EFFECT OF CLAY CONTENT ON ROCK PHYSICS PROPERTIES: A CASE STUDY IN SABAH BASIN

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ABSTRACT

Located within the Sabah Basin, SB field is located in the vicinity of Baram Delta province and consist of a broad spectrum of sand/shale content facies, thus creating the heterolithic sandstone in the basin. The presence of a high amount of clay within the sandstone had raised some issues in interpreting the target reservoirs, due to the lack of understanding of the characteristics of clays in the reservoirs. In this work, several good logs and seismic data were integrated to construct a numerical model of rock physics which then used to evaluate the effects of clay on rock physics properties. From the rock physics models, the relationship between the clays and rock properties were examined that eventually qualitatively assessed the quality of the reservoirs.

Keywords: clay content, elastic properties, Sabah Basin, P-wave velocity, S-wave velocity.

INTRODUCTION

Sandstone composed of various minerals, but the major components are quartz and clays. The presence of clays is affecting the reservoir properties, as well as their elastic properties because clays are complex minerals, and their existence conjures up the interpretation of rock properties. Those properties of clays like fine grain, small aspect ratio on grains contact, sheet–like particles, anisotropy and variable elastic moduli changed with compaction, scatter the data and introduce bias in interpretation.

Previous studies have been conducted to study the effect of clay content on rocks properties, and it has been revealed that the clay content has a devastating impact on rock properties. One of the popular models used to study the effect of clay effect is the velocity–porosity relationship that use average time equation to correlate the relationship between the velocity and porosity, even though the models do not consider the presence of clay content. Therefore, the porosity–velocity link has been scattered by the presence of clays. On the other hand, the empirical relationship of P–wave velocity forming the linear function with both porosity and clay content [1], decreasing with increasing porosity or clay content. Furthermore, it is observed that the increase in P–wave velocity with clay content attributed to the decrease in pore space between grains [2]. Then, once the clay content reaches the critical porosity, the P–wave velocity will start to decrease as the clay content increase the porosity within the rock. Nevertheless, none of the models can explicitly express the relationship between clays content and rock properties.

BACKGROUND OF THE STUDY

The distribution of clays–dispersed, structural and laminated, can also induce different impact on the rock properties. It is investigated that the effect of clay on different elastic properties while considering different clay distribution [3]. The results of their studies show that clay content has a significant impact on the features of the rocks like P–velocity, S–velocity, porosity and clay volume. Besides, the clay contributes some effect on the elastic properties of rocks, depending on the distribution of clays located within the sandstone, such that the qualitative suggested that dispersed clay can increase the P–velocity by stiffening the pore fluid. On the other hand, if the clay minerals enter the grain contacts, the velocities will be dramatically reduced.

in the silty sand reservoir, integration of rock physics together with petrophysical analysis will be used, for investigating the characteristics of the silty sand reservoirs and understand the reservoir quality in the Sabah basin. Subsequently, the behaviour and character of clays presence within the SB field require an integrated petrophysical and rock physics analysis. This is to be achieved along with an estimation of SB field's reservoir properties such as the volume of shale, porosity as well as its reservoir quality.

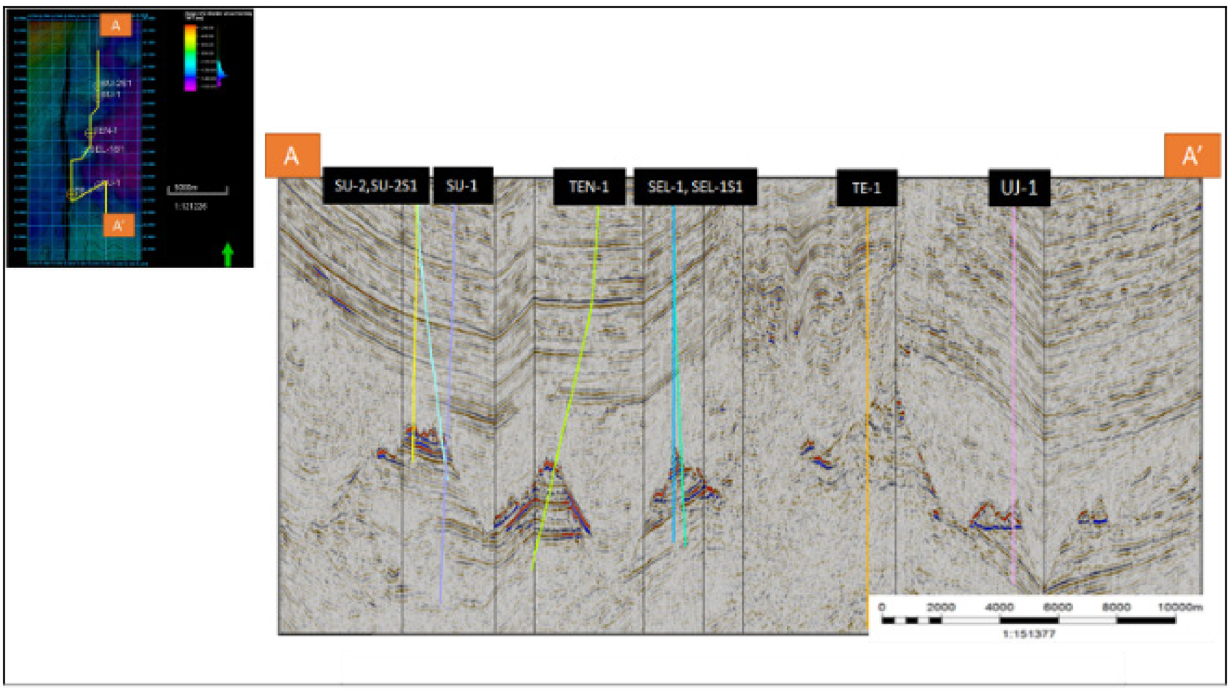

Figure 1 Seismic cross section of SB Field, Sabah Basin

In the previous study on the reservoir characterisation in the SB field (Figure 1), the reservoir's facies were determined comprises of a broad spectrum of sand and shale. Subsequently, the high amount of shale interbedded with the reservoirs jeopardises the interpretation on the reservoirs, as the understanding of the characteristics of the clays is minimal. The presence of the high amount of clays affect the petrophysical analysis and also the elastic properties of reservoirs. This could lead to erroneous interpretation or characterisation on the reservoirs, assuming it to be marginal field rather than a potential commercialise field with a vast reserve of hydrocarbon. To cope with the effect of clay effect

METHODOLOGY

In this paper, the good log and 3D post–stack seismic data were incorporated and integrated. First, a quick interpretation of good logs was conducted to evaluate the exciting intervals and thus, identify the occurrence of hydrocarbon from logs responses. Horizon and structural interpretation were also implemented, to create the subsurface model on the target reservoirs, which allow a field–scale understanding of the tectonic evolution and development of the target reservoirs. Also, the multi–attributes seismic interpretation, such as curvature and RMS amplitude, were incorporated to analyse the presence of hydrocarbon and sand quality qualitatively. From the data obtained in the analysis, the reservoir properties, i.e. porosity, water saturation and volume of shale, were computed. Finally, several cross plots were determined to identify the reservoir's fluid and lithology characteristics, which provided a whole picture of reservoir quality within the SB field. A workflow summary is shown in Figure 2.

WELL LOG ANALYSIS

The target reservoir is deposited during the age of middle Miocene. From biostratigraphy and well analysis, the exciting intervals extend from depth 975 m to 2090 m (TVD_{SS}), where the horizon defined for this interval cover from stage IVC middle unconformity

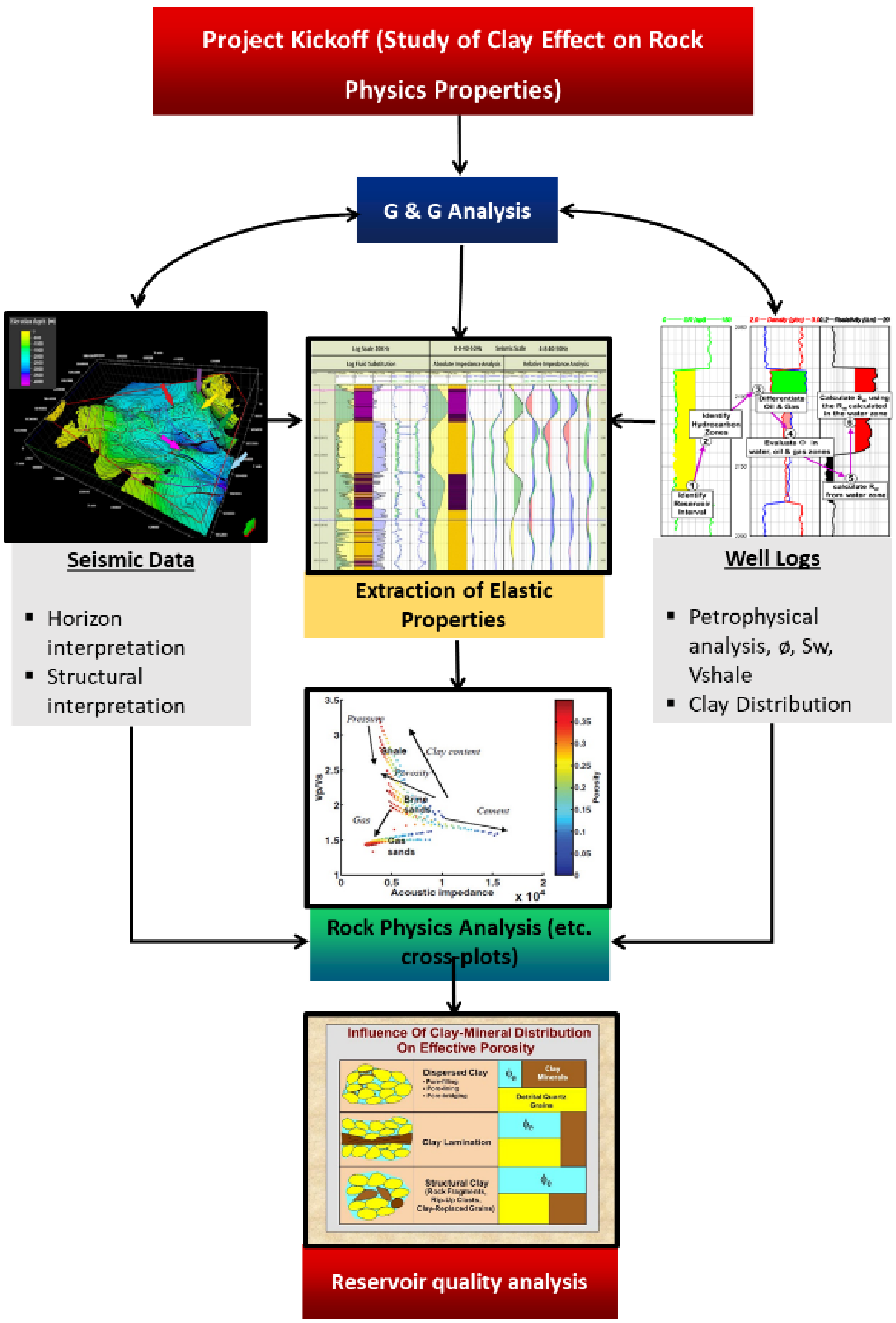

Figure 2 Integrated workflow for rock physics analysis

until base magenta. The entire intervals (975 m – 2090 m, TVD_{SS}) is assigned as upper Miocene and thought to be stage IVC. In general, the environment of deposition of the interesting intervals ranges from the lower coastal plain to holomarine middle neritic (Figure 3).

unconformity and unit–9. The well is drilled up to 1830 m (TVD_{SS}). Well SB–2 the lithology is described as interbedded of claystone and sandstone with a high amount of volume of shale content (1% –70%). But it has porosity values, ranging from 13% – 27%. Within well SB–2, four working intervals were defined; stage

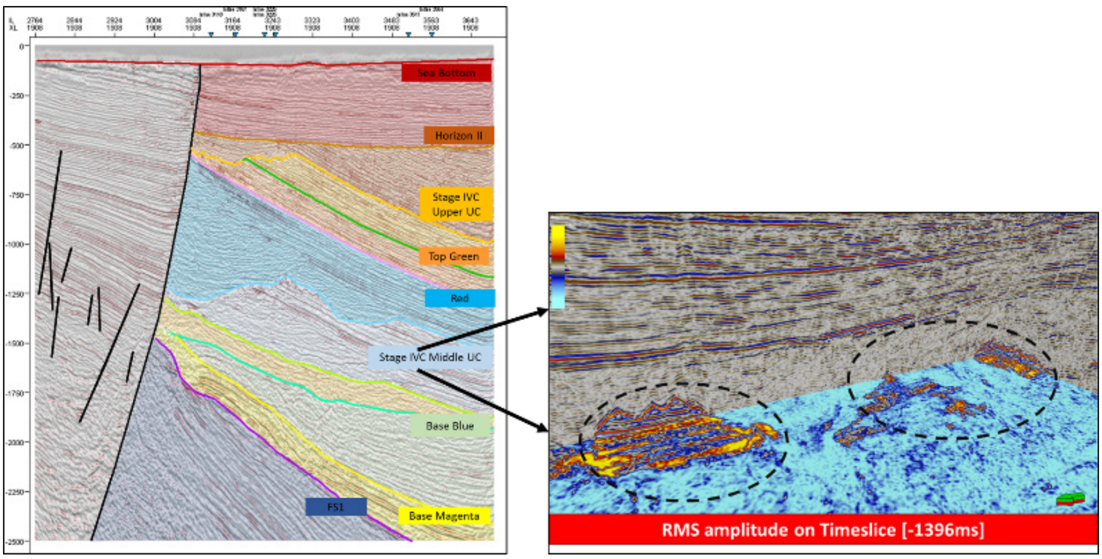

Figure 3 Hydrocarbon occurrence (black dotted line) identified by RMS amplitude attributes analysis on Stage IVC middle unconformity (top reservoir)

From the good log analysis, well SB–1 was identified as a deviated exploration well located at the northern part of the field, with the primary objective of the well is to test the presence of hydrocarbon potential of stage IVC unconformity and magenta sands. Few intervals have been defined to ease the interpretation. The well was drilled to the depth of 2170 m (TVD_{SS}). From the interpretation of facies, the target reservoir of well SB–1 is dominated by silty sand, with a high amount of clay content (shale content – 47%). However, it has good reservoir properties with good porosity rage, ranging from 20 – 325%, with no gas show in the reservoir but only oil and water. Besides, from Thomas–Stieber shaly sand analysis, well SB–1 is dominated by lamented clay, followed by structural clay and minor contribution of dispersed clays.

In addition to well SB–1, well SB–2 is a vertical exploration well that is located at the southern of the survey area. The objective of the well is to test the potential hydrocarbon show below stage IVC middle IVC unconformity, unit–9, shale–1 and shale–2. It has been found that the clay distribution of well SB–2 is similar as well SB–1, where laminated clays dominated followed by dispersed clay and minor structural clays.

The third well has been investigated as well SB–3, which is a vertical exploration well located in the middle of the survey area. The objectives of the well are to test the potential hydrocarbon show below stage IVC middle unconformity and base magenta. The well is drilled up to 1641 m (TVD_{SS}). The lithology described as interbedded of siltstone and claystone (clay content ranges from 20 – 60%) but with good porosity values, ranging from 18% – 35%. For well SB–3, 6 working intervals; shale–1, unit–4, unit–5, unit–6, unit–7 and unit–8.). There is a presence of gas, oil and water in the hydrocarbon reservoirs. Moreover, well, SB–3 is dominated by laminated clay. Some dispersed clay formed within the shale and minor distribution of structural clays. All working intervals for well SB–1, SB–2 and SB–3 are defined as in Table 1.

Table 1 Working intervals defined for Well SB–1, SB–2 and SB–3

Well SB–1		Well SB–2		Well SB–3	
Working Intervals	Depth, m (TVDss)	Working Intervals	Depth, m (TVDss)	Working Intervals	Depth, m (TVDss)
Shale–1	1390 – 1409	Shale–1	1460–1520	Shale–1	1270–1329
Sand–1 (Stage IVC Unconformity)	1409–1440	Stage IVC UC	1520–1541	Unit–4 (Stage IVC Middle UC)	1329–1352
Shale–2	1440–1457	Unit–5	1541–1561	Unit–5	1352–1385
Sand–1 (Magenta Sand)	1457–1469	Unit–6	1461–1589	Unit–6	1385–1408
				Unit–7	1408–1462
				Unit–8 (Base Magenta)	1462–1542

ELASTIC PROPERTIES ANALYSIS

From the provided P–wave velocity, S–wave velocity and density logs, elastic properties of rocks will be extracted out, and these elastic properties will be used as the critical input parameters for cross plot analysis on the effect of clays on rock physics properties. Some of the elastic features like acoustic impedance, shear impedance, velocity and more have been extracted (Table 2).

Rock physics analysis was performed using the elastic properties against the petrophysical properties computed. The elastic properties of rocks will be evaluated under the presence of clays with different porosity and water saturation. According to Han et al. [1], wave velocity reduces with the presence of clays. However, the presence of clays increases the P–wave velocity in well SB–1, and this is because the porosity of the shale intervals is lower compared to sand intervals. In contrast, well SB–3 and SB–2 show the

Table 2 Elastic properties that have been extracted using V_P, V_S and density

Elastic Properties	Descriptions
Compressional Sonic Log	$V_p = 1/DT$
Shear Sonic Log	$V_s = 1/DS$
Bulk Modulus	$K = \left(pV_p^2 - \frac{4V_s^2}{3}\right)$
Shear Modulus	$G = pV_s^2$
Acoustic Impedance	$AI = \text{Þ}*V_p$
Shear Impedence	$SI = \text{Þ}*V_s$
Velocity Ratio	$V_p = V_s$
(Poisson Ratio)	$PR = V^2{}_p - 2V^2{}_s / 2(V^2{}_p - V^2{}_s)$
LambdaRho	$A\text{Þ} = AI^2 - 2SI^2$
MuRho	$v\text{Þ} = SI^2$

response of Marion's velocity–porosity relationship for shaly sand [2] where the P–wave velocity decreases within increases with clay content (increase in porosity) but increases after the critical porosity (45%). For water saturation, the increases in shale layer increased the water saturation due to the clay–bonded water in well SB–1, but the water saturation does not increase a lot within the shale intervals in well SB–3 and SB–2. The decrease of porosity in shale interval in SB–1 could indicate that the shale intervals are much compacted than the other two wells; well SB–3 and SB–1. Besides, the water saturation can also be used to study the effects of clay content on rock physics properties. The increases in clay content will increase the water saturation but not so apparent in well SB–3 and SB–2 (Figure 4).

From the analysis, the surveys area has increased in porosity in shale from north to south of the survey area. The increase in porosity reduces P– and S–wave velocity. However, the data is more scattered in S–wave; this could be due to the high–water saturation content present in the shale intervals. The S–wave in shale intervals is generally slower than sand intervals as they have higher water saturation than sand and shear wave is not sensitive to liquid like water. Thus, the data scatter and decrease. For the shale layer, the lower porosity at the northern part (well SB–1), could indicate that the shales are hard shale with high water saturation.

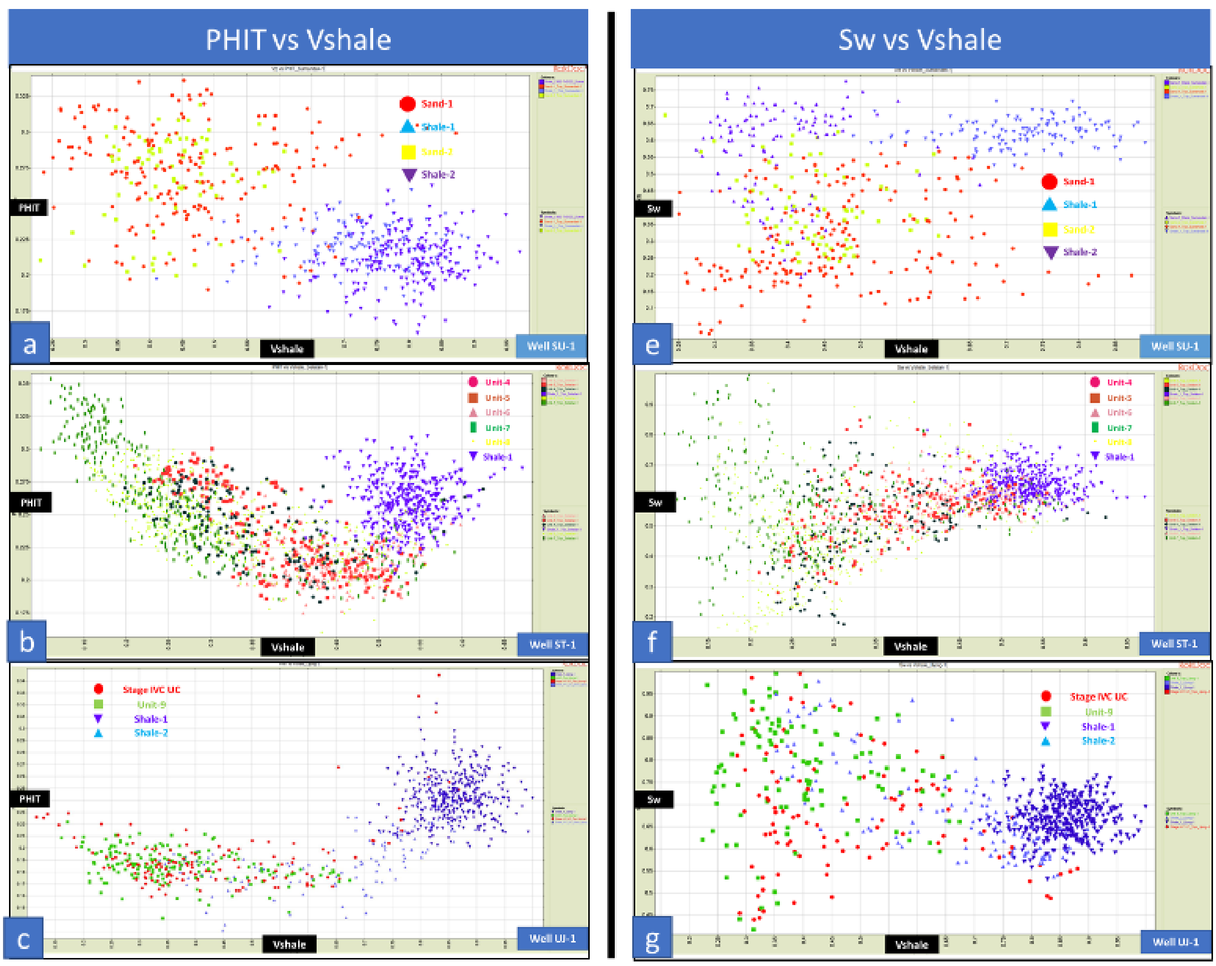

Figure 4 Cross plot of PHIT vs V_{SHALE}, (a) well SB–1, (b) well SB–3, (c) well SB–2; Cross plot of S_W vs V_{SHALE}, (d) well SB–1, (e) well SB–3, (f) well SB–2

Moreover, the low porosity of shale could also be due to the water saturation like irreducible water that occupies the pore space. Conversely, the shale moving to the south is becoming soft shale with high porosity and reduce in water saturation. The higher porosity can also be interpreted as the reduction in water saturation allow more space for the hydrocarbon to move in and reduce in irreducible water amount (Figure 5).

DISCUSSION

From the rock physics analysis, the clays content present in the reservoir shows an increase in porosity while a decrease in water saturation from North to South of the investigated field, even though the sand intervals indicate the opposite trend. This reduced the net pay of the reservoir as porosity decreases and water saturation increases. The increase in porosity, which can soften the clay content, and this will jeopardise the interpretation on the reservoirs as the elastic properties of the rocks will be mixed up (Figure 6).

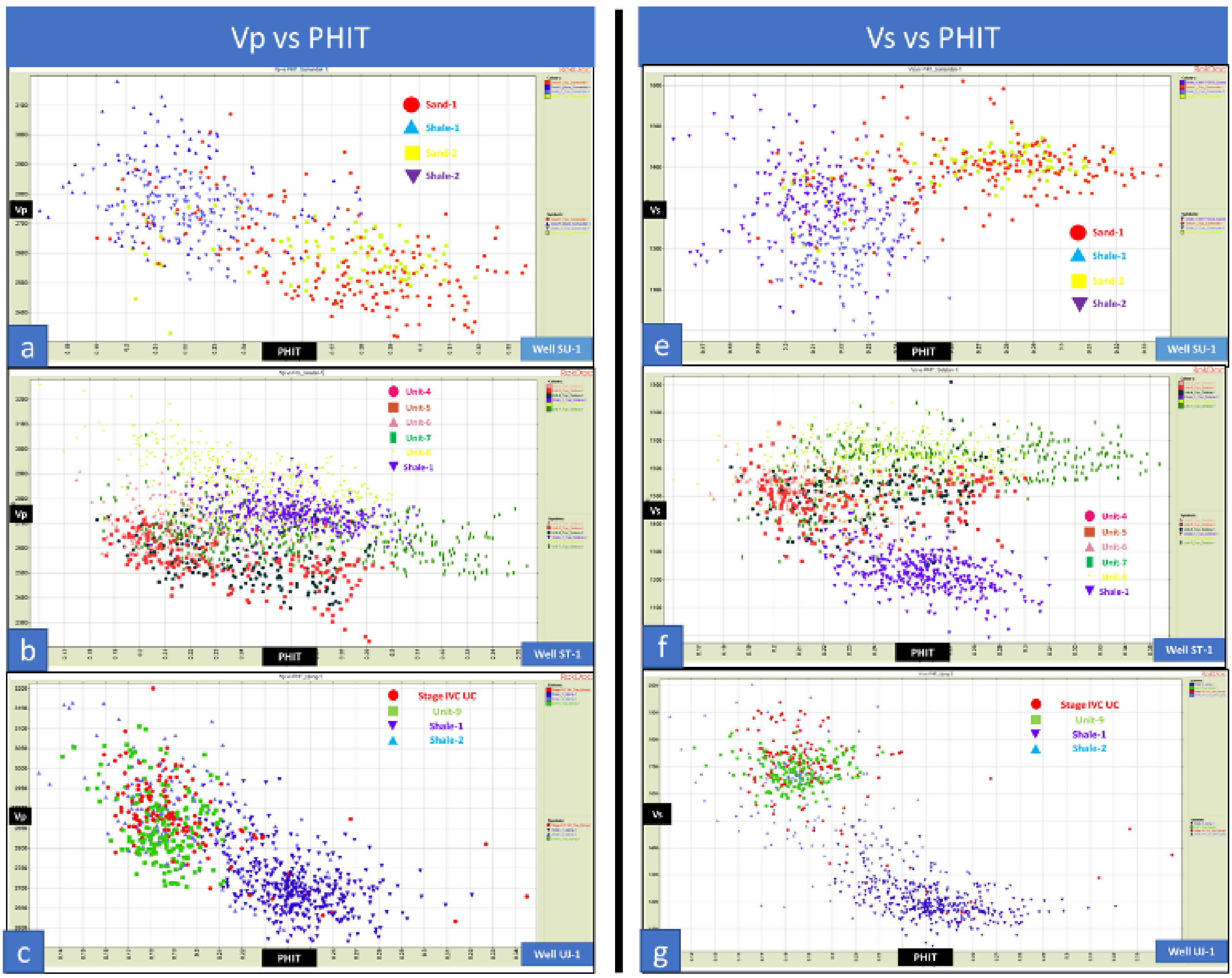

Figure 5 Cross plot of V_P vs PHIT, (a) well SB–1, (b) well SB–3, (c) well SB–2; Cross plot of V_S vs PHIT, (d) well SB–1, (e) well SB–3, (f) well SB–2

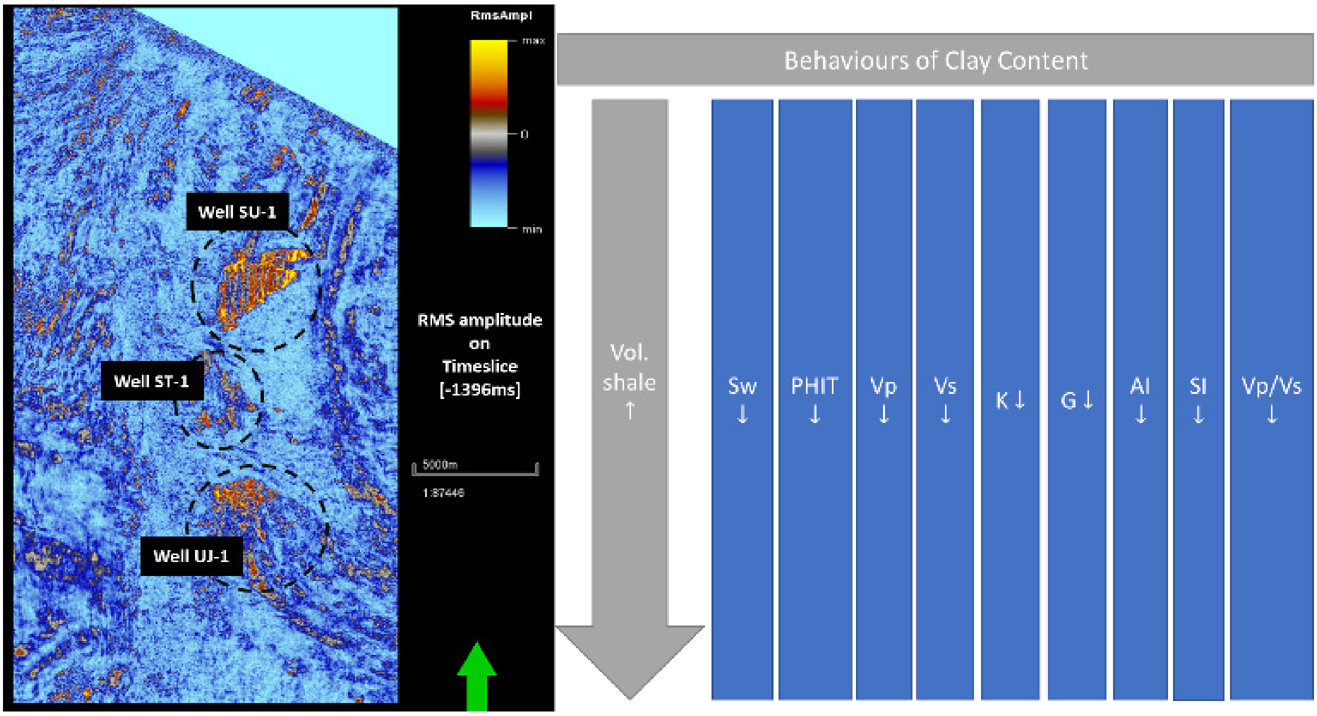

Figure 6 Overall behaviours of the clay properties in the SB field, Sabah Basin

Thus, to evaluate whether the clay will have any harmful impact on the reservoirs, rock physics template on the identification of lithology and fluids will be used [4]. Cross plot of V_P/V_S versus acoustic impedance (AI) and Mu–Rho versus Lambda–Rho had been constructed to examine the lithology and fluids content. From the cross plot of V_P/V_S versus AI, the shale intervals can be identified from the hydrocarbon reservoirs, even the properties of clays are changing across the survey area.

In general, shale intervals show an increase in V_P/V_S, while the hydrocarbon reservoirs all display a lower V_P/V_S and AI, as the presence of hydrocarbon reduces the S–wave velocity travelling in the sands. Furthermore, Mu–Rho (measure the rigidity of rock) and Lambda–Rho (measure the incompressibility of rock) can also distinctively separate the clays content from the hydrocarbon reservoirs as shale which has higher incompressibility but lower rigidity (Figure 7).

CONCLUSION

The reservoirs studied shows that the basin is dominated by the silty sand, with a broad range of volume of shale present (0.10 – 0.70). However, the reservoirs have good porosity ranges, averaging from 0.2 – 0.3, even though with a high amount of clays present. Based on the cross plots' analysis, the clay distributions dominated in the reservoirs are laminated clays, but well SB–1 indicated a higher amount of structural clays with a minor contribution from dispersed clay, whereas well SB–2 and well SB–3 had shown a higher amount of dispersed clay with minor contributions of structural clays. From the cross–plot analysis, the elastic properties like P–wave and S–wave velocity are depended not only on clay content, but porosity and fluid content play some part in changing the elastic properties with porosity has a higher weightage in its influence. For instance, an increase in P–wave velocity with clay content with the porosity is high and low water saturation, just as shown in well SB–1. In general, the clays in the SB field is much compacted at the northern part, with gradually softening when moving to the south. While the study indicates that it is a good quality reservoir, the high amount of clay content does not jeopardise the quality of the reservoirs as the clays content can be separated clearly from the oil and gas reservoirs.

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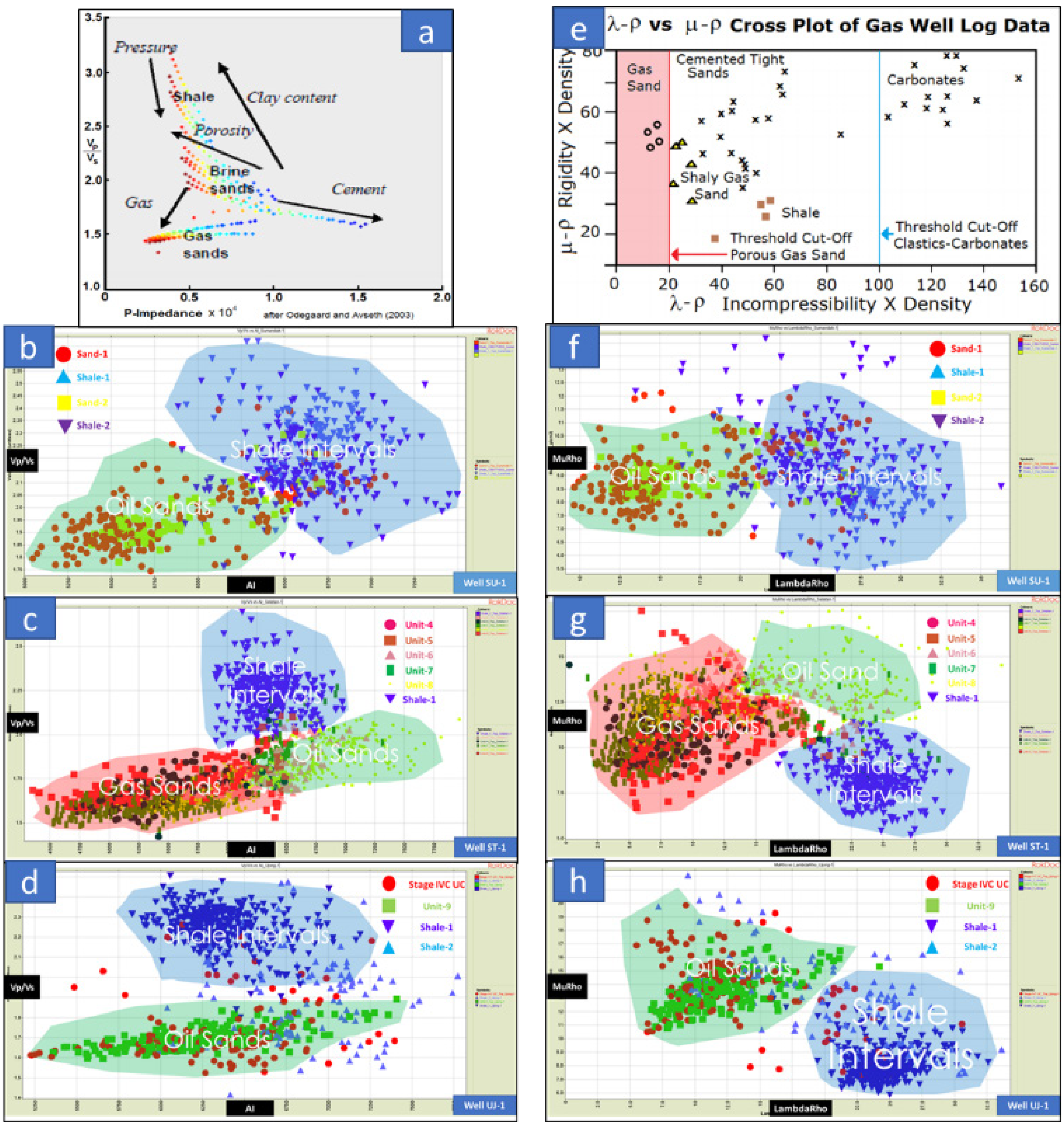

Figure 7 (a) Template model of V_P/V_S vs AI [5]; Cross plot of V_P/V_S vs AI for (b) well SB–3, (c) well SB–2, (d) well SB–1; (e) Template model of Mu–Rho vs Lambda–Rho by Goodway et al. (2013); Cross plot of Mu–Rho vs Lambda–Rho (f) well SB–3, (g) well SB–2, (h) well SB–1

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