Mineralogy and CO_2 Storage at the Weyburn IEA CO_2-EOR Site

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Summary

Water-rock reactions are critical to the short- and long-term storage of injected CO_2. Carbonate-CO_2-fluid reactions releases CO_2 while silicate-CO_2-fluid reactions potentially store CO_2 in the fluid and as newly formed carbonates. The detailed, quantitative mineralogy of the Weyburn reservoir is described in the context of flow units as defined by the operator of the Weyburn Field, EnCana Resources Ltd. Detailed, quantitative mineralogy is also presented for the units that overly the Weybrun Reservoir. Storage calculations show that even in a carbonte reservoir such as Weybrun, there are sufficient silicate minerals to provide long term storage of CO_2 by reaction with silicates. Also, overlying units that represent a wide array of rock types have the capacity to store CO_2 that might escape from the reservoir.

Introduction

Burrowes and Gilboy (2000) have described the detailed geological setting of the Weyburn reservoir. The Weyburn field lies along the Mississippian subcrop belt on the northern extent of the Williston Basin, approximately 130 kilometers southeast of Regina, Saskatchewan. Medium gravity crude oil is produced from the Midale beds of the Mississippian Charles Formation (Figure 1). The Weyburn reservoir is comprised of the tight dolomitic Marly zone and the underlying calcitic more permeable Vuggy Shoal and less permeable Vuggy Intershoal zones and is sealed by the Midale Evaporite anhydrite cap. EnCana has established a core-based, sequence stratigraphic interpretation of the Midale Marly and Vuggy units (Figure 2). Burrowes and Gilboy (2000) list general porosity and permeability estimates for the various flow units: The Midale Marly is characterized by high porosity (26%), and variable permeability (10 MD). The Midale Vuggy shoal has lower porosity (15%), but high permeability (50MD), and the Vuggy intershoal unit is characterized by low porosity (10%) and low permeability (3 MD).

Trapping potential for CO_2 is related to mineralogy and the nature of reactions that occur in the fluid phase. Carbonate reservoirs typically containing Fe-, Mg- and Ca-bearing carbonates have less trapping potential for CO_2 than do silicate reservoirs, as can be shown by the reactions:

1. CO_2 dissolution

$$H_2O + CO_2 \Rightarrow H_2CO_3^- \Rightarrow H^+ + HCO_3^-$$

Calcite dissolution

$$H^+ + CaCO3 \Rightarrow Ca^{2+} + HCO_3^-$$

Both CO_2 and calcite dissolution

$$H_2O + CO_2 + CaCO_3 \Rightarrow Ca^{2+} + 2HCO_3^-$$

CO_2 dissolution results in the modified fluid having a lower pH and higher [HCO_3^-]. Calcite dissolution leads to higher carbonate alkalinity and higher cation concentrations. If both reactions take place, as shown by the final reaction, then for each mole of injected CO_2 that reacts, we can expect one mole of cation, and 2 moles of HCO_3^- dissolved in the in situ fluid.

In siliciclastic aquifers, CO_2 may be stored in the mineral and/or aqueous phase by reacting with silicate minerals. Although the Weyburn reservoir is dominantly calcitic and dolomitic, significant concentrations of potentially reactive silicate minerals may be present to assist in CO_2 storage. The overlying units to surface are comprised of a mixture of carbonates and siliciclastics that also contain significant volumes of silicate minerals. Gunter et al. (2000) have grouped mineral trapping into two types. Type 1 capture is defined as occurring when a mineral is precipitated incorporating the anion formed by the dissolved gas. Type 2 capture is defined as occurring when an acid gas is neutralized in solution forming a non-volatile soluble salt and subsequently leading to brine formation. Type 3 capture is characterized by CO_2 trapping in both solid and aqueous phases:

Geological units containing aluminosilicate mineral assemblages such as feldspar, zeolite, illite, and chlorite act as a base and facilitate CO_2 storage. If the assemblage contains Fe/Ca/Mg-bearing silicate minerals, neutralization of CO_2 results in precipitation of siderite, calcite or dolomite (i.e. Type 1 reaction), if it contains Na/K-bearing silicate minerals, neutralization of the CO_2 results in development of bicarbonate brines (i.e. Type 2 reaction). The reaction of the CO_2-charged fluid with silicate mineral assemblages is key to trapping CO_2, especially if reservoir containment is compromised.

Results - Mineralogy

Approximately 100 core samples were obtained from each of the flow units shown in Figure 2 and a further 9 samples were obtained from units below and 48 above the Midale Beds. EnCana supplied flow unit interval information and cores were selected to maximize each sampled flow unit. Cores were also selected to correlate with wells sampled for the Geochemistry fluid/gas program (see paper by Raistrick et al, this volume). Five primary analytical methods were utilized for the samples:

1. polished thin section examination – general textural and mineralogical information.
2. X-Ray Diffraction – mineral identification and relative proportions.
3. X-Ray Fluorescence and Inductively-Coupled Plasma Mass Spectrometry – whole rock major and trace element composition.

4. Electron Probe Microanalysis – mineral identification and chemistry.
5. Linear Programming Normative Analysis – quantitative mineralogy for each sample.

The reservoir and nearest units include the Midale Marly, the Midale Vuggy, The Midale Evaporite Three Fingers Zone (TFZ) and the Frobisher Marly and Evaporite. The Midale Marly flow units comprise 50-65% dolomite,10-25% calcite, with some anhydrite and have the greatest amount of silicate minerals (7.5-16%). The Midale Vuggy flow units are dominated by calcite mineralization (70-90%), relatively minor amounts of dolomite (5-15%) and traces of anhydrite (3-13%). Silicate minerals are minor to trace amounts (2-15%). The Midale Evaporite-TFZ is the cap rock for the reservoir. The lowermost sub unit is the "Three Fingers Zone" (TFZ, Burrowes and Gilboy, 2000). The TFZ is a dolomite-dominant rock, with minor quartz, feldspar, anhydrite, and illite. Silicate minerals form approximately one-third of this flow unit. The Frobisher Marly immediately underlies the reservoir units. This flow unit is marked by a dolomite-rich (>70%) rock with minor anhydrite, quartz, calcite, and feldspar. Silicates make up approximately 15% of this unit. The Frobisher Evaporite underlies only a portion of the Weyburn reservoir, and is essentially anhydrite (59%) and carbonate (39%).

Over- and Underlying Regional Units

The geology and depositional settings of stratigraphic units in Southeast Saskatchewan has been comprehensively studied, and is too voluminous to summarize here. The reader is referred to Saskatchewan Industry & Resources' website (http://www.ir.gov.sk.ca). Geologists at the SIR subsurface facility provided access to preserved and logged core from Southeast Saskatchewan. Using SIR's stratigraphic correlation chart, a number of units in Southeastern Saskatchewan were sampled (50 samples). The three aquifers, which lie below the Midale beds, and the six aquifers, which lie above the Midale beds, are represented by samples in this study. In addition, 5 aquitards, which lie above the Midale beds, are represented in the sample suite. The samples were correlated to corresponding aquifers/aquitards defined courtesy of B. Rostron.

The regional samples are not described, but include samples from all units spanning the Triassic-Jurassic Watrous Formation "red beds", the Middle Jurassic Upper Watrous Formation evaporite, the Middle Jurassic Gravelbourg Formation, Upper Shaunavon Formation, the Vanguard Group, the Lower Cretaceous Mannville Group, the Lower Cretaceous Colorado Group and the Upper Cretaceous Sandstone and Shales. A wide range of lithologies and mineralogies are represented by these rocks.

Discussion and Conclusions

Although the Midale reservoir mineralogy is dominated by carbonate and sulfate minerals, Silicate minerals have been quantified using petrographic, analytical, and computational techniques. Silicate minerals are dominated by quartz (up to 17 vol%), followed by K-Feldspar (up to 9%), plagioclase (up to 3%), illite (up to 5%), and kaolinite (up to 1%). The most "promising" unit for silicate-reaction CO_2 sequestration is the uppermost Midale Marly and the Midale Evaporite Three Fingers Zone, where silicates form 15 to 35 % of the whole rock by volume. Although CO_2 is liberated by carbonate-CO_2-fluid reactions, some of the CO_2, be it injected or created from reservoir mineral dissolution, can potentially be stored as newly formed minerals from silicate mineral reactions.

Given:

1. a 20 km • 20 km • 20 m reservoir with 20% porosity
2. 2% reactive silicate minerals
3. a closed system (i.e. no CO_2 leakage)
4. silicate density = 2.8 g/cc, approximately 300 g/mol
5. approx. 1 mol CO_2 stored for 1 mole reactive silicates
6. complete reservoir saturation with CO_2-charged fluid

Then:

1. total rock volume of $8 \cdot 10^{15}$ cc
2. total reactive silicate volume of $1.6 \cdot 10^{14}$ cc
3. total reactive silicate volume in contact with pore space of $3.2 \cdot 10^{13}$ cc
4. total reactive silicate mass of $9 \cdot 10^{13}$ g
5. total weight CO_2 stored: approx. $1.3 \cdot 10^{13}$ g

This means that for just 2% reactive silicates by volume, 13 million metric tones of CO_2 could potentially be stored under ideal conditions in the Weyburn reservoir. The Alberta Research Council is currently evaluating the reservoir's capacity to store or produce CO_2 due to CO_2 injection. Should leakage from the reservoir occur, units which overlie the reservoir (e.g. Watrous, Vanguard, Mannville, etc.) would store orders of magnitude more CO_2, given sufficient time for silicate-CO_2 reactions to reach completion. The mineralogical characterization of the overlying units improves the long-term risk and amount of CO_2 storage potential in these units.

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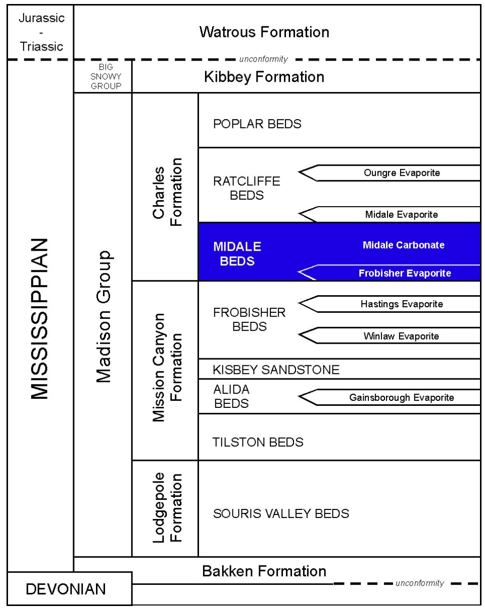

Figure 1: Mississippian stratigraphy in the Weyburn area.

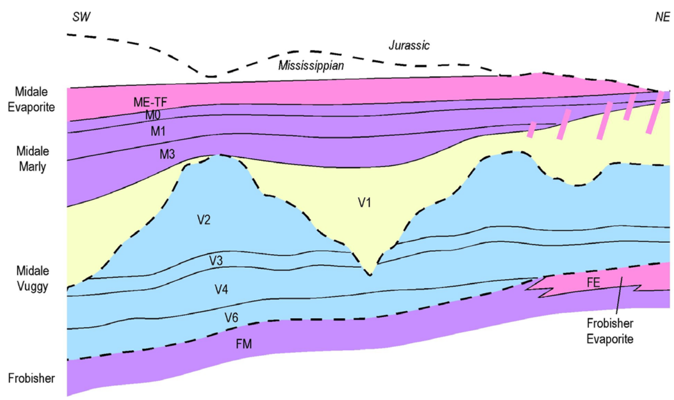

Figure 2: Geological cartoon of the Weyburn Unit reservoir, showing “flow units”, as described by Burrowes and Gilboy (2000). Samples were obtained from each of these flow units. Dashed lines represent unconformities/erosional horizons. The hatched area in the upper V1 flow unit corresponds to anhydrite pore filling.