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An Organic Porosity Evolution Model through Machine Learning, Example from Upper Devonian Duvernay Formation, Western Canada Sedimentary Basin

Zhuoheng Chen[1], Jon Liu[1], Edward Little[1], Jijin Yang[2], Yu Zhou[3] & Dennis Jiang[1]

[1]Geological Survey of Canada, Natural Resources Canada
[2]Institute of Geology and Geophysics, Chinese Academy of Science
[3]Calgary

Summary

The objective of the study is to improve our understanding of the fundamental controls of pore structure and organic matter/clay minerals on fluid flow and their evolution with thermal maturity in shale formation by analyzing feature objects extracted from high-resolution scanning electron microscope (SEM) images and geochemical analysis of a series of naturally matured shale samples using Deep Learning and AI techniques. The outputs from this project will form a basis for resource potential estimation, and provide key inputs required for simulation of petroleum occurrence and fluid flow in shale formation.

Theory / Method / Workflow

Seven core samples of the upper Devonian Duvernay Formation were imaged using FIB-SEM at the Institute of Geology and Geophysics, Chinese Academy of Sciences. The seven samples are organic-rich shale with different thermal maturities from early oil to dry gas windows. We present images and extracted features from the sample data set to illustrate the use of ML in nanopore structure characterization and to reveal the evolution of organic pores within organic matter along with other hosting rock material with thermal maturity.

We chose the “U-net” (Ronneberger, *et al*., 2015) with a train strategy utilizing strong data augmentation in facilitating available annotated samples in training. The U-net, developed for biomedical image segmentation, is based on a fully convolutional neural network, has its architecture extended to work with fewer training images and yet yield more precise segmentation. The contracting path repeats application of convolutions, each of which is followed by a rectified linear unit (ReLU) and a max-poolling operation, resulting in reduction in spatial information and enhancement in feature information. The expansive pathway combines the feature and spatial information through a sequence of up-convolutions and concatenations with high-resolution features from the contracting path (Ronneberger, *et al*., 2015).

Results, Observations, Conclusions

Seven source rock samples of the upper Devonian Duvernay Formation were imaged using FIB-SEM (Focussed Ion Beam Scanning Electron Microscope) for nanopore characterization to improve resource assessment and recovery prediction in tight reservoirs. Machine Learning algorithms were developed to

extract features that can characterize pore-structure and their evolution with thermal maturity. The preliminary results of feature extraction using Deep Learning show that:

a) The U-NET can be effectively used to extract features associated with nano-pore structure and their evolution with increasing thermal maturity to a precision >95% in segmenting and classification in general;

b) Machine Learning represents a cost-effective and time-efficient alternative for data analysis. Extracting features (objects of organic matter, pore/fracture, clay particles, mineral grain and others) from and classification of 184 high resolution images (6144x6144 pixels for each image) of different maturity source rock samples take about 5 day computation time using one computer. It would be years of workload for a skilled person to achieve if attempted manually;

c) The results are more objective (avoiding the bias from subjective selection of features that favor a specific model or interpretation), better representative (exhaustive of available data), more robust statistics (from very large collections of feature count), and reproducible results.

Preliminary data analysis of the results suggest that

a) Extracted features from samples of different thermal maturities vary significantly in abundance, character and distribution of the organic pores within organic matter as well as the characteristics of clay particles and organic matter object and mineral grains as a result of thermal decomposition in combination with mechanical and chemical compaction;

b) The size of organic pore appears to follow a power law distribution in the oil window;

c) Organic pore within organic network starts to generate in the oil window. The pore size appears to be at maximum at end of the oil window and start to shrink gradually with maturity in dry gas window due to perhaps precipitation of excess carbon from oil cracking to gas and mechanical/chemical compactions, while the total number of pores seems to increase with maturity extended into dry gas window as indicated by increasing the slope of the pore size distribution curve.

d) Pores connected through organic matter and clay minerals form complex networks in organic-rich shale reservoir, facilitating petroleum fluid flow during primary migration and production. Clay particles show close affinity with organic matter and appear to be involved in petroleum generation and organic pore creation, which are consistent with observations of positive correlation between TOC and clay mineral content, and geochemical evidence that led to inference that clay may play a catalytic role in HC generation.

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References

Ronneberger, O, Fischer, P. and Brox, T. 2015. U-Net: Convolutional Networks for Biomedical Image Segmentation. arXiv:1505.04597.