[PS]Porosity and CO_2 Storage Capacity of the Maryville - Basal Sandstone Section in the Kentucky Geological Survey 1 Hanson Aggregates Stratigraphic Research Well, Carter County, Kentucky*

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Abstract

The Kentucky Geological Survey drilled the 1 Hanson Aggregates stratigraphic research well, Carter County, northeast Kentucky, to test in situ rock properties in the subsurface for their potential as CO_2 storage reservoirs and confining intervals (cap rock). The Middle Cambrian Maryville Basal sands interval (4600 - 4720 ft) were evaluated to determine effective porosity, clay volume, and standalone potential CO_2 storage reservoir capacity. The interval is composed of two muddy dolomitic sandstones, each about 30 ft thick, separated by about a 40-ft interval of sandy dolomitic mudstones. The upper unit is the Maryville Sandstone, an informal subsurface member of the Maryville Limestone, whereas the lower is the informal Basal Sandstone which overlies a thin Granite Wash on Precambrian Grenville basement. Effective porosity and clay volume in the strata were calculated from the density log using a three matrix shaly-sand model. Four formation lithologies were identified from primary lithology and clay volume: muddy sandstone, sandy mudstone, dolomitic mudstone, and dolomitic claystone. Average effective porosity calculated in the Maryville Sandstone is 8.9% with clay volume of 35.3%. Average effective porosity in the Basal Sandstone is 8.7% with 41.2% clay volume. Effective porosities calculated in this evaluation are a good match with porosity measured in core plugs from the intervals.

Porosity and net reservoir thickness for calculating potential CO_2 storage volume were determined using an industry-standard 7% porosity cutoff. In the 664,500-acre study region around the 1 Hanson Aggregates estimated effective porosity greater than the 7% cutoff is 13.7% and average net reservoir thickness is 34 ft. Storage volume was determined using the methodology of the U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory. Estimated P50 supercritical CO_2 storage volume for the Maryville Basal sandstone interval is 654 metric tons/acre and 434.6 million metric tons in the study region. Thus, about 1530 acres would be required to store 1 million metric tons of supercritical CO_2 in the Maryville Basal sands interval.

Thin reservoir sandstones, low permeability (~50 mD), low reservoir volume, and low fracture gradient of 0.581 psi/ft measured in a step-rate test, however, probably makes the Maryville Basal sandstone interval unsuitable for standalone CO_2 storage in the southern Appalachian Basin. More likely is that the interval would be part of a stacked-reservoir CO_2 storage project, although there are no current or future plans to store CO_2 in the region.

References Cited

EPA Region 8, 1999, Step-Rate Test Procedures: Denver, CO, 6 p.

Schlumberger, 1972, Log Interpretation: Volume I – Principles: Schlumberger Limited, New York, NY, 113 p.

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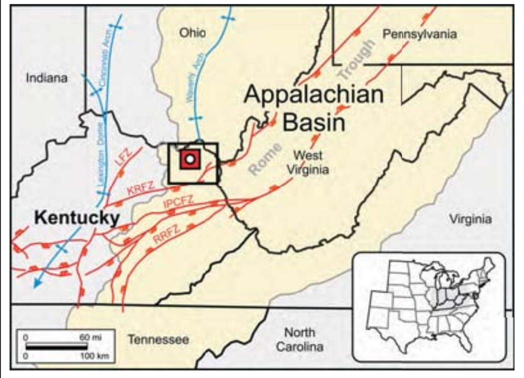

Project location, northern Carter County, Kentucky.

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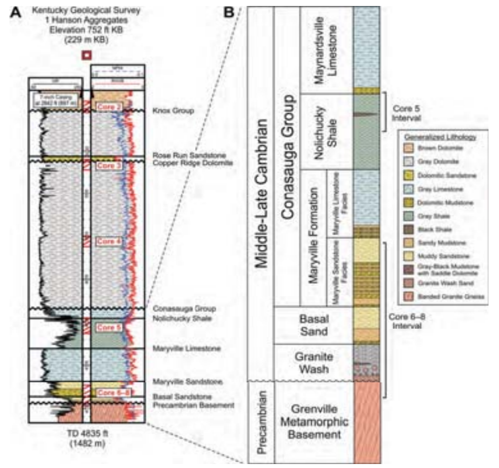
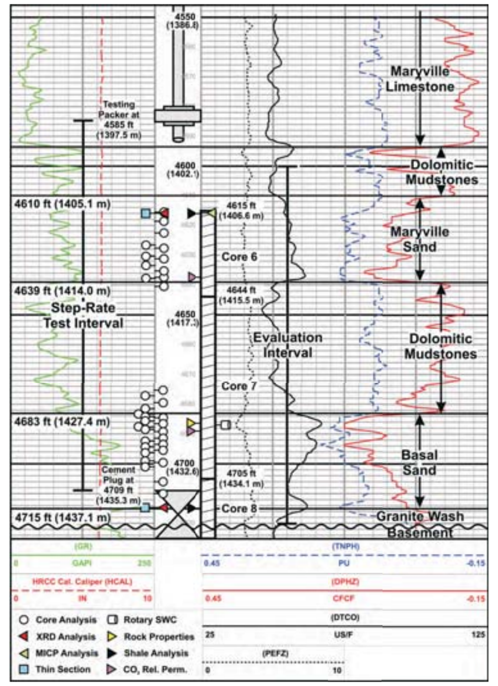
Stratigraphy and Annotated Log

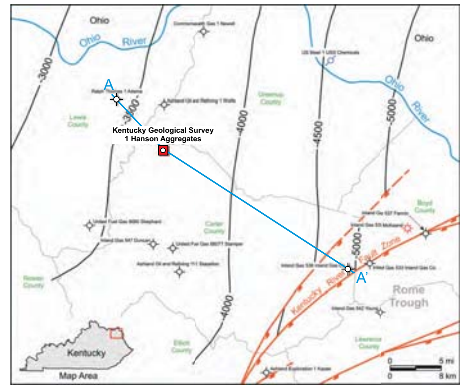


A. Correlated Formation density log curve (red line), neutron porosity curve (dashed blue line), and gamma-ray log curve (black line) from the top of the Knox Group to the well TD in Precambrian Grenville granite gneiss basement. Lithology fills from generalized lithology key. **B.** Generalized lithostratigraphy of the sub-Knox strata in the 1 Hanson Aggregates (not to scale) showing stratigraphic intervals of cores 5–8.

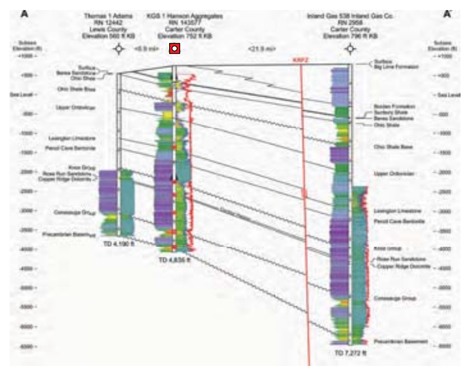


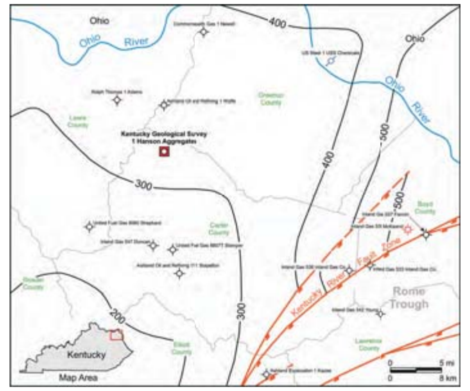
Correlated electric logs for the Maryville–Basal sands section annotated with conventional whole core intervals, locations of core analysis plugs, and the step-rate test interval. Cores 6–8 cored the entire Maryville sand to basement interval with 100% core recovery. GR, gamma ray; HCAL, high-resolution borehole caliper; TNPH, neutron porosity; DPHZ, formation density; DTCO, acoustic compressional wave; PEFZ, photoelectric cross section.

Geology

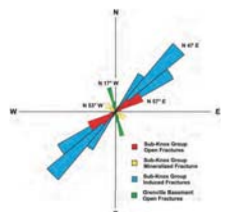


Subsurface structural contours on top of the Maryville Formation show gentle dip (< 1°) to the east northwest of the Kentucky River Fault Zone.

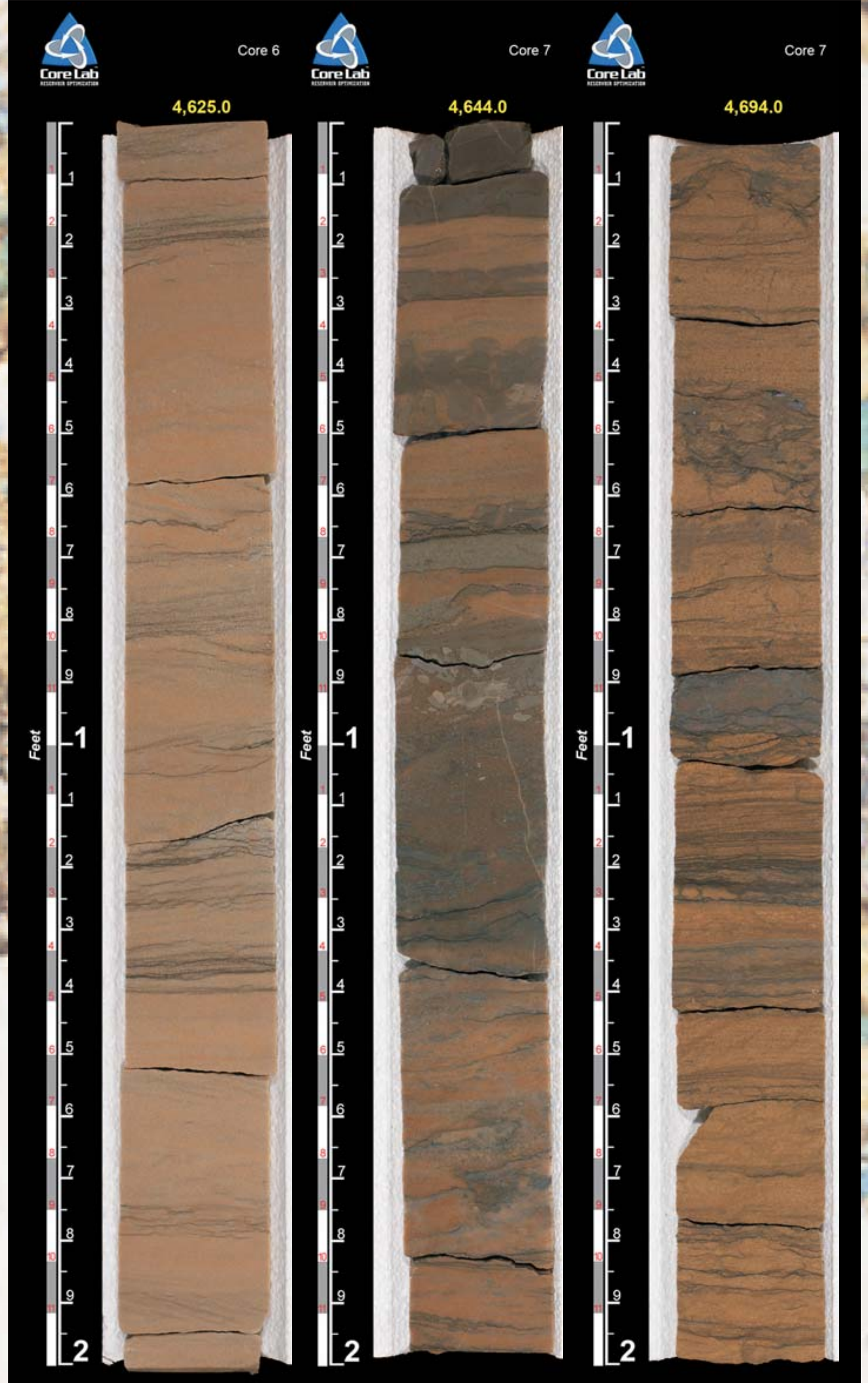




Isopach thickness of the section from the top of the Maryville Formation to Precambrian basement. Thinning of the section to the south is largely caused by thinning of the Maryville limestone facies.

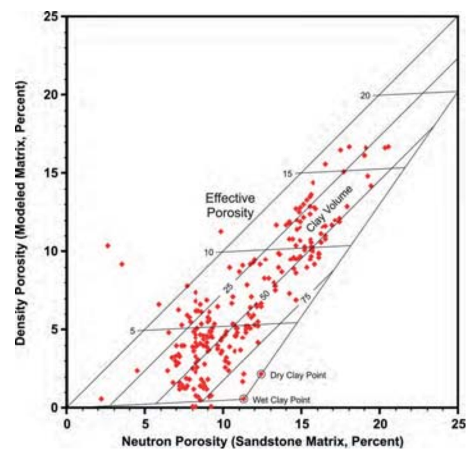


Plot of orientations 34 natural fractures and 52 drilling-induced fractures interpreted from the FMI and UBI logs in the interval of 4170–4835 ft. Open and drilling-induced fractures parallel the modern tectonic stress axis, whereas mineralized and open fractures in the Grenville basement are conjugates of the northwest stress axis of the Alleghenian convergence front.

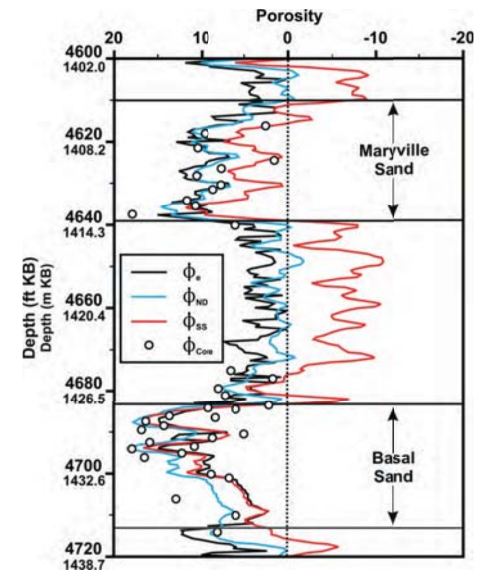


Full-size core photos of the Maryville sandstone (left), interbedded dolomitic shale (center), and Basal sandstone (right). Shaliness and dolomite content of the sandstones makes conventional calculation of porosity from the logs difficult. The methodology in this evaluation used techniques more commonly applied to western shaly sand reservoirs. Please see Steve Greb's poster at this conference (Poster 18).

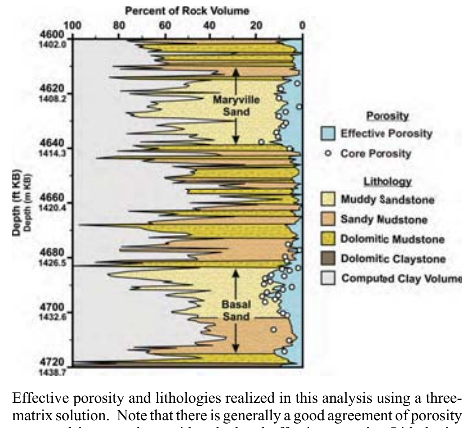
Calculating Effective Porosity in the Maryville and Basal Sandstones: The Hard Way and the Easy Way



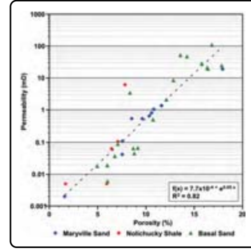
The Hard Way: Neutron porosity/density porosity crossplot for determining effective porosity and clay volume in the Maryville–Basal sands interval (from Schlumberger, 1972). Points lying outside of the effective porosity envelope represent lithologic compositions that were not realized in this analysis.



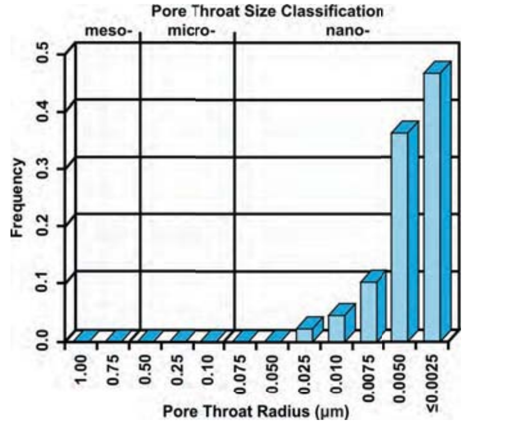
Plot of approximated effective porosity (φ_e)for the Maryville and Basal sands. After testing ten other methods for calculating porosity, the far less complicated solution in the Maryville sand is to calculate porosity as the average of neutron and density porosity(φ_{ND}) using a sandstone matrix. In the Basal sand a good approximation for effective was calculated from the density porosity log calculated using a sandstone matrix (φ_{SS}). Sometimes there are easier and equally valid solutions to complex problems. ☺



Effective porosity and lithologies realized in this analysis using a three-matrix solution. Note that there is generally a good agreement of porosity measured in core plugs with calculated effective porosity. Lithologies were verified with thin sections, XRD analysis, and core descriptions.

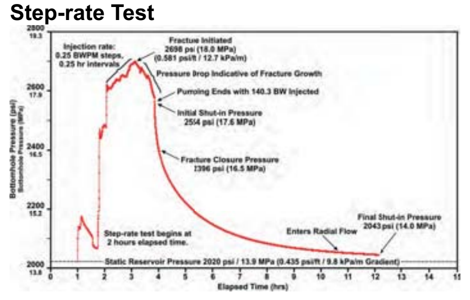


Permeability and porosity measured in 37 core plugs from the Maryville-Basal sands section in the 1 Hanson Aggregates. Although core plugs from the Maryville sand have good porosity, their permeability is largely less than 1 mD because of their clay content and dolomite cement. Core plugs from the Basal sand show a bimodal distribution of porosity. This likely stems from preferential sampling of the core plug depths.



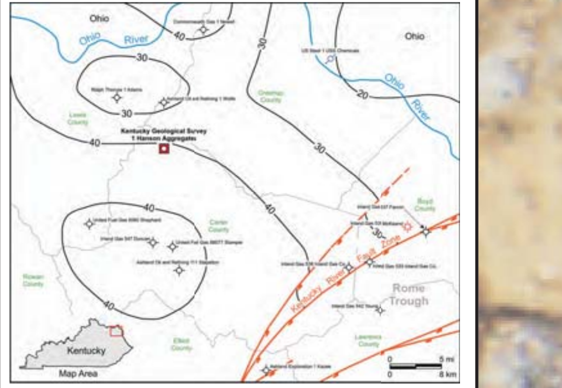
Pore throat radius histogram from MICP analysis of a core plug from a potential confining layer at 4615.95 ft (1406.94 m). Median pore throat radius is 0.00332 µm, well within the nanopore range, and permeability of this core plug is 4×10^{-6} mD, suggests that this bed could serve as a caprock.

Step-rate Test



Annotated plot of pressure from the step-rate test in the Maryville–Basal sands section at 4585–4709 ft. Testing procedure was modified from that of EPA Region 8 (United States Environmental Protection Agency Region 8, 1999). Mechanical noise in the pressure data has been filtered from this plot. Testing was interrupted early at 1.15 hrs because of a flowline leak, then restarted at 1.75 hrs. Injection rate increased in 0.25 BWPM steps every 15 minutes. The test interval fractured at an injection rate of 1.5 BWPM, however injection continued to a peak rate of 2.0 BWPM for an additional 0.70 hrs until the well was shut-in to monitor pressure falloff. The fracture gradient for the Maryville–Basal sands section was 0.581 psi/ft (12.7 kPa/m).

CO_2 Storage Capacity



Isopach thickness contours of the Maryville–Basal sands section in the region northwest of the Kentucky River Fault Zone and Rome Trough at 7% porosity cutoff. Average net reservoir thickness in this region is 34 ft.

CO_2 Storage Capacity where Reservoir Porosity > 7%

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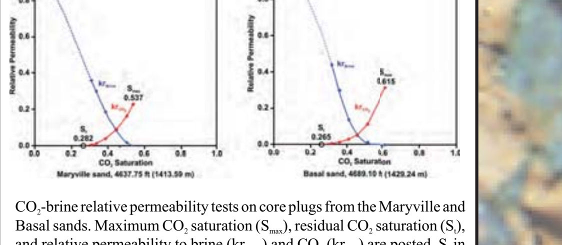
Facies	ϕ_e (avg %)	h_n (net ft)	V_{pn} (ac-ft/ac)	ρCO_2* (kg/m³)	ρCO_2* (t/ac-ft)	Weighted E_{saline} P_{10}	Weighted E_{saline} P_{50}	Weighted E_{saline} P_{90}	Storage Capacity G_{CO_2}* (Mt) P_{10}	Storage Capacity G_{CO_2}* (Mt) P_{50}	Storage Capacity G_{CO_2}* (Mt) P_{90}
Maryville-Basal Sands	13.7	34	4.66	813	1,003	0.074	0.140	0.240	229.7	434.6	745.0

*At reservoir conditions; Peace Software, www.peacesoftware.de/einigewerte/co2_e.html

*Mapped evaluation area northwest of the Kentucky River Fault Zone is 664,500 acres

The 1 Hanson Aggregates penetrated a net total of 44 ft of reservoir sands with φ_e > 7% in the Maryville–Basal sands section, and in the 664,500-acre mapped region northwest of the Kentucky River Fault Zone surrounding the well (above) averages only 34 ft of potential reservoir sands with φ_e > 7%. P_{50} reservoir volume insufficient to store the average annual CO_2 emissions from a source in the MRCSP region.



CO_2-brine relative permeability tests on core plugs from the Maryville and Basal sands. Maximum CO_2 saturation (S_{max}), residual CO_2 saturation (S_t), and relative permeability to brine (kr_{Brine}) and CO_2 (kr_{CO_2}) are posted. S_t in both plots was determined by regression. Capillary trapping efficiency, the percentage of residually-trapped CO_2 ($R_{\%} = (S_t/S_{max})\times100$; Burnside and Naylor, 2014), is 52.5% in the Maryville sand and 43.1% in the Basal sand. That is, ~50% of CO_2 injected into the Maryville–Basal sands section would be trapped in the pore space and unable to migrate out of the reservoirs in the event of a seal failure.

CONCLUSIONS

1. Shaly sand analysis of effective porosity of the Maryville–Basal sands section in the 1 Hanson Aggregates compares favorably to porosity measured in core plugs. Considering the complexity of shaly-sand log analysis, however, quick-look porosity evaluations of the Maryville Sand, an arithmetic average of neutron and density porosity computed using sandstone matrix density, and the Basal Sand, density porosity calculated using a sandstone matrix density, are recommended to approximate effective porosity.

2. Thin reservoir sands, low porosity and permeability, and low fracture gradient preclude the Maryville–Basal sands section as deep-saline CO_2 storage reservoirs.

ACKNOWLEDGMENTS

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Kentucky Geological Survey

University of Kentucky.