Using Multivariate Linear Regression to Estimate Permeability from Thin Section Image Analysis

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Abstract The pore system of conventional sandstone reservoirs consists of pore bodies, that constitutes the bulk of the pore space, and pore throats that represent constrictions between pore bodies. The number and size of pore throats control many important rock characteristics, including the ability to transmit fluids (permeability), and capillary pressure.

Compared to 3D images, 2D thin section images can be readily segmented for porosity, and 2D estimates of pore body and pore throat size distributions can be generated at relatively low cost. We illustrate a multivariate linear regression model that uses the measured characteristics of pore bodies and pore throats in thin section to estimate absolute permeability of sandstones.

The important characteristics of the pore system that are used for modeling permeability include mean pore body size, standard deviation of pore body size, 2D estimate of specific surface area, mean pore throat size, and the average pore body coordination number (number of pore throats connected to each pore body). A fractal dimension correction was applied to the estimates of specific surface area to remove the influence of image magnification on that parameter. Results of image analysis were calibrated using brine permeability and NMR T2 distribution measurements on companion core plugs.

Objective Build a multivariate linear regression model for estimating permeability from thin section images based solely on the measured characteristics of the pore system. This allows permeability modelling to be performed in substantially lower time than a complete analysis. Finally, assess the sensitivity of exported image analysis measures characteristic of the pore system to the image analysis protocols applied.

Multivariate Linear Regression

- A method used to measure the degree to which more than one independent variable (predictors) and more than one dependent variable (responses), are linearly related.
- Can a superstore owner maintain stock of water, frozen foods, meat and ice cream as a function of temperature and fuel price during hurricane season in August?
- If the temperature is high, ice cream sales will increase. If a hurricane hits, water sales will increase, while ice cream, frozen foods and meat sales decrease. However, if fuel prices go high, cost of all goods will increase.
- Hence, a question like this is addressed by using a mathematical model based on multivariate linear regression.

Why Permeability?

- The constriction between two pore bodies is called a pore throat.
- The number and size of pore throats control many important characteristics of the rock, including the ability to transmit fluids i.e. permeability and capillary pressure, the force resisting hydrocarbon entry into the pore system.
- A loose sand, composed of grains about half mm in diameter, has permeability of about 1 Darcy.

Conclusion and Future Work

- Thin section image analysis is a cost-effective method to estimate permeability.
- A fractal dimension correction can be applied to the estimates of specific surface area (porosity perimeter).
- Many larger pores are edge pores. Therefore, their complete size was not captured, which gives smaller values for parameters.
- Larger region of interest can help capture more large pores, as the exclusion of larger pores on edge has resulted in big deviation in estimated permeability of Boise sample.
- Adding more samples will help expand the scope of the model.

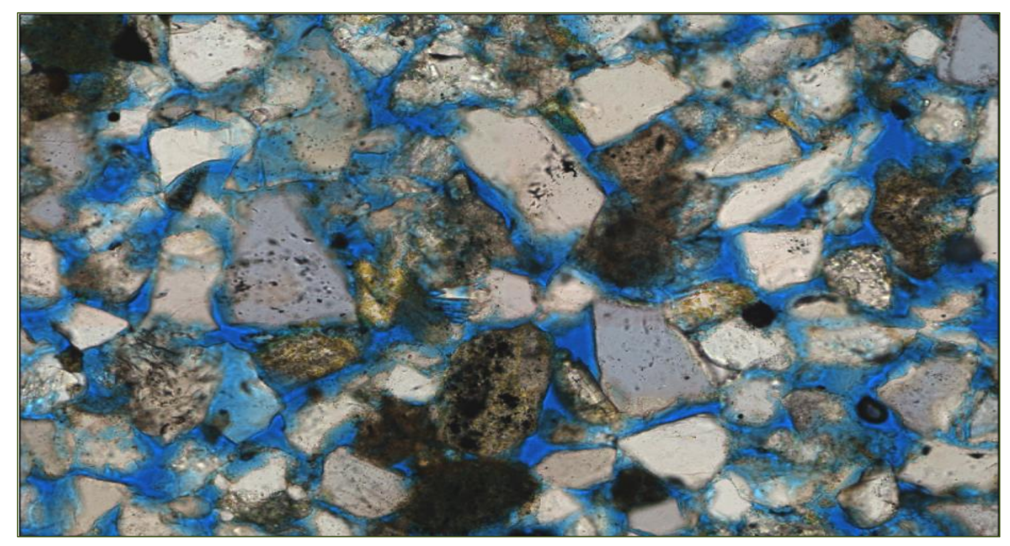
Reference

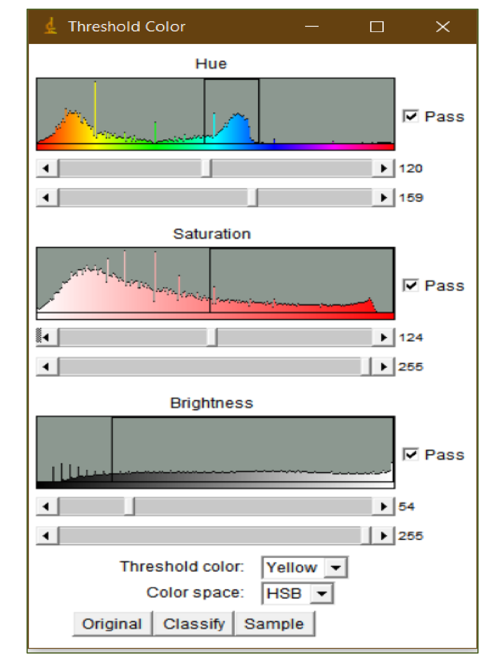
- Tripathi, D. (2018). Determining a Standard Protocol for Permeability from Thin Section Image Analysis.

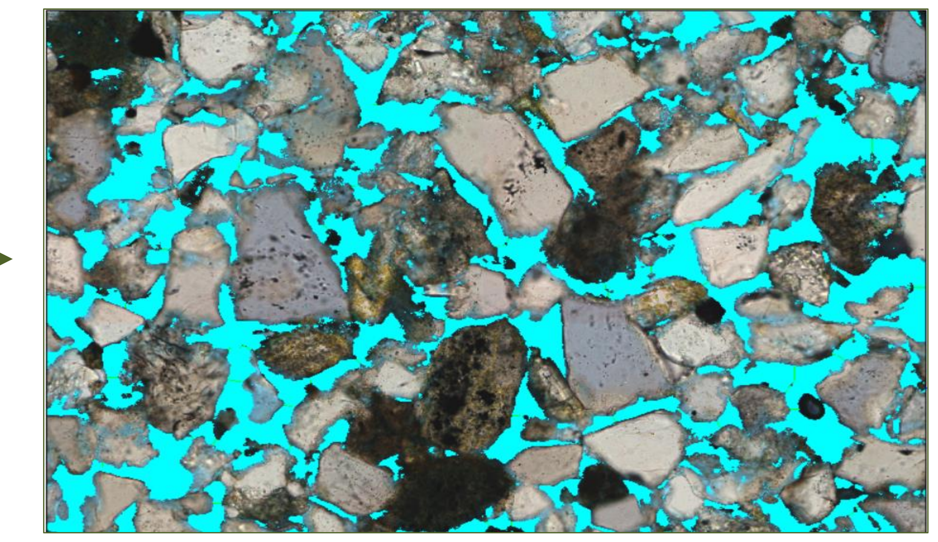
Methodology

General workflow for thin section image analysis

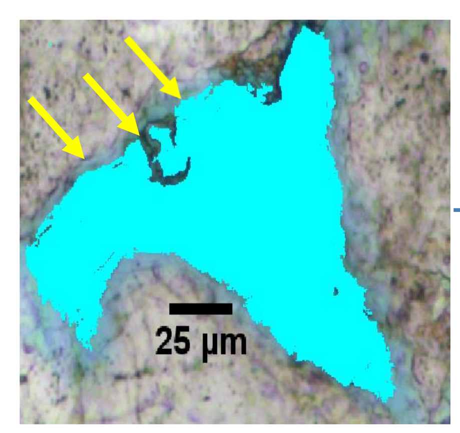
Threshold

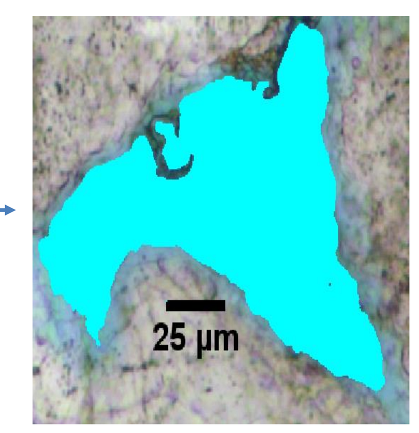


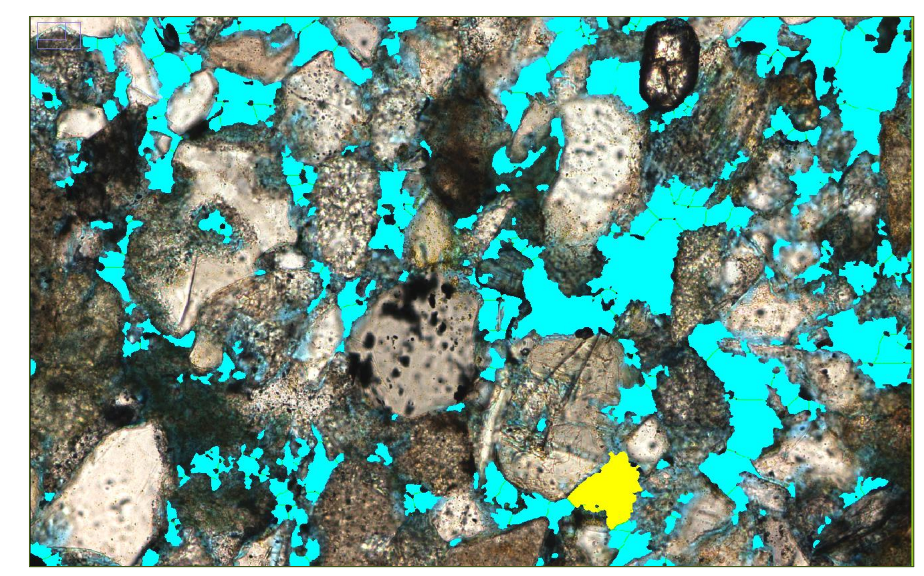




De-speckle Filter: A median filter that takes the median of the colour value of a segmented pixels in a specified size window and applies on the pixel at the center of the window.







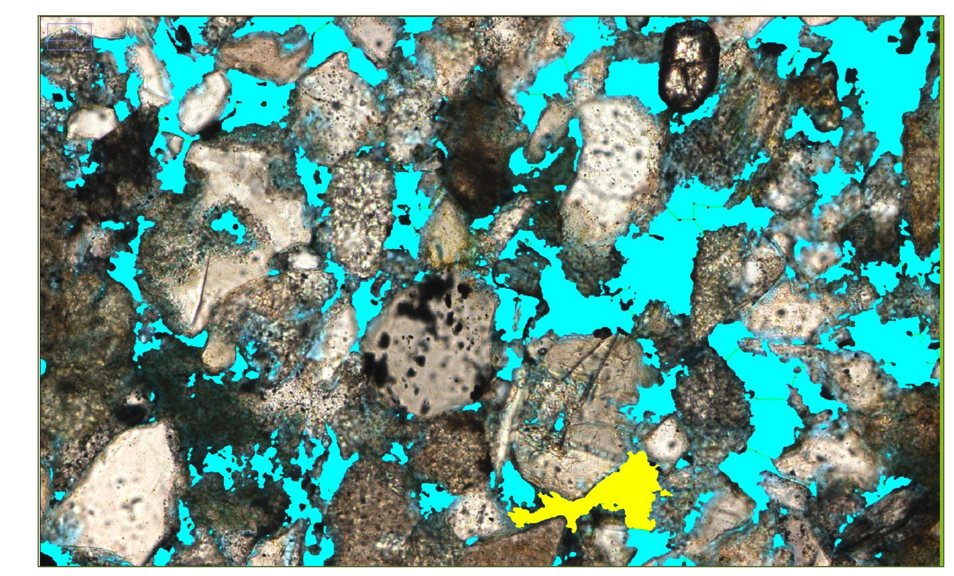
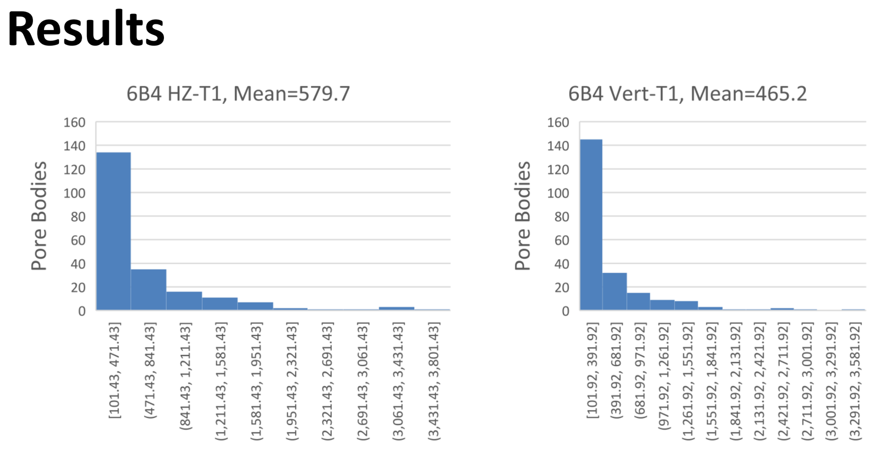


Image Analysis ImageJ is an image analysis software that allows external plugin to be used for segmentation. Quantitative Petrographic Interpretation (QPI-plugin), developed at UH was used to analyse thin section images. QPI lets porosity to be segmented from grains based on colour and identify grain mineralogy. This gives 2D thin section image analysis edge over 3D image analysis, as they are inexpensive to make, and regions of interest can be selected for detailed analysis.

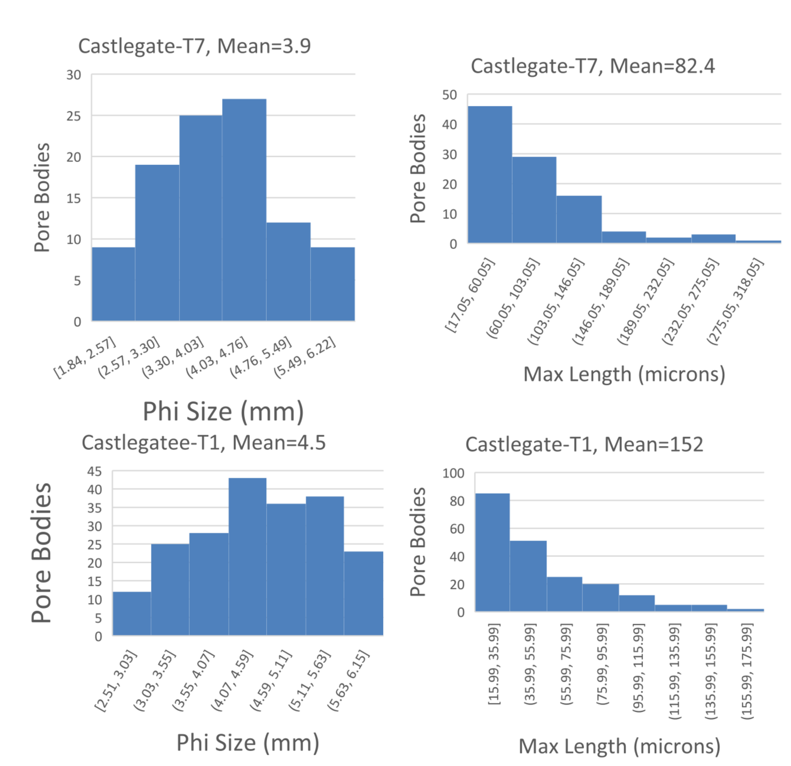
The thin sections were scanned using Zeiss polarizing microscope at relatively high magnification (X100-X200). Scanned image can be as large as 20 GB. Therefore, reigions of interest are selected and exported for further analysis. Regions of interest separated after applying watershed algorithm at tolerance values of 1, 3, 5 and 7. Increasing tolerance value from 1 (L) to 7 (R) increases the area of the pore body as seen in the image above.

De-classify segmented regions under certain area range, 25 pixel^2. Exported data is then edited manually. The pores with area under 100 sq. microns are excluded, as most of these are inferred to be artifacts of sample preparation. The key characteristics of the pore system used for image analysis include mean pore body size, 2D estimate of specific surface area, and mean pore throat size.

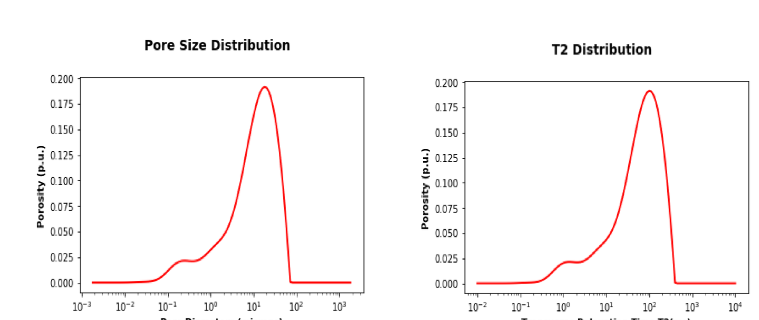
Results



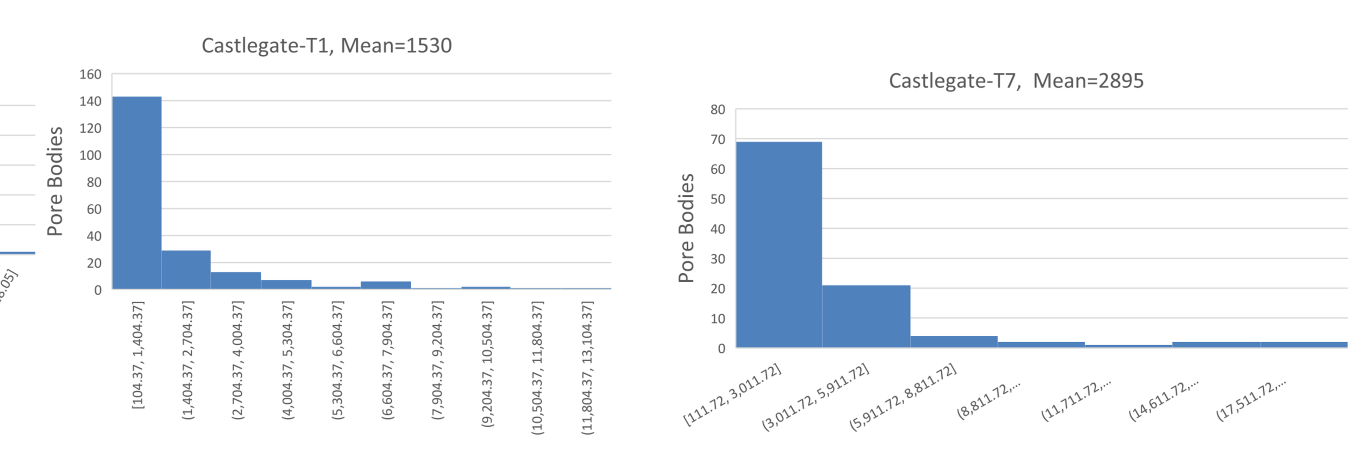
Sample 6B4, Horizontal orientation (L) has relatively larger area compared to vertically oriented thin section of the same sample at a Tolerance value of 1.

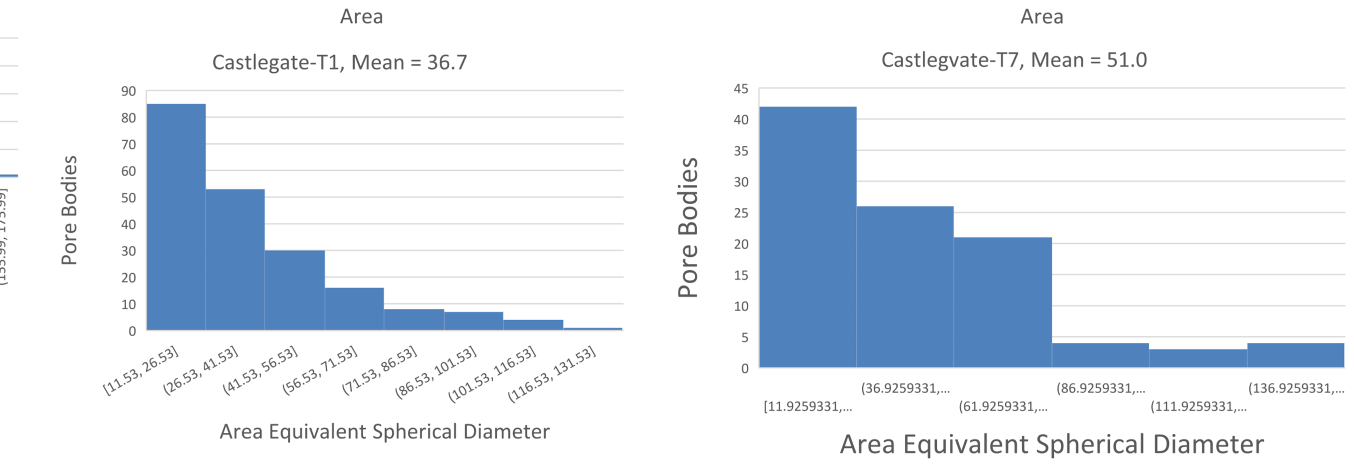


An increase in tolerance value decreases the maximum length and grain size



NMR-T2 Distribution





An increase in tolerance value reduces the number of pore bodies, as smaller pore bodies combine to form larger pore bodies, thereby, increasing the area.

Sample	Permeability	Area	Perimeter	A/P Ratio	Aspect Ratio	Max Length (microns)
6B4 HZ,VERT at T1/T7	56mD	579.7, 465.2/ 3284.1, 919.3	105.1, 58.8/ 222.5, 86.5	4.5, 4.0/ 6.0, 2.4	2.1,2.2/2.4,1.8	36.8, 33.4/ 91.3, 25.9
Castlegate T1/T7	613.8mD	1530.3/2895.0	157.2/269.3	36.7/ 51.0	2.0/2.3	52.9/82.4
Boise T1/T7	7.7D	3675.2/22938.7	211.4/738.6	8.89/ 18.6	1.8/2.0	68.3/196.2

Table on the left shows influence of orientation and tolerance values on key parameters. Vertical orientation gives relatively lower values.