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Predictive Analytics for Full Pore System Characterization of an Arab D Carbonate Reservoir

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Summary

This paper shows how Machine Learning can be an integral part of any petrophysical workflow. Our focus is on modeling the techniques described by Phillips[1] et al. for the characterization of most Arab D reservoirs in Saudi Arabia. Permeability, Petrophysical Rock Types (PRT), Capillary Pressure and modeled saturation are all estimated or calculated in order to characterize these complex carbonate reservoirs. Clerke's[2] Arab D Rosetta Stone core analysis database is used as the calibration data.

These calibration data are from Ed Clerke's Rosetta Stone, Arab-D carbonate dataset from Ghawar field. This is a very special carbonate dataset. Clerke randomly selected the final calibration data from thousands of core plugs for the final data set, and these Rosetta Stone data cover the full range of poro-perm space and Petrophysical Rock Types (PRTs) observed in the Arab D reservoir. For each sample, Clerke acquired High Pressure Mercury Injection (HPMI) data and fit the capillary pressure curves using a Thomeer hyperbola (Figure 1) created from the Initial Displacement Pressure (Pd_i) curvature term G_i that relates to the variability of pore throats and Bulk Volume Occupied ($BVocc_i$) that is related to the Pore Volume of each pore system "i".

We used our own version of KNN to estimate the Permeability and Thomeer Capillary Pressure Parameters and then used Python's Sklearn to predict the PRTs.

Workflow

For this Arab D reservoir, most rock types have a dual pore system, as sShown in Figure 1. This paper describes the workflow and processing required to interrogate, process, interpret, and model the petrophysical properties of a typical Arab D carbonate reservoir using Clerke's Arab D Rosetta Stone Carbonate database as calibration data.

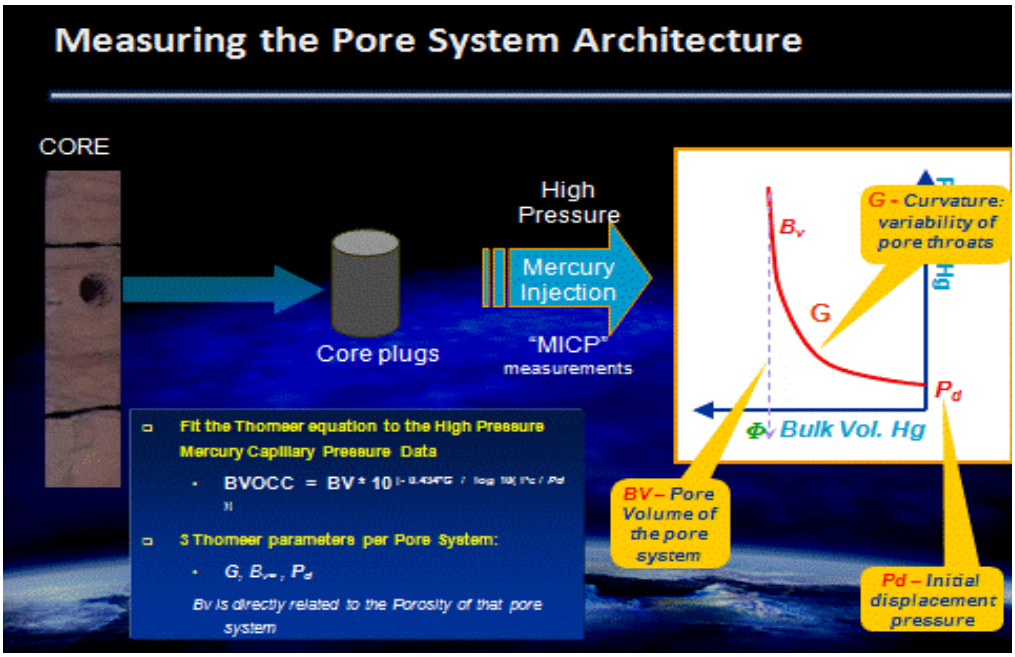

Figure 1: Thomeer parameters obtained by fitting the Thomeer hyperbola to the High-Pressure Mercury Inject Capillary Pressure curve data.

The workflow consists of the following:

- Interrogate the well log, Rosetta Stone calibration data, and Petrophysical Rock Types using Python's Altair.
- Run commercially available log analysis software to model the typical minerals found in the Arab D reservoir; limestone, dolomite, anhydrite and illite.
- Use available core data from reservoir/field to build a petrophysical model to estimate permeability for all wells in the field. In this instance, we use "K" nearest neighbor to estimate permeability from well log data and petrophysical results.
- With the estimated permeability and calculated total porosity calculated using Geolog Multimin on each well, we then query Clerke's Rosetta Stone core database to predict the following:
  - Petrophysical Rock Types (PRT) as defined by Clerke
  - Thomeer Capillary Pressure parameters
    - Bulk Volume Occupied for up to 3 pore systems
    - Curvature term G for up to 3 pore systems
    - Bulk Volume Occupied for up to 3 pore systems
- Use the Thomeer Capillary Pressure parameters to model saturations based on the buoyancy due to fluid density differences and height above the Free Water Level (FWL).
- We also used Python's Sklearn as published by Hall[3] to predict the PRTs. This could be Depositions of Environment or other geologic facies used in this prediction process.

Results

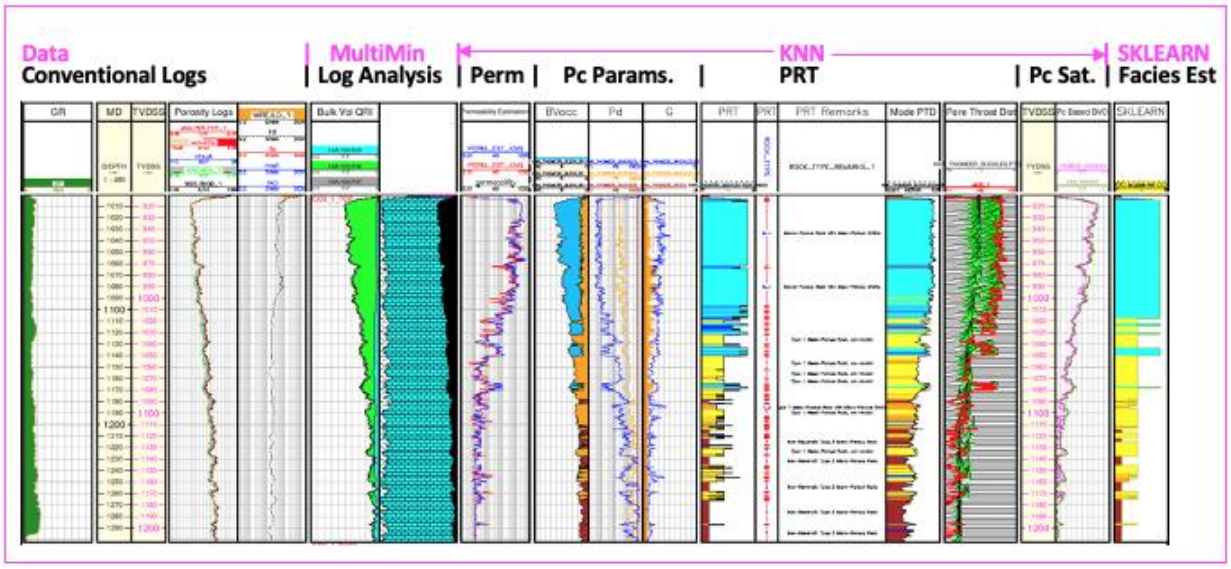

Figure 2: Typical results from the Carbonate Reservoir Characterization workflow discussed above.

Acknowledgements

We would like to thank Emerson EP Software for the use of Geolog to develop and run the characterization workflow used in this example.

References

1. Phillips, E. C., Buiting, J. M., Clerke, E. A, “Full Pore System Petrophysical Characterization Technology for Complex Carbonate Reservoirs – Results from Saudi Arabia”, AAPG, 2009 Extended Abstract.

2. Clerke, E. A., Mueller III, H. W., Phillips, E. C., Eyvazzadeh, R. Y., Jones, D. H., Ramamoorthy, R., Srivastava, A., (2008) “Application of Thomeer Hyperbolas to decode the pore systems, facies and reservoir properties of the Upper Jurassic Arab D Limestone, Ghawar field, Saudi Arabia: A Rosetta Stone approach”, GeoArabia, Vol. 13, No. 4, p. 113-160, October 2008.

3. Hall, Brendon, “Facies classification using Machine Learning”, The Leading Edge, Volume 35, Issue