Regional Variability of Michigan Niagaran Reefs and the Impact on CO₂ Storage Resources

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Abstract

There are over 800 identified Silurian-aged Niagaran Pinnacle Reefs in the northern Trend (NPRT) in the Michigan Basin in Michigan, USA. The complex internal architecture, production history, lithology, and diagenetic changes in these reefs strongly affect the carbon dioxide (CO₂) storage capacity, pressure response, and ultimately the reservoir performance of each individual field. Therefore, these fields provide an excellent opportunity to evaluate the geologic variability in complex carbonate reservoirs and its impact on CO₂ storage configurations. The reefs have historically been studied on an individual scale which does not represent the potential of the entire trend. Workflows were established to characterize reefs from an individual scale to a regional scale, capturing the entire NPRT. The reefs are being analyzed in three parts: 1) geologic characterization using wireline logs, whole core, and production records, 2) assessment of enhanced oil recovery (EOR) and carbon capture utilization and storage (CCUS) feasibility and comparison in the reefs by constructing representative static earth models, dynamic models, and geomechanics models, and 3) estimates of CO₂ resources across the NPRT using three methods.

Data was collected for over 6,000 wells along the NPRT including digital and raster wireline logs, whole core and sidewall core measurements, production history, pressure history, brine chemistry, and publicly available records. Formation tops for major confining units and reservoirs were identified at all locations. Key wells were identified for regional cross sections along the trend to capture geologic variability. Structure and isopach maps for on and off reef wells were constructed for all major formations.

Wireline logs were quality checked and digitized to fill critical data gaps. Logs were used to determine reef lithology, porosity, and water saturation. Additionally, petrophysical characteristics where calculated for select reefs including average porosity, gross and net thickness, and porosity-feet. Whole core and sidewall core measurements were available from several hundred wells. Data was used to describe changes in lithology, diagenesis, and reservoir characteristics. Computerized tomography (CT) scans were collected on select core and image analysis was run to quantify and predict secondary porosity.
Annual and cumulative production data was publicly available and organized for each reef. The data was used to determine reef type (oil, gas, water, mixed, or dry). When available, pressure data was collected to determine variability in reservoir pressure and pressure gradients.

Variability in the geologic characteristics, reservoir characteristics, and production were used to bin the reefs into representative categories. Categories included dolomitic, limestone, mixed carbonate, single and multipod reef fields, oil and gas reefs, and highly salt plugged reefs. Two dimensional (2D) and three dimensional (3D) conceptual models were constructed for each category to represent the variability. Conceptual models were then used to inform geomechanical and dynamic models. All models were used to compare reef performance for each category and assess the feasibility for CO₂ storage and EOR.

Finally, all analyses were used to estimate CO₂ storage resources following three methodologies: 1) fluid substitution using pressure, temperature, and cumulative production, 2) mass balance of reefs from each category using pressure and production history, and 3) simulated fluid flow and storage using dynamic models.

Results show the geologic variability in the reefs impacts the storage feasibility across the trend. Significant factors include lithology, diagenesis, and reef connectivity. A comprehensive dataset successfully identified trends in the NPRT and characterized variability while also providing a resource and guide for future CCUS activities. New methodologies and techniques were developed which were used consistently and efficiently to analyze hundreds of fields. Some of the highlights are listed below:

1) Image analysis techniques were developed to quantify diagenetic features in whole core using CT scan data and to statistically derive porosity indicators
2) Petrophysical techniques were developed for complex carbonates and identified reefs better suited for CCUS
3) Reservoir characteristics changed across reef types and lithofacies, however the diagenetic overprint primarily controlled the reservoir performance through secondary porosity development or evaporite plugging
4) Reefs were ranked by CCUS feasibility using the results from dynamic modeling and storage resource calculations
5) Assessment of caprocks and geomechanical models showed the effectiveness of CCUS in reefs
6) An interactive database was established to quickly provide assessments of individual reefs as well as summaries across the entire NPRT

The study is part of the Midwestern Regional Carbon Sequestration Partnership (MRCSP) Michigan Basin Large-Scale Injection Project, which is part of a larger national carbon storage research program headed by the United States Department of Energy. Since the current research began on this project in February 2013, MRCSP has successfully injected and monitored the net storage of more than 900,000 metric tons of carbon dioxide into Niagaran reefs, while the cumulative injection since 1996 is more than 2 million metric tons. The goal of the MRCSP project is to monitor at least one million metric tons of carbon dioxide into depleted oil and gas fields. The MRCSP (www.MRCSP.org) is funded under DOE/NETL Cooperative Agreement # DE-FC26-0NT42589 with co-funding by Core Energy, LLC, and several other partners.