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Reservoir characterization using sand, silt, clay model in the upper Cibulakan Formation, North West Java Basin

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Abstract
Characterization of clastic reservoirs in the North West Java basin has many challenges due to the presence of Clay which influences the reservoir. Until now, there are differences in whether the calculation of the fine fraction is calculated by shale volume (Vsh) or clay volume (Vcl), which are currently considered the same. The first is rock type and the next is naming which uses grain size or mineral type as the basis for naming rocks. Inaccurate Vcl quantification can provide errors in porosity and saturation calculations due to the impact of clay density and conductivity if the equations used depend on the conductivity of the clay
Alternative models are offered to evaluate reservoir composition in the form of sand, silt and clay, which may be applicable in some local areas and not applicable in other areas. One of the fundamental things is the availability of a mixture model between the volume of Sand, Silt and Clay because dispersed Clay has an impact on the calculation of porosity and effective water saturation, especially when evaluating low resistivity and contrast (LRLC) reservoirs
In this research, we discuss the use of the Sand Silt Clay ratio model which is commonly used in the Malaysian Basin to see whether this model can be used in other basins. To validate the results, they were compared with the results of core analysis in the form of grain size distribution and the results of X-ray diffraction (XRD) analysis in the research area.
The proposed technique helps in calculating the effective porosity and maximum volume of Clay as an important parameter in petrophysical analysis besides being used for formation characterization and sedimentology purposes. The proposed model will help minimize uncertainty as a suitable approach for improving accuracy in mineralogy, porosity, saturation calculations, and ultimately in volumetric calculations.

Keywords: Reservoir characterization, upper Cibulakan, Java Basin

Introduction
There are many publications discussing various classifications of clastic reservoirs; one of the most recent publications is from Kola *et al*. (2021) [5] who concluded that fine-grained rocks can be represented in the full spectrum of clastic sedimentary rocks on a triangular diagram with percentages of sand, Coarse Clay and Fine Clay as end members (Fig. 1). The grain size limits in this triangle are defined as follows: fine silt (clay and very fine silt) less than 8 µm, medium silt (fine and medium silt) range from 8 to 32 µm, coarse silt (coarse silt) range from 32 to 62.5 µm, and sand ranges from 62.5 to 2000 µm. The benefits of the proposed grain size limits are very well explained by Kola *et al*. (2021) [5].
Siltstone and mudstone are terms that are deeply entrenched in the fine-grained sedimentary rocks literature, however, their definitions vary somewhat and their usage has caused confusion in the past. Following proposed grain size limits (Fig. 1) and made a clear separation between texture and composition.

Although there are many books and papers that discuss shale and clay, they do not differentiate between them explaining them clearly or correctly. Until recently, the term "Shale volume" (Vsh) and the term "Clay volume" (Vcl), were used interchangeably. One piece of literature that discusses this is a paper from Luay Ahmed *et al*, 2022 [6], according to him, shale is a rock and is typically defined as sedimentary rock that is hardened, finely layered, and consists mainly of clay, mud and silt.

The important thing to note is that this definition does not describe the mineralogy but rather the grain size. In this definition, clay refers to clay-sized particles (i.e. <1/256 mm).

Millimeters (mm)		Micrometers (µm)	Phi (ϕ)	Wentworth size class	
	4096		-12.0	Boulder	Gravel
	256		-8.0	Cobble	Gravel
	64		-6.0	Pebble	Gravel
	4		-2.0	Granule	Gravel
	2.00		-1.0	Very coarse sand	Sand
	1.00		0.0	Coarse sand	Sand
1/2	0.50	500	1.0	Medium sand	Sand
1/4	0.25	250	2.0	Fine sand	Sand
1/8	0.125	125	3.0	Very fine sand	Sand
1/16	0.0625	63	4.0	Coarse silt	Silt
1/32	0.031	31	5.0	Medium silt	Silt
1/64	0.0156	15.6	6.0	Fine silt	Silt
1/128	0.0078	7.8	7.0	Very fine silt	Silt
1/256	0.0039	3.9	8.0	Clay	Mud
	0.00006	0.06	14.0		

Fig 1: Distribution of sedimentary rock grain sizes, adapted from Wentworth, Bharat Prasad Bhandari (2021)

This means that one can use the terms siltstone, mudstone and mudstone as alternatives to these terms, while clay itself, apart from referring to its size, can also refer to the mineral and it is the double meaning of the word Clay that often creates confusion in the industry

When calculating porosity, we must take clay minerals into account (e.g., in determining when their density differs from the matrix density). When calculating water saturation, we must take into account the excess conductivity resulting from clay minerals. In both cases what needs to be corrected is the volume of clay minerals, not the volume of shale. In this alternative scheme, mudstone, for example, is a rock composed of more than two-thirds fine mud-sized grains, less than one-third coarse mud-sized grains, and less than one-quarter sand-sized grains.

Likewise, siltstone is a rock composed of more than two-thirds coarse mud-sized grains, less than one-third fine mud-sized grains, and less than one-quarter sand-sized grains. According to Hammad S (2023), the presence of silt 1) reduces the electrical resistivity of the productive zone, 2) increases the natural gamma ray activity of the rock, 3) increases neutron porosity, and 4) conversely, does not reduce the spontaneous potential. (SP) deflection. These four silt influences can result in interpretation errors in identifying reservoirs or productive zones, clay volume, porosity and fluid saturation.

Application of the binary sand shale litho-porosity model (Figure 2) shows that the effective porosity, should be close to zero in the peak area of the boomerang distribution on a typical neutron density crossplot (Yudiyoko, 2019) [7]. Core samples from the same facies (in the Malaysian basin) give porosity values in the range of 10% to 15%.

Because the core porosity is assumed to represent the effective porosity, while the sieve data shows the presence of a large number of silt-sized grains, usually ranging from 30% to 60%, it is concluded that the sand-shale binary litho-porosity model is not suitable for shale reservoirs with effective porosity, then new models need to be accommodated. Development of a shale reservoir model in the Malaysian Basin consisting of clay minerals, or shale and silt.

This model has been validated with core data in the form of petrographic descriptions (TS, SEM), as well as XRD, XRF (Fig. 3). The result of this model is the presence of clay minerals (20% to 40%) at the silt point. This paper discusses the use of a sand-silt-clay volumetric calculation technique model in the Malaysa Basin using data from the North West Java Basin, in this way it will be known whether this Malaysian model can only be used in the Malaysian Basin or can also be used in other places

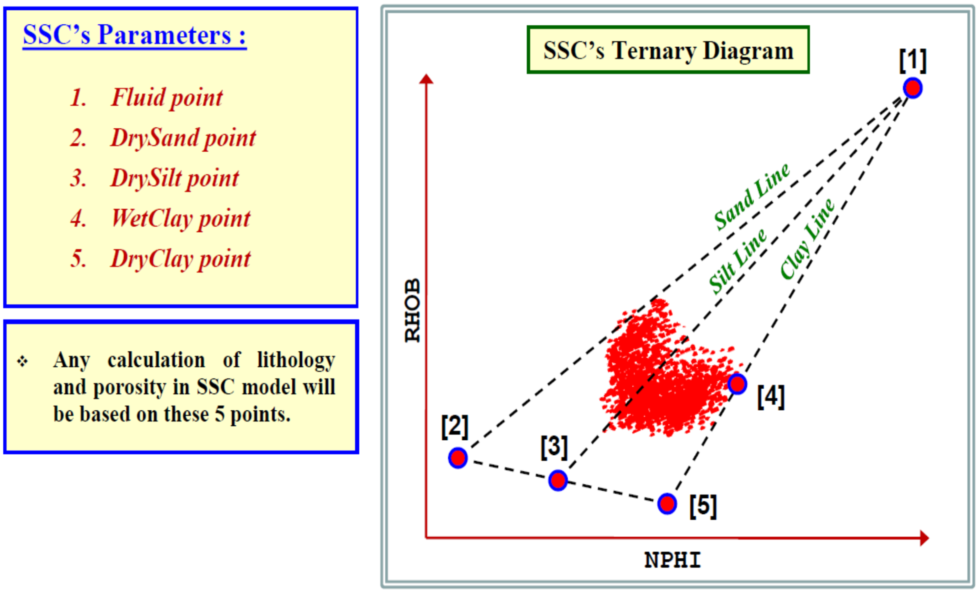

Fig 2: Triangular diagram model of Sand, Silt Clay of the Malaysian Basin (Yudiyoko, 2019) [7]

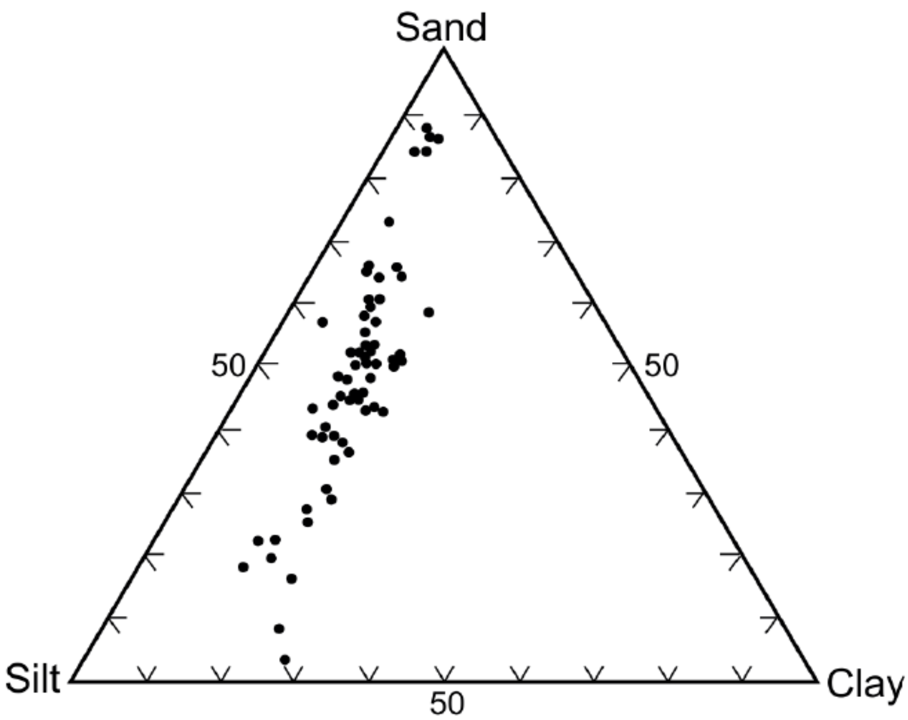

Fig 3: Malay Basin core sieve analysis displayed in ternary diagram, Gamal Ragab *et al* (2016)

Methodology

There are several different models developed to evaluate sand-silt-clay reservoirs, among them the one used and discussed in this paper. There are three models commonly used, namely; the first is based on a neutron - density crossplot while the third uses an NMR porosity model. Barlai's Phi_max technique (1971) shows that clay gradually fills the sand porosity to a maximum. Thus, the sandstone does not contain silt. The effective porosity value for a certain clay content, Vsh, is (Øsd Max - Vsh). If in this type of rock there is a Vsilt silt fraction that increases gradually, it will replace the Vsand sand fraction, it can be assumed that with increasing silt volume, the macro porosity of the sandstone decreases linearly with increasing Vsilt according to the following function:

$$Øsd = Øsd\text{Max} - \text{V}sh.\ \frac{1-Vsh-VSilt}{1-Vsh} \quad (1)$$

By rearranging this equation, we can solve for the volume of Silt, Vsilt. Some commercial software uses the following equation:

$$\text{V}Silt = 1 - \text{Vcl} - \frac{Øef}{Ømax} \quad (2)$$

Where,
Vcl = Clay Volume
Vsh = Shale Volume
Vsilt = Silt Volume
Øef = Effective Porosity
Øsd = Macro Porosity
Ømax = Maximum Reservoir Porosity

Malaysian Model

The litho-porosity model based on neutron-density crossplot is illustrated in Figure 2 (Yudiyoko *et al*. 2019) [7]. The basic framework of this model is defined in terms of quartz (2), water (1), dry Clay (5), and Silt "mineral" (3). Data points that have a boomerang-type distribution can be associated with the basic framework of the model. So, all points on the sand line represent clean quartz sandstone, all points on the Clay line represent wet and pure Clay, and all points on the Silt line represent wet and pure siltstone. These three were then referred to as Sand, Silt and Clay respectively. Thus, each rock (matrix and porosity components) can be described based on this model.

The position of the dry silt point (3) is determined by the extension of the water-silt line to the grain density of 2.68 g/cc. The dry Clay point (5) is obtained by extending the sand-silt trend (1-4) until it intersects the water-Clay trend (1-5). Although this method of obtaining 5 is a completely constructional approach, the density and neutron response at this point are within the range of acceptable values. The actual location of point 5 is not important for interpretation. In this model, based on the end members defined above, sand and Silt are considered mutually exclusive. So the 1-2-3 trend, is basically Silt free, and the 1-3-5 trend is basically sand free.

The NMR model is not discussed in this paper due to limited NMR log data available in the research area

Case Study

Miocene sandstone reservoirs are very well developed in the North West Java Basin. More than hundreds of wells in the North West Java Basin have been drilled and penetrated sandstone reservoirs both in onshore and offshore areas, to date there are still many wells that are still producing from reservoirs which until now were believed to only come from shaly sand reservoirs located in many fields in onshore areas as well as in fields and oil and gas fields in offshore areas. Even though there is a lot of subsurface data in the form of geophysical, geological and reservoir data in the North West Java Basin, in this paper only log and core data are used.

The characteristics of sandstone reservoirs can be studied based on log responses and also rock core data. It is hoped that the available data can answer questions about the sandstone model as an oil and gas reservoir, so that hydrocarbon potential that may have been overlooked can be discovered. In general, even though the reservoir is a shallow sand reservoir, its productivity is generally good.

The triple combo log obtained during drilling (Figure 4) shows that the reservoir is a sand-shale sequence. Neutron-density logs as well as test data indicate that it is an oil-containing reservoir. In addition, there are several coal seams in several drilled sections. The relatively high levels of gamma rays are interpreted to result from the presence of feldspar. The core description shows the presence of silt content in the sandstone reservoir which alternates with Clay and Shale.

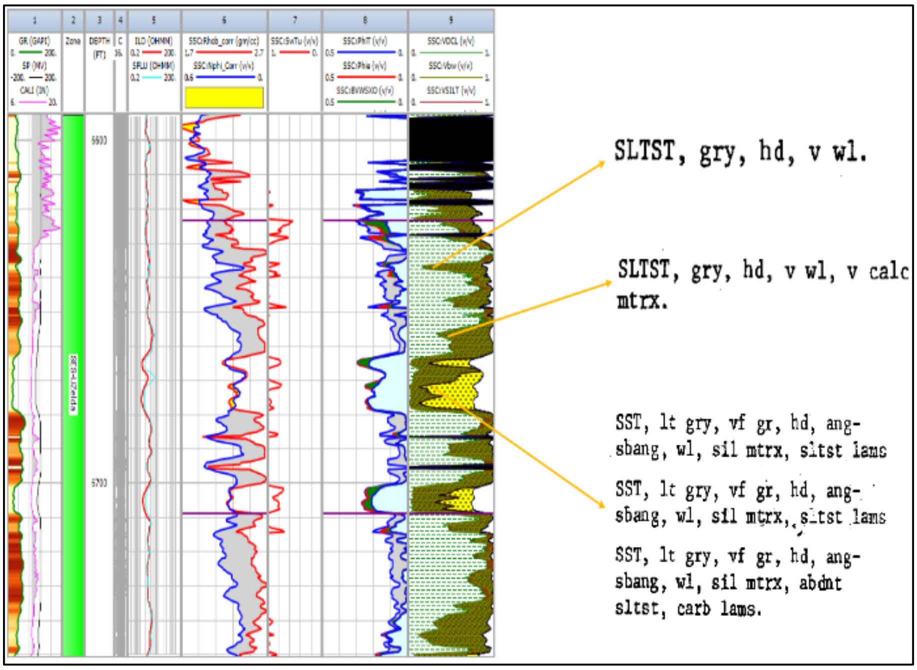

Fig 4: Composite of Triple Combo Log and Core Description

Discussion

As previously discussed in this paper, only one method is used for modeling Sand, Silt, Clay, the results of analysis on 3 wells from 3 different fields using this method can be seen in Figure 5:

In general, Wells X-01, X-02 and X-03, shows a comparison between Sand and Clay where Clay is more dominant than Sand where the Clay volume in the X-02 well seems to be too large compared to the volume of Silt, this will cause a decrease in the effective porosity value and hydrocarbon volume.

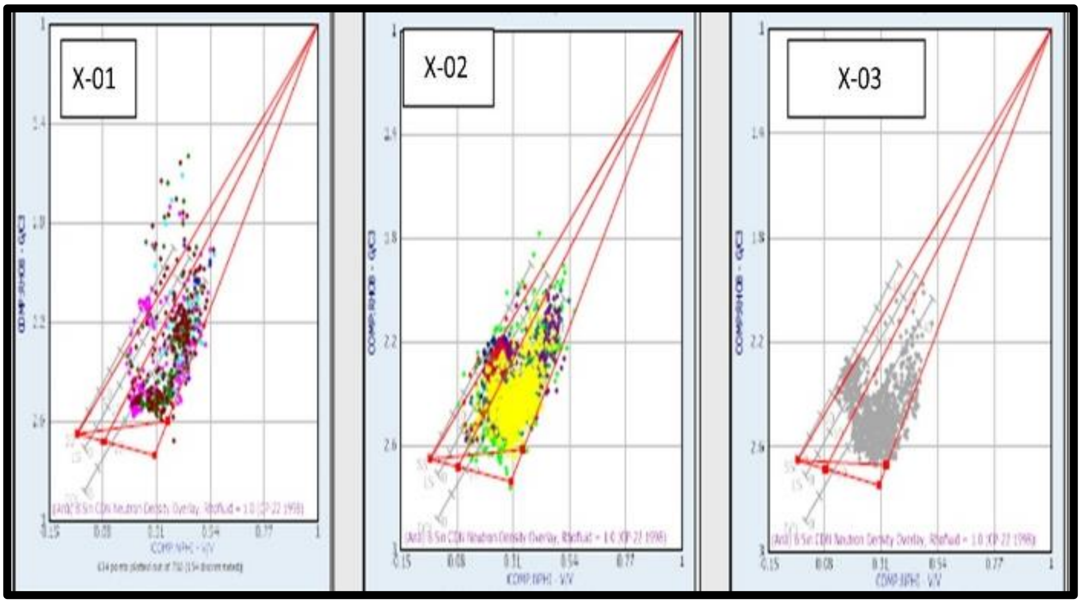

Fig 5: Sand, Silt, Clay Model Using Neutron-Density Crossplot Method

Validation of Results

Core analysis data is very important data in making the Sand, Silt Clay model which will be used for model validation, thus even though the results of core analysis and/or XRD during the making of this paper are very limited, they are still used to validate the model which divides the reservoir into Sand, Silt and Clay

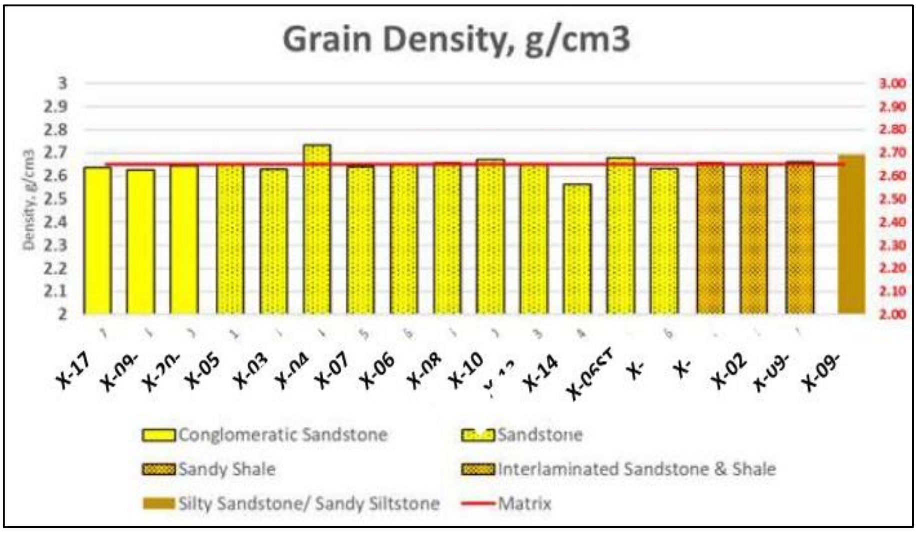

Fig 6: Distribution of Sand Silt Clay/Shale Core Analysis Results

Figures 6 and 7 show the distribution of data from core analysis of the ratio between Sand, Silt, Clay and validation of Clay calculations using logs with Clay volumes obtained from XRD analysis. From the validation of the two volumes, the log calculation results with the core analysis results show quite good results.

Comparing the results of models using log data is usually also validated using the results of NMR analysis, because as we know, NMR logs can provide estimates of grain size distribution, but as previously mentioned, unfortunately very little NMR data in the research area has been processed to be able to provide depiction of grain size distribution, thus, in this paper cannot be used to validate the model.

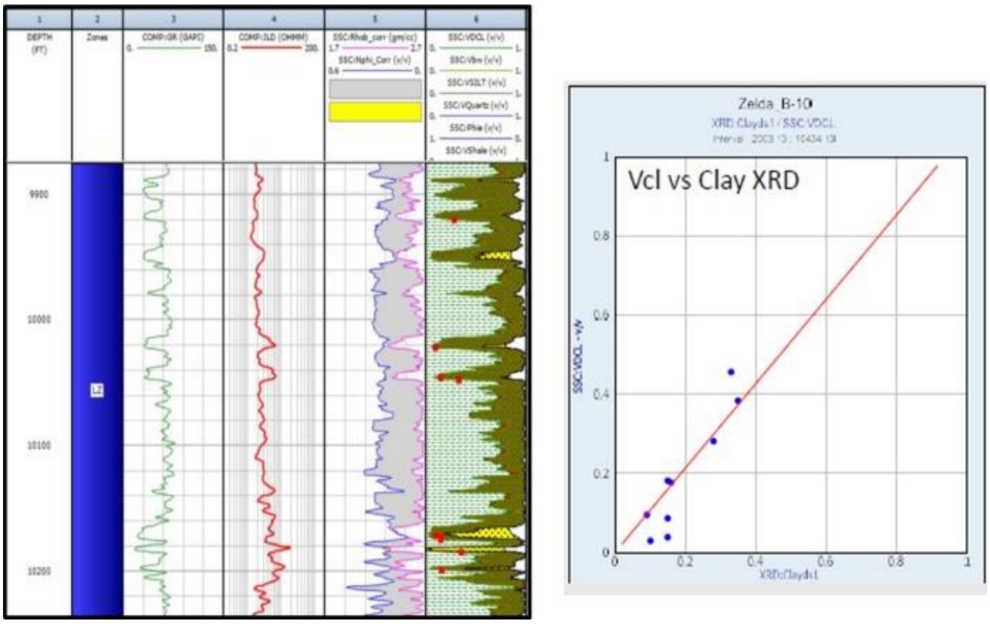

Fig 7: Comparison of Clay Calculations from the Model with Clay Volumes from XRD

Conclusion

- The Sand, Silt and Clay model can be applied not only in the Malaysian Basin but can also be used in other basins that have similar geological characteristics
- This model can be used to reduce the uncertainty in the amount of clay volume which affects the effective porosity value which will also affect the volumetric calculation
- The presence of Silt in a reservoir is basically almost the same as the presence of Clay where the presence of both can complicate reservoir characterization work
- Validation with core rock is needed to prove the results of the Sand, Silt, Clay model that has been created
- If there is no core analysis data then NMR can be used to validate sand-silt-clay calculations using size distribution using the T2 relaxation spectrum

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