

Carbon Dioxide Storage Capacity in the Upper Cambrian Basal Sandstone of the Midwest Region: A County-Based Analysis

MEDINA, Cristian R., Indiana Geological Survey, Bloomington, Indiana (crmedina@indiana.edu); RUPP, John A., Indiana Geological Survey, Bloomington, Indiana (rupp@indiana.edu)

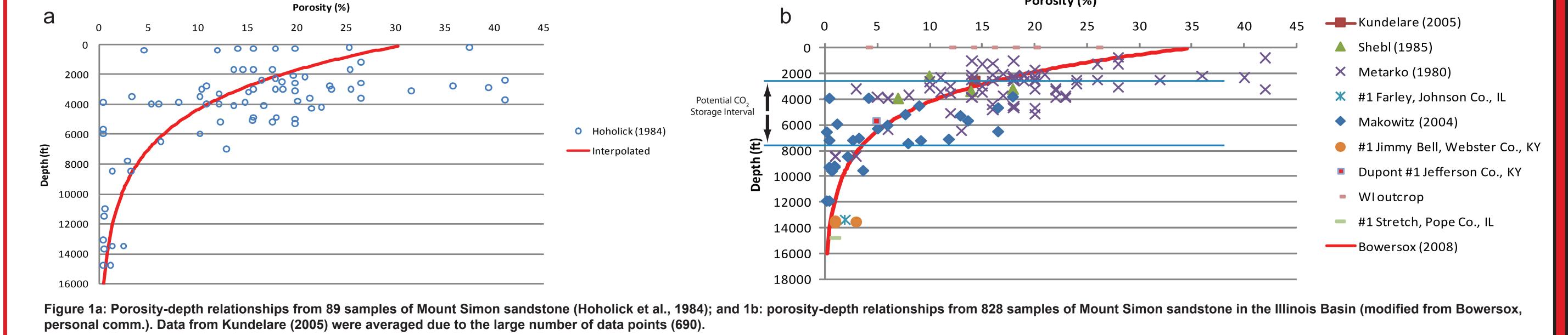


ABSTRACT

Porosity values collected from core analyses and geophysical logs from the Upper Cambrian Mount Simon Sandstone in the Midwest Regional Carbon Sequestration Partnership (MRCSP) region indicate a predictable decrease in porosity with depth that is best described by the relationship ϕ (d, in feet) = 16.36 * $e^{0.00012^{\circ}d}$ (r^2 =0.41). This relationship and the Mt. Simon's thickness were used to calculate net porosity feet, which was incorporated into the methodology presented in the Carbon Sequestration Atlas of the United States and Canada for estimating the potential storage capacity of CO₂ in deep saline aquifers. The variables that affect the volumetric calculations include: 1) the area that defines the region being assessed (county by county assessment in this study); 2) the mean porosity of the stratigraphic unit; 3) the gross thickness of the basal sandstone; and 4) the CO₂ storage efficiency factor, which accounts for material properties, including reservoir continuity and effective porosity. We conducted a sensitivity analysis to create two scenarios for CO₂ storage capacity, including efficiency factors of 0.01 and 0.04, respectively. To gain some insights into how applicable this methodology is, we compared the theoretical values of net porosity obtained from core analyses with those obtained from geophysical logs. This approach generated solutions for the spatial distribution of net porosity feet that facilitated the calculation of storage volume potential for each county within the region. The total storage capacity for the region, calculated using efficiency factors of 0.01 and 0.04, is estimated to be 37.8 and 151.2 billion metric tons of CO₂ respectively. This is approximately 74 percent higher than the values of 21.7 and 86.9 billion metric tons of CO₂ estimated by the MRCSP for the capacity of the Mount Simon Sandstone in the states of Indiana, Kentucky, Michigan, and Ohio.

PREVIOUS STUDIES

Studies on the relationship of porosity and burial suggest that porosity generally decreases with depth. Most of the porosity observed in the Mount Simon Sandstone in the Illinois Basin is secondary, formed by postdepositional processes such as dissolution of authigenic cements, grains, and fractures (Hoholick et al., 1984). These data indicate that the decline in porosity with depth is best described by the exponential equation: φ (d) = 31.08 * e^{-0.00026*d} (figure 1a). Extrapolation of these results suggests that at depths greater than 7,000 feet, porosity decreases exponentially to values below 5%. Similarly, core analyses from 828 samples taken in the Illinois Basin (J. R. Bowersox, personal comm.) suggest that porosity decreases exponentially to values as low as 5% at approximatly 6,500 feet (figure 1b).

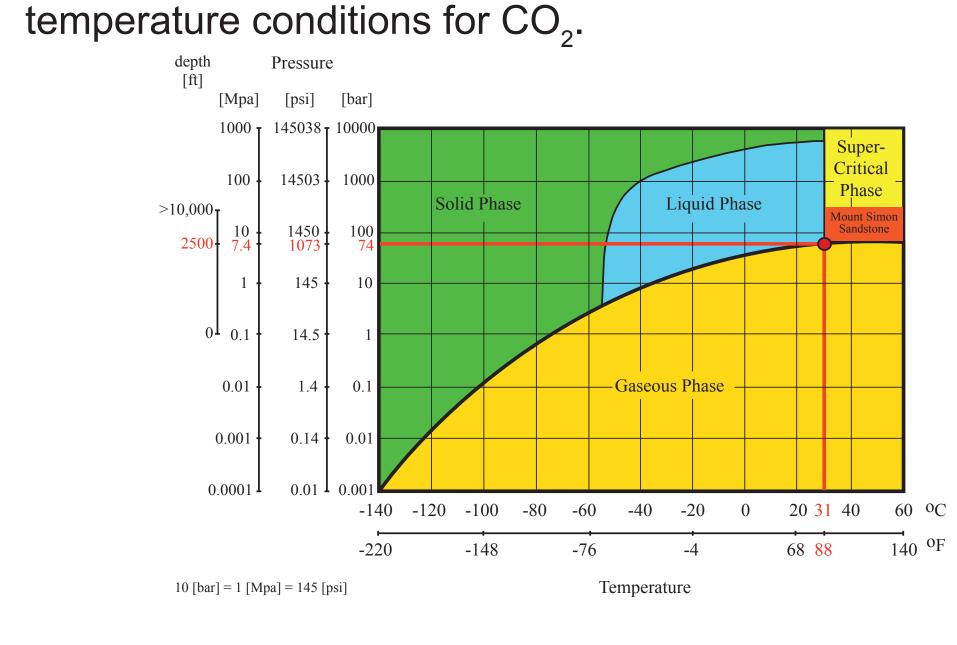


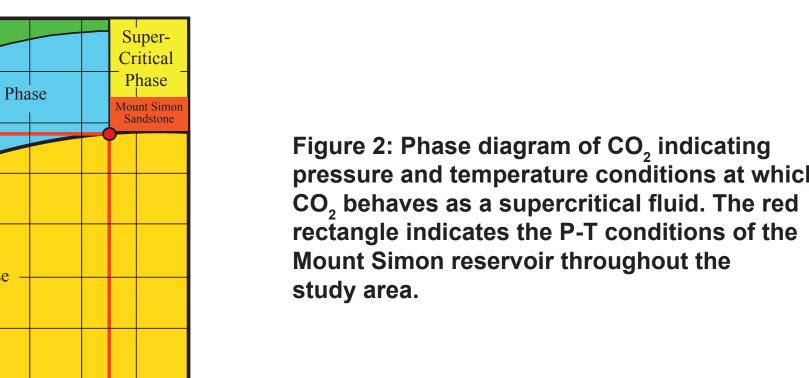
MINIMUM DEPTH

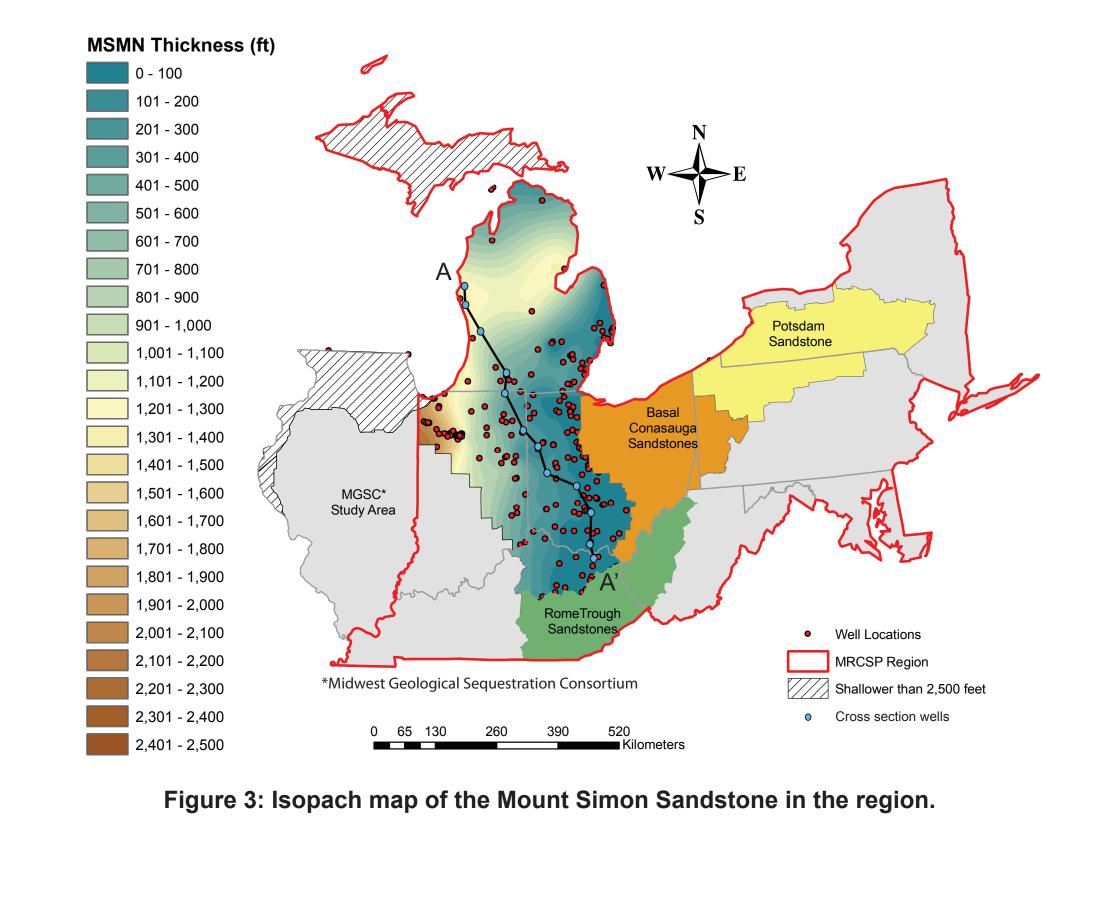
In order to ensure that the CO₂ injected into deep saline aquifers is in the supercritical phase (hence avoiding the gaseous phase), the pressure and temperature in the reservoir should be at least 7.4 MPa and 31°C (above the critical point of CO₂, figure 2). At surface conditions (0.1 MPa and 25°C), CO₂ behaves as a gas (ρ=1.8 kg/m³). If we assume a hydrostatic pressure gradient of 10.5 MPa/km (0.43 psi/ft) and a geothermal gradient of 30°C/km (1.63°F/100 ft), CO₂ can be stored as a supercritical fluid below a depth of 800 m (~2,500 ft).

This minimum threshold value for depth corresponds to a minimum density of CO₂ of 260 kg/m³, allowing for greater quantities of CO₂ to be stored in deeper aquifers.

The top of the Mount Simon Sandstone occurs at depths greater than 2,500 feet throughout the region (figure 3), corresponding to supercritical pressure and







POROSITY, PERMEABILITY, AND DEPTH RELATIONSHIPS

Methods (Geophysical Logs to Porosity)

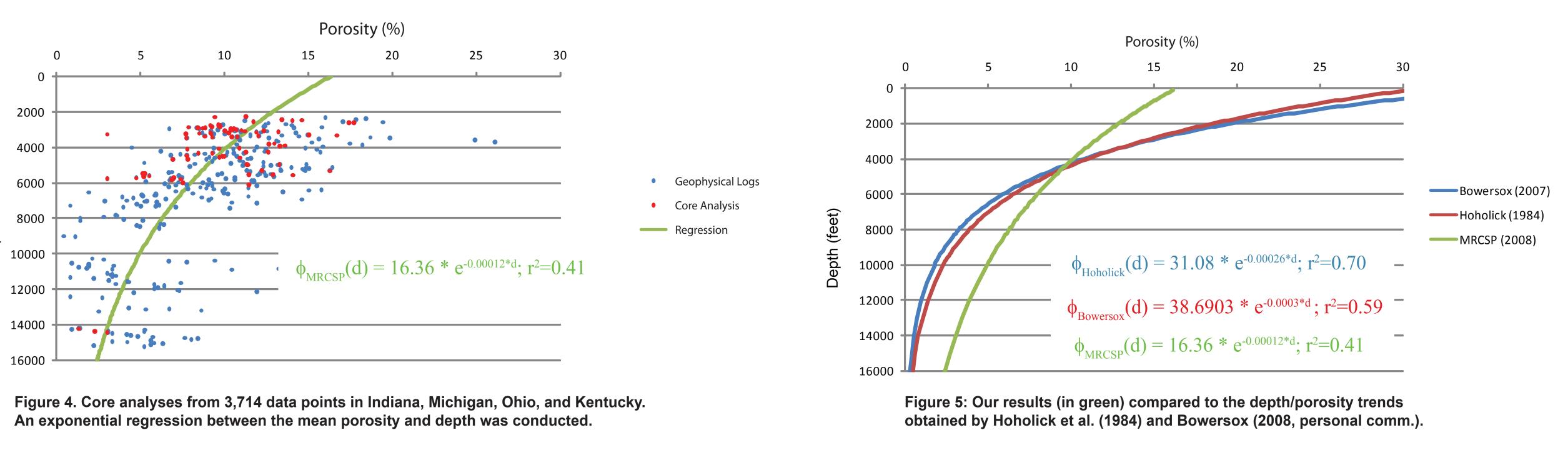
Log-derived porosity values were obtained from sonic, density, and neutron porosity logs. The formulas applied were (Asquith and Krygowski, 2004):

$$\varnothing_{\text{sonic}} = \frac{\Delta t_{\text{log}} - \Delta t_{\text{ma}}}{\Delta t_{\text{f}} - \Delta t_{\text{ma}}} \qquad \qquad \varnothing_{\text{density}} = \frac{\rho_{\text{ma}} - \rho_{\text{ma}}}{\rho_{\text{ma}}}$$

where \emptyset_{sonic} = sonic-derived porosity; Δt_{ma} = interval transit time of the matrix = 47.6 µs/ft in limestone (Schlumberger, 1972); Δt_{log} = interval transit time of formation; and Δt_{f} = interval transit time of the fluid in the well bore (fresh mud = 189 µs/ft); ϕ_{density} = density-derived porosity; ρ_{b} = formation bulk density; ρ_{ma} = matrix density = 2.71 gr/cc in limestone (Schlumberger, 1972); ρ_{f} = fluid density (1.1 in salt mud, 1.0 in fresh mud (used here), and 0.7 in gas, in gr/cc). Porosity values derived from neutron porosity logs were adjusted to reflect the fact that the log was run in a limestone matrix. Consequently, a linear transformation was applied by adding a decimal value of 0.04 to the original value of the neutron log curve to account for the change in matrix value.

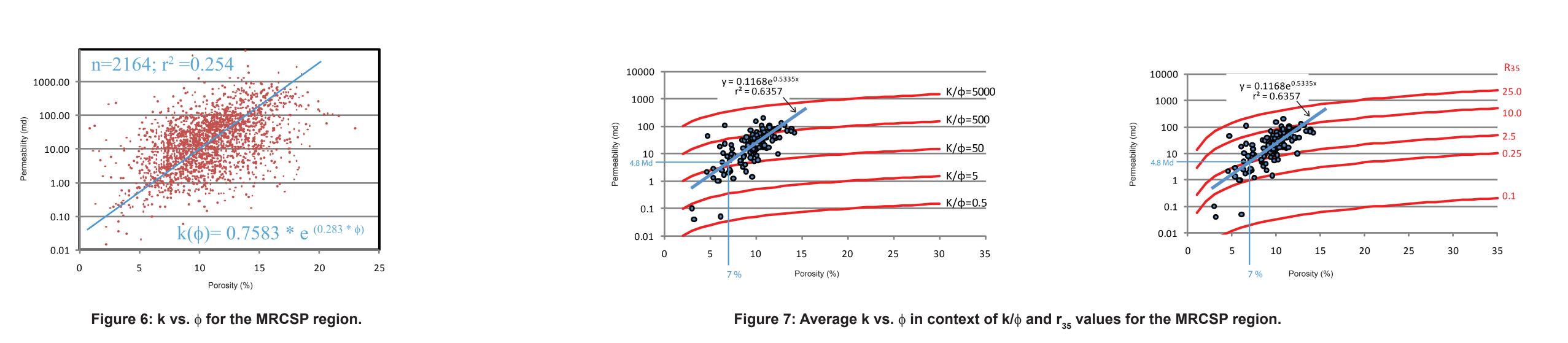
a) Porosity - Depth Relationships

Available core data and geophysical logs from the MRCSP region indicate a wide range of porosity values in the depth range 2,000 to 16,000 feet (figure 4). This trend is consistent with those observed by Hoholick et al. (1984) and Bowersox (2008, personal comm.) (figure 5).



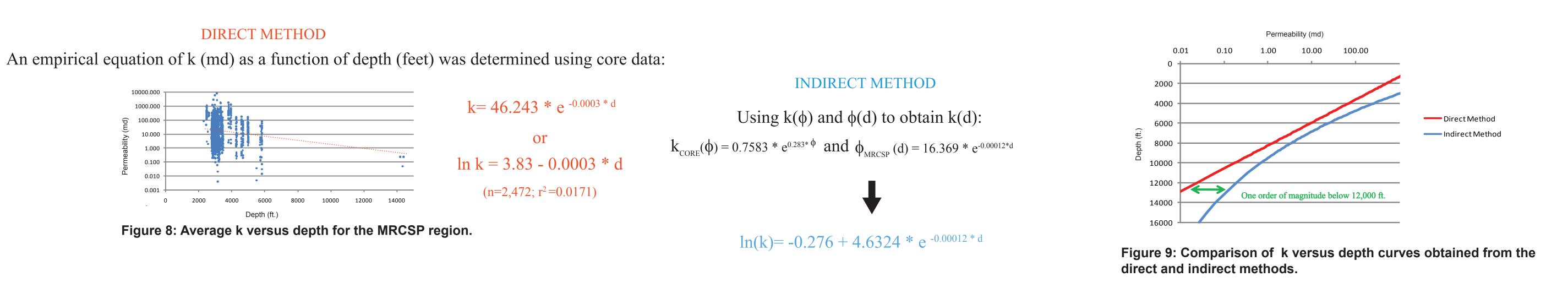
b) Permeability - Porosity Relationships

The reservoir characterization is incomplete if permeability (k) and porosity (ϕ) are analyzed independently (figure 6). Analyzing k and ϕ simultaneously is more effective and leads to a more realistic characterization of the porous media (Beaumont and Foster, 1999 eds.). The k/ ϕ ratio or the r₃₅ method (Pittman,1992) is applied here to determine the quality of the Mount Simon Sandstone as an effective reservoir (figure 7). Higher values of k/ ϕ or r₃₅ reflect the higher quality of the reservoir. The equations for the r₃₅ values as a function of k and ϕ were obtained from Beaumont and Foster (1999).



c) Permeability - Depth Relationships

Core analyses from 2,472 samples taken from Kentucky (8 data points), Indiana (1,875 data points), Michigan (458 data points), and Ohio (131 data points) indicate a negative exponential relationship between permeability and depth (figure 8).



STRATIGRAPHY AND STORAGE CAPACITY OF THE MOUNT SIMON SANDSTONE

The Mount Simon Sandstone in the Midwest region is characterized by predominantly quartzose sandstone with minor amounts of shale and dolomite, which was first described in an outcrop in Wisconsin. The unit in most places is a quartz arenite but in some localities the lower portion of the unit becomes arkosic with significant amounts of glauconite, orthoclase feldspar and detrital mica.

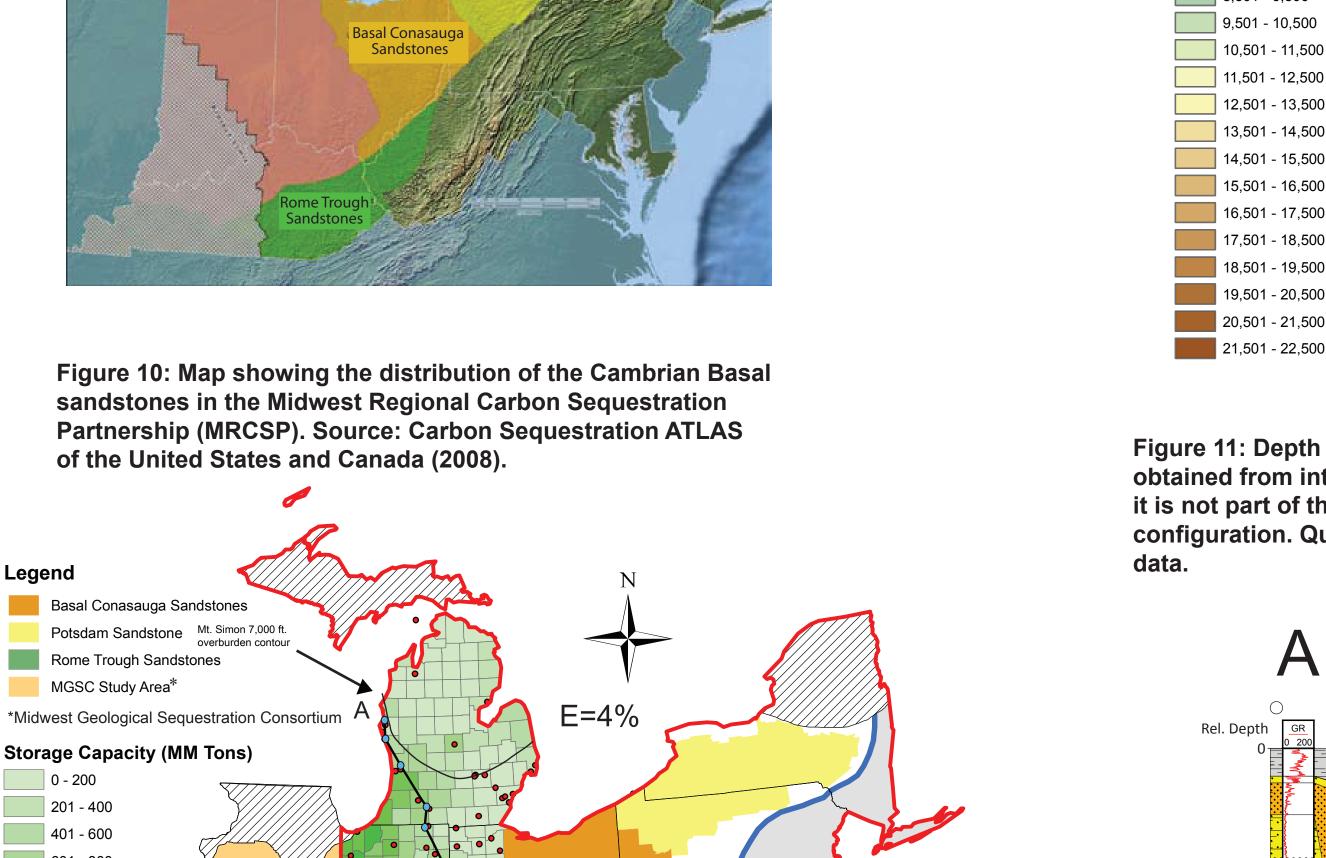
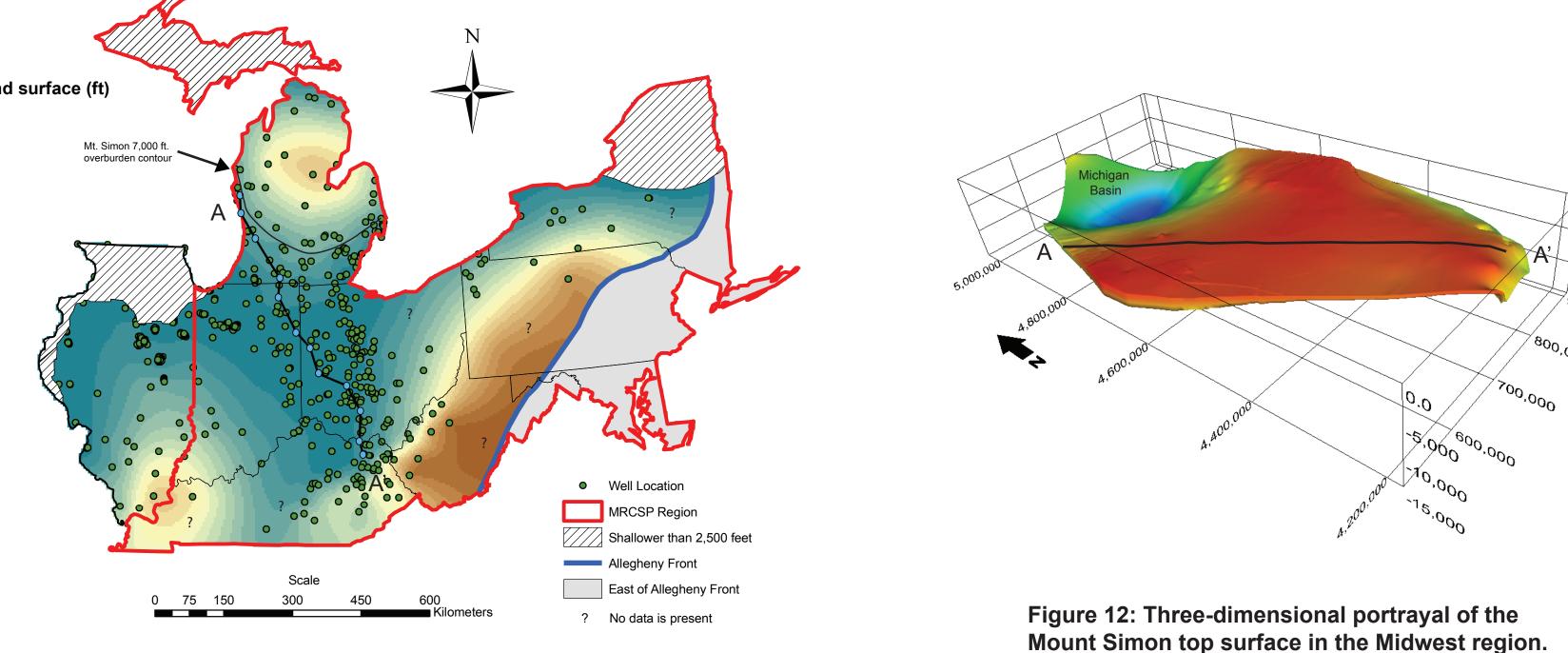
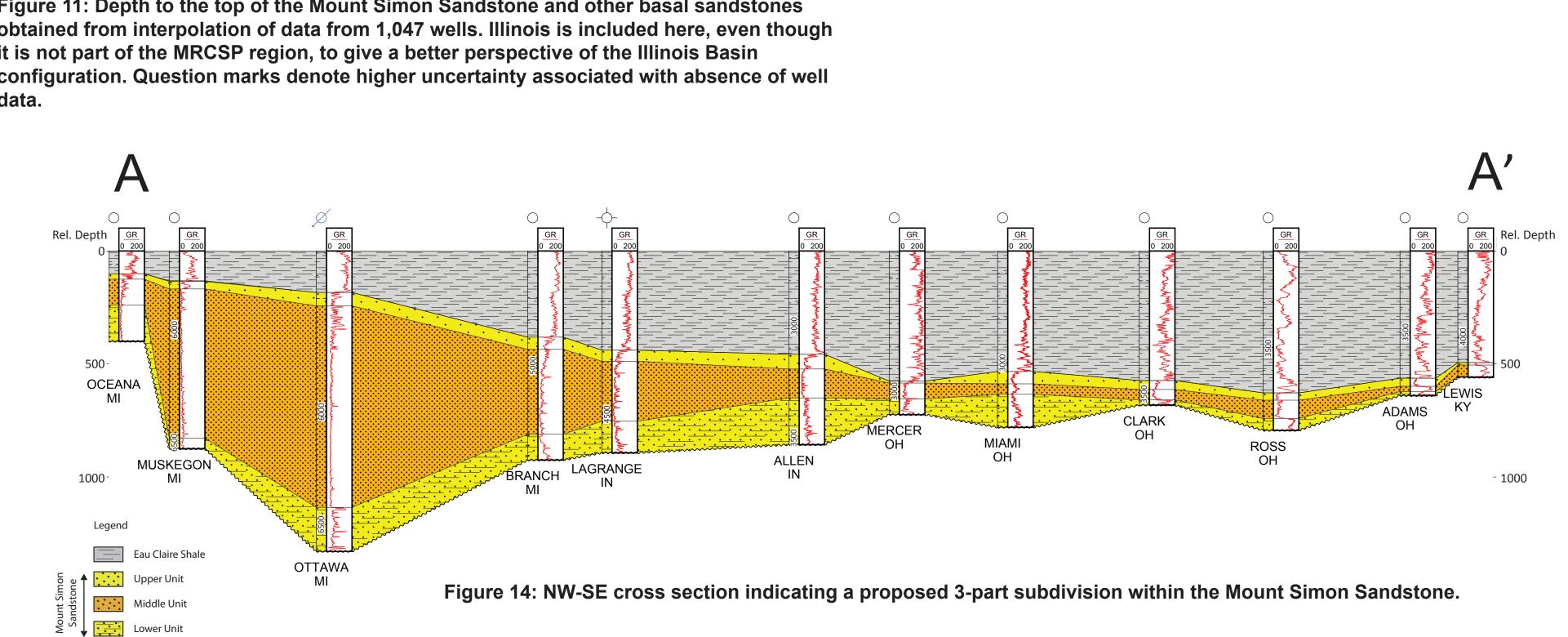
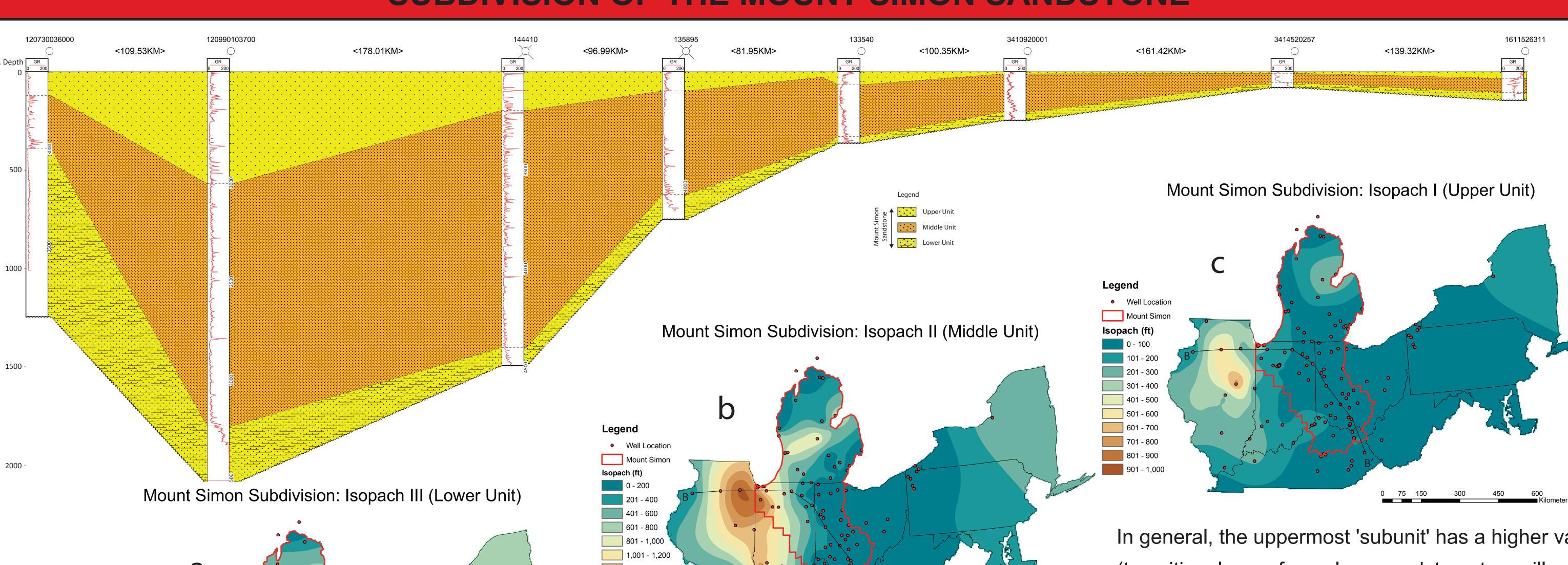


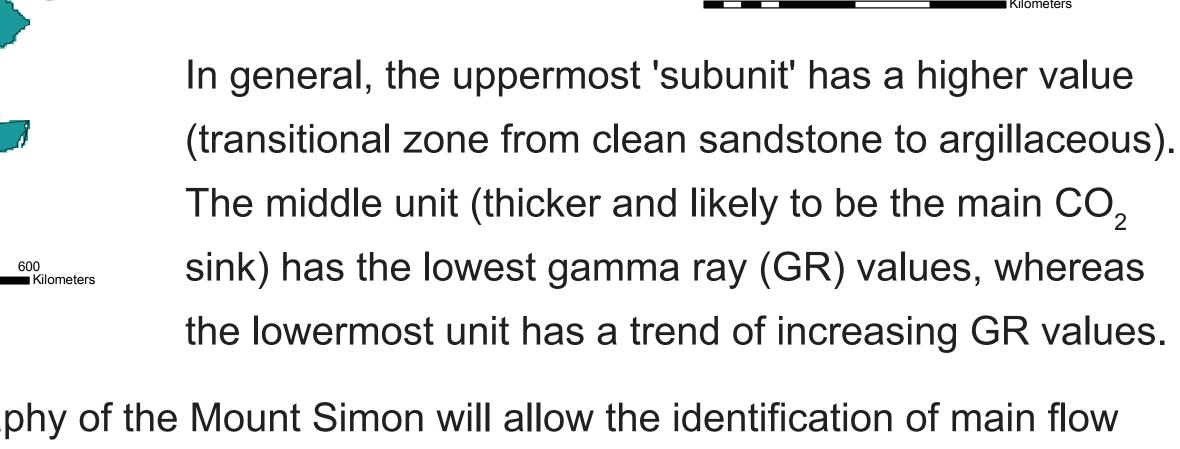
Figure 13: Storage capacity calculated by county (E=4%) in the Mount Simon Sandstone.

601 - 700









This subdivision of the internal stratigraphy of the Mount Simon will allow the identification of main flow and reservoir units that will result in a higher efficiency factor. Consequently, the final storage capacity will be increased with decreasing uncertainty of the reservoir characterization process.

Pigure 15: NW-SE cross section indicating a proposed three-part subdivision within the Mount Simon Sandstone. Interpolation of well data allowed us to calculate isopach maps for a) the lower unit; b) the middle unit (main flow unit); and c) the upper unit.