Rock Physics and Petrographic Parameters Relationship Within Siliciclastic Rocks: Quartz Sandstone Outcrop Study Case

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Abstract. Rock physical parameters value (Vp and Vs) is one of fundamental aspects in reservoir characterization as a tool to detect rock heterogeneity. Its response is depend on several reservoir conditions such as lithology, pressure and reservoir fluids. The value of Vp and Vs is controlled by grain contact and contact stiffness, a function of clay mineral content and porosity also affected by mineral composition. The study about Vp and Vs response within sandstone and its relationship with petrographic parameters has become important to define anisotropy of reservoir characteristics distribution and could give a better understanding about local diagenesis that influence clastic reservoir properties. Petrographic analysis and Vp-Vs calculation was carried out to 12 core sample which is obtained by hand-drilling of the outcrop in Sukabumi area, West Java as a part of Bayah Formation. Data processing and interpretation of sedimentary vertical succession showing that this outcrop comprises of 3 major sandstone layers indicating fluvial depositional environment. As stated before, there are 4 petrographic parameters (sorting, roundness, clay mineral content, and grain contact) which are responsible to the differences of shear wave and compressional wave value in this outcrop. Lithology with poor-sorted and well-rounded has Vp value lower than well-sorted and poor-rounded (sub-angular) grain. For the sample with high clay content, Vp value is ranging from 1681 to 2000 m/s and could be getting high until 2190 to 2714 m/s in low clay content sample even though the presence of clay minerals cannot be defined neither as matrix nor cement. The whole sample have suture grain contact indicating telogenesis regime whereas facies has no relationship with Vp and Vs value because of the different type of facies show similar petrographic parameters after diagenesis.

1. Introduction

Physiographically, the sandstone outcrop in the study area is located in Sukabumi area along the boundary of Bandung Zone and Central Depression Mountain Zone. It is belong to Bayah Formation in Walat Mountain and reliable as a good analogue of sandstone reservoir with good porosity. A method of reservoir characterization had been applied to this outcrop, named rock physics.
Rock physics is a method to identify rock characteristics based on its physical parameters are P-wave velocity ($V_p$), S-wave velocity ($V_s$), bulk density, acoustic impedance, shear modulus and elastic modulus.

2. Geological Overview
West Java had been clearly divided into 5 physiography zone by Van Bemmelen (1949). The study area is located along Bandung Zone and Central Depression Mountain zone based on this zoning. Bandung Zone is formed by intramontaine depressions that consists of Tertiary rocks. Structurally, this zone is a collapsed West Java anticline crest after uplift tectonic and filled by young volcano deposits afterwards while regionally it is located on volcanic-magmatic part of Sunda Arc (Martodjodjo, 1984). Sunda arc lies from Sumatra towards East until Nusa Tenggara as manifestation of interaction between Indo-Australia plate and Eurasian. It is occured through subduction process (Fachri, 2001).

Plate activity has a significant role to configure structural setting and stratigraphy of a certain area. Panigoro (1984) in Martodjodjo (1984) made general structural trend map of West Java based on integrated seismic and gravity data (Figure 1). According to that map, structural trend that developed in West Java is divided into three:

a. Southwest – Northeast Trend (Meratus Trend) with Late Cretaceous to Early Tertiary age that responsible to Tertiary Basin forming along Ciletuh to Meratus.

b. North – South Trend with Eo-Oligocene age. This trend is marked by N-S orientation of normal and transform faults.

c. West – East Trend (Java Trend) with Oligo-Miocene age, marked by W-E orientation of fold and thrust fault which controlled Bogor trough and its turbidite deposits.

Bayah Formation consists of quartz sandstone with calcareous shale and coal intercalation that deposited during Middle to Late Eocene (Martodjodjo, 1984) (Figure 2). It lies unconformably by shale of Batuasih Formation which is interfingering with Oligo-Miocene Rajamandala Formation.

![Figure 1. Geological structure trend map of West Java (modified from Panigoro, 1981 in Martodjodjo, 1984)](image-url)
Figure 2. West Java regional stratigraphy (modified form Martodjodjo, 1984)

3. Rock Physics Analysis
Physical rock properties could be defined through elastic parameters e.g. P-wave velocity (Vp), S-wave velocity (Vs), density (ρ), Lambda-Rho (λρ), Mu-Rho (μρ), and Poisson Ratio (σ) that describes subsurface rock conditions and create wave transmission type within the rock as well. These parameters are controlled by matrix, porosity and pore fluids (Biot, 1956).

Every earth material has a certain Vp value. Generally, it will be increasing as well as increasing of medium compacity that passed by. P-wave or compression wave is also known as longitudinal wave that can be vine through solid, liquid or gas medium while it velocity can be calculated as a function of bulk modulus (k), shear modulus (μ), and densitas (ρ) (Gassman, F, 1951) by using this following equation.

\[ V_p = \sqrt{\frac{\lambda + 2\mu}{\rho}} = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}} \]  

(1)

In other hand, S-wave (shear wave) is defined as transversal wave with particle movement perpendicular from its wave transmission direction. S-wave could not pass liquid and/or gas medium because of zero value of shear modulus. Vs is affected by density (ρ) and shear modulus (μ), without modulus bulk (k), can be expressed as following.

\[ V_s = \frac{\mu}{\sqrt{\rho}} \]

(2)
4. Methods
This study began by doing observation of the outcrop and made detail description afterwards (Figure 3). The results used as guidance to choose facies that can be taken for further analysis. Laboratorium activities including rock physics parameters calculation, Routine Core Analysis (RCAL) and petrographic investigation was carried out for each sample from the outcrop (Figure 4). Then, interpretation was done based on integration of these processes to identify sample characteristics and physical properties. Result of integration process is visualized by cross plot to lead a brief conclusion (Figure 5).

Figure 3. The sandstone outcrop in the study area
Figure 4. Sampling techniques sketch

Figure 5. Study workflow
5. Interpretation and Result
The outcrop in the study area is dominated by quartz sandstone interbedded with shale and coal intercalation. It comprises of four lithofacies based on their grain size are conglomeratic sandstone, fine-grained sandstone, medium sandstone, and coarse sandstone. Several sedimentary structures found e.g. cross lamination and current ripple. Sedimentary/rock textures (sorting, roundness, fabric, grain contact, and clay content) also be an important part and included to lithology description.

This study is focused on medium to coarse sandstone which is good sorted, close fabric, sub-rounded to sub-angular indicating that grains has been transported far from its source and during a long time. The grain interacts each other and formed some types of grain contact such as long, point, concave-convex and suture contact that could be observed obviously by petrographic observation.

Rock classification in this study refers to Pettijohn’s Classification (1975) based on clay (as matrix) percentage of rocks. Petrographic analysis result shows that most of sample is classified into arenite because of low clay content (<15%).

Figure 6 showing the relationship between petrographic parameters and rock physics. Generally, there are 3 major group of sample based on their clay content (0-15%; 16-30%; >30%). Cross plot of Vp and Vs among matrix percentage gives a unique trend (Figure 6). Sample with low matrix percentage has the highest value of Vp and Vs and vice versa. It can be said that the presence of matrix within rocks gives significant effect to Vp and Vs value.

Fracture is another factor that controlled rock physics parameters (especially for Vs). It can decrease S-wave velocity due to its perpendicular position to wave direction (Figure 7). Sorting and roundness also give contribution to the response of Vp and Vs value. Poorly sorted lithology with subrounded grain shape has value of Vp and Vs lower than well sorted lithology with subangular grain shape whereas grain size is not clearly effected to Vp and Vs value.
6. Conclusion
Vp and Vs value are strongly affected by matrix content, quartz mineral and fracture also controlled by sorting and roundness. However, grain size has no significant role to Vp and Vs value.

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