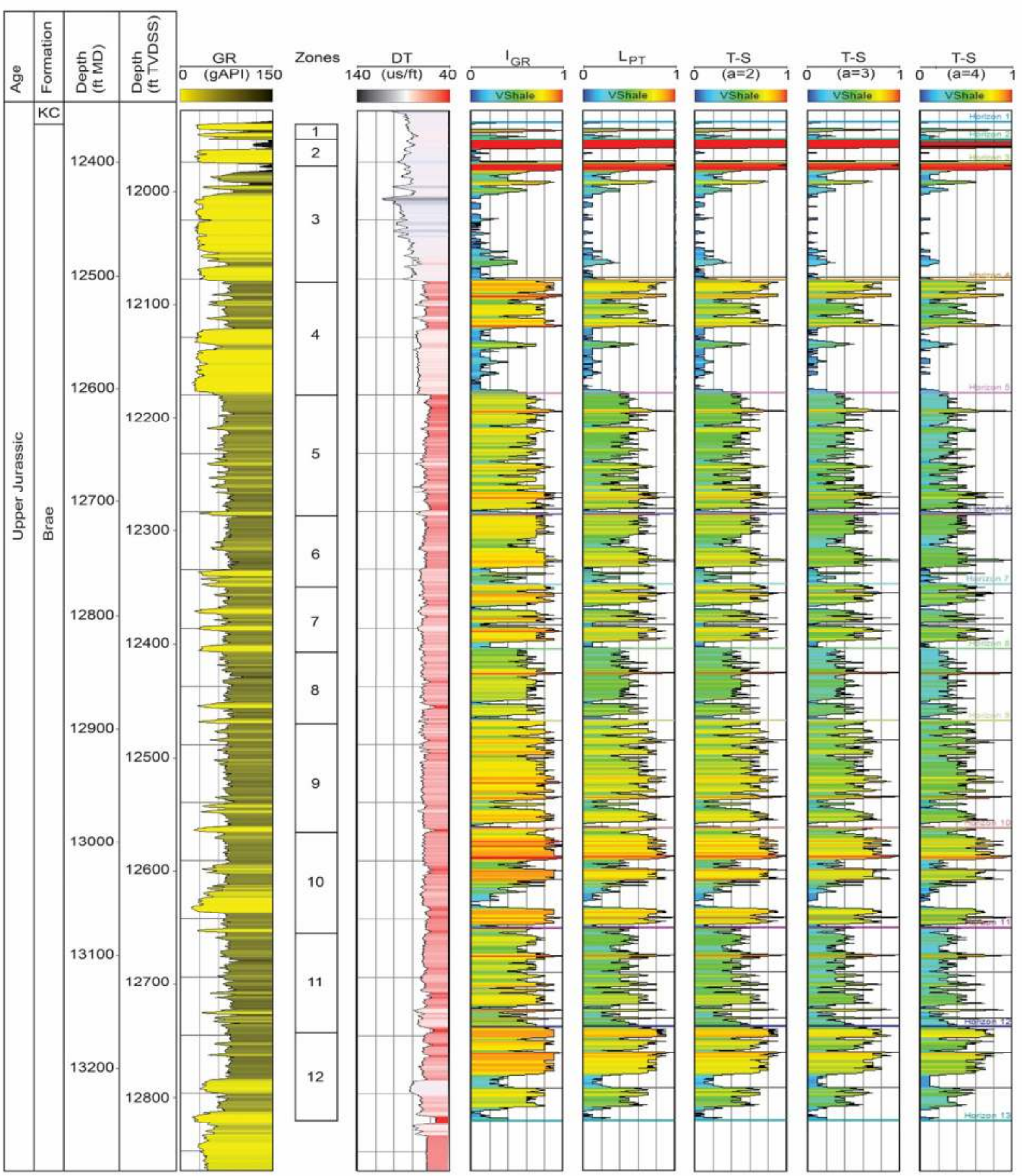

Figure 5. Volume of shale models generated from gamma ray index, Larionov pre-Tertiary, and Thomas-Steiber models for B1.

Volume of shale directly impacts net-to-gross, which may be overestimated or underestimated, and hence net sand distribution and hydrocarbon-in-place. As shown in the results, different methods tested for a well that penetrates channel elements yield variable volume of shale, noticeably overestimated in the gamma ray index model, moderate in the Larionov pre-Tertiary model, and significantly lower in the Thomas-Steiber model. Based on facies-conditioned 3-D model (Figure 6), this variability is more pronounced over spatial distribution (Figure 7), thus creating large contrast in volume of shale across the lateral extent of channel elements that dominate the internal architecture. This contrast will significantly impact average volume of shale value that is used to derive net-to-gross and may overestimate or underestimate hydrocarbon-in-place. Beyond this impact, uncertainty in volume of shale will influence spatial distribution of net sand and sway results of flow simulation in either direction.

5. Conclusions

This study demonstrates variability in the volume of shale calculated based on five techniques that utilised gamma ray log. While gamma ray index technique produces overestimated volume of shale, Larionov pre-Tertiary and Thomas-Steiber methods yield more accurate volume of shale. Adopting a multi-technique approach that compares volume of shale from these techniques with volume of shale computed from spontaneous potential and combined neutron and density log will largely reduce uncertainty and the attendant risk of overestimation or underestimation of average net-to-gross value that is used in resource/reserve calculation and flow simulation.

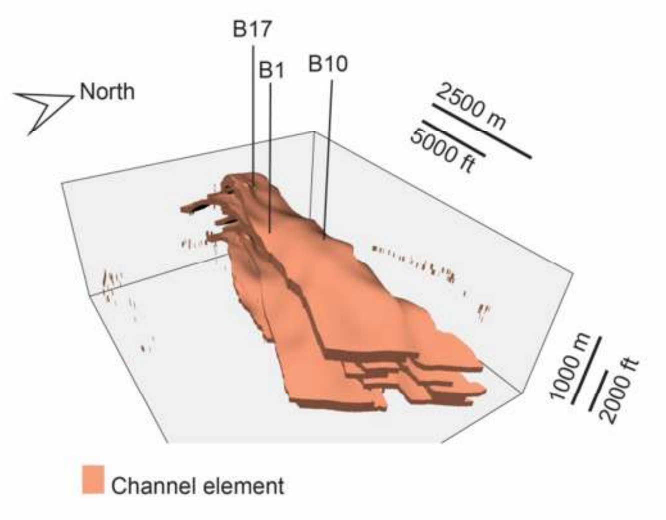

Figure 6. 3-D object model of channel elements penetrated by B1, B10, and B17.

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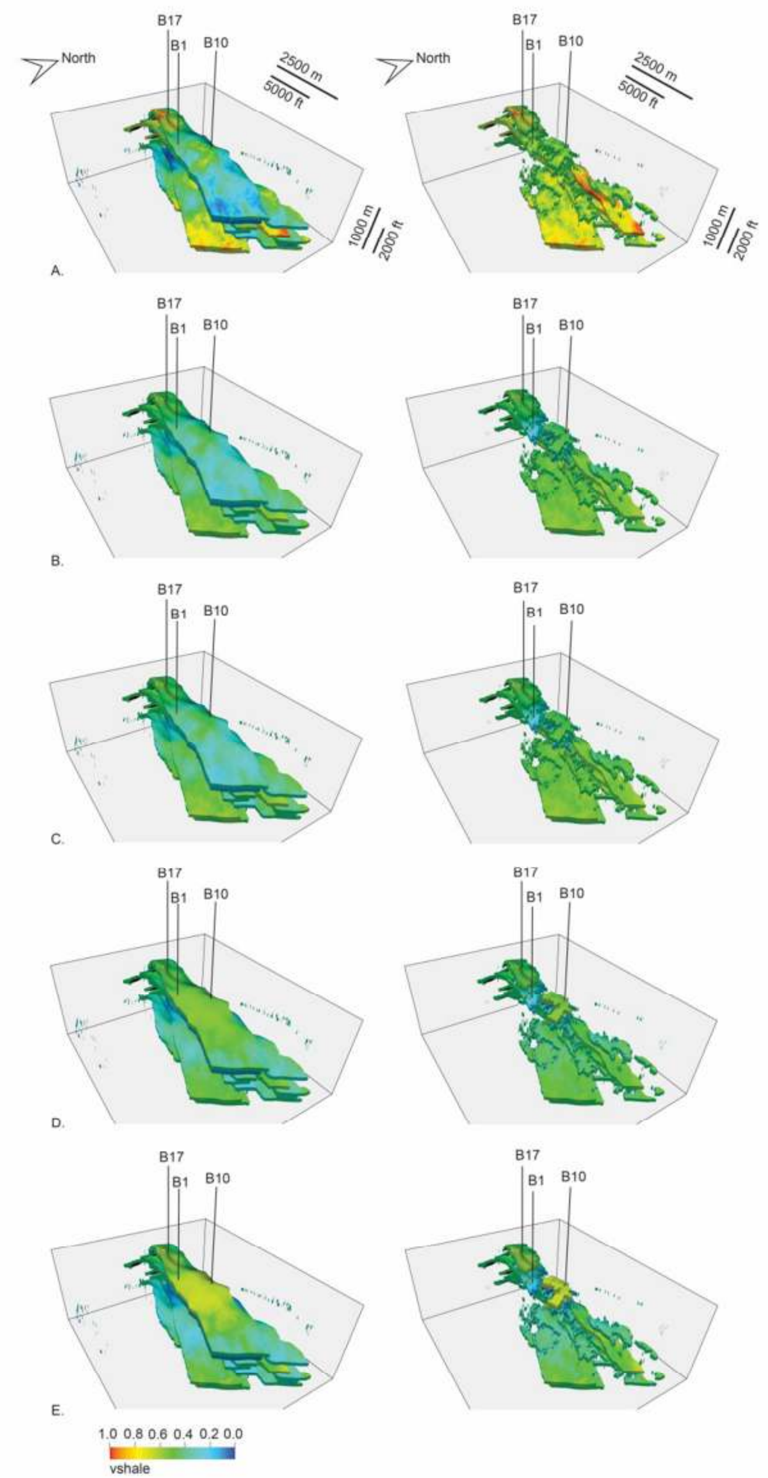

Figure 6. 3-D models illustrating variability in spatial distribution (left) and derivative (right) of volume of shale generated based on: (A) gamma ray index, (B) Larionov pre-Tertiary, (C) Thomas-Steiber (a=2) (D) Thomas-Steiber (a=3), and (E) Thomas-Steiber (a=4) techniques.

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Availability of data and materials

The data and materials used for this study are available on request.

Ethic statement

This work has not been published previously, and it is not under consideration for publication elsewhere.

Conflict of interest

The authors declare that there is no conflict of interest regarding this submission.

References

Alberty, M.W., 1992. Wireline methods, in: Morton-Thompson, D., Woods, A.M. (Eds.), Development Geology Reference Manual. American Association of Petroleum Geologists, Methods in Exploration Series, 10; p. 151-153.

Asquith, G., Krygowski, D., 2004. Gamma ray, in: Asquith, G., Krygowski, D. (Eds.), Basic Well Log Analysis. American Association of Petroleum Geologists Methods in Exploration 16, p. 31-35.

Khan, M.N., 1989. Introduction to wireline log interpretation. Oil and gas development corporation, 193 p.

Kumar, T., Seelam, N.K., Rao, G.S., 2022. Lithology prediction from well log data using machine learning techniques: A case study from Talcher coalfield, Eastern India. Applied Geophysics 199, 104605. https://doi.org/10.1016/j.jappgeo.2022.104605

Larionov, V.V., 1969. Radiometry of Boreholes, Nedra, Moscow, 127 p.

Omoniyi, B.A., Stow, D.A.V., Gardiner, A., 2018. Characterization of thin-bedded turbidites in the North Brae field, South Viking Graben, North Sea, in: Turner, C. C., Cronin, B.T. (Eds.), Rift-related Coarse-grained Submarine Fan Reservoirs; the Brae Play, South Viking Graben, North Sea. American Association of Petroleum Geologists, Oklahoma, Memoir 115, pp. 257-282. https://doi.org/10.1306/13652184M1153811

Rider, M., 2002. The Geological interpretation of well logs, second edition. Sutherland, Rider-French Consulting, 280 p.

Sharma, R.K., Chopra, S., 2018. Uncertainty in the Estimation of Volume of Shale from Well Log Data, in: Ray, R.R, Hardage, B.A., Chopra, S. (Eds.), Downhole Geology. American Association of Petroleum Geologists Explorer, Geophysics Corner, December 2018.

Szabó, N.P., 2011a. Shale volume estimation based on the factor analysis of well–logging data. Acta Geophysica 59(5), 935-953. https://doi.org/10.2478/s11600-011-0034-0

Thomas, E.C., Stieber, S.J., 1975. The distribution of shale in sandstones and its effect on porosity. SPWLA Proceedings of the 16th annual logging symposium. Society of Petrophysicists and Well-Log Analysts, June 4-7.