

Clay volume calculation from acoustic and density curves using the Gyllenhammar equation.

Introduction

Clay volume plays a vital role in defining the characteristics of rocks, which in turn affects the assessment of deposit reserves. By understanding the content of clay minerals within the rock, we can gain valuable insights into its properties, including permeability, porosity, and brittleness. This knowledge not only enhances our ability to evaluate resources but also informs strategies for effective resource management. Gamma-ray (GR) logging, spontaneous potential (SP), and a combination of neutron porosity (NPHI) and bulk density (RHOB) methods are typically used to calculate clay content (Serra, 2008). However, these methods cannot be derived from seismic data interpretation. Understanding the connections between seismic data and well data is essential, using density and acoustic logs (DT). By focusing on how to derive the necessary parameters from sonic transit time (DT) and bulk density (RHOB) data, we can effectively evaluate petrophysical properties using seismic data, leading to more accurate interpretations and informed decision-making in reservoir assessments.

This case study calculates clay volume from acoustic and density logs (VCL_DS) using the Gyllenhammar methodology, illustrated with examples from North Sea wells. In the examined clastic rocks, clay volume (VCL) serves as a key criterion for reservoir assessment, since the total porosity can be high in both sandstones and shales. Estimating the clay volume in the inter-well space using seismic exploration data can provide valuable insights into rock heterogeneities and the structural features of formations. This information allows for a more accurate identification of location for drilling new wells, optimizing the oil and gas production process, and improving the overall efficiency of field development.

Clay volume calculation

Background

The subject of the study is the oil and gas fields in the northern North Sea, covering an area of 80,000 square kilometres. Over 800 wells have been drilled in the area, revealing numerous geological layers from the Neogene to the Permian deposits. The geological section consists primarily of terrigenous deposits. However, in the Shetland interval, carbonate deposits are found in the northern part of the studied area. Additionally, salt layers are present in the Permian deposits of the Zechstein interval.

Well wireline logging and measurements while drilling (MWD/LWD) encompasses GR, resistivity (RT), SP and DT down to the reservoir. Entering the reservoir several new measurements are added. The most important are RHOB and NPHI. With those two measurements we get the caliper (CALI) and photoelectric factor (PEF) measurements. Logging data allows for a comprehensive petrophysical interpretation, evaluating porosity, saturation, clay volume, and identifying rock lithology.

Initially, the original clay volume (VCL) in the wells was calculated using the Gamma Ray (GR) index, as shown in Equation 1. For consolidated sandstones, located below approximately 1500 metres in the North Sea fields, an integrated approach utilizing both neutron and density methods was employed to determine the clay content, as illustrated in Equation 2 (Gyllenhammar, 2020).

$$VCL_{GR} = \frac{GR - GR_{min}}{GR_{max} - GR_{min}} \quad (1)$$

$$VCL_{ND} = \frac{(RHOB_B - RHOB_A) \cdot (NPHI - NPHI_A) - (RHOB - RHOB_A) \cdot (NPHI_B - NPHI_A)}{(RHOB_B - RHOB_A) \cdot (NPHI_C - NPHI_A) - (RHOB_C - RHOB_A) \cdot (NPHI_B - NPHI_A)} \quad (2)$$

The cross-plot shown in Figure 1a can be used to determine the values of neutron porosity and density at points A, B, and C (Schlumberger, 1989). In gas reservoir intervals or wellbore washout zones, VCL_ND values may be distorted.

Since the previous equations are inadequate for estimating clay volume in seismic interpretation, the Gyllenhammar equation was used instead, with parameters calibrated to the original VCL curve.

Vcl calculated from the sonic and density logs (VCL_DS)

The calculation principle of VCL_DS is similar to the method used to determine clay volume through neutron and density logs (VCL_ND) (Gyllenhammar 2020, 2022). Point C, the 100% clay point in Figure 1 is relatively constant in the Neutron - Density cross plot. If it is assumed that the VCL calculated from that plot is correct, point C on the Sonic - Density cross plot will have to be moved closer and closer to point B with depth to calculate the same Vcl. And that is the principle of this method.

Initially, the quality of the logging data was analyzed, and adjustments were made to the parameters, specifically excluding wells with poor-quality logging caused by wellbore washouts. Then, three reference points were established: two clean rock points—Point A representing rock with minimal porosity and Point B indicating maximally porous rock—and a 100% clay point designated as Point C, as illustrated in Figure 1b. The VCL_DS derived from Equation 3 was compared with the VCL, and reference points were corrected for each interval as needed. By selecting individual coefficients for each study interval, we can achieve even greater accuracy in the results.

$$VCL_{DS} = \frac{(RHOB_B - RHOB_A) \cdot (DT - DT_A) - (RHOB - RHOB_A) \cdot (DT_B - DT_A)}{(RHOB_B - RHOB_A) \cdot (DT_C - DT_A) - (RHOB_C - RHOB_A) \cdot (DT_B - DT_A)} \quad (3)$$

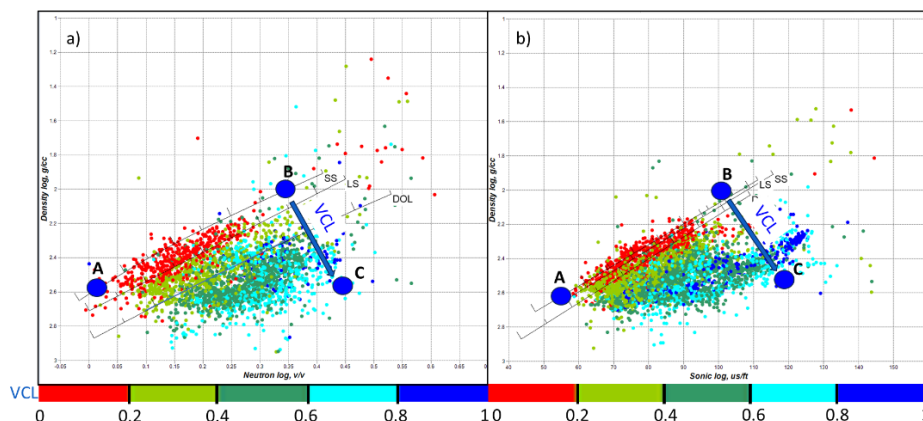


Figure 1 The Neutron – Density cross-plot (a) and the Sonic-Density cross-plot (b) constructed using data from reference wells within the Jurassic interval. The colour shows the VCL.

Point A is the most consistent, with a known reservoir lithology. If the rock type is quartz sandstone, Point A will have a density value ($RHOB_A$) close to 2.65 g/cc, and an acoustic value (DT_A) of 55 μ s/ft. When the lithology of rocks varies from field to field within the same interval, the coefficients in the equation must be determined separately for each lithology. Failing to do so may lead to an incorrect increase in VCL_DS due to the miscalculation of reference points. The most significant differences are observed in the clay parameter (Point C in Figure 1b), which is related to the compaction of rocks with increasing depth.

A preliminary analysis of data revealed the presence of gas in one of the northern fields within Jurassic deposits. However, the coefficients used for these Jurassic deposits were derived from wells where the fluids were primarily water and oil, leading to a significant overestimation of VCL_DS in the gas intervals. Upon conducting a more detailed analysis, it was observed that in the gas-saturated intervals,

the acoustic logging readings exceeded 120 $\mu\text{s}/\text{ft}$. Therefore, this DT cut-off value was incorporated into the equations for parameter selection.

Table 1 presents the coefficients of the Gyllenhammar equation for various intervals within the studied area.

Table 1 Parameters in the Gyllenhammar formula for each zone, where the RHOB values are in g/cc and DT in $\mu\text{s}/\text{ft}$

Geo chronology	Zone	RHOB _A	RHOB _B	RHOB _C	DT _A	DT _B	DT _C
NEOGENE	NORADLAND	2.02	1.5	2.27	107	156	160
PALAEOGENE	HORDALAND	2.62	1.6	1.9	57	137	157
	ROGALAND	2.55	2	2.3	61	103	154
CRETACEOUS	SHETLAND	2.68	2.12	2.6	50.1	95.1	140
	CROMER KNOLL	2.62	2.1	2.5	54	95	120
JURASSIC	VIKING (if Sonic > 120)	2.25	1.784	2.38	108	148	145
	VIKING (if Sonic <120), VESTLAND, TYNE, BRENT, STATFJORD	2.63	2	2.55	53.1	101	118
TRIASSIC	HERGE	2.47	2.1	2.96	58	94	99
PERMMIAN	ZECHSTEIN	VCL = + 1.1061*RHOB + 0.0405568*DT - 5.04805					
Basement		2.64	2.48	2.8	50.6	64	75

In Table 1, it is evident that there are no coefficients present in the Zechstein interval; only a linear equation is displayed. This absence is attributed to the presence of salt rocks within this interval, which results in minimal variability in the acoustic logging values. Additionally, the data points on the graphs do not exhibit a classic shape, as illustrated in Figure 1b. Consequently, it was not possible to derive coefficients for Equation 3.

As the acoustic impedance (AI) is a function of velocity and density, we transformed the Gyllenhammar equation into a new format: $VCL_DS = a/\text{Velocity} + b \times RHOB + c$. The coefficients a, b, and c are listed in Table 2 and were calculated using Equation 3 with constants from Table 1.

Table 2 The coefficients for equation $VCL_DS = a/\text{Velocity} + b \cdot RHOB + c$, where the RHOB values are in g/cc and Velocity in m/s

Geo chronology	Zone	a	b	c
NEOGENE	NORADLAND	3981.363477	1.230846521	-3.883948757
PALAEOGENE	HORDALAND	7002.254054	1.801801802	-6.03018018
	ROGALAND	4124.03936	1.033210332	-3.4600246
CRETACEOUS	SHETLAND	3651.596782	0.962690399	-3.180215643
	CROMER KNOLL	5391.091156	1.394557823	-4.608843537
JURASSIC	VIKING (if Sonic >2540)	6329.14464	1.782372338	-6.252918635
	VIKING (if Sonic <2540), VESTLAND, TYNE, BRENT, STATFJORD	5182.202672	1.292673054	-4.302523276
TRIASSIC	HERGE	3437.289851	1.097226455	-3.364218226
PERMMIAN	ZECHSTEIN	12361.87487	1.1061	-5.04805
Basement		8063.597884	2.215608466	-7.187830688

Limitations

The most significant difference between the original clay volume (VCL) and the volume calculated using the Gyllenhammar equation (VCL_DS) occurs in the intervals where there is wellbore washout. Therefore, it is essential to conduct a thorough analysis of the quality of the density and acoustic logs

before using this method. Any intervals affected by wellbore washout should either be excluded from the analysis or corrected beforehand on the logs.

The classical Gyllenhammar equation is not effective in salt rocks. Instead, a linear equation can be selected to determine VCL_DS from density and acoustic curves.

It is crucial to analyze the presence of a gas reservoir in advance, and to establish criteria for its identification. This is important because using the same parameters applied to a water reservoir or an oil reservoir can lead to an overestimation of clay content, which will not accurately reflect the actual reservoir characteristics.

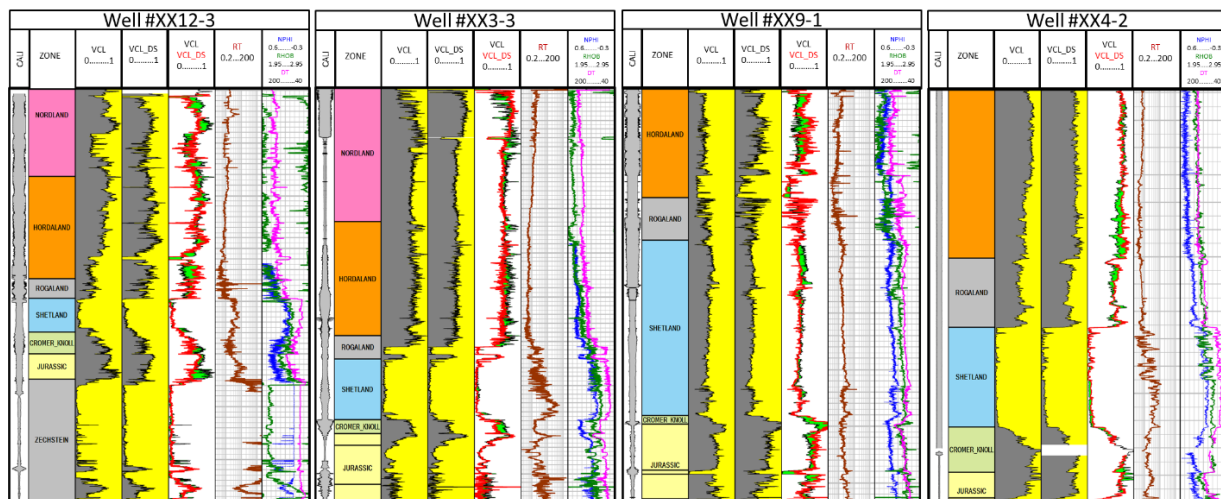


Figure 2 Comparison of the VCL and VCL_DS for four wells. The bright green colour in track #5 highlights the discrepancies between the two clay contents.

Conclusion

The case study clearly demonstrates the effectiveness of using velocity and density curves to estimate clay volume. With a straightforward equation that includes calibrated coefficients for each interval, we can calculate clay volume using seismic data. By deriving parameters from several reference wells, the resulting equations can be confidently applied to numerous wells. This method ensures rapid and precise calculations of one of the most critical geological parameters in inter-well spaces, all achieved within a short time frame (Figure 2).

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