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Geology constrained rock physics modeling

Abstract

Rock physics laws relates reservoir properties such as porosities, mineralogies, saturations, pore fluids, rock texture, deposition and diagenetic history to elastic velocities. In view of availability of a large number of rock physics model, it is not trivial to select the correct rock physics model suiting a particular study. Rock physics diagnosis is an important step when selecting and building a rock physics model. The rock physics modelling procedure should be guided accurately with geological constrains and the uncertainties associated with each input for a particular rock physics model should be well understood when working with log data alone. The objective of this work is to use rock physics diagnostic to first analyse the data, validate the understanding with the geology and then finally apply the rock physics model with the available geological constrains in mind. We also assess the uncertainty associated with each of the inputs in form of the geological trends. This study is carried out on a well from West Tryal Rocks of Northern Carnarvon basin which brings out that quartz cementation and sorting in this area has a dominant role to affect the velocity-porosity relationship.

Introduction

Rock physics models can provide an accurate link between porosities and velocities. These relationships depend upon the lithology as well as the rock texture. Rock physics has far wider applications beyond predicting shear velocities which is the most common and widely used practice in contemporary times. As proper rock physics modelling provides greater insights into basin level of understanding of a reservoir, it is quite important and critical to have an initial rock physics diagnostics of the data. It involves analysis, understanding and integration of all geological information available in form of cores, thin sections etc. In case of data limitation like absence of core data, uncertainties in inputs as well as the results should be understood when drawing conclusions from rock physics model as uncertainties in different input parameters will affect uncertainty in the final results. As more data is available with time, it is always advisable to update the rock physics model so that geologically meaningful conclusions could be drawn from rock physics diagnostics.

In this study, we focus on an appraisal well- West Tryal Rocks 4A located within West Tryal Gas field nearly 75km northwest of Barrow Island.

Figure 1 shows the location map of West Tryal Rocks 4A.

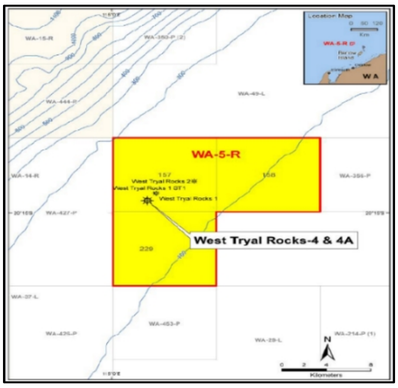


Figure 1: Well Location map for West Tryal Rocks 4A

West Tryal Rocks of North Carnavoran Basin have recorded Late Triassic sediments throughout the area. These contain Mungaroo formation underlain by Locker Shales. Hydrocarbon bearing sands namely M, N and O sand of Mungaroo formation are the focus of this study.

Geological understanding

Sedimentology report compiled by Erin et al. (2012) give detailed account of geological setup of the area. Mungaroo formation at West Tryal Rocks 4A is considered to have been deposited in a non-marine paleoenvironment in the Late Triassic. The Mungaroo formation comprises of fluvial sandstones and non-marine to brackish siltstones and coaly shales. The cored interval contains non-marine strata comprising fluvial and floodplain deposits. Fluvial depofacies association comprise fine to coarse-grained cross-bedded, structure less and rippled sandstone deposits interpreted as fluvial channels and are arranged into stacked channel belts. These fluvial channel beds are further divided into barform dominated, abandonment fill and massflow. Floodplain depofacies display repeated upwards-drying cycles composed of multiple creavasse splays, crevasse deltas and minor crevasse channel sandstones. Mungaroo is divided into three units named M,N and O sands. They exhibit considerable variation in grain size among depositional settings and within individual sandstone bodies.

The M sand is comprised of fluvial channel deposits with intervening floodplain and crevasses splay deposits. The sandstones are fine to medium and coarse-grained and moderately well sorted. The floodplain facies comprises of siltstones, mudstones and occasionally sandstone deposits overlain by fluvial channel sandstones. The fluvial channel deposits are majorly barform dominated with around 10m of fluvial channel abandonment fill. The N sand is dominated by fluvial channel deposits and is fine to very coarse-grained, poorly to moderately sorted. The base of the fluvial sands overlies floodplain strata. The O sand is also dominated by fluvial channel deposits same as M and N sands. The hydrocarbon bearing sandstone is fine to very coarse-grained, predominantly poorly sorted. The sandstone below the hydrocarbon sands deposited as fluvial channel sands is fine to very coarse-grained, generally moderated to well sorted.

Data

West Tryal Rocks 4A was selected for this study because it was quite new with acquired shear log and a considerable number of core data. With this study, we will specifically analyse 3 hydrocarbon bearing sands of different porosity ranges from well-4A namely M, N and O sands and understand present sands in Mungaroo. In terms of data availability, we have all the basic suite of conventional logs (with P and S-Sonic logs) as well as cores studies including thin section studies. The conventional log suite is used for petrophysical volumes computation and the results from core studies are used to validate the data analysis and guide for final rock physics building. The objective of this work is to understand the significance of the rock physics diagnostic by incorporating lab measurements in gaining insight about the reservoirs, i.e. hydrocarbon sands of M, N and O sand.

Petrophysics

The first step towards rock physics analysis is computation of petrophysical volumes which will be used as an input for theoretical rock physics model along with the model parameters depending upon the model being used. The basic outputs from such a rock physics model are elastic logs like P-velocity, S-velocity, density and their transforms like P-Impedance, VP/VS ratio, Poisson's ratio etc. that are further used in building seismic reservoir models. Figure 2 shows petrophysical volumes computed from logs for WT-4 well which will be used in rock physics modelling.

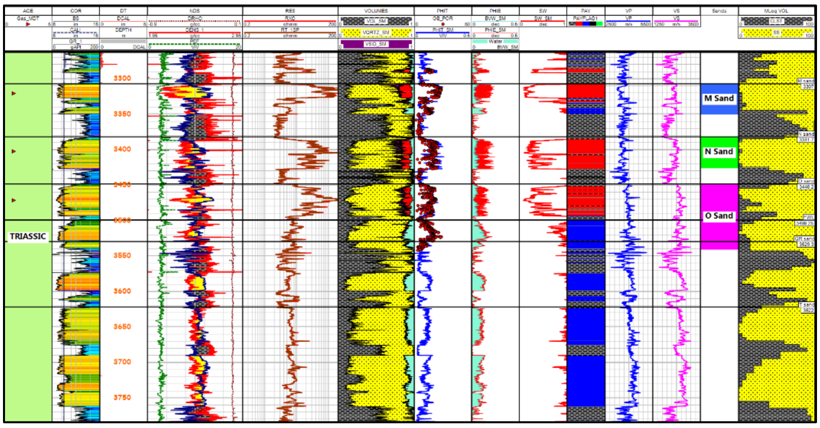


Figure 2: Petrophysical interpretation used for rock physics modelling: Track 2 shows GR and Caliper, Track 3 shows depth in MD, Track 4 shows NPHI-RHOB and PEF curves, Track 5 shows Resistivity curves, Track 6 shows Mineral volumes (Clay, Quartz, Coal and Siderite) and Fluid volumes (BVW and BVH), Track 7 shows Total porosity

The focus here is on M, N and O sands respectively. Here the average total porosity computes around 16% in HC bearing sands and average clay volume around 15%. Porosity has been calibrated using routine core analysis overburden corrected porosity and mineral volumes have been calibrated using XRD data. Trace mineral volumes less or equal than 1% have not been included. Siderite volume has been incorporated to address high density values in the formation as small volumes of Siderite (density of 3.91 g/cc) can cause substantial effect on elastic logs.

Data analysis for rock physics

The next step is to analyse the trends in the data and check for any discrepancy. For initial data analysis, crossplot between S-velocity vs porosity is used. S-velocity is used to mitigate the effect of fluid on logs and understand more of rock textural effect. Figure 3 shows S-velocity vs porosity colored by sands (M, N and O). These hydrocarbon-bearing sands show good porosity varying from 10% to 25%.

The M and N sand units have nearly identical ranges and the data distribution overlap except for few data points where N sands have higher velocity than M sands. However, O sand unit shows increase of velocity in comparison to both M and N sands, which is very clear from velocity histograms. However, to understand the reason for this porosity-velocity variation among the hydrocarbon-bearing sands of the same Mungaroo formation with same depositional environment at the given well. This will broaden our understanding of porosity-velocity relationship for this dataset, which should be consistent with available geological information and physical principles.

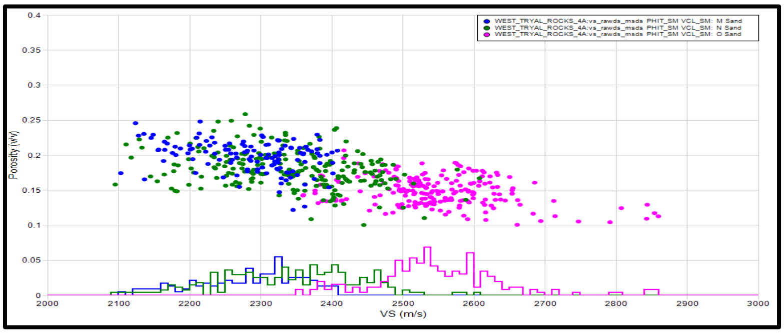


Figure 3: Vs vs. Porosity (Sand wise). Blue (M Sand), Green (N Sand) and Pink (O Sand)

The next step is rock physics diagnosis with suitable rock physics model and validate the understanding with the core studies.

Rock physics diagnosis

Rock physics diagnosis becomes an important step for better understanding of the data and aids in selection of suitable rock physics model for elastic logs driven studies. Involvement of geological data to this diagnosis further strengthens the understanding of internal rock properties. For this study, we use contact rock physics model for diagnosis.

Dvorkin and Nur (1996) introduced two theoretical rock physics models namely contact-cement model and friable-sand model. Contact-cement model assumes that the porosity reduces from critical porosity due to uniform cement deposition on the grains surface, which increases stiffness of the rock. On the other hand, friable-sand model assumes that the porosity reduces from critical porosity due to deposition of solid grains away from grain contacts as well as mechanical compaction. This model assumes grains to be un-cemented. They also introduced different contact-cement deposition schemes (Figure 4). Scheme 1 shows that all cement is deposited at grain contacts and scheme 2 shows that the cement is deposited on the grain surface.

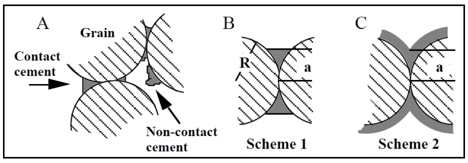


Figure 4: Contact cementation schemes (from Dvorkin and Nur, 1996)

Later, Avseth et al (1998) introduced constant-cement model, which assumes that the porosity reduction from critical porosity due to cement deposition on the grains happens only up to a certain lower porosity. Below this porosity, the reduction in porosity is due to deposition of solid grains away from grain contacts. This model is combination of contact-cement model and friable-sand model.

The schematic diagram representing the difference between these models is shown in Figure 4.

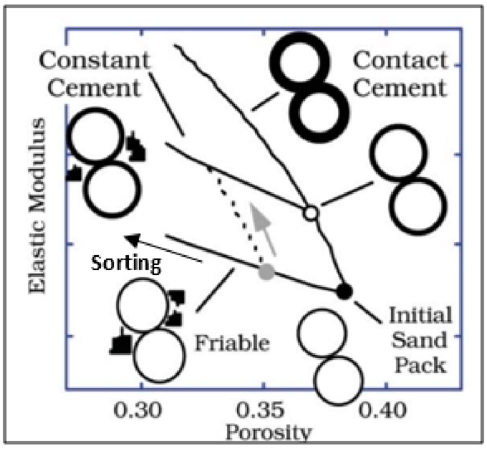


Figure 5: Porosity vs. Elastic Modulus crossplot (after Avseth et al., 1999)

For selection of the suitable rock physics model for rock physics diagnosis, we compare the data to above schematic crossplot. We assume the sands to be random pack of identical spherical grains with critical porosity of 40% and average contact per grain to be 9 referred to as coordination number.

With this diagnostic, we can assess the suitable model for rock physics studies like selection between friable and cemented sandstone model.

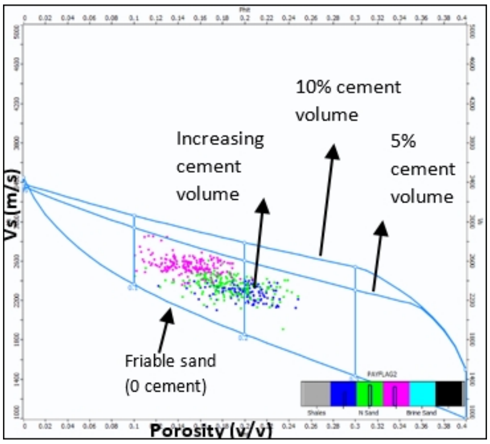


Figure 6: Porosity vs. Vs crossplot. Blue (M Sand), Green (N Sand), Pink (O Sand)

Comparing Figure 5 and 6, it is evident that these sands follow constant-cement model with indication of some cement volume presence. This is further confirmed by thin section and SEM images indicating the presence of quartz overgrowth cement (Figure 7a), and therefore for future analysis constant-cement model will be used. Quartz cement is the dominating cement and is present throughout all samples from M, N and O sands.

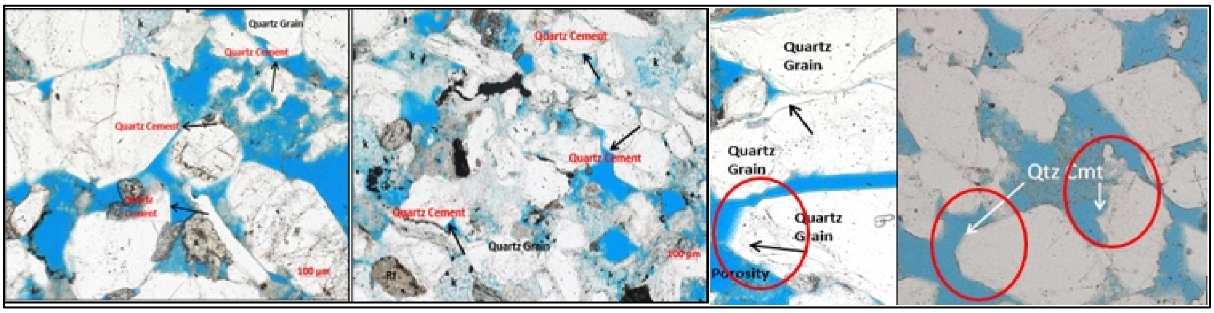


Figure 7: Presence of quartz cementation (arrows)

Although, the initial rock physics diagnostic without core studies can give qualitative idea on the rock texture, however, drawing conclusions directly from this diagnostic (for example cement volume) could be highly uncertain, as there are other geological parameters, which affect the. The key parameters that impact the velocity are i) the type of cement, ii) cement volume, ii) grain angularity iv) cement cohesion, i.e. cement distribution around the grain surface or at grain contact depending upon cement deposition scheme, co-ordination number etc. It is also important to mention that not all the cement present in the rock would glue other grains to increase overall stiffness of the rock. For example, Figure 6 shows even 5% cement to be too high for these sands when all the cement is assumed to be gluing other several grains. However, Figure 7b red circles shows that not all quartz overgrowth cement growing in continuity with original grain are gluing other grains. Hence, to quantify these uncertainties it become essential to involve core studies.

In Figure 8, we show the variability trend of different geological parameters like co-ordination number, cement cohesion and grain angularity. Increasing cement volume trend is shown in Figure 6.

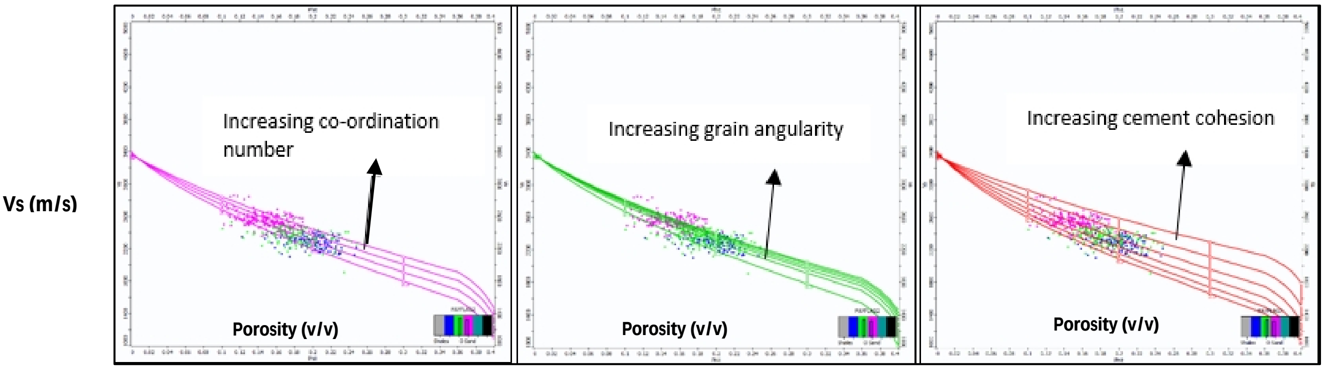


Figure 8: Porosity vs. Vs crossplot (Different Textural trends)

Next step is to finalize these parameters with the help of core information available and understand the velocity differences among the sands.

On the average, these sands are sub-angular to rounded in shape as shown in core studies. This gives some information on grain angularity to be incorporated in the model since we started to analyse the data with initial framework grains to be spherical. We now have information about grain angularity, presence of quartz cement and its distribution. In terms of cement distribution, the thin section images indicate the presence of cement on the grain surface and not entirely at grain contact. Also not all quartz cement are gluing nearby grains. Visual inspection shows that nearly 60% of the cement is actually occurring between two or more grains. With this information, we try to estimate average cement volume in the sands as in Figure 9.

The parameters being used here are grain angularity equal to 0.7, coordination number as 8 and cohesion coefficient of 0.6. Cohesion coefficient indicates about the adhesion between the grains due to cement. Value of 1 indicates that all the cement is at the grain contact and value less than 1 indicates cement distribution (uniform and non-uniform) on the grain surface. The left image shows constant cement volume lines. The sorting trend shows porosity decrease with deteriorating sorting.

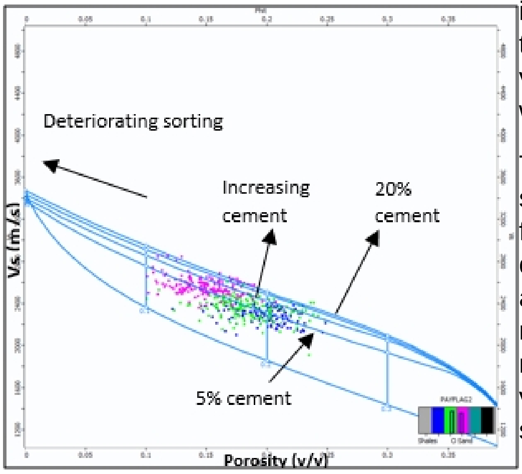


Figure 9: Porosity vs. Vs crossplot- Estimation of cement volume

The estimation of average cement volume occupying the sands is 4.5%, which is close to average cement volume from point count data for these sands. Thus, this difference of Shear-velocities with porosities may be attributed predominantly to the sorting effect. The reduction in porosity is likely due to non-contact pore-filling material (Avseth et al., 2000) causing increase of velocities. Core studies from thin section confirms that the sorting deteriorates from M to O sands with M sands being moderately to well sorted and O sands being poor to very poorly sorted.

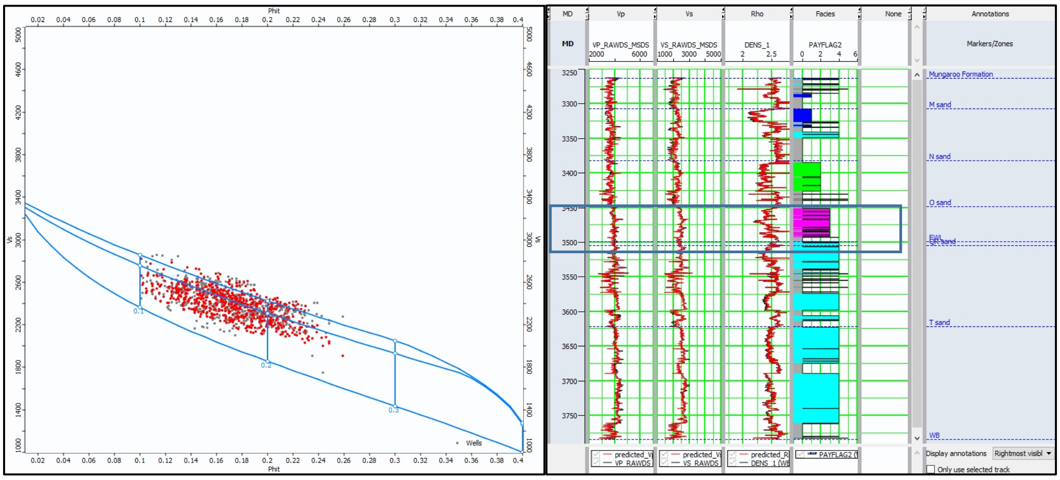
Table below highlights the cement volume and sorting information for M, N and O sands.

Sands	Trask Sorting Measurement	Quartz Cement (%)
M	1.92	5.7
N	2.01	3.4
O	2.11	4.5

Table 1: Grain Sorting and Cement information. Higher trask sorting number indicates poor sorting

Applying rock physics model

Using this estimated constant cement volume and all previous estimated parameters, we run the rock physics model. Figure 10a shows the porosity vs S-velocity crossplot respectively for M, N and O sand units. Grey points being original data points and red being predicted data. Figure 10b shows the overall rock physics prediction for the entire well.



a b

Figure 10a: Porosity vs. Vs crossplot (grey original data, red predicted data), top left logplot shows cementation effect on Vp and Vs (Green, Red, Blue are 0, 4.5 and 10 percent cement, Black is original elastic log) Figure 10b: Rock physics prediction in the logplot view. Track 1 is Depth, Track 2 is Vp, Track 3 is Vs, Track 4 is Density and Track 5 is Facies (blue, green and pink are M, N and O sand units respectively. light blue, grey and black are brine, shales and coals respectively)

Conclusions

Geology guided rock physics modeling helps to understand the reservoir better. Rock physics diagnostic forms a crucial step for selection of appropriate rock physics model and can help to assess rock texture. However, without geological guidance, the conclusions drawn from the initial diagnostics using just logs could be qualitative and uncertain and therefore, any information in form of geological studies should be incorporated in the model. In addition, any uncertainty in model inputs should be understood which could be due to the lack of sufficient data. With more data availability over time, the model should be updated. With this study from West Tryal Rocks, it is evident that rock physics modeling not only helps in shear velocity estimation but also better understanding of the reservoir when guided by geology constraints.

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