Lithostratigraphic Division of the Mount Simon Sandstone (Cambrian) along the Cincinnati Arch: Implications for Reduction of Uncertainty in Estimations of Geologic Sequestration Storage Capacity*

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Abstract

The Mount Simon Sandstone (Cambrian) in the Midwest region has significant potential to serve as a reservoir for geologic Carbon Capture, Utilization and Storage (CCUS). Despite numerous recent studies of the Mount Simon, petrophysical heterogeneities controlled by the changes in lithologic and diagenetic character of these rocks remain poorly understood. The process of reducing uncertainty in the storage capacity of this reservoir is challenging. The Carbon Sequestration Atlas of the United States and Canada defines the storage “efficiency factor” as the proportion of the accessible pore volume that could conceptually be occupied by the injected carbon dioxide. Values of efficiency factors used in regional reservoir characterization studies are typically 1-4 percent based on Monte Carlo simulations. To employ higher efficiency factor values, uncertainties associated with the three geologic parameters must be reduced. These include: (1) actual versus approximate area to be occupied by the CO₂ plume, (2) net versus gross reservoir thickness, and (3) effective versus total porosity. To accomplish this, gamma-ray logs were interpreted in the Cincinnati Arch region to define three lithostratigraphic subunits within the Mount Simon Sandstone: (1) an upper unit that has relatively high gamma-ray values, owing to the admixture of argillaceous material; (2) a middle unit defined by relatively lower gamma-ray values that result from a cleaner quartzose sandstone; and (3) a lowermost unit defined by gamma-ray values that, in general, progressively increase with depth toward the base of the formation. This downward increase is due to the increased non-quartz fraction in the formation as the top of the Precambrian basement complex is approached. To reduce uncertainties associated with the vertical distribution of reservoir facies, storage capacities for all three units were calculated using the standard Department of Energy methodology, using values from geophysical porosity logs. A minimum porosity of 7 percent was imposed as a threshold for this assessment. Results from 14 wells in the study area show a linear relationship between calculated capacities for the entire Mount Simon Sandstone and its lower unit. The relationship established when comparing these two variables ($R^2 = 0.97$) can be used to help reduce uncertainties associated with the net-to-total area ($E_{An/At}$), net-to-gross thickness ($E_{hh/hg}$), and effective-to-total porosity ($E_{qe/φtot}$) components in the efficiency factor. Although this methodology reports enhanced
efficiency factor values for the Mount Simon Sandstone in the study area, more detailed assessments of the vertical distribution of porosity and permeability will further reduce uncertainties and will allow the use of even higher values of the efficiency factor at specific localities.
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ABSTRACT

The Mount Simon Sandstone (Cambrian) in the Midwest region has significant potential to serve as a reservoir for geologic Carbon Capture, Utilization and Storage (CCUS). Despite numerous recent studies of the Mount Simon, petroleum geologists have avoided the area due to the challenges of understanding the variability and uncertainty in the storage capacity of the reservoir. The Carbon Sequestration Atlas of the United States and Canada defines the storage “efficiency factor” as the proportion of the accessible pore volume that could conceivably be occupied by the injected carbon dioxide. Values of efficiency factors used in regional reservoir characterization studies are typically 1+ percent based on Monte Carlo simulations. To improve the efficiency factor values, uncertainties associated with the three geologic parameters must be reduced. These include: (1) initial mineral precipitate state was occupied by the CO₂, (2) net versus gross reservoir thickness, and (3) effective versus total porosity. To accomplish this, gamma-ray logs were interpreted for the Cincinnati Arch region to define three lithofacies subunits within the Mount Simon Sandstone: (I) an upper unit that has relatively low gamma-ray values, (II) a middle unit defined by relatively lower gamma-ray values that result from a change in quartz content, and (III) a lower unit defined by high gamma-ray values that result from a change in argillaceous material. These lithofacies represent different reservoir heterogeneities, and porosities associated with the different lithofacies are estimated using the standard methods of reservoir analysis. An estimate of porosity and permeability by facies type is provided, and the resulting porosity and permeability changes are compared to the efficiency factor. Although these methods may result in higher efficiency factor values for the Mount Simon Sandstone in the study area, more detailed analysis of the vertical distribution of porosity and permeability will provide new insights into the geologic storage capacity of this critical reservoir.

STUDY AREA: MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP (MR CSP)

Figures 1-4: (a) Map of Midwest Geological Sequestration Consortium (MGSC) and Midwest Regional Carbon Sequestration Partnership (MR CSP); (b) representative well in Michigan with geochemical logs indicating the interbedded subunits of the Mount Simon Sandstone; (c) CO₂ sources located in the MR CSP region; and d) map indicating the wells used in this study.

Figures 5-8: Generalized cross sections indicating the proposed three-facies subunits within the Mount Simon Sandstone. Interpretation of well data was used to construct isopach maps for the Lower Unit, the Middle Unit, and the Upper Unit (Figures 3-4).

This work is funded by the DOE and is part of the regional carbon sequestration assessment being conducted by the Midwest Regional Carbon Sequestration Partnership (MR CSP).

SOUTHERN OHIO DIVISION OF THE MOUNT SIMON SANDSTONE

Sisson (1970) identified a subzone in northeastern Indiana, also called the "O-Cap," which ranges between 10 and 60 feet in thickness. Based on both geological and lithological log and thinsection log of well cuttings from the sample library of the Indiana Geological Survey, we have delineated this subzone throughout northern Indiana.
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STANDARD DOE STORAGE CAPACITY (SC) CALCULATION METHOD

\[ G_{CO2} = A \cdot h \cdot \phi \cdot \rho \cdot \varepsilon \]

where:
- \( G_{CO2} \) = Mass
- \( A \) = Total Area
- \( h \) = Total Porosity
- \( \phi \) = Total Permeability
- \( \rho \) = Density
- \( \varepsilon \) = Efficiency

The Efficiency Factor (\( \varepsilon \)) reflects the fraction of the total pore volume that will be occupied by the injected CO2 (Gorecki et al., 2002; OECD/NEA, 2010).

ENHANCED STORAGE CAPACITY CALCULATION METHOD

\[ E_{\text{net}} = E_{\text{Av}} \cdot E_{\text{ht}} \cdot E_{\text{p}} \cdot E_{\text{v}} \]

The following methods are used to determine the efficiency factors:

- \( E_{\text{Av}} \) = Salinity Formation Efficiency Factor for Geogroge and Depositional Sediments
- \( E_{\text{ht}} \) = Temperature Dependent Efficiency Factor
- \( E_{\text{p}} \) = Pressurization Efficiency Factor
- \( E_{\text{v}} \) = Volume Efficiency Factor

Table 1: Parameters for Salinity Formation Efficiency Factor

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<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>20°C</td>
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<tr>
<td>Pressure</td>
<td>50 MPa</td>
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<tr>
<td>Salinity</td>
<td>35 ppt</td>
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</tbody>
</table>

Figure 1: Model of Total Area (T) and network of storage, Formation, and Reservoir (x).

Table 2: Salinity Formation Efficiency Factors for Geogroge and Depositional Sediments

<table>
<thead>
<tr>
<th>Parameter</th>
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<tbody>
<tr>
<td>E_{\text{Av}}</td>
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<tr>
<td>E_{\text{ht}}</td>
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<tr>
<td>E_{\text{p}}</td>
<td>0.7</td>
</tr>
<tr>
<td>E_{\text{v}}</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Figure 8: Gamma Ray vs MHP log for Mount Simon Sandstone showing the correlation to gamma ray values at the reservoir scale and the correlation to auxiliary permeability measurements (x).

Figure 9: Sensitivity analyses to the ratio of storage capacity to the reservoir rock (x).

Figure 10: Porosity that reduces the application of gamma ray and porosity threshold in the middle and lower end of the Mount Simon Sandstone (x).

CONCLUSIONS

1. Evidence from geophysical logs, core descriptions, and previously published work suggests that the Mount Simon Sandstone can be subdivided into three facies characterized by varying amounts of quartz rich, clay minerals, and feldspars.

2. In general, the groundwater flow is lower in the gamma ray values, whereas the lowermost has a trend of increasing gamma ray values with depth. This is attributed to the internal heterogeneity of the Mount Simon Sandstone with the lowermost formation of lower permeability (x).

3. Previous calculations of storage capacity included the entire extent of the Mount Simon Sandstone and used threshold values of 75 MPa and 75% for gamma ray and porosity target, respectively (Medina et al., 2010). The new approach assesses the middle and upper end of the Mount Simon Sandstone, which shows that the storage capacity in the middle end is similar to the storage capacity previously estimated for the entire section (Medina et al., 2011).

4. Sensitivity and characterization of storage capacity also help to reduce uncertainties associated with the assumption of reservoir properties, which will lead to more accurate estimates of flow models for the prospective storage reservoir. Storage capacity calculations are also made for the substations of the Mount Simon Sandstone, allowing for higher values of efficiency factors and allowing for the estimation of storage capacity in the formation.

5. Higher values of efficiency factors are proposed when estimating the storage capacity of a specific subs and within the Mount Simon Sandstone. However, the overall calculated storage capacity of the reservoir is lower due to the fact that only a portion of the reservoir is considered as effective reservoir. This method proposes a decrease in the uncertainty of reservoir capacity and further studies are necessary to quantify the potential resolution in uncertainty.

REFERENCES


