Characterization of Diagenesis and Porosity in the Mount Simon Sandstone in the Illinois Basin: Implications for a Regional CO_2 Sequestration Reservoir

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Abstract

The Cambrian Mount Simon Sandstone has been targeted as an important geologic reservoir for carbon dioxide sequestration in the Illinois Basin and throughout the Midwest region. Given its presumed reservoir quality, proximity to underlying Precambrian crystalline basement, and the suitability of the overlying Eau Claire Formation as a confining unit, **the Mount Simon may serve as a high capacity, spatially extensive reservoir that is ideal for long term sequestration of injected CO_2.** However, details of the controls on spatial changes in petrophysical characteristics of this reservoir including the nature of the porosity and authigenic mineralogy are not well understood. These factors have important implications on the effectiveness of the storage capacity, injectivity, and security of the Mount Simon as a sequestration reservoir.

Previous studies have suggested an exponential decrease in porosity from over 40% near the surface to less than 1% at the maximum depths of 15,000 ft. However, at mid-level depths, where carbon dioxide injection is most plausible, **porosity varies over nearly that entire range, suggesting more complex controls beyond simple compaction** on porosity. The loss and formation of porosity in the Mount Simon is a result of a complex history of both physical and chemical diagenesis that varies with depositional facies and subsequent groundwater chemistries. Mount Simon core samples representative of varying formation thicknesses and depths in the Illinois Basin were examined petrographically and mineralogically to characterize authigenic minerals and diagenetic textures, with special emphasis on quantifying the amount and character of porosity. Image analysis software of digital micrographs was used to quantify the porosity percentage and identify classes of pores. **Characterization of porosity and diagenetic facies will better constrain the factors influencing heterogeneity within this complex and significant reservoir.**

Introduction

Currently anthropogenic emissions of carbon dioxide are on the rise. Carbon dioxide capture and storage (CCS) has been proposed in order to stabilize and potentially reduce atmospheric CO_2 levels (IPCC, 2005). One means of reducing CO_2 is to capture and sequester it into geologic formations. The most attractive targets for CO_2 injection include mature or abandoned oil and gas reservoirs, unmineable coal seams, and into deep saline formations. These deep saline formations offer some of the best potential for CO_2 sequestration in terms of capacity and proximity to coal burning plants (Midwest Geological Sequestration Consortium, 2005).

The Cambrian Mount Simon Sandstone of the Illinois Basin is one potential formation being targeted as a carbon dioxide reservoir (Figure 1). Multiple large scale injection tests are scheduled to commence in the near future. The Mount Simon has been previously described as a sub mature to mature arkosic to quartz arenite overlain by the dolomitic to shaley Eau Claire Formation, the proposed confining unit (Driese et al., 1981). A detailed study of Mount Simon's authigenic mineralogy and porosity trends will help to provide a greater understanding of the reservoir's integrity, capacity potential, and reactivity.

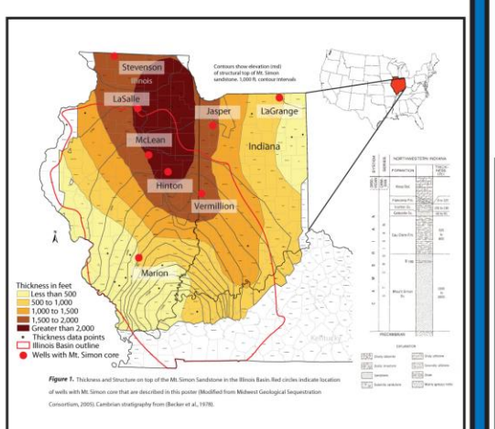


Figure 1. Thickness and Structure on top of the Mt. Simon Sandstone in the Illinois Basin. Red circles indicate location of wells with Mt. Simon core that are described in this poster (Modified from Midwest Geological Sequestration Consortium, 2005). Cambrian stratigraphy from (Becker et al., 1978).

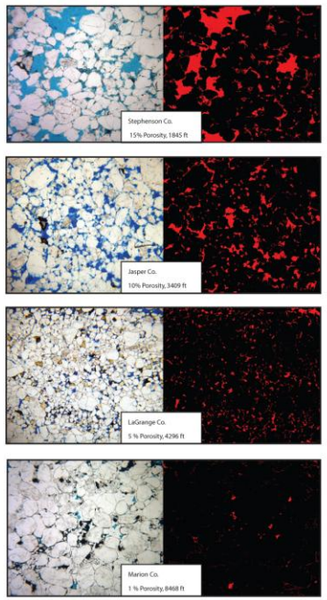


Figure 2. Petrographic images from thin sections on left (2X Magnification). Black and red image on right is ENVI result with region of interest highlighted in red i.e. pore space. Label indicates county name, porosity percentage, and depth.

Porosity Trends

ENVI, image analysis software program, was used in this study to calculate porosity trends within the Mount Simon Sandstone. Petrographic images were taken from multiple thin sections from different wells across the Illinois Basin with varying depth. In ENVI, we defined a ROI (Region of Interest). The ROI in this case was the blue epoxy impregnated into thin section samples during preparation for identification of pore space. Using maximum likelihood algorithm with an 80 threshold in ENVI we were able to quantify the percentage of pore space filled by the blue epoxy. From a swath of four micrographs that best represented each thin section a mean was calculated per depth for each well.

- Porosity results showed a range of less than 1 % porosity up to 15 to 20 % in the Mount Simon (Figure 2). Calculated minimum 2-D porosity exhibit similar trends with Helium 3D porosity calculations from the Hinton well (Figure 3 C.).
- At intermediate depths where carbon sequestration is most plausible we can see a range in porosity for a given depth (Figure 2 A.).
- Prior studies have described the porosity in the Mount Simon to show an exponential decrease attributed to compaction and framework collapse (Hoholick et al., 1984). Although for a given depth range porosity varies dramatically and the porosity variability cannot be explained by simple compaction with depth (Figure 3). There still appears to be other heterogeneities associated with the Mount Simon Sandstone which have implications for CO_2 injection.

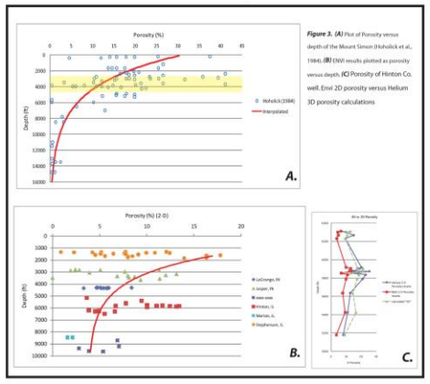


Figure 3. **(A)** Plot of Porosity versus depth of the Mount Simon (Hoholick et al., 1984). **(B)** ENVI results plotted as porosity versus depth. **(C)** Porosity of Hinton Co. well. Envi 2D porosity versus Helium 3D porosity calculations

Authigenic Mineralogy

The heterogeneity of the reservoir can affect the integrity and reactivity within this pore space. Therefore identification of diagenetic facies and authigenic minerals can help with better calibration of models and better estimates of carbon potential storage capacity.

Reflectance spectroscopy was used for basic authigenic mineral assemblage identification. Reflectance spectroscopy is a non destructive means which implements visible and short wave infrared reflectance for estimating relative abundance of some minerals.

- Quartz and feldspars yield a flat lying signature where other authigenic minerals have distinct aborption features (Iron oxides, carbonates, sulfates, clays).
- The Mount Simon's pore space is typically affected by precipitation of Quartz overgrowths, Iron oxides, and clays (Figure 4). Iron oxides have absorption features in the Mount Simon that fall within wavelengths of ~800-1000 nm. Focusing in on this zone we can better identify the Fe Oxides as hematite and geothite (Figure 5).

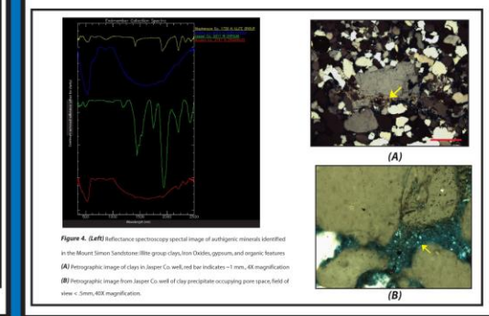


Figure 4. **(Left)** Reflectance spectroscopy spectal image of authigenic minerals identified in the Mount Simon Sandstone: Illite group clays, Iron Oxides, gypsum, and organic features **(A)** Petrographic image of clays in Jasper Co. well, red bar indicates ~1 mm, 4X magnification **(B)** Petrographic image from Jasper Co. well of clay precipitate occupying pore space, field of view < .5mm, 40X magnification.

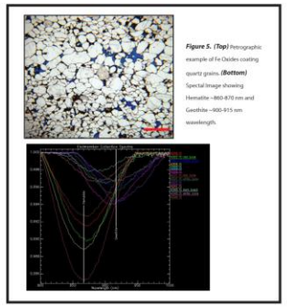


Figure 5. **(Top)** Petrographic example of Fe Oxides coating quartz grains. **(Bottom)** Spectal Image showing Hematite ~860-870 nm and Geothite ~900-915 nm wavelength.

Diagenetic Facies

The amount of available pore space in the Mount Simon Sandstone is significantly changed by physical and chemical diagenetic changes. Diagenetic facies vary regionally and with depth. Characterizing diagenetic facies across the Illinois Basin can refine diagenetic models and further calibrate carbon sequestration predictions.

- The Mount Simon's burial history along with non-quartz precipitate constraints has been used to model relative timing of quartz overgrowths (Makowitz et al., 2006) (Figure 6).
- A number of factors account for the pore space reduction such as mineral cements like quartz and feldspar overgrowths and Iron oxides, precipitation of calcite and clay cements such as illite, kaolinite, and chlorite (Mircrographs below).
- Typically iron oxides vary regionally and limit the precipitation of other cements such as quartz and clays. Facies that contain abundant quartz overgrowths lack precipitation of clays (Figure 7).

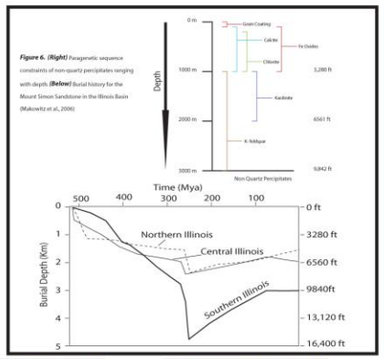
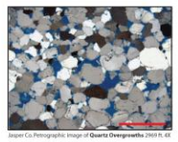
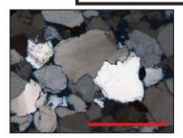


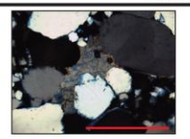
Figure 6. **(Right)** Paragenetic sequence constraints of non-quartz precipitates ranging with depth. **(Below)** Burial history for the Mount Simon Sandstone in the Illinois Basin (Makowitz et al., 2006)



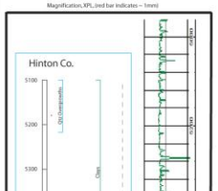
Jasper Co. Petrographic Image of **Quartz Overgrowths** 2969 ft. 4X Magnification, XPL, (red bar indicates ~ 1mm)



Jasper Co. Petrographic Image of sutured grains during **compaction**. 2969 ft. 10X Magnification, XPL, (red bar indicates ~ 1mm)



Jasper Co. Petrographic Image of **Calcite cement** 2872 ft. 10X Magnification, XPL, (red bar indicates ~ 1mm)



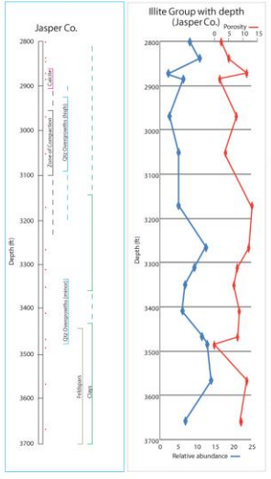
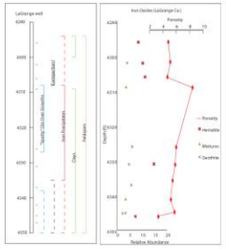
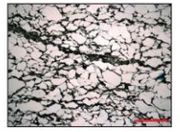


Figure 7. **(From left to right)** Schematic illustration of diagenetic facies of Hinton Co. -note Feldspathic zone correlates with high gamma ray zone in well-log data, Jasper Co. diagenesis facies varying with depth from petrographic observations with Illite relative abundance from Reflectance Spectroscopy and ENVI mean porosity; LaGrange Co. highlighting relative abundance of Iron Oxides in their associated zone with porosity in the well. Wells not to scale.



Hinton Co. Petrographic Image of **Feldspathic zone** 5879 ft. 2X Magnification, PPL, (red bar indicates ~ 1mm)



Stephenson Co. Petrographic Image of **Iron Oxides** and compaction. 1339 ft. 4X Magnification, PPL, (red bar indicates ~ 1mm)

Preliminary Geochemistry

Fifty-three representative samples were collected from the Stephenson Co. well and Jasper Co. well for trace element and major oxides analyses. Analyses were conducted by ICP-MS (Inductively Couple Plasma Mass Spectrometry). Stehpenson and Jasper wells were chosen because they both have over 800 feet of continous core.

- Barium and Strontium show two populations for the two wells. The Stephenson well can be interpreted as having two populations or no relation between Barium and Strontium. Jasper Co. well shows an increasing trend of Barium to Strontium (Figure 8).
- Iron oxides show little variability in the Jasper Co. well where no Iron oxides were observed in thin section (Figure 7 and 9).

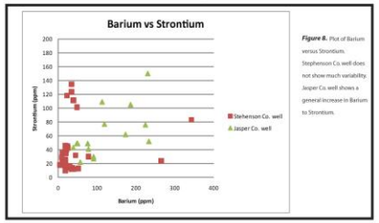


Figure 8. Plot of Barium versus Strontium. Stephenson Co. well does not show much variability. Jasper Co. well shows a general increase in Barium to Strontium.

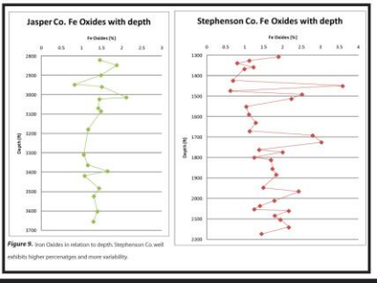


Figure 9. Iron Oxides in relation to depth. Stephenson Co. well exhibits higher percentages and more variability.

Preliminary Conclusions

- Available pore space for carbon sequestion in the Mount Simon Sandstone is being affected by diagenetic factors in addition to compaction.
- Authigenic mineralogy contirbutes to the stability of the grain and porosity framework.
- Zones of compaction, mineral, and clay cements make up different diagenetic facies that vary spatially across the Illinois Basin.

Ongoing Work

- XRD analyses for precise identification of Illite group clays.
- Quartz overgrowth assessment by Cathodoluminescence.
- Bulk rock composition and correlating how trace element and major oxides vary spatially across the basin.
- Devising a basin wide model of diagenetic facies with paragenetic sequences with relative timing across the basin and with depth.

References:

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