Rock Typing and Generalization of Porosity-Permeability Relationship for tight syn-rift HPHT gas reservoir - KG Offshore

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Keywords:

Summary:
Tight gas reservoirs are characterized with low porosity and permeability, small drainage radius hence low productivity, require significant well stimulation – hydraulic fracture treatment to produce at economic rates. Among the Indian sedimentary basins Krishna-Godavari basin, hold the substantial reserves in tight reservoirs and Deen Dayal field is the first offshore HPHT tight sandstone reservoir under production. Understanding the reservoir in terms of flow unit characterization is important step in designing stimulation and completion plans. The paper deals with methodology to establish generalized porosity-permeability relationship for each identified rock type utilizing cluster analysis.

Introduction:
Reservoir characterization methods play a crucial role in reservoir simulation model as they provide a better description of the storage and flow capacities of a hydrocarbon reservoir and more so in deep seated, tight gas reservoir in HPHT conditions. Upper Jurassic to Lower Cretaceous syn-rift sandstone encountered in Deen Dayal and Yanam offshore fields of KG Basin have been deposited during the early to late rift climax stage mainly driven by mass gravity flows down the basin bounding fault escarpment with some amount of lateral reworking. These reservoirs have undergone considerable compaction as well as higher order of diagenesis hence are tight, and at present under HT-HP environment requiring stimulation for economic flow. This paper covers systematic integration of core analysis, small scale rock petrology with petro-physical rock properties to establish porosity-permeability relationship for low-permeability sandstone reservoirs based on rock-typing derived using cluster analysis.

Methodology:
Among the various quantitative rock-typing techniques presented in the literature, HFU method as well as Winland Method were used for Deen Dayal Field of KG Offshore. In the study routine core data from five wells were considered to develop improved generalized porosity-permeability relationship using the above mentioned techniques.

The gravity driven early rift to rift climax stage has given rise to multi-cycle, fining and coarsening upwards cycles, thickness of each flow unit varies on the pace of sediment. The effect of diagenesis have resulted in complex heterogenetic petrophysical system. The reservoir rock-types could be classified into four hydraulic flow units, each rock-type representing different physical and chemical processes affecting rock properties during depositional and paragenetic cycles.

Based on the hydraulic flow units, the rock-type in terms of electrofacies were identified using the hierarchical clustering analysis technique based on petro-physical log responses (Vp, Vs, RHOB, Deep Resistivity, Poisson’s Ratio, Brittleness Index, effective porosity, and Water Saturation) to extract petro-physical rock types, and unravel reservoir characteristics.

The extraction of clusters from dendrogram was based on the cutoff values derived from cross-plot of Poisson’s ratio and brittleness index, wherein the rock typing could be done based on separation of five clusters. Each cluster or electrofacies has related log response that in fact reflects geological (textural and diagenetic) and petro-physical (porosity and permeability) characteristics of the reservoirs.

Geological Setup:
Deen Dayal Field is located along the East Coast in KG Offshore adjoining Yanam Shallow Field to the west of Kakinada Spit (Fig 1). Nineteen wells in the Deen Dayal Block and six wells in Yanam have been drilled and hydrocarbon exploited from late Jurassic to early Cretaceous tight sandstone reservoirs deposited during the early rift to rift climax sedimentation. The east-west trending fault escarpment has contributed to widespread sub-lacustrine fan system with few feeder channel connecting from north-east as well as cutting across the horst block during the rift climax stage. The fluvo-lacustrine depositional along with major sedimentation by development of fan deltaic setup is also corroborated by integration of core and electro-log facies analysis substantiated by seismic facies analysis.
Rock Typing Methods:

Conventional Rock Typing:

Conventional method for rock typing is based on simple regression evaluating permeability from log derived porosity. In conventional reservoir cases, a linear relationship between log permeability and porosity is obtained.

The data set for Analysis comprise 540 routine core data from 12 conventional cores cut in the lower syn-rift sequence from 5 wells drilled in the main field area. The syn-rift sequence demonstrates poor relationship between permeability and porosity (Fig 2) hence demanding other methods for developing porosity permeability relationship.

HFU Method:

HFU is based on physics of flow in pore scale and geological parameters. Rock Quality Index (RQI) is computed using equation $RQI = 0.0314 \sqrt{\frac{k}{\Phi_e}}$. The core derived porosity is then normalized using equation $\Phi_z = \Phi_e / (1-\Phi_e)$. Finally Flow Zone Indicator is calculated using $FZI = RQI/\Phi_z$

On a log-log plot of RQI vs $\Phi_z$ all samples with similar FZI values will lie on a straight line with unit slope (Fig 3).

Winland Method:

Winland approach links Petrophysical properties such as porosity and permeability to the pore-throat radius $r_{35}$ which is the pore throat radius measured in a mercury-injection capillary pressure experiment at mercury saturation of 35%. The core samples of similar $R_{35}$ values represent a single rock type. Petrophysical units would be defined using below classification of $R_{35}$ values:

- Megaport: units with $R_{35}$ values greater than 10 micron.
- Macroport: units with $R_{35}$ values between 2 and 10 micron.
- Mesoport: units with $R_{35}$ values between 0.5 and 2 micron.
- Microport: units with $R_{35}$ values between 0.1 and 0.5 micron.
Nanoport: units with R35 values smaller than 0.1 micron.

The core analysis (Fig 5) of syn-rift sequence suggests that major part of the data (94%) falls under last three classification i.e. the diagenesis of the sediments deposited during the early to climax rift sedimentation in KG Basin has destroyed megaport reservoir and only few sweet spots of macroport reservoir exists, while major part of the reservoir falls under the tight reservoir classification with permeability falling between mesoport to nanport.

These three units identified on the Winland classification were populated from the cored intervals over the complete well based on the definition of electro-facies using k-mean cluster analysis.

**Cluster Analysis:**

Cluster analysis is a multivariate approaches which aims to distribute a sample of subjects of a set variable measured into a different number of groups where similar subjects are placed in the same group. Well log cluster analysis is process aim to look for similarities and dissimilarities between data points in the multivariate space of logs, in order to distribute them into classes called electrofacies.

Poisson’s Ratio to Young’s modulus plot of the syn-rift sequence (Fig 6) depicts that the non-reservoir shale with high value of clay content having high degree of plasticity with high Poisson’s ratio and low Young’s Modulus. The reservoir rocks on other hand lie on the upper left corner depicted with low clay content having high degree of brittleness with low Poisson’s ratio and higher Young’s Modulus. The spread for the brittle reservoir divides it into good sweet spot located on the bottom right having higher effective porosity retention to tight reservoir having low effective porosity. The middle part of the spread depicts moderate brittleness and depicts shaly to silty-sandstone to silty-shale, the silty-sandstone have also been considered as reservoir based on the water saturation.

Cluster analysis (Fig 7) of basic logs (p-wave velocity and s-wave velocity derived from DTCO and DTSM, Density) and derived logs (effective porosity, water saturation and vshale) along with elastic properties (Young’s Modulus, Poisson Ratio and Brittleness Index) have been used to generate numerous clusters to match the Facies utilizing Interactive Petrophysics. Clustering the electrolog into various number of cluster and final cluster size of 23 were used to reduce error of estimation of five electrofacies groups over the complete sequence of syn-rift sequence encountered in the Deen Dayal field.

These clusters based on the properties depicted in the E-PR crossplot (Fig 8) can be classified into five rock types, viz Shale, Siltstone, Silty Sandstone, Sandstone and tight sandstone. The shale and siltstone have been merged into one group comprising as non-reservoir in Petrel Modeling. The tight sandstone which have undergone the maximum
amount of diagenesis is considered as rock type retaining minimum permeability. The silty sandstone or sandy siltstone can be considered as retaining moderate permeability while the reservoir sandstone would retain good permeability.

**Generalized Porosity-Permeability Correlation:**

The cores samples were classified into four identified reservoir rock types and used for rock typing using facies based RQI relationship.

These generated four generalized poro-permeability correlation given by equation:

- **RT-01:** $\text{PERM} = 0.00169 \times \text{Exp}(34.578 \times \text{PHIE})$
- **RT-02:** $\text{PERM} = 0.01391 \times \text{Exp}(29.434 \times \text{PHIE})$
- **RT-03:** $\text{PERM} = 0.04890 \times \text{Exp}(31.978 \times \text{PHIE})$
- **RT-04:** $\text{PERM} = 0.11772 \times \text{Exp}(39.822 \times \text{PHIE})$

The computed over measured permeability in the cores samples exhibits good fit (Fig 11) over the identified rock types. For modelling in Petrel the silty sand and shale were clubbed into a single non reservoir unit, the lowest poro-perm relationship (RT-01) was assigned to tight sandstone, next poro-perm relationship (RT-02) was assigned to sandy siltstone and RT-03 to sandstones. The high permeability sweet spots observed were difficult to capture within resolution of 1 meter vertical thickness considered for model upscaling.

**Fig 9. Rock Typing Well A**

These generalized porosity-permeability relationship were used to construct permeability from computed effective porosity over the complete syn-rift sequence in all the drilled wells in the study area.
Conclusion:
The cores samples were classified into identified four reservoir rock types and used for rock typing using facies based RQI relationship. The established rock typing from cores were populated in the entire well utilizing electro-facies classification based on cluster analysis using k-mean relationship optimized with 23 clustering. The generated permeability curves have a strong correlation with the core samples with a large sample size.

The generalized poro-perm relationship were used to generate permeability curve along the complete synrift sequence at wells. The same relationship was used in the static model to generate permeability cube to be utilized for well placement during dynamic model generation.

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