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Permeability prediction from well logs using clustering methods and its application in designing of Flow zone indicators.-A case study in Cambay Basin.

Abstract

Accurate prediction of permeability is an important factor for the determination of oil and gas reservoir quality and its flowing capability. It is difficult to visualise solutions to many reservoir engineering problems without having accurate permeability value. One such aspect is producibility which can be addressed by flow zone indicator. Flow zone indicator is parameter group which predicts the producibility of a reservoir on the basis of its porosity and permeability. Though porosity data is available for every well, not all wells have permeability data recorded or computed. The conventional methods for permeability determination are core analysis and well test techniques which are expensive and time consuming. This paper aims to predict permeability of reservoirs utilizing clustering method i.e. multi-resolution graph-based clustering (MRGC). The results were validated with wells having permeability data and a very good match was obtained. The paper shows that utilizing this methodology permeability can be predicted for wells even where no permeability data is available. Based on this predicted permeability, flow zone indicator for various reservoirs were constructed to assess their producibility. Heterogeneous reservoirs of Kalol formation in Cambay basin have been studied for this paper. The results obtained were quite encouraging and matched well with the production testing data of these wells.

Introduction

Oil and gas well completion relies heavily on the right porosity and permeability to ensure the oil and gas can be extracted. Porosity and permeability are the reservoir rock most significant physical properties. Porosity and permeability are geometric properties and are the result of its lithological, structural and compositional behaviour (composition). However, for assessing the producibility, of a reservoir rock, the most fundamental reservoir rock property is its permeability. Though porosity data is available for every well, not all wells have permeability data recorded or computed. The conventional methods for permeability determination are core analysis and well test techniques which are expensive and time consuming. This paper aims to predict permeability of reservoirs utilizing clustering method i.e. multi-resolution graph-based clustering (MRGC). The results were validated with wells having permeability data and a very good match was obtained. The paper shows that utilizing this methodology permeability can be predicted for wells even where no permeability data is available. Based on this predicted permeability, flow zone indicator for various reservoirs were constructed to assess their producibility. Heterogeneous reservoirs of Kalol formation in Cambay basin have been studied for this paper.

Methodology

The study has been carried out in two parts. In part A permeability has been predicted utilizing clustering method - multi-resolution graph-based clustering (MRGC). The results were validated with wells having permeability data and a very good match was obtained. Once the methodology was validated, the technique to predict permeability was extended to other wells where no permeability data was available. In part B of this study, the predicted permeability along with porosity has been used for the construction of flow zone indicator charts to assess the producibility of heterogeneous reservoirs in Kalol formation. Study was taken up for 10 wells in this paper and the results are quiet encouraging and match well with the initial production testing data. The methodology in two parts is discussed below.

A. Prediction of permeability

Permeability has been predicted using the MRGC clustering technique. MRGC is based on non-parametric K-nearest neighbour and graph data representation. MRGC is a tool which analyses the structure of the complex data and partition natural data groups into different shapes, sizes, and densities. MRGC automatically determines the optimal number of clusters. Clusters produced by MRGC are organized in a hierarchical manner so that the high order clusters are the subcluster of low order clusters. Consequently, depending on the needed resolution, we can select an appropriate number of clusters. In the lowest order, 14 clusters and in the highest order, 26 clusters were partitioned. Then, each model was used to predict permeability. The predicted permeability on the basis of each model was compared with NMR log derived permeability. The model with the maximum value of R2 was selected as the optimal number of clusters for MRGC model. 10 wells have been taken up for the studies, out of these two wells were having NMR derived permeability data (KSDR). Conventional log suit consisting of RHOB, NPHI, Deep resistivity and GR were used and MRGC method was used for synthetic Permeability estimations. Estimated permeability was then validated with recorded KSDR from the NMR log, and the constructed MRGC model was used for the permeability prediction (KSDR_PRED) in the test wells.

Ye and Rabiller proposed multi-dimensional dot-pattern recognition (MRGC) as a new clustering method for electro-facies analyses. The minimum number of clusters (14 clusters) is optimal for using in the prediction (Figure 1). MRGC model with 14 clusters was used to predict permeability in blind test well and a regression coeff. Of 0.89 was observed.

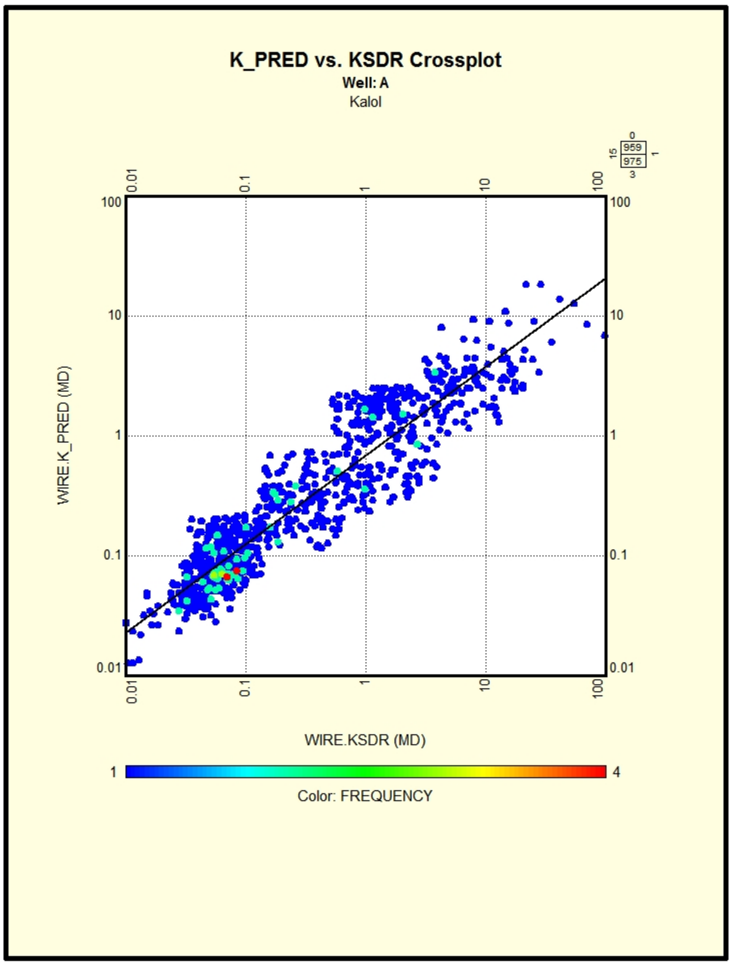

Fig-1- Regression analysis of Well-A between KSDR and K_PRED

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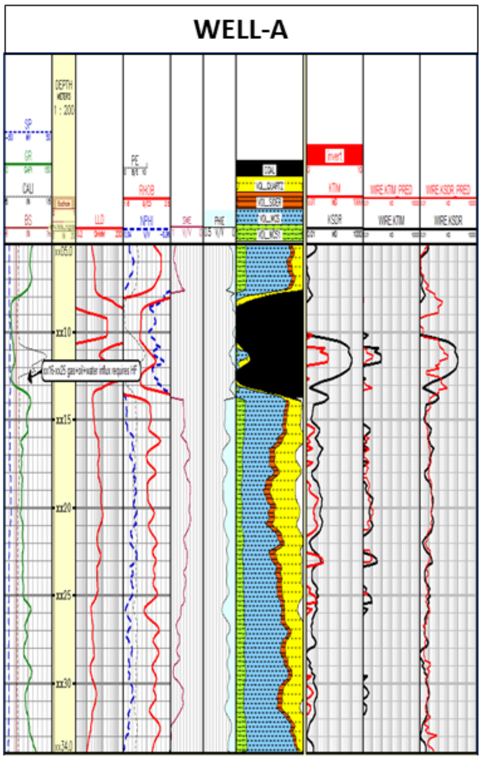


Fig-2: shows the overlap of predicted and NMR derived permeability

B. Construction of Flow Zone Indicators

Taking predicted permeability for 10 wells Flow Zone indicators have been constructed and its utility in predicting the producibility of the reservoirs has been analysed.

Flow Zone Indicators

The hydraulic flow unit is defined as the representative elementary volume of total reservoir rock within which geological and petrophysical properties that control fluid flow are internally consistent and predictably different from properties of other rocks. (Amaefule et al, 1993). Samples that have same **FZI** will be classified into the same Hydraulic Flow Unit **(HFU) or** rock type. Different authors have proposed various FZI charts. All these charts have been used for the construction of Flow zone indicators and their analysis. These charts are basically Permeability vs Porosity plots. The construction of the charts and their analysis are discussed in brief below:

i. Winland R 35

Winland developed an empirical equation relating porosity, permeability and pore aperture based on mercury injection capillary pressure data. Winland developed the following equation:

$$\log r35 = 0.732 + 0.588 \times \log(\kappa_{air}) - 0.864 \times \log(\varnothing)$$

Log is to base 10. $\varnothing$ "r" is the modal pore throat radius in microns. Because the process is based on mercury injection which requires all water to be removed (including clay bound water), it is possibly implied that the input porosity is total porosity PHIT.

ii. Pittman

Pittman modified the equation to

$$\log r35 = 0.225 + 0.565 \times \log(\kappa_{air}) - 0.523 \times \log(\varnothing)$$

iii. RQI vs. PHIZ - FZI

These are Rock Quality Index vs inter-particle porosity of PHIZ plots overlaid with flow zone indicator charts. Amaefule (1993) defined RQI (Rock Quality Index) and FZI (Flow Zone Indicator), from theoretical equations involving Carmen Kozeny. RQI is defined as:

(Eq. 2) $RQI = 0.0314 \times \sqrt{\kappa/\varnothing}$

where κ is in md and $\varnothing$ is a fraction

For the flow zone indicator FZI the relationship is:

$$\log(RQI) = \log(PHIZ) + \log(FZI)$$

where Log is to base 10

PHIZ is the pore volume to grain volume ratio or normalized porosity:

$$PHIZ = \varnothing/(1-\varnothing)$$

On a crossplot of RQI versus PHIZ (both scales logarithmic), FZI numbers are represented by straight lines.

iv. FZI

These are permeability vs porosity plot overlaid with FZI chart lines.

v. KPHI

These are permeability vs porosity plots overlaid with KPHI chart lines.

Fundamental to Amaefule's work is the ratio of $\kappa/\varnothing$. This is also present in the original work documented by Leverett in 1943 on the J function[3]. Of interest, is the similarity in shape of the chart lines between the $\kappa/\varnothing$ plot with Winland and Pittman, even though $\kappa/\varnothing$ is from fundamental theory and Winland/Pittman are from empirical relationships.

vi. Lucia Rock Class

These are PHIZ vs permeability plot overlaid with Lucia rock class charts.

Lucia working in carbonates during the 1990s discovered that on a Log-Log porosity permeability crossplot, that coarser grains and fabrics were represented more in the north western region of the plot and conversely finer grains and fabrics in the south eastern area of the crossplot. Although his work was on carbonates, the general principles apply to clastics as well. The coarser grained rocks have a lower rock fabric number (RFN) and finer grained rocks a higher RFN. The lines correspond to rocks of similar grain size not pore throat radii. Lucia's subdivision often relates more directly to core sedimentary facies than the other reservoir rock types.

NoteThe chart lines curve on a porosity permeability Linear Log plot.

Lucia developed the following global permeability transform:

(Eq. 5) $\log\kappa = A - B \times \log(RFN) + (C - D \times \log(RFN)) \times \log(\varnothing)$

where:

κ is permeability in md

Log is to base 10

A = 9.7982

B = 12.0838

C = 8.6711

D = 8.2965

$\varnothing$ = PHIE (clay bound water removed, but capillary bound water in fines remaining)

Lucia defined rock classes according to the RFN:

Class 1 – RFN <1.5

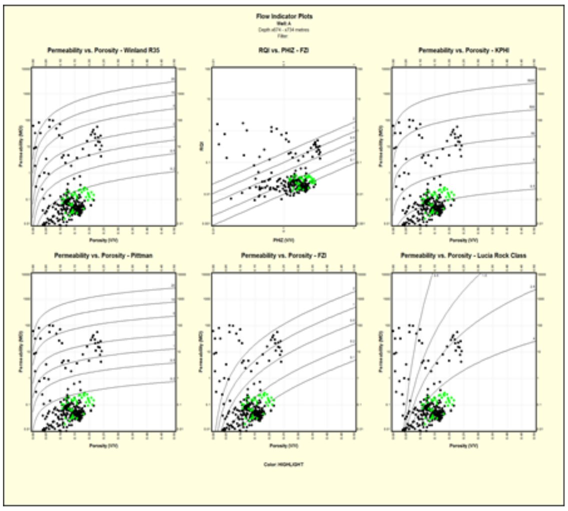
Class 2 – RFN >=1.5 < 2.5

Class 3 - RFN >=2.5 < 4.0

Class 4 - RFN >=4.0

Discussion

Fig.- 3 shows different flow zone unit charts namely- Winland R35, Amaefule-FZI, LeverettK/PHI, Pittman R35, Amaefule-FZI (logarithmic) , Lucia RFN (Rock Fabric Number). For the validation purpose Flow Zone Indicators were constructed using log recorded permeability as well as the predicted permeability and it is observed that the flow zone units matches well in case of predicted permeability and recorded permeability. As shown below:



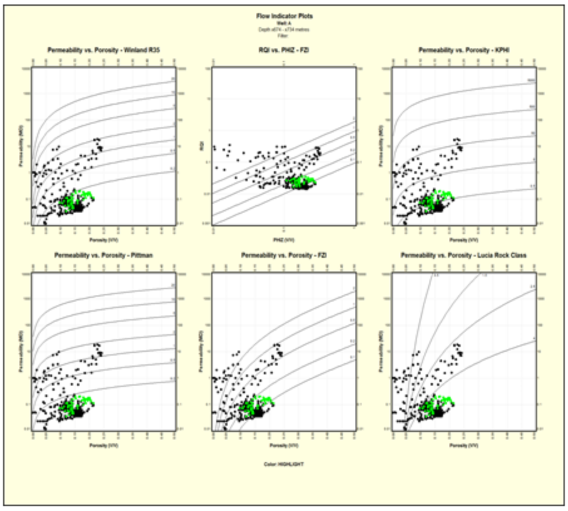


Fig-3 (a) FZI from recorded permeability from NMR log   Fig-3 (b) FZI from Predicted permeability

Using the above mentioned approach predicted permeability was used in a blind test Well-B, Flow zone units are depicted in (fig-4). In (fig-4) highlighted green color shows the tested zone in Well B which is a part of Kalol formation. The above mentioned interval was recommended for testing. On testing it was found to be hydrocarbon bearing but required Hydrofracturing job because of the poor producibility. And our study as well shows that the K_PRED values are also less. Flow zone unit indicators also shows the poorest flow zone. Variation and frequency of defined flow units have been used to achieve a satisfactory understanding of the level of heterogeneity and the possible effect on well production.

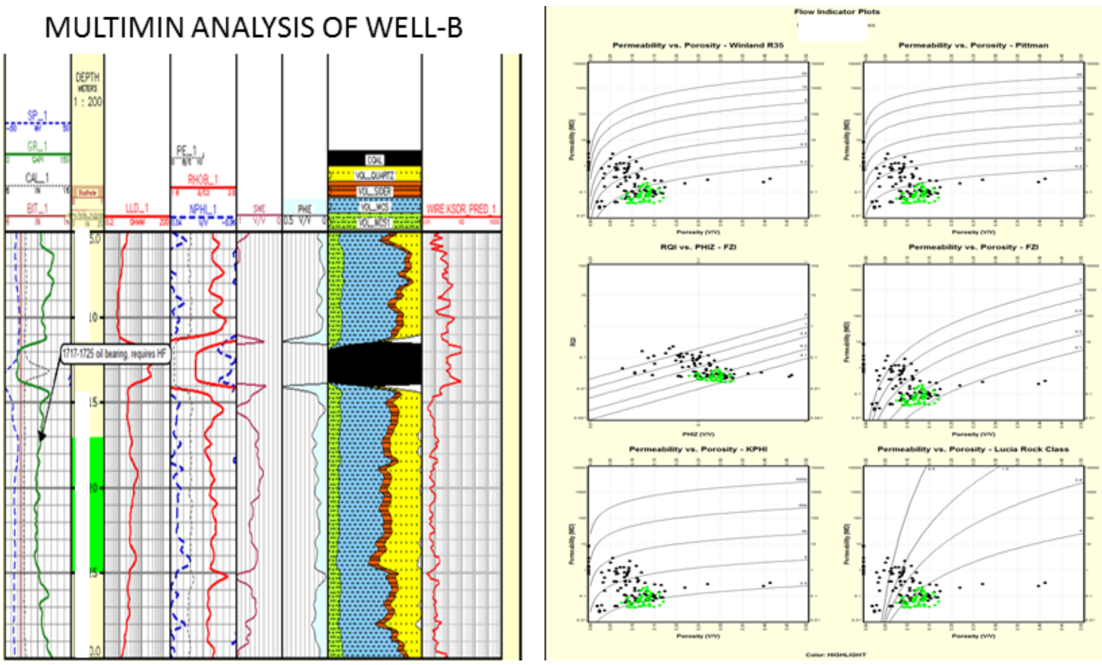


Fig-4: Results of permeability prediction and flow zone indicators in a test Well-B

Conclusion

The paper shows that utilizing this methodology, permeability can be predicted for wells even where no permeability data is available. Based on this predicted permeability, flow zone indicator for formation reservoirs can be constructed to assess their producibility. Study was specifically carried out for heterogeneous reservoirs of Kalol formation of ten wells in Cambay basin. The predicted permeability along with flow zone indicator for different reservoirs could predict their producibility. The results match well with the initial production testing data for these wells.

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