Delineating Shale Reservoir Through Electrofacies Analysis: A New Approach*

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Abstract

Facies analysis is an important methodology accepted worldwide to properly characterise a hydrocarbon reservoir and exploit the remaining volumes in development phase. In this study, shale reservoir is targeted, which generally are enriched with high TOC, have ultra-low permeability yet produce hydrocarbon for a long time using hydraulic fracturing. We have tried to capture the heterogeneity of the unconventional reservoir through electrofacies analysis. Electrofacies is developed by Heterogeneous Rock Analysis (HRA), a clustering workflow to define rock classes based on multivariate input data. It runs Principal Components Analysis (PCA) to transform the input data (gamma ray, density and neutron porosity) onto independent axes front-loading the variance, ensuring that the data used in the clustering are functionally independent. Subsequently, the principal components are used in a clustering algorithm to create HRA classification. There are several plots to quality control the clustering process and choose the number of clusters required to best classify the rock.

Core measurements (gas-filled porosity, permeability) are used to define dynamic properties such as Rock Quality Index and Flow Zone Indicator (RQI and FZI, functions of porosity and permeability). RQI and FZI aid to determine the Pore Throat distribution in the reservoir, which in turn define the existence of distinct zones (hydraulic units) with similar fluid flow characteristics. A hydraulic (pore geometrical) unit is defined as the representative elementary volume (REV) of total reservoir rock within which geological and petrophysical properties that affect fluid flow are internally consistent and predictably different from properties of other rock volumes. The key thing for this approach is that, the hydraulic units are directly related to (a) geologic facies distribution and (b) petrophysical properties like porosity, permeability and capillary pressure.

In this work, we defined electrofacies through HRA using well logs and integrated it with lithofacies (facies based on core lithological description). The integrated results were further validated with core measurements (RQI, FZI and TOC). The work has two aims, first (a) to build a robust model involving well logs and core data to predict electrofacies in un-cored wells and then (b) to delineate the shale reservoir into distinct units based on electrofacies to identify the sweet spots. Six facies were generated from this analysis, which helps us to delineate the best productive facies within the reservoir and place the laterals in sweetest part both laterally and stratigraphically. Electrofacies analysis

using dynamic properties is a common practice in conventional reservoirs. We attempted this methodology in an unconventional reservoir to characterise it and identify the sweet spots.

Introduction

Shale gas plays are a type of unconventional reservoirs where hydrocarbons are trapped within ultralow permeable (nanodarcies) shale formations with high TOC content. The natural gas is stored in two forms, free gas (within natural fractures) and adsorbed (on the surface of organic matter). Due to its low permeability, conventional recovery methods cannot exploit these reservoirs and special techniques like horizontal drilling and hydraulic fracturing are required to extract hydrocarbons from these reservoirs. Though shale reservoirs are continuous and extensive, heterogeneity plays an important role in its production. Electrofacies analysis can be a major tool to know the sub-surface heterogeneity of these shale plays.

Facies is the aspect, appearance, and the characteristics of a rock unit, allowing its separation from the surrounding beds, usually reflecting the physical, chemical and biological conditions of its origin (Glossary of Geology, 1980). Facies can be described based on various geological aspects like lithology (lithofacies), fossil content (biofacies) etc. Similarly, facies can be determined from well log responses, including borehole wall images, which determine an electrofacies. The term “electrofacies” was introduced by Serra and Abbott (1982) and has been defined as “the set of log-responses which characterizes a bed and permits this to be distinguished from others.” Electrofacies can usually be assigned to one or more lithofacies as log responses are measurements of the physical properties of rocks. The most common technique for electrofacies identification is to cross plot suitable wireline log responses and corroborating with core data. In this work, we would take a critical approach towards identifying the lithological and electrofacies from wireline logs using an approach based on Principal Component Analysis and K-means Clustering using software that utilizes both the methods in classifying electrofacies.

HRA Clustering

HRA (Heterogeneous Rock Analysis) Clustering was used for facies delineation. This method uses the input data (wireline logs) and transforms into independent variables for principal component analysis. The results are sorted into K-means algorithm to generate clusters of distinct datasets resembling different facies. We have identified six clusters based on three input logs Gamma Ray (GR), Neutron Porosity (NPHI) and Bulk Density (RHOB).

Analysis of Electrofacies

An electrofacies corresponds to a cluster in this space that is, an area of closely spaced points that have similar log responses. The distinct electrofacies correspond to different and separated clusters. The present study uses multivariate statistics, which have been applied to the conventional logs for high-resolution facies analysis in a marine environment. The numerical description of electrofacies has the potential of providing a classification of strata in the subsurface that is more precise and more objective than the merely qualitative description of lithofacies. The detailed workflow is shown in Figure 1.

Multi-Well Histograms-Input Logs

Application of multivariate statistical techniques requires that a common set of logs be available from all wells under study. Because the purpose of electrofacies analysis was to discriminate among lithofacies, resistivity logs were not considered; they record chiefly variations caused by differences among fluid saturations in the formation. The common dataset available for all the wells are:

- Core measurements (permeability, gas filled porosity, saturation etc. from cores)
- Wireline basic raw log data (Gamma Ray, Bulk Density and Neutron Porosity)

The log data have been verified, edited, depth shifted, and environmentally corrected real time by the vendor.

Facies Analysis

Based on the log inputs, six clusters (Figure 2) have been identified using HRA cluster analysis. These distinct six clusters are characterized as six different electrofacies and further integrated with six lithofacies described by core sedimentology. Table 1 represents an example of lithofacies description of one particular well from the study area where four major lithofacies were encountered and compared with electrofacies from HRA clustering. Dynamic functions such as Reservoir Quality Index (RQI) and Flow Zone Indicator (FZI) were derived using core measurements like permeability (K), gas filled porosity (PHIE) and these were used to validate the identified electrofacies. The study area was divided into different sub-areas and lateral facies correlation panels were generated to check the extent of various electrofacies (Figure 3). Six identified electrofacies are shown in Table 2. Validation of the facies generated by electrofacies analysis was done by TOC data (core) and RQI (Figure 4a & b).

To know the pore throat distribution of the reservoir, a cross plot of PHIZ vs RQI with FZI on third axis is generated (Amaefule et al, 1993). On a log-log plot of RQI versus PHIZ, all samples with similar FZI values will lie on a straight line with same slope. Samples with different FZI values will lie on other parallel lines. Samples that lie on the same straight line have similar pore throat and constitute a hydraulic unit (Figure 5). Six generated facies corresponds to different hydraulic units with different flow potential.

Conclusion

Six distinct facies are identified and validated with their hydrocarbon richness (TOC, RQI) and flow potential (FZI). Based on this analysis, facies 5 and 6 are identified as the best productive facies, which are resolved along the wellbores for the entire zone of interest across the study area. Summing up these best productive facies thickness, an isopach map can be generated which represents the areal distribution of sweet spots within a shale reservoir.

To exploit a shale reservoir effectively, it is important to land the lateral in the sweetest zone (with respect to hydrocarbon richness and higher fraccability) and remain in that zone throughout the entire lateral length. Another application of this study is to predict the proper landing point for laterals and geo-steer the well within best productive facies. This work simultaneously stands as a post-drill analysis for already drilled wells or wells under production, and as a predictive tool for future development wells.

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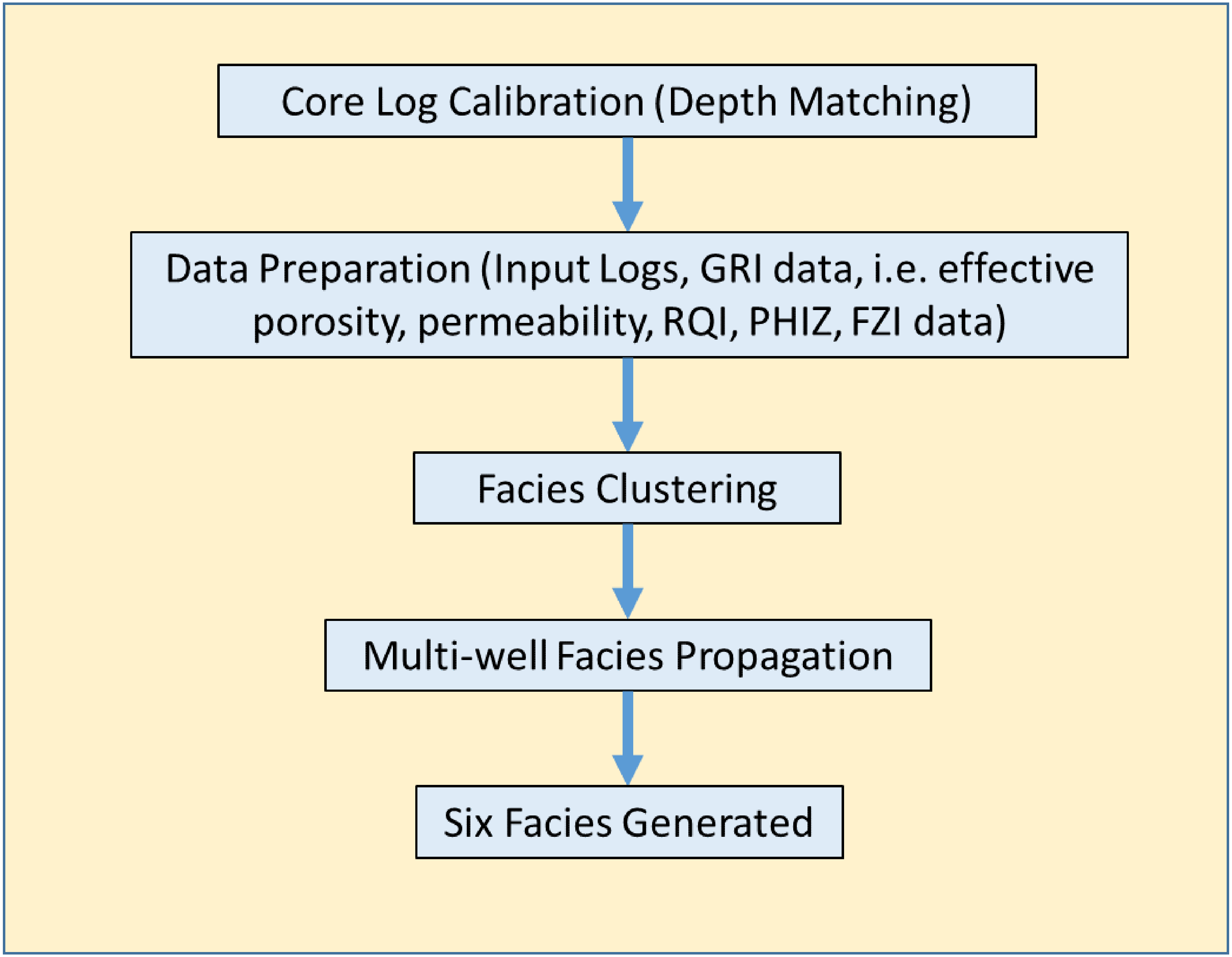


Figure 1. Workflow of electrofacies analysis.

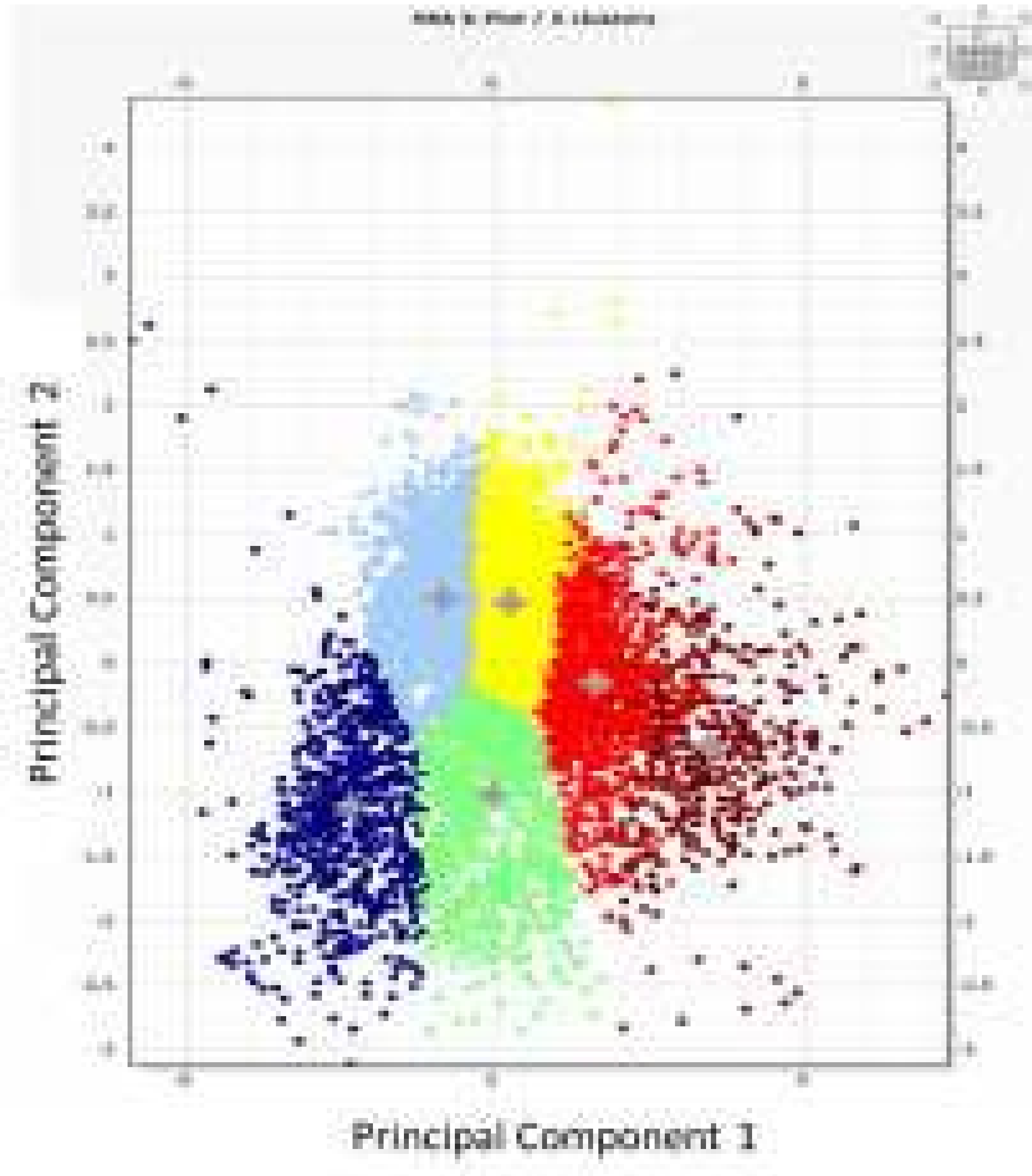


Figure 2. Six clusters identified from PCA.

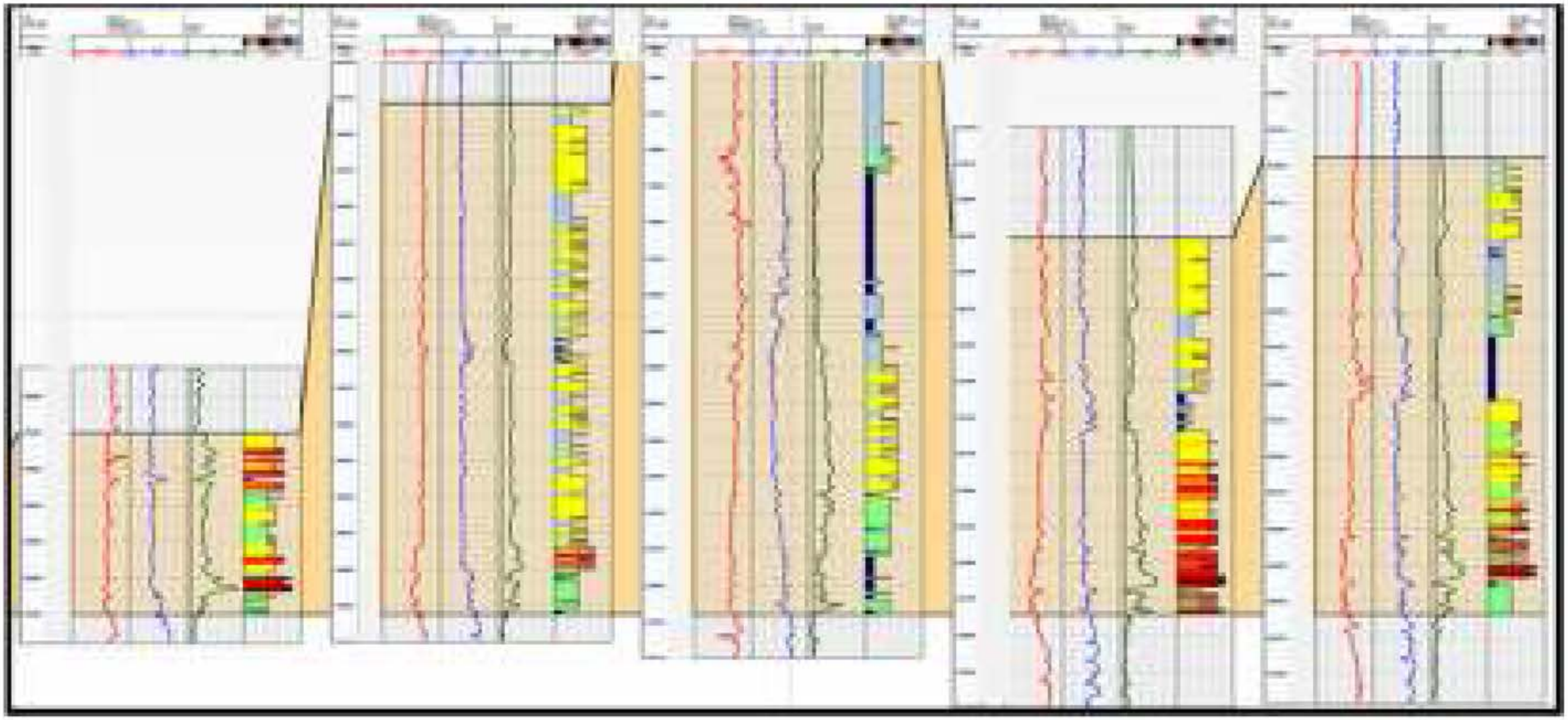
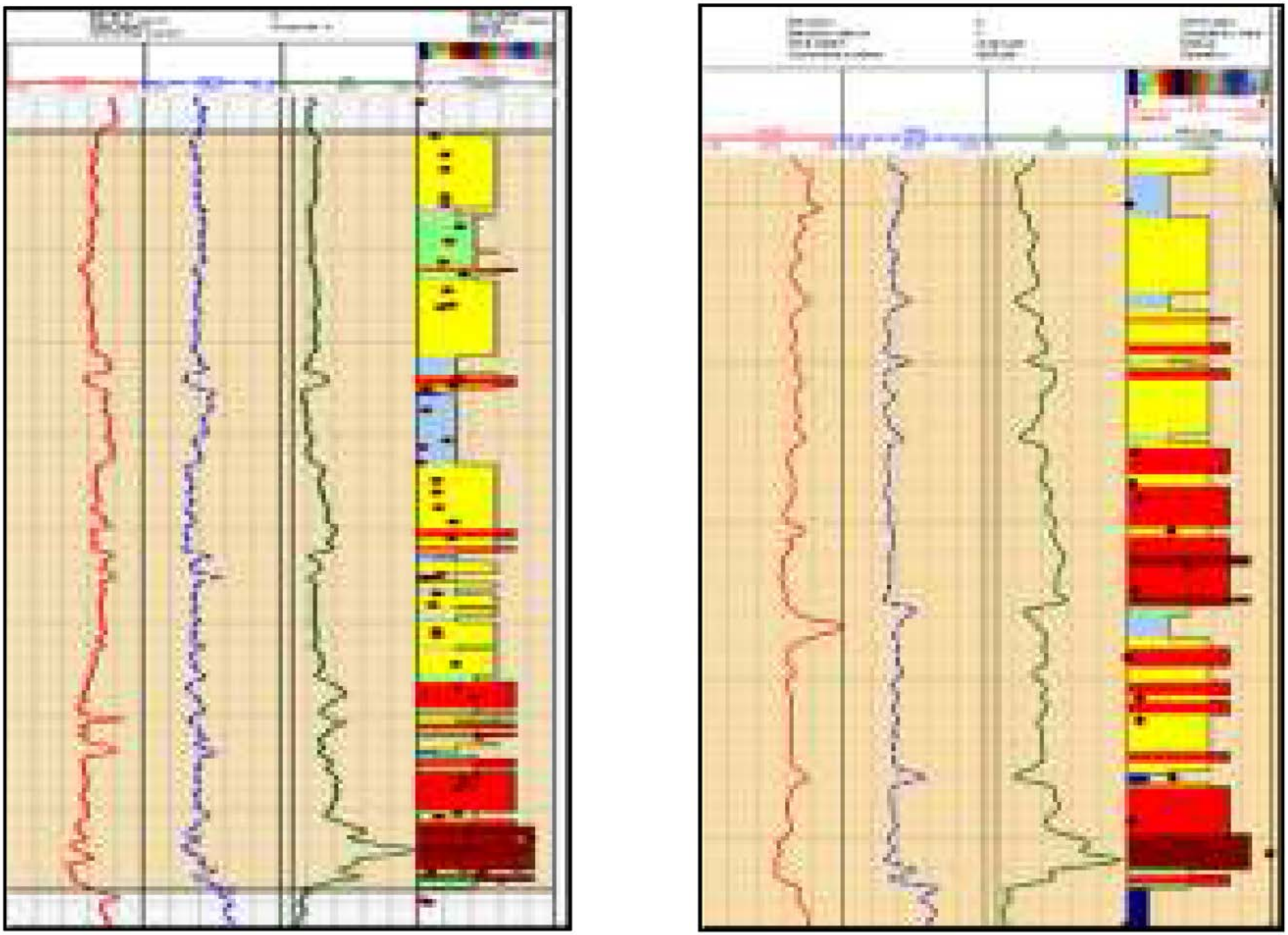


Figure 3. An electrofacies correlation across studied wells. Density, Neutron porosity, Gamma ray and electrofacies are shown in 1st, 2nd, 3rd and 4th tracks respectively.



(a) (b)

Figure 4. TOC data (circle) is plotted along with electrofacies. Facies 5, 6 (good and best facies) are validated with high TOC (a) and Reservoir quality index (RQI) (b); Density, Neutron porosity, Gamma ray and electrofacies are shown in 1st, 2nd, 3rd and 4th tracks respectively.

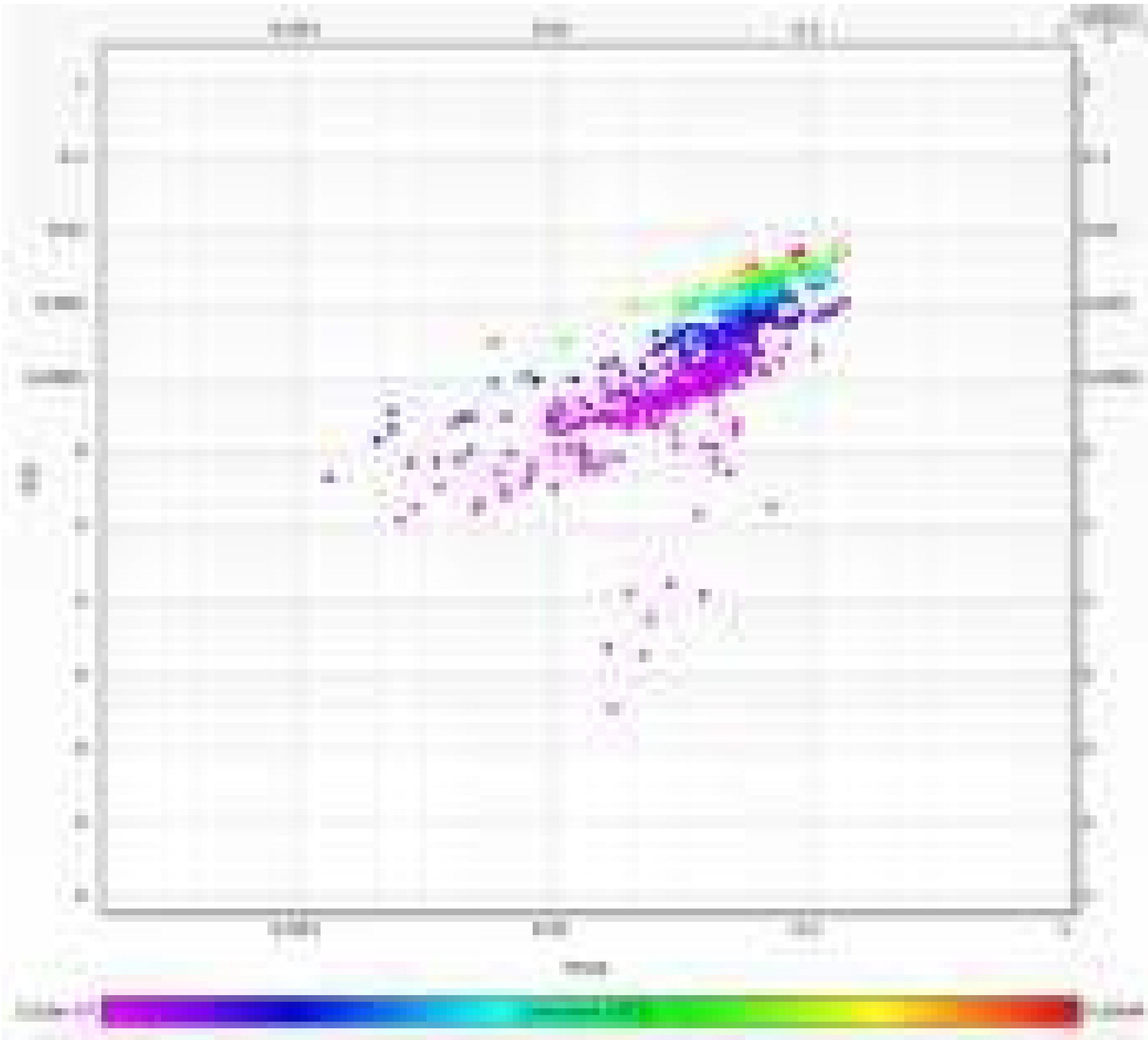


Figure 5. RQI vs. PHIZ plot for Target formation wells.

Depth	Electrofacies	Core Lithofacies
X 10	2	Dark grey to black mudstone
X 20	2	Dark grey to black mudstone (Slight calcareous)
X 30	4	Dark grey to black mudstone (High TOC)
X 40	4	Slight calcareous medium to dark grey mudstone
X 50	2	Medium to dark grey mudstone (minor calcareous)
X 60	2	Dark grey to black mudstone
X 70	1	Dark grey to black mudstone
X 80	2	Medium to dark grey mudstone (minor calcareous)
X 90	2	Dark grey to black mudstone
X 100	1	Dark grey to black calcareous mudstone
X 110	2	Dark grey to black mudstone (Slight calcareous)
X 120	2	Dark grey to black mudstone (Slight calcareous)
X 130	2	Dark grey to black mudstone (Slight calcareous)
X 140	2	Dark grey to black calcareous mudstone
X 150	4	Dark grey to black calcareous mudstone

Red	No match
Green	Match
Light green	Slight variation

Table 1. Electrofacies and lithofacies integration.

Colour	Facies Code	Facies
	1	Poorest quality facies
	2	Poor quality facies
	3	Average quality facies
	4	Medium quality facies
	5	Good quality facies
	6	Best quality facies

Table 2. Six identified electrofacies.