Rock physical diagnostic of diagenetic cement with additional input from M-N lithology Cross-Plot: Study from wells in East coast of India.

Shantanu Chakraborty, Samit Mondal and Ashok Yadav, Reliance Industries Limited, Navi Mumbai, 400701.*

Email:shantanu.chakraborty@ril.com

Keywords

Diagenetic cement, rockphysics modelling, M-N cross plots, core data.

Summary:

Cementation is an important stage of diagenetic processes inside a rock which involves dissolution and precipitation of minerals. Rock physics diagnostic for quantification of cement is an important part of the reservoir characterisation as it controls the fluid flow and mechanical stiffness of the reservoir. Sensitivity of reservoir rocks towards fluid/hydrocarbon presence is highly dependent on reservoir diagenesis, and it is important to include these diagenetic factors in rock physics analysis. In quantitative interpretation, focus is made on the quantity of cementation, hydrocarbon presence and rock strength apart from petrophysical inputs like reservoir porosity, hydrocarbon saturation and shale content. Rock physics cross plot like velocity-porosity (or elastic modulus-porosity) analysis gives a qualitative estimation of percentage of diagenetic cement presence in the reservoirs (*The Contact Cement Model* by *Dvorkin and Nur* in *1996*, *Constant Cement Model* by *Avseth et al.* in *2000*). In this study in addition to conventional rock physics cross-plots, we have plotted normalised M versus N to study the type of minerals present in the reservoir. Then from normalisation of M and N plot, we have calculated the percentages of cement presence in those reservoirs. Quantitative values have been compared with the core data available for the reservoir rocks which are in good agreement.

Methodology

Rock physics cross plot analysis e.g. Modulus-Porosity has been carried out which shows good agreement with the Hertz-Mindlin contact theory model. Fraction of cementation can be represented with variable cement lines as shown in the figures (fig 3-5). Estimation of cement from these rock physics models are difficult. Moreover to predict logs in forward modelling requires continuous cement fraction log which cannot be obtained from discrete core data readings. An additional approach has been attempted to quantify the percentage of diagenetic cement with M-N cross-plots which are extensively used in petrophysics to determine mineralogy. We have used processed logs (corrected for hydrocarbon and clay volume) to discriminate the clean sand and shale points on M-N cross plot. Transition paths of data points from clean sand to shale depends upon the type of shale and amount of digenetic material present within the zone of interests (figure1). M and N values are calculated as

$$M = \frac{\Delta t_{fl} - \Delta t}{\rho_b - \rho_{fl}} \times 0.01 \quad \text{........................(1)}$$

$$N = \frac{\varphi_{Nfl} - \varphi_N}{\rho_b - \rho_{fl}} \quad \text{........................(2)}$$

Where Δt_{fl}, ρ_{fl}, φ_{Nfl} are fluid properties of sonic transit time, density and neutron readings respectively. Whereas Δt, ρ_b and φ_N stands for recorded sonic transit time, density and neutron log readings respectively.

In M-N cross plot transition from clean sand to shaly sand and then shale is almost linear in nature. But in presence of diagenetic materials, transition is not linear rather curvilinear as shown in Fig 2. This bending of transition paths may be due to the cementation effect on sonic log and very little effect on density readings resulting in variations on estimated N and M values. It may be an initial indication of the diagenetic material present in reservoir rocks. An effort has been made to quantify the percentage of diagenetic materials by using deviation of actual sand-shale transition trend from normal sand-shale trend. To quantify the deviation, M is normalised and N is normalised in reversed direction and plotted together. Further the amount of overlay between the two logs (ΔMN) is estimated.It is seen that ΔMN is proportional to the amount of cement/diagenetic material present in the reservoirs. Finally this ΔMN log is calibrated with core data points to get absolute amount of cement/diagenetic material. Un-calibrated and calibrated ΔMN logs are shown at the right in Fig 2.

Study area and challenges:

Wells used for this study are located in deep-waters of East coast of India. Well A is a deepwater well drilled to Cretaceous sediments, Well B was drilled to Miocene sediments and Well C was drilled for Late Pliocene reservoirs. All the above mentioned wells encountered diagenetically altered reservoirs. Temperature and pressure conditions of these reservoirs do satisfy the criteria of diagenetic alterations. Core analysis of reservoir rock samples shows evidences of diagenetic cement presence. In rock physics modelling with contact models comprising of variable fraction of cement, the velocity with associated porosity can be well explained.

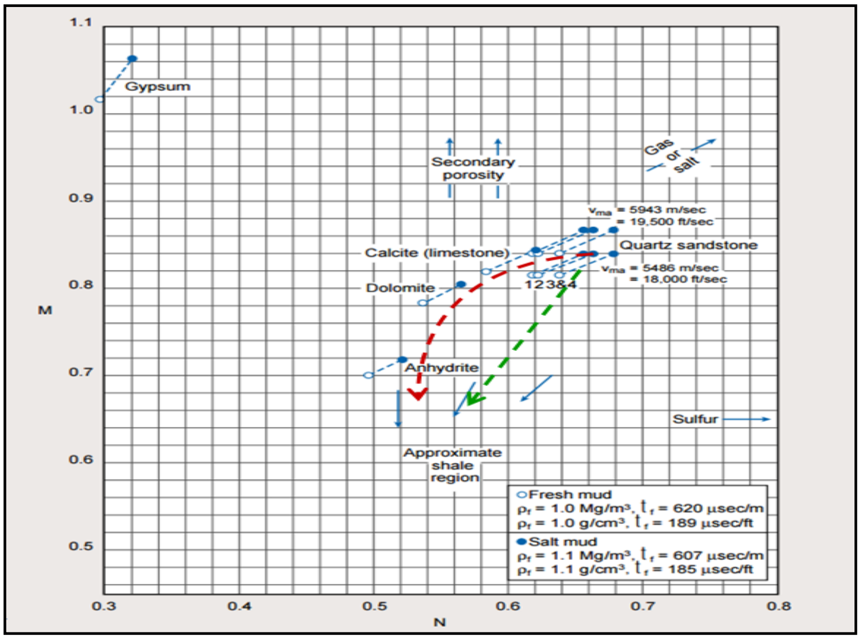

Figure 1: M-N Crossplot showing approximate clusters of clean sand/quartz, dolomite/calcite, shale. Green dashed line shows transition from clean sand to shaly sand to shale in absence of diagenetic material/cementation effect. Red dashed line indicatestransition from clean sand to cemented sand to shale. Presence of cement causes sand to shale transition to be a curvilinear in nature. (Figure modified after Schlumberger log charts, SLB Inc)

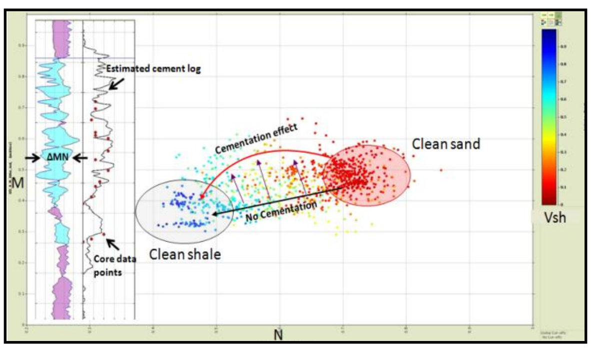

Figure 2: M-N cross plot showing the data point of sand and shale points of well C. Alongside tracks showing overlaps of normalised M & N logs used for estimation of ΔMN and calibrated cement fraction log with core data in red dots.

To quantify presence of diagenetic cement in this area is a challenge in absence of core data. Rock physics modelling in addition to this M-N cross plot study can give an insight of diagenetic effect in these wells (which has been validated with core measurement) and their effect in reservoir characterisation.

Results of the study:

Fig 3 shows Vp vs. Total porosity cross plot for the reservoir zone (with Vsh ≤ 0.4) of Well A, coloured by estimated cement log. Red lines showing constant cement rock physics model of different volume fraction of cement.

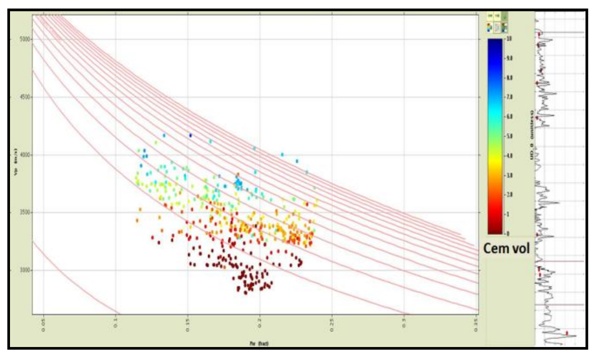

Figure 3: Vp-Porosity cross plot with variable cement lines (starts with top red line of 6% cement with step of 0.5% below) overlaid for Well A, coloured by estimated cement log. Alongside curve showing calculated cement fraction log with core points in small red circles.

Derived cement fraction log from M-N cross plot has been shown as black curve and also as colour code in the cross plot. There is a good agreement between rock physics model cement fraction and estimated cement fraction log. Core data points (red dots on derived cement log) also shows similar trend.

Fig 4 shows Vp versus Total porosity for the reservoir zone (with Vsh ≤ 0.4) of Well B, coloured by estimated cement log. The red lines show the volume fraction of cement present for this rock model which shows a good agreement with the estimated cement fraction log (in colour scale). Constant volume of shale has been considered in this analysis.Resulted cement fraction log has also been compared with the hard data and shows good match with the derived cement log.

Mismatch seen between data points and overlaid rock physics models of variable cement lines may be due to the fact that the reservoir sand contains variable amount of shale (up to 40%) but the overlaid curves are for clean sand. Deviations of derived cement fraction log with core data may be attributed to the resolution issues with petrophysical logs and depth mismatch between the two datasets. Moreover,

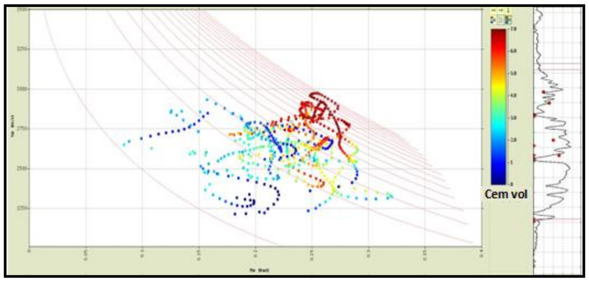

Figure 4: Vp-Porosity cross plot with variable cement lines(starts with top red line with 7% cement with step of 0.5% below) overlaid for Well B, coloured by estimated cement log. Alongside curve showing calculated cement fraction log with core points in small red circles.

in some places core plugs were taken from places having locally higher shale material content and shows as outlier.

Vp versus Total porosity plot of Well C with Vsh≤ 0.4 has been shown in figure 5, colour coded by estimated cement log data. The rock physics constant cement modelled curves are

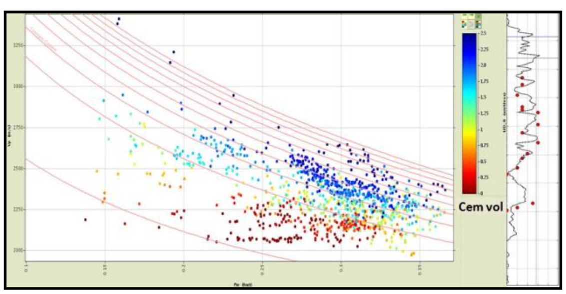

Figure 5: Vp-Porosity cross plot with variable cement lines(starts with top red line with 2.5% cement with step of 0.25% below) overlaid for Well C, coloured by estimated cement log. Alongside curve showing calculated cement fraction log with core points in small red circles.

put in red lines. Here also a good agreement can be seen between rock physics model cement fraction and estimated cement fraction log. Core data also shows overall good agreement with the derived cement fraction log.

Conclusion:

Rock physics cross-plot analysis along with M-N cross-plot can quantify the percentage of diagenetic cement in the reservoirs. Integrating geological models,(depositional environment, basin model input, sedimentological analysis etc) with this type of study can lead to a better understanding of the presence and quantification of diagenetic cement in the reservoirs. These results are very much useful for the cases where there is no sidewall core data available, or in the zone where core points had not been taken.

In our cases, we have not considered variable shale percentages which is a limitation of this study. Uncertainty associated with log-depth correlation with core data, exact picking of the clean sand and shale points in M-N cross-plot and lastly the considered rock physics model have the scope of introducing minor error in our results. Current study cannot even discriminate between contact and pore fill cements.

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