Geocellular Model Development for Simulation of CO_2 Storage in the Arches Province of the Midwestern United States

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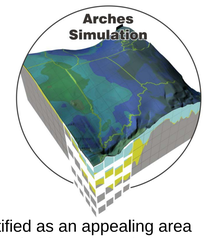
Abstract

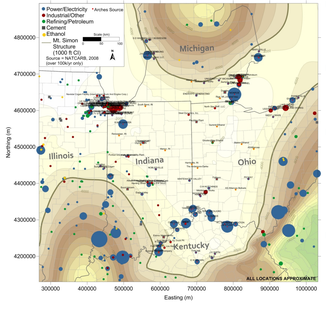
A geocellular model was developed for areas of the midwestern United States to facilitate numerical simulations on the injection of supercritical carbon dioxide into the Mount Simon Sandstone (Cambrian). These simulations are focused on evaluating the infrastructure necessary to implement large-scale CO_2 storage in the region. The Arches Province includes areas in northern Indiana, northern Kentucky, western Ohio, and southern Michigan where Paleozoic rocks form broad arch and platform structures. The main rock formation for potential CO_2 storage in the study area is the Mount Simon Sandstone (Cambrian), which has been used as a repository for waste disposal for many decades. Geophysical well logs, deep injection operational data from wells, reservoir test results, and geotechnical core test data were collected for the Mount Simon Sandstone and the overlying Eau Claire Formation (Cambrian) confining layer. This study integrates these various types of data into a geocellular model. For example, reservoir permeability was estimated using reservoir test results obtained at injection well sites. In addition, geostatistical analysis was used to interpret spatial trends in parameters. The geocellular model includes parameters for numerical simulations, such as porosity and permeability distribution. The model development improves the understanding of the nature of the Mount Simon Sandstone in the Arches Province, and will provide input for numerical simulations of large-scale CO_2 injection in the region. This work was supported by U.S. Department of Energy National Energy Technology Laboratory award DE-FE0001034 and Ohio Coal Development Office of the Ohio Air Quality Development Authority grant D-10-03.

Introduction

The objective of this project is to develop a simulation framework for regional geologic CO_2 storage infrastructure along the Arches Province of the Midwest United States through development of a geologic model for the Arches province and advanced reservoir simulations of large-scale CO_2 storage along the province.



The Arches Province in the Midwest has been identified as an appealing area for CO_2 storage because of the intersection of reservoir thickness and permeability along the province. The province includes areas of Indiana, Kentucky, Michigan, and Ohio along several regional geologic structures. The main injection target is the Mount Simon Sandstone, which is also the most promising reservoir for the entire Midwest. There are many existing CO_2 sources in proximity to the Arches Province, and the area is adjacent to the Ohio River Valley corridor of coal fired power plants such that it may be feasible to access the area with a pipeline network.



- 131 point sources in the Arches Province have emissions over 100,000 metric tons CO_2 per year[1].
- These sources have combined emissions of 286 million metric tons CO_2 per year.
- Approximately 221 million metric tons per year emissions are from power plants, mostly concentrated along the Ohio River Valley and the Great Lakes coastline.
- In addition, there are many sources in adjacent areas, which may access the Arches area with a pipeline distribution system.

[1]based on DOE 2008 Carbon Atlas Data

Geologic Setting

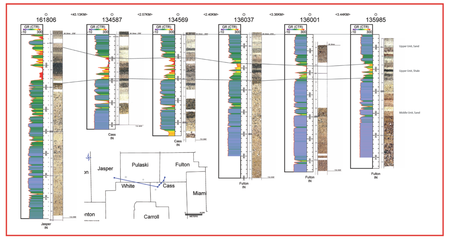
- The Middle Cambrian Mount Simon Sandstone is a regional deep saline formation with the largest projected CO_2 storage reserve in the Midwest.
- Mapping of the formation in the Arches Province was undertaken to better constrain CO_2 storage estimates and reservoir characteristics for regional modeling.
- The Mount Simon is overlain by the Eau Claire shale and Knox Supergroup and underlain by Precambrian crystalline bedrock.

	Illinois	Indiana	Michigan	Ohio	Kentucky	Numerical Model
ORDOVICIAN	Knox	Knox	Trempealeau-Franconia-Ironton-Galesville	Beekmantown-Copper Ridge	Knox	Knox
CAMBRIAN	Eau Claire	Eau Claire	Eau Claire	Eau Claire	Conasauga	Eau Claire
	Mt. Simon	Mt. Simon	Mt. Simon	Mt. Simon	Mt. Simon	Mt. Simon
	Precambrian-Granite-Rhyolite Complex	Precambrian-Granite-Rhyolite-Middle Run	Precambrian-Granite-Rhyolite Complex	Precambrian-Middle Run-Greenville	Precambrian-Middle Run-Grenville	Precambrian-Granite-Rhyolite-Middle Run

- Geophysical well logs were compiled for 496 wells and examined to determine the depth of key formations, including the Knox, Eau Claire, Mount Simon, and Precambrian.
- Geologic cross sections through key areas were constructed to better understand the distribution of the rock formations.

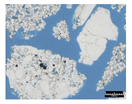
Evidence from core, geophysical logs, and previously published work has allowed us to identify a shaly unit within the upper unit of the Mount Simon. This was originally defined in northwestern Indiana as a shaly unit with gray micaceous siltstone, also called as "B-Cap" (Becker et al., 1978). This unit may also serve as an additional sealing unit to avoid vertical migration of CO_2.

Becker, L. E., Hreha, A. J., and Dawson, T. A., 1978, Pre-Knox (Cambrian) Stratigraphy in Indiana: State of Indiana Department of Natural Resources Geological Survey, 72 p.

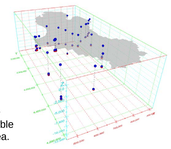


Supplementary Core Test Data

- Over 4,000 geotechnical core test data were compiled for Mount Simon wells in the Arches Province.
- 85 untested rock core identified by the state geological surveys were plugged and tested for standard permeability, porosity, and other selected tests. These samples fill data gaps in the region.
- Permeability values of 100-1000 mD were observed in many samples, demonstrating the high permeability of the Mount Simon in the Arches Province.

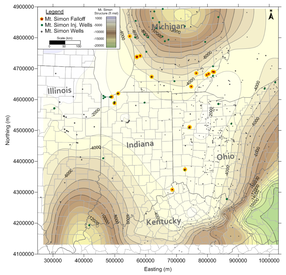


Thin section of rock cuttings from Mt. Simon Well in Kentucky.



3D post of core test data available in the study area.

Deep Well Injection Data

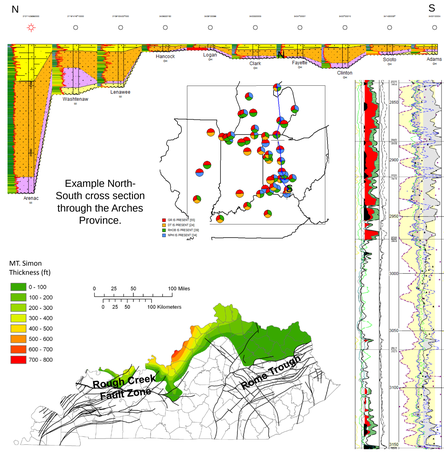


Map showing Mt. Simon Injection Well Locations on Mt. Simon structure map.

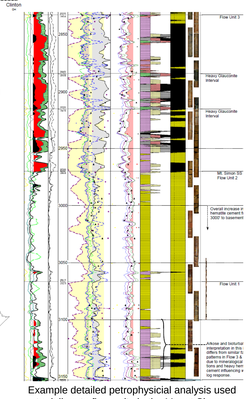
- Data was obtained for 31 Mount Simon deep injection wells.
- Records indicate total Mount Simon injection of over 18 billion gallons in the Arches Province over the past ~40 years. Equivalent to roughly 50 million metric tons CO_2.
- Injection rates generally range from 50-300 gallons per minute.
- Injection wells provide practical information on reservoir properties for Mount Simon through operation data and pressure falloff tests.

Mapping and 3D Database

- Geological cross sections and maps were completed through the Arches Province, delineating structure, flow units, and facies distribution in the Mount Simon and Eau Claire.
- Geophysical porosity logs from 176 wells were also compiled into a 3D database, with total of >960,000 data points in the study area.
- These items define the framework for the geocellular model.



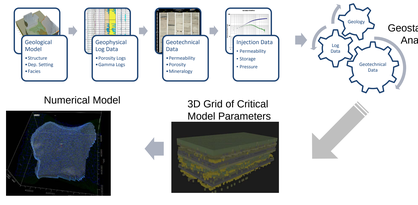
Map showing Mount Simon Thickness in Kentucky.



Example detailed petrophysical analysis used to delineate flow units in the Mount Simon.

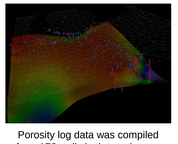
Data Integration

- A specialized data evaluation process was developed to assign model parameters and integrate operational, geotechnical, geophysical, and geological information.
- The process include calibrating geocellular permeability distribution to reservoir test data at deep well injection sites.

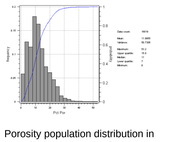


Geostatistics

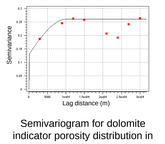
- Geostatistical methods were employed to evaluate spatial covariance structure of petrophysical rock properties.
- Variogram analysis, co-kriging, and indicator geostatistics were utilized to evaluate spatial trends.



Porosity log data was compiled from 176 wells in the study area



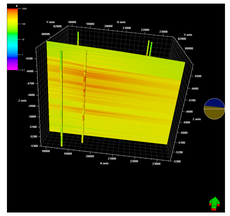
Porosity population distribution in the lower Mount Simon



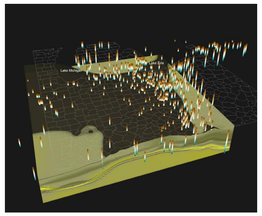
Semivariogram for dolomite indicator porosity distribution in the Eau Claire formation

Geocellular Model Development

- Based on porosity log data, geostatistical parameters, and structural boundaries, a 3D grid of porosity is being developed throughout the model domain.
- Cokriging and gaussian simulations methods are being employed to produce permeability distribution.
- End product will be a 3D grid of permeability and porosity which accounts for regional variations in Mount Simon.



Example geocellular model of porosity for southwestern Michigan.



Geocellular model development process was used to provide model input for the Arches Province Area.

Conclusions and Next Steps

- Geocellular model development improves the understanding of the nature of the Mount Simon Sandstone in the Arches Province, and will provide input for numerical simulations of large-scale CO_2 injection in the region.
- Mt. Simon injection wells provide 31 valuable calibration points for simulation of CO_2 storage in the Arches Province such as pressure, permeability, storage parameters (compressibility), and reservoir geometry.
- Overall, data suggests the presence of broad trends in permeability and porosity in the Arches Province, possibly related to depositional setting and diagenetic processes.
- Next steps include translating the geocellular model into multi-phase numerical simulations of CO_2 injection and storage. Two regional storage infrastructure scenarios have been identified for simulation: 1) On-site injection for 52 large CO_2 point sources, and 2) regional CO_2 injection fields. The scenarios will address storage rates of 70-140 million metric tons CO_2/year, enough to reduce CO_2 emissions in the Arches Province 25-50%.

Acknowledgements

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