Leveraging Spontaneous Potential and Neutron Density Porosity Logs to Construct a Geocellular Model: An Example from the Thick Cypress Sandstone at Noble Field, Illinois

Nate Grigsby and Nathan Webb (nategrig@illinois.edu)
Illinois State Geological Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign

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PRAIRIE RESEARCH INSTITUTE

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Abstract

Detailed geocellular models of reservoir architecture and geologic features reduce uncertainty in projections made for field developments such as CO2 enhanced oil recovery (EOR) and storage. In mature oil producing basins, such as the Illinois Basin, the data required for the construction of such models is limited, due to the lack of wells with neutron-density porosity logs. A method was developed to derive porosity from widely available spontaneous potential (SP) logs. This method was enhanced with neutron-density porosity logs, which were available but much less abundant than the SP logs for this field example.

The volume of shale (Vsh) was calculated from SP logs using clean sandstone and shale baselines. Using 385 SP logs, a geocellular model of Vsh was made for the thick Cypress Sandstone at the Noble Oil Field in Richland County, IL. The spatial coverage of the SP logs was sufficient to detect a strong NW/SE trending anisotropy, and condition simulations to model the distribution of sandstone and shale. Using the available neutron-density logs with SP from the same well, Vsh was cross plotted and regressed against porosity. This crossplot was used to convert the Vsh in the geocellular model into porosity.

From detailed evaluation of whole core and the porosity logs, thin (0.5-1 m thick) layers of low porosity calcite cement were found, which were not observed on the SP log. These were interpreted to have formed at the oil water contact and act as a laterally continuous baffle to vertical fluid flow. Data from 125 wells with neutron-density porosity logs was used to detect and incorporate the calcite cemented intervals into the model. There were too few of these logs to characterize the field-wide lateral anisotropy in sandstone and shale, but geostatistical analysis of the porosity logs did indicate two parallel layers of calcite cement; one at the oil water contact and one about 9 meters below it. The cells within these layers were assigned porosity values from the neutron-density logs and the remaining cells were assigned the porosity derived from the Vsh.

This study demonstrates the importance of understanding the strengths and weaknesses of data types, and how different log types can be leveraged to construct a geocellular model.

Background

- A geocellular model was constructed for the thick Cypress Sandstone at Noble Field as part of a study to assess the potential for nonconventional CO2 enhanced oil recovery
- Detailed geoloic characterization concluded that the thick Cypress at Noble Field is a multistory sandstone built through three or more fluvial to estuarine depositional episodes puncutated by a marine incursion (Figure 1)
- 100-180 feet of clean sandstone with interbedded shale
- Because the field is so old (discovered in 1937), the majority of data avalible for the construction of the model was spontaneous potential (SP) logs (Figure 2)

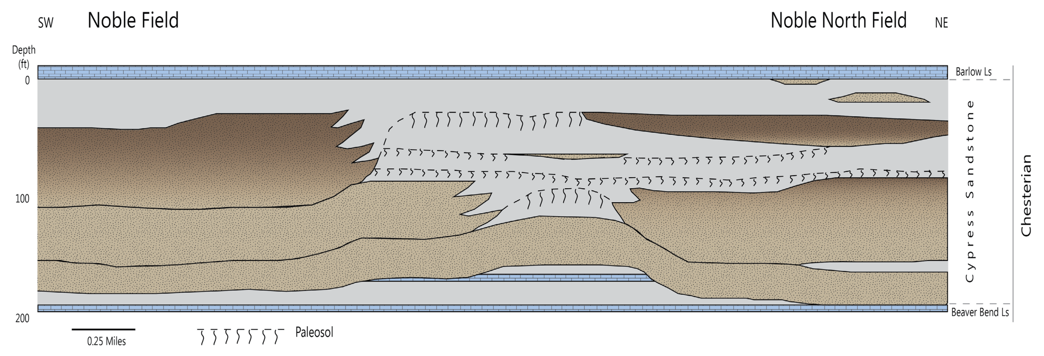


Figure 1: Conceptual geologic model of the thick Cypress at Noble field. Middle and upper sandstone amalgamate at Noble but are less persistent to the north.

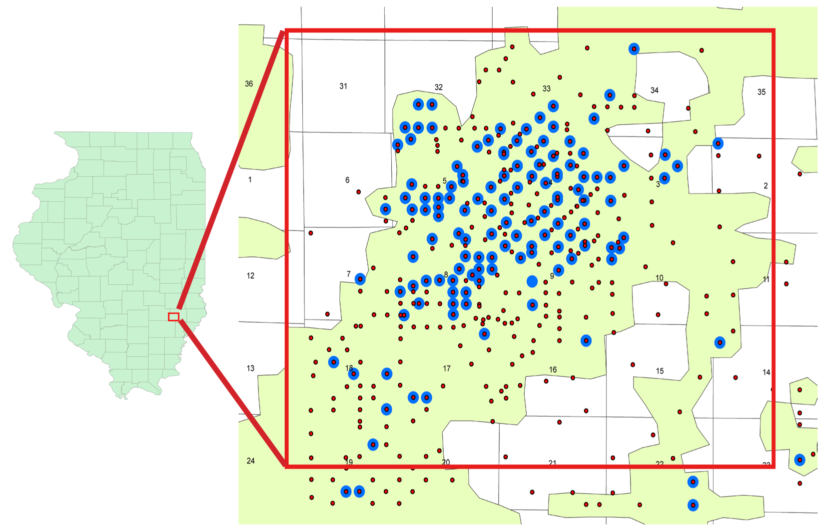


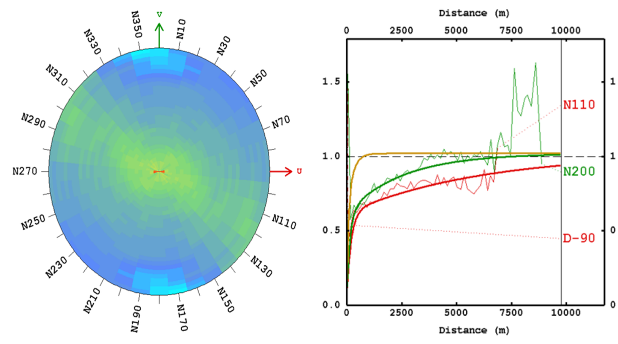
Figure 2: Data distribuion and model boundary. The extent of the geocellular model is shown with a red box. 125 wells with neutron density porosity logs are shown with large blue circles and 385 wells with SP logs are shown with small red circles.

Methods

SP Logs

- To compensate for well to well variation in SP logs caused by fluid chemistry or other borehole conditions, each well's SP log was normalized by calculating the volume of shale
- The normalized SP data was flattened on an overlying marker bed and used to construct variogram maps, empirical variograms (Figure 3), and as conditioning data for Sequential Gaussian Simulations
- The distribution of sandstone and shale in the resulting geocellular model (Figure 4) matched the conceptual geologic interpretation

Figure 3: Variogram map (left) and variogram (right) of the normalized SP of the thick Cypress. Data distribution was sufficient to detect a strong NW/SE trending anisotropy and fit variogram models.



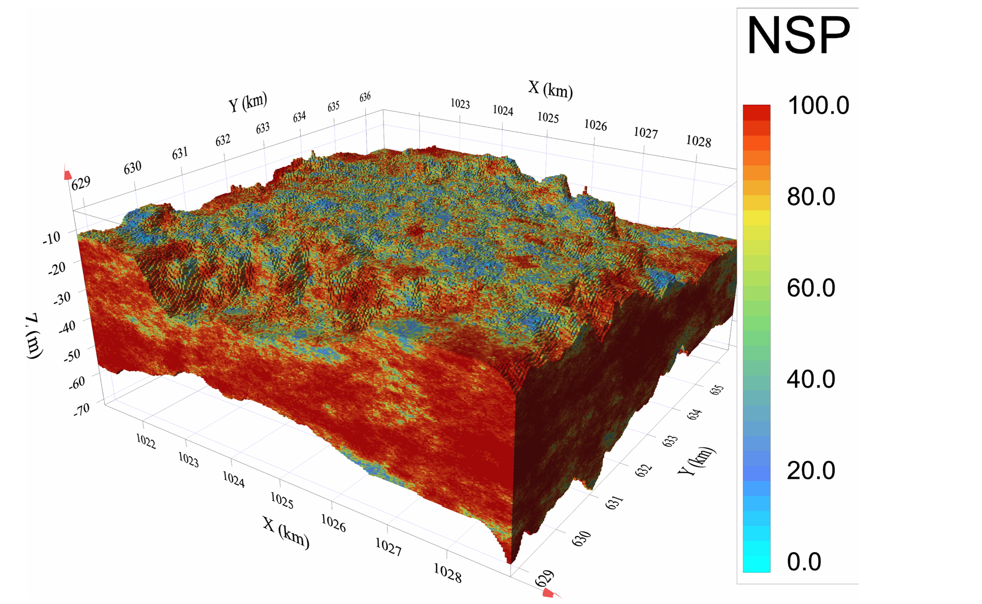


Figure 4: Normalized SP geocellular model. Warmer colors indicate a higher percentage of clean sand. The model has very clean sand with some discontinous shale bodies throughout the middle that transitions to shale at the top and base.

Porosity Logs

- Inspection of core revealed a calcite cement at the oil water contact that was not detected by the SP logs
- Neutron density porosity logs were able to detect two calcite cement zones; one at the oil water contact and one below it (Figure 5)
- The porosity logs were flattened on the oil water contact instead of a marker bed
- A 5% porosity cutoff was used to divide the porosity logs into sand and cement facies
- Vertical Proportion Curves (VPC) were developed for each well to detect the odds of encountering the cement facies in each layer
- Wells were grouped according to VPC character and trends were extrapolated over the entire grid
- The resulting model represents the likelyhood of encountering low porosity layers (Figure 6)
- This method smooths lateral variability but was sufficient to capture the depths and trends of continous cement layers

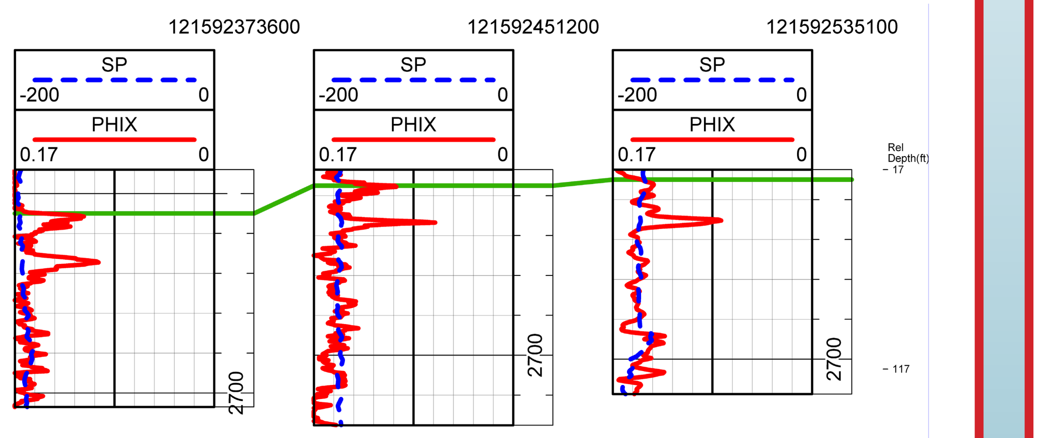


Figure 5: SP and cross plotted porosity (PHIX) logs for three wells from south (left) to north (right). The green line is the oil water contact. The SP is able to approximate the porosity logs, except for two zones near the top, interpreted to be calcite cement. The upper cement occurs at the oil water contact and dissapears to the northeast. The lower cement is more pronounced and consistant.

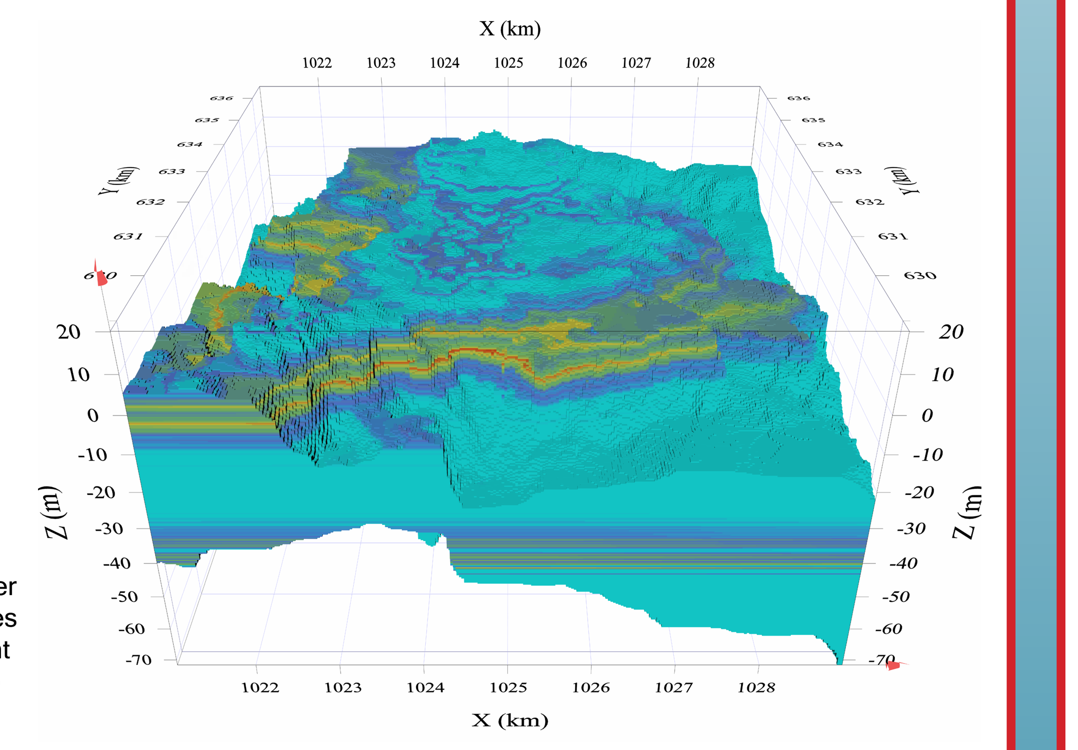


Figure 6: Porosity model. 50x vertical exaggeration. Warmer colors indicate better odds of encountering the low porosity facies (cement). The two parallel layers of cement appear near the oil water contact (0 depth) and disappear to the northeast.

Transforms

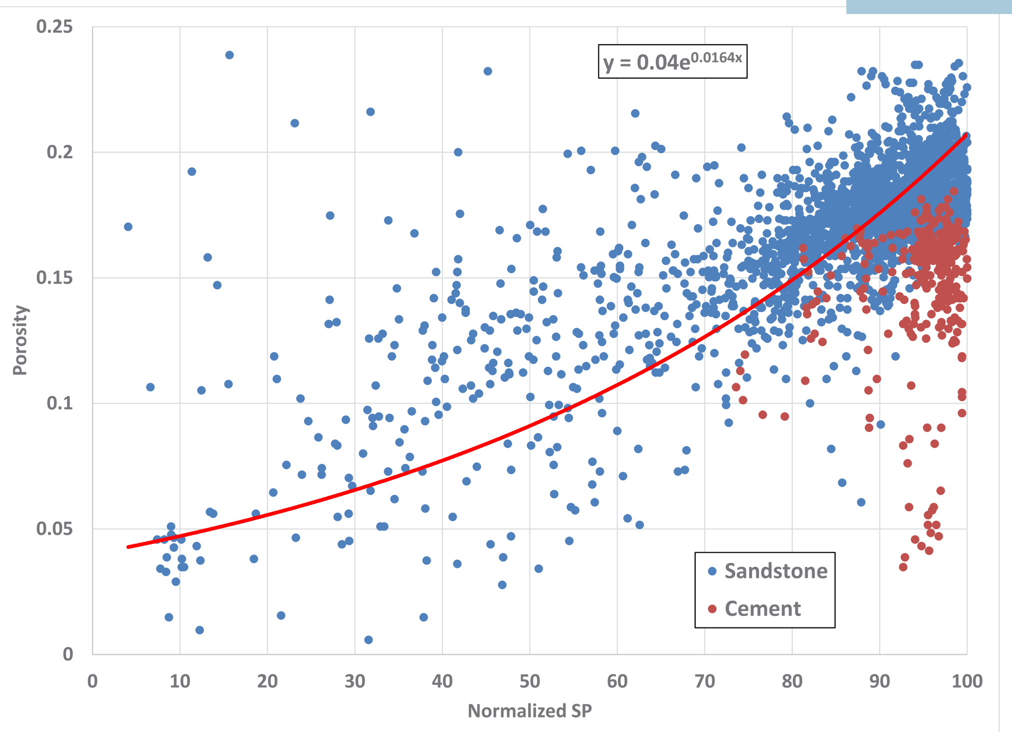


Figure 7: NSP to porosity transform. NSP was cross plotted and regressed against neutron density porosity. Each well was analyzed, and data points found to be within the cement (red dots) were not used in the regression. The equation defining the curve was used to transform simulated NSP into porosity.

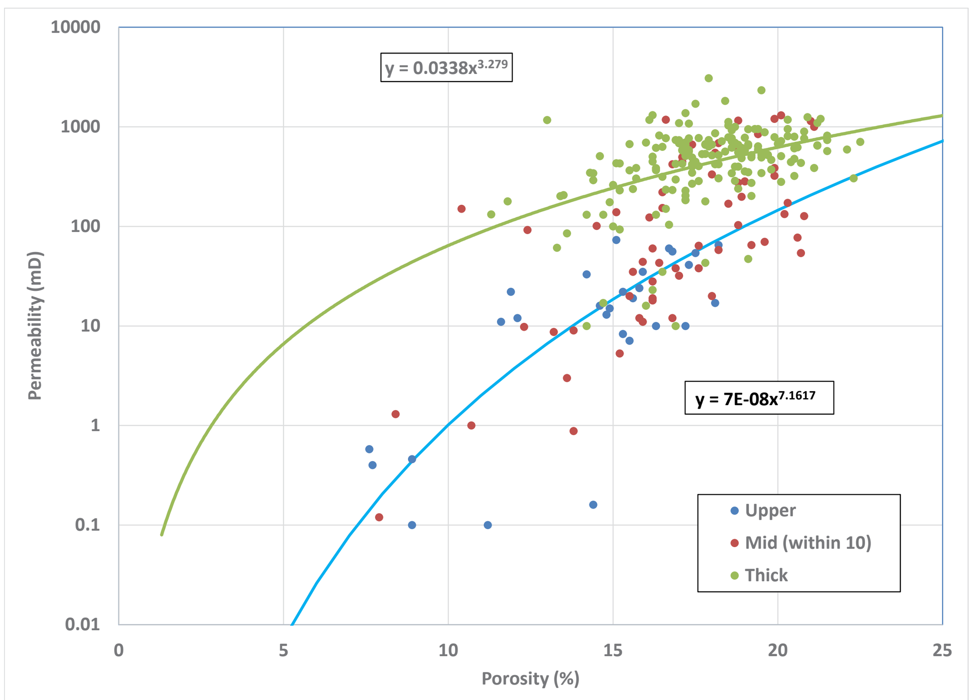


Figure 8: Porosity to permeability transform. A porosity to permeability transform was developed using core analysis reports for the Cypress Sandstone at Noble field. Data from the sand rich middle of the formation (green dots) had a different trend than the data in the shale rich top (blue dots). Data near the interface (red dots) fell into both trends.

Results and Conclusions

- Models that were initially flattened were returned to structural space
- Cells that had a high liklyhood of containing a low porosity indicator (the two calcite cement layers) were assigned a low porosity value and all other cells were assigned a porosity value derived from the normalized SP to porosity transform
- The deep bands of low porosity were not included
- The porosity to permeability transform was used to calculate a permeability for each cell
- The resulting model had the distribution of sandstone and shale and large scale anisotropy that matched the geologic interpretation with two diagenetic calcite cement zones imprinted
- The model will be used in reservoir simulations and may be updated as history matching progresses

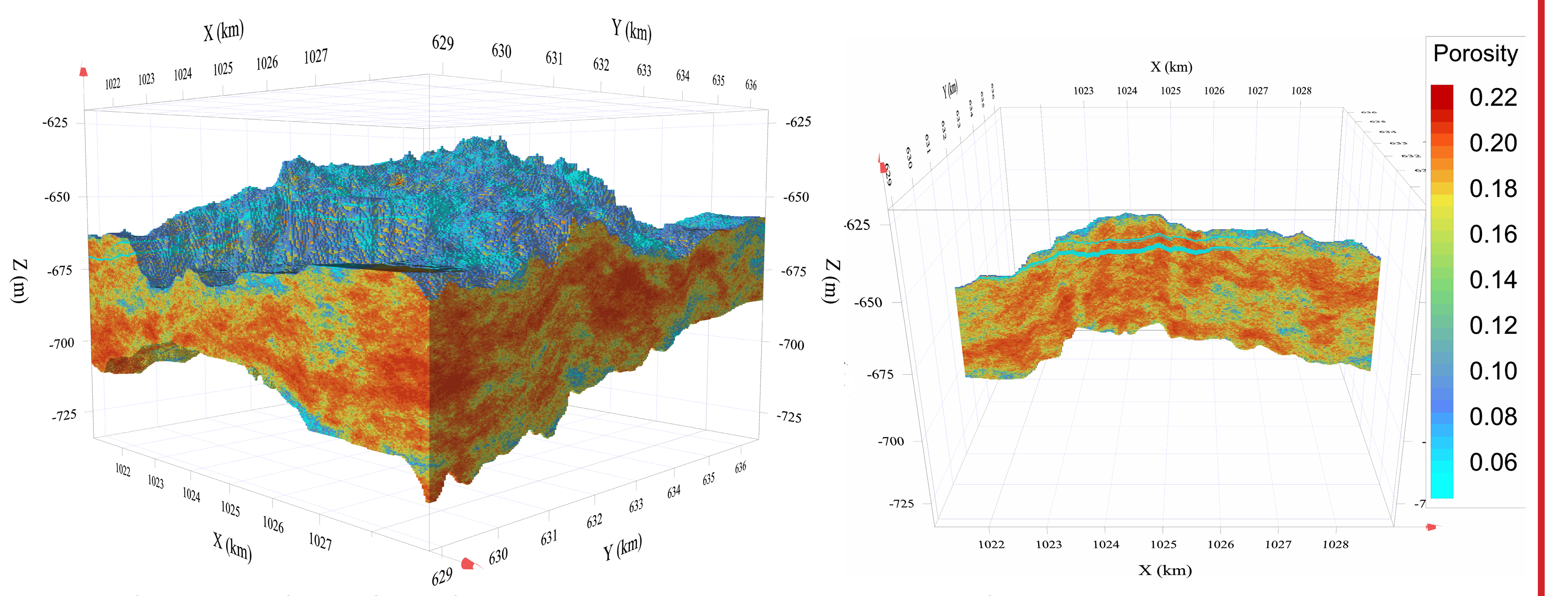


Figure 9: Distribution of porosity from the final geocellular model. The whole model is shown on the left and a single E/W slice is on the right. The whole model shows that the majoirty of the model is clean sand that transitions to an overlying shaley zone. The slice reveals two paralell cement zones at the top that disappear off structure.

	Normalized SP	Modeled Porosity (%)	Modeled Permeability (mD)	Core Porosity (%)	Core Permeability (mD)
Minimum	0	4	3	8	0.12
Maximum	100	21	689	23	3070
Mean	88	17	402	18	482
Median	94	18	456	18	427

Table 1 Final model and core statistics. Core data is from the thick cypress intervals from core analysis reports from Noble field.

- SP logs were used to create a geocellular model of sandstone and shale, which was improved by incorporating diagenetic alteration with information from neutron density porosity logs
- Different log types can be leveraged to construct a geocellular model, but it is important to understand the strengths and weaknesses of log type used
- A strong understanding of the geology is vital to construct a representative geocellular model
- Identification of calcite cement
- The datum selection, simulation method, transform alteration, model extent were all informed by knowledge of the geology

Acknowledgements

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For project information, including reports and presentations, please visit: http://www.isgs.illinois.edu/research/oil-gas/doe

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