

# **Enhanced CO<sub>2</sub> Storage as a Result of CO<sub>2</sub>-Water-Silicate Mineral Reactions; Evidence from Produced Fluid Geochemistry and Geochemical Modeling at the IEA Weyburn Project**

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## **Summary**

Geological CO<sub>2</sub> storage with or without the added benefit of CO<sub>2</sub> EOR provides a means of reducing CO<sub>2</sub> emissions to the atmosphere. To confirm the efficiency of storage and obtain credit for avoided CO<sub>2</sub> emissions a range of monitoring data needs to be collected and interpreted. Chemical data collected over four years of produced fluid monitoring at Weyburn suggest that alteration of K-feldspar has buffered the pH decrease resulting from CO<sub>2</sub> injection, enhancing aqueous CO<sub>2</sub> storage and possibly leading to mineral storage of CO<sub>2</sub> as CaCO<sub>3</sub>. Using geochemical modeling software, reaction path simulations over 100s of years, calibrated via history matching over the first few years, show that reaction of K-feldspar and other silicate minerals present in the Weyburn oilfield reservoir will lead to further storage of injected CO<sub>2</sub> in the aqueous phase and as carbonate minerals.

## **Introduction**

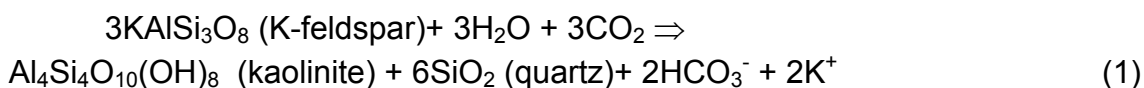
At the IEA Weyburn Project in Saskatchewan, CO<sub>2</sub> storage research takes place alongside CO<sub>2</sub> enhanced oil recovery (EOR) in the Weyburn reservoir (Wilson and Monea 2004). Chemical and isotopic measurements of fluids collected from monitored production wells at Weyburn confirm the integrity of CO<sub>2</sub> storage, trace CO<sub>2</sub> dissolution in the hydrocarbon and aqueous fluids and record CO<sub>2</sub>-water-rock reactions (e.g. Emberley et al. 2005, Raistrick et al. 2006). Not only do monitoring data confirm the occurrence of CO<sub>2</sub> storage, they also provide important information for reservoir management, demonstrating the effectiveness of CO<sub>2</sub> flooding and recording reservoir mineral stability.

## Results and Discussion

The majority of the measured geochemical changes over a four year period following the arrival of CO<sub>2</sub> in the reservoir volume sampled by the selected monitoring wells are due to:

1. carbonate mineral dissolution
2. dissolution of injected CO<sub>2</sub> and dissociation to form HCO<sub>3</sub><sup>-</sup>

Changes in Ca<sup>2+</sup>, Mg<sup>2+</sup> and SO<sub>4</sub><sup>2-</sup> concentrations constrain the quantity of HCO<sub>3</sub><sup>-</sup> formed from carbonate mineral dissolution, which is caused by the pH decrease from dissolution and dissociation of injected CO<sub>2</sub>. An increase in K<sup>+</sup> concentration suggests that the pH decrease led to silicate mineral alteration. The most likely silicate reaction is alteration of K-feldspar (1) to kaolinite, a reaction that buffers pH and leads to enhanced aqueous CO<sub>2</sub> storage as K<sup>+</sup> - HCO<sub>3</sub><sup>-</sup> brines, and if sufficient Ca<sup>2+</sup> is available, the potential for mineral storage of CO<sub>2</sub> as Ca-carbonate.



The chemical data support the conclusions drawn from previous studies (e.g. Raistrick et al. 2006), confirming that the majority of the increase in HCO<sub>3</sub><sup>-</sup> over the period since CO<sub>2</sub> entered the reservoir volume sampled by the selected monitoring wells resulted from dissolution and dissociation of injected CO<sub>2</sub>.

Geochemical reaction pathway modeling software GWB (Geochemists Workbench React) was used to simulate the measured changes in the selected monitoring well chemical data over 750 days following the arrival of injected CO<sub>2</sub>. This history matching confirms the type and magnitude of CO<sub>2</sub>-aqueous fluid-mineral reactions recorded in the chemical data (Figure 1). Using measured geochemical, physical, and geological data to define model conditions, the GWB-React simulations confirm that, following CO<sub>2</sub> injection, the dominant source of HCO<sub>3</sub><sup>-</sup> is ionic trapping of injected CO<sub>2</sub> with carbonate mineral dissolution as a subordinate HCO<sub>3</sub><sup>-</sup> source. The simulations also provide an estimation of the amount of injected CO<sub>2</sub> required to react with aqueous fluids and minerals to produce the measured chemical changes, and support the hypothesis that K-feldspar alteration is an effective pH buffer during CO<sub>2</sub> injection, promoting gradual mineral storage of CO<sub>2</sub>.

The modeling timescale was extended to investigate the fate of CO<sub>2</sub> over post injection timescales (i.e. 100s of years). These longer term simulations highlight the importance of pH buffering via a range of silicate mineral reactions, including K-feldspar, plagioclase and illite alteration, which lead to mineral storage of the added CO<sub>2</sub>. As a result of alteration of these silicate minerals, up to 50% of the HCO<sub>3</sub><sup>-</sup> generated from CO<sub>2</sub> dissolution over the monitoring interval may be stored as calcite (CaCO<sub>3</sub>) over timescales of a few 100 years.

## Conclusions

Chemical data, with support from history matched reaction path simulations suggest that pH buffering via K-feldspar alteration has enhanced aqueous CO<sub>2</sub> storage (as HCO<sub>3</sub><sup>-</sup>) and may have led to mineral storage of CO<sub>2</sub> as CaCO<sub>3</sub> over the monitoring period. The majority of the increase in the concentration of HCO<sub>3</sub><sup>-</sup> that took place since CO<sub>2</sub> injection began resulted from dissolution and dissociation of injected CO<sub>2</sub>, with a minor contribution from carbonate mineral dissolution. Longer term reaction path simulations conducted to simulate 100s of years of CO<sub>2</sub>-aqueous fluid-mineral reactions, calibrated via history matching over the first few years, show that reaction of K-feldspar,

plagioclase and illite has the potential to lead to further storage of injected CO<sub>2</sub> in the aqueous phase and the precipitation of injected CO<sub>2</sub> as carbonate minerals.

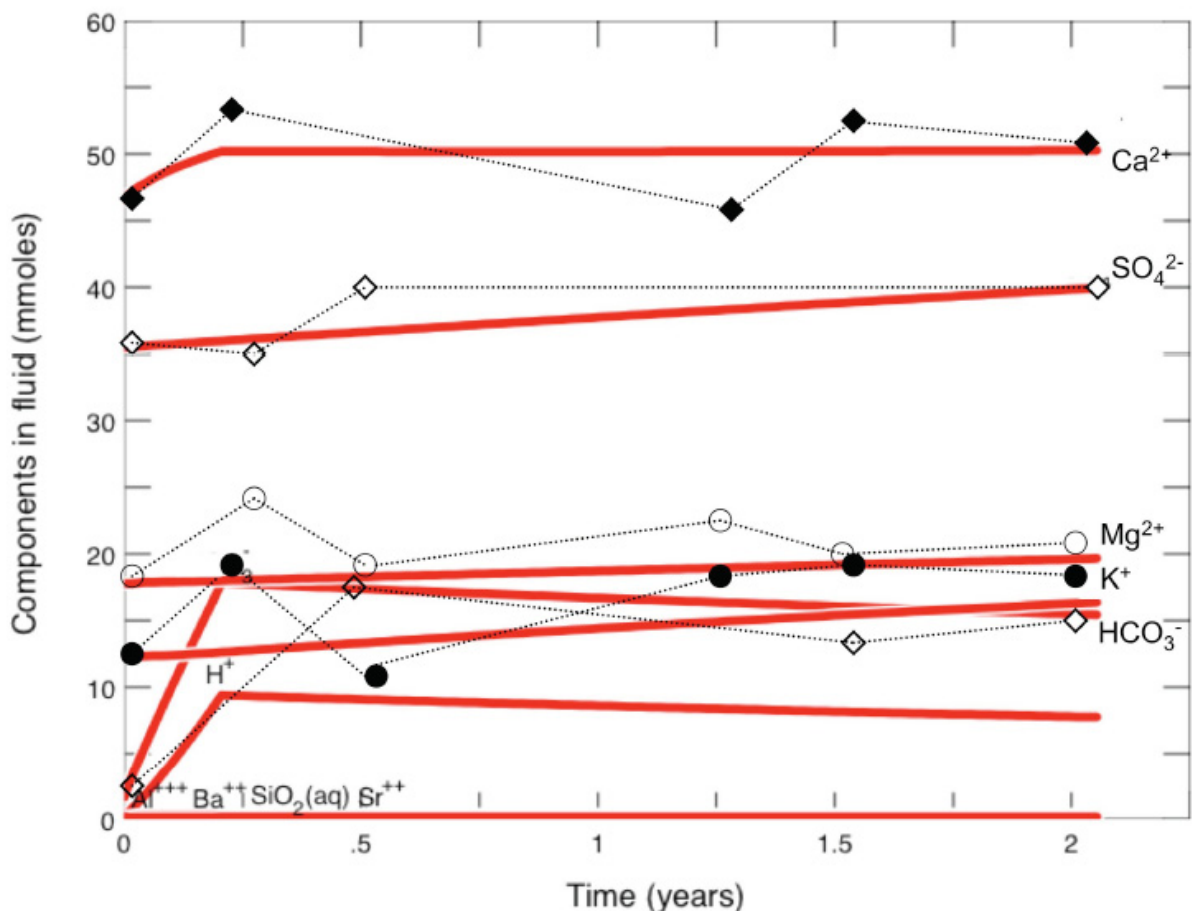


Figure 1: Well 1, 750 day simulation, comparison of simulation results with measured chemical data (dotted black lines and symbols are from measured chemical data). Simulation conditions: temperature 55°C, atmospheric pressure, 0.56g CO<sub>2</sub> added over first 75 days.

## Acknowledgements

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## References

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