Geological sequestration capacity of the Dundee Limestone, Michigan Basin, United States

Joshua P. Kirschner and David A. Barnes

ABSTRACT

Several Middle Devonian formations in the Michigan Basin are potential targets for geological sequestration of CO_2, including the Dundee Limestone and the Rogers City Limestone. The Rogers City and Dundee limestones are disparate carbonate formations but are typically combined in subsurface nomenclature as the Dundee Limestone because they are difficult to differentiate in some areas. In much of the basin, however, the Rogers City and Dundee can be differentiated using wireline logs. Subdivision of the two formations was first accomplished in outcrop and is also straightforward in core on the basis of starkly different lithologic properties. Subsurface subdivision is especially important for reservoir characterization and/or geological sequestration studies because the Rogers City and Dundee differ in lithology, thickness, and reservoir properties. Regional geological sequestration capacity estimates for the undifferentiated Dundee Limestone obscure the relative contributions of the Rogers City and Dundee and oversimplify known geological heterogeneity. When evaluated separately using wireline logs supported by limited conventional core studies and porosity and permeability data, the Rogers City is clearly demonstrated to be only a local sequestration target with an estimated geological sequestration capacity of 0.13 Gt. In contrast, storage capacity in the Dundee is estimated at 1.88 Gt. This analysis indicates that the Dundee is a more laterally extensive, regional sequestration target compared to the Rogers City. Individual geological sequestration capacity estimates for the Rogers City and Dundee reflect differences in reservoir properties for the two units and are therefore more geologically defensible than estimates for the undifferentiated Dundee Limestone.

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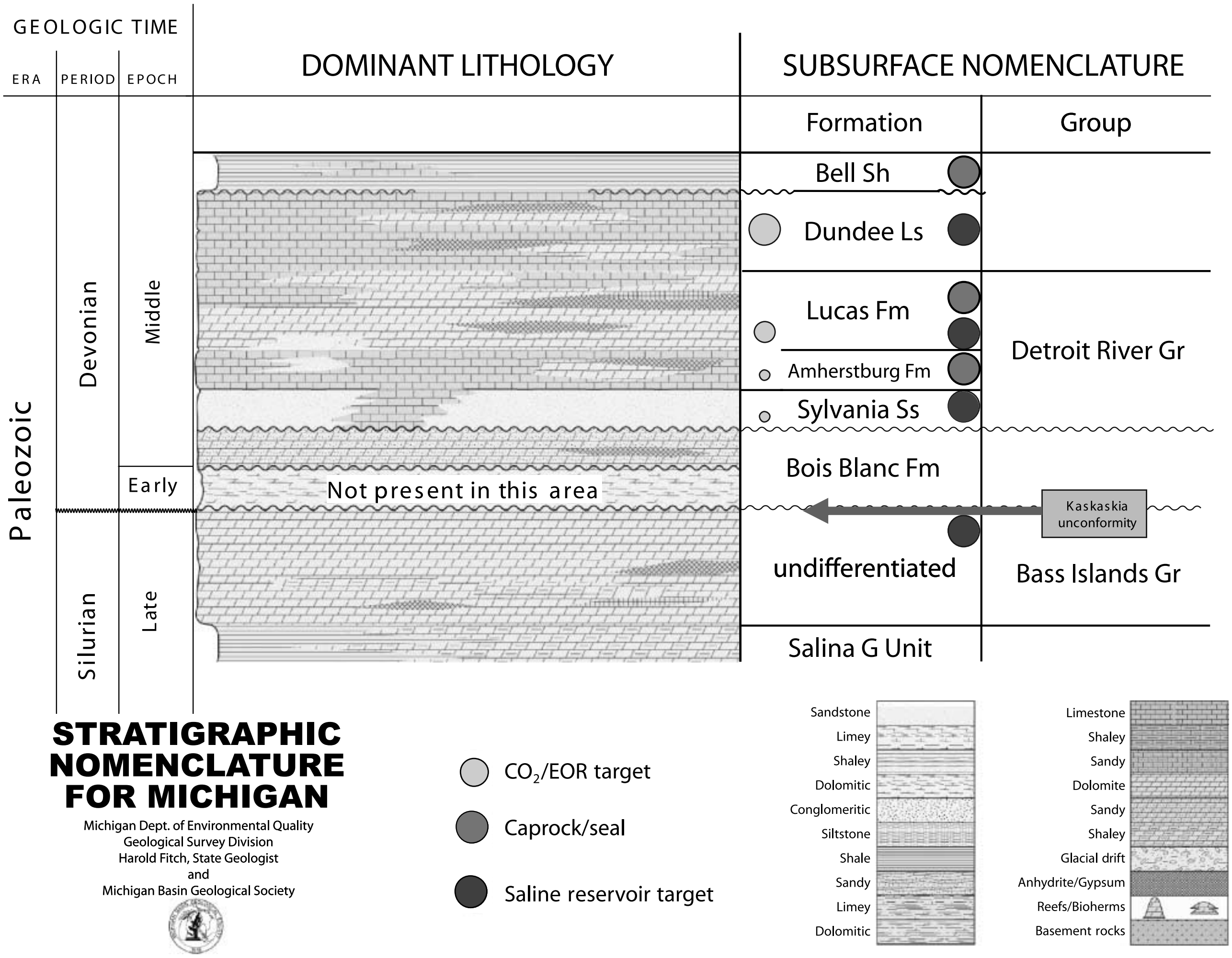

Figure 1. Upper Silurian–Middle Devonian stratigraphy in lower Michigan (modified from Catacosinos et al., 2001). The Dundee Limestone is both a potential saline reservoir injection zone and an enhanced oil recovery target. The Bell Shale is the regional confining unit above the Dundee.

INTRODUCTION

Several Middle Devonian formations in the Michigan Basin are prolific oil producers. More than 225,000 bbl of oil per year are still being produced from Middle Devonian carbonate reservoirs, but the most historic production occurred in the 1930s–1950s with a peak production of 23 million bbl of oil per year in 1939 (Wylie and Wood, 2005). Some of these formations are also potential geological sequestration targets for carbon dioxide (CO_2), including the Dundee Limestone (Figure 1). The Dundee is a relatively shallow reservoir target throughout the basin and ranges from surface outcrops to about 4300 ft (1311 m) deep. An overburden thickness greater than 2600 ft (792.5 m) retains CO_2 in its supercritical phase and defines the limit of the study area for this analysis (Figure 2).

The Dundee is a complex carbonate succession that stratigraphically underlies the Bell Shale and overlies the Lucas Formation. In this article, we argue that the Dundee is really two distinct carbonate units, both stratigraphically and petrologically. This was first established by Ehlers and Radabaugh (1938), who subdivided the Dundee on the basis of faunal assemblages observed in limited outcrop. Ehlers and Radabaugh (1938) further defined the Dundee Limestone as the lower of two carbonate formations and named the upper formation the Rogers City Limestone. In the subsequent 70 yr, Rogers City and Dundee have been treated both separately (e.g., Cohee and Underwood, 1945; Curran and Hurley, 1992) and as members of one formation (e.g., Gardner, 1974; Catacosinos et al., 1991; Luczaj et al., 2006). Currently, formal Michigan Basin stratigraphic nomenclature separates the Rogers City

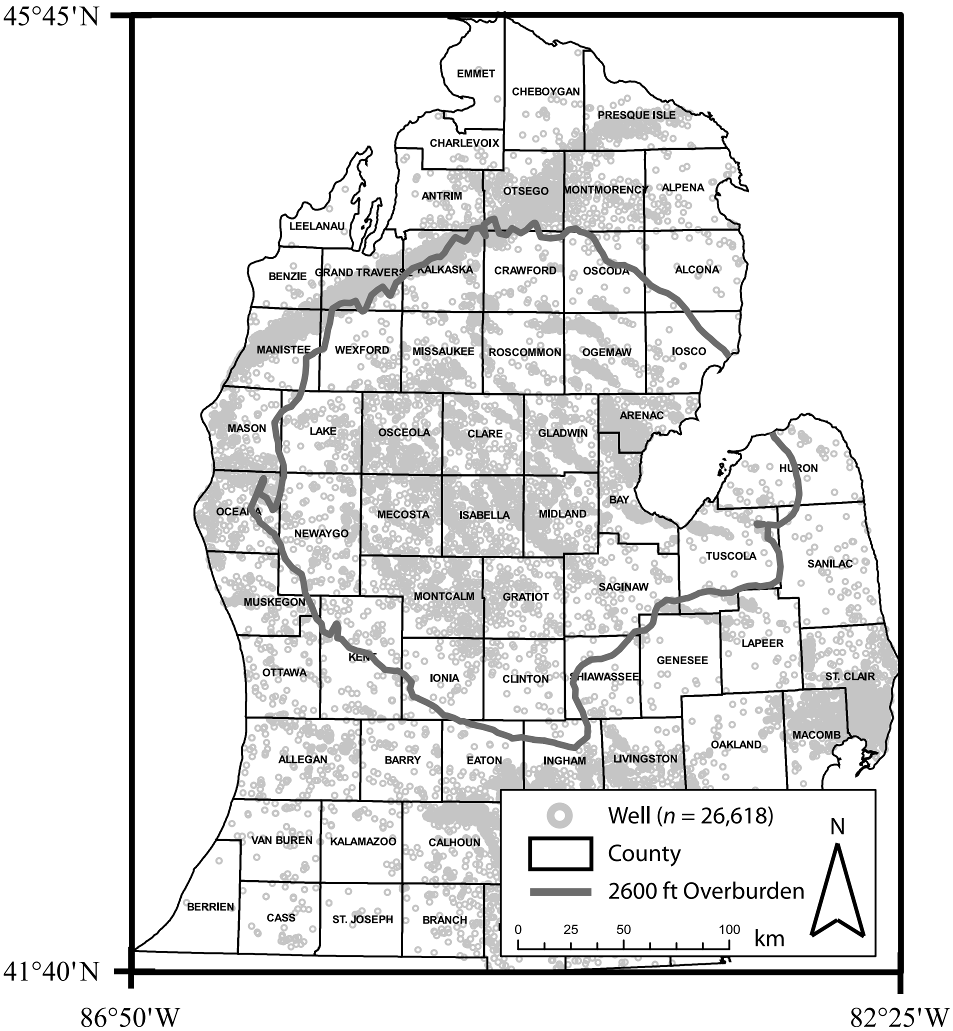

Figure 2. County map of Michigan. The study area is defined by the 2600-ft (792.5 m) overburden contour, which was obtained using 26,618 wells.

and Dundee in outcrop but combines them in the subsurface as the Dundee (Catacosinos et al., 2001). This article argues the importance and utility of identifying these two distinct units in the subsurface, especially for reservoir characterization. To avoid confusion, the name Dundee (undifferentiated) is used when referring to the combined succession of Rogers City and Dundee between the Bell Shale and Lucas Formation, whereas the names Rogers City and Dundee are used as formally identified by Ehlers and Radabaugh (1938).

A defensible evaluation of geological sequestration capacity (GSC) in a particular stratigraphic interval requires detailed consideration of reservoir properties in that interval. In addition, porosity, permeability, and injectivity must be reasonably consistent within the interval of interest to characterize that interval using average petrophysical values (e.g., porosity and permeability). In the Michigan Basin, substantial regional heterogeneities in the Dundee (undifferentiated) are well known from decades of petroleum exploration and production. Most noteworthy are the stark differences in petrophysical properties between Rogers City and Dundee throughout the subsurface. The feasibility of geological sequestration in either unit depends on the relationships among petrophysical properties. Some of the variability in porosity and permeability is attributable to original facies and depositional environment, but subsequent diagenesis and dolomitization are equally important. A detailed discussion of sedimentary facies and the effects that dolomitization has had on porosity is beyond the scope of this article, but the general relationships are summarized in the next section. Changes in formation thickness also affect GSC estimates. The purpose of this

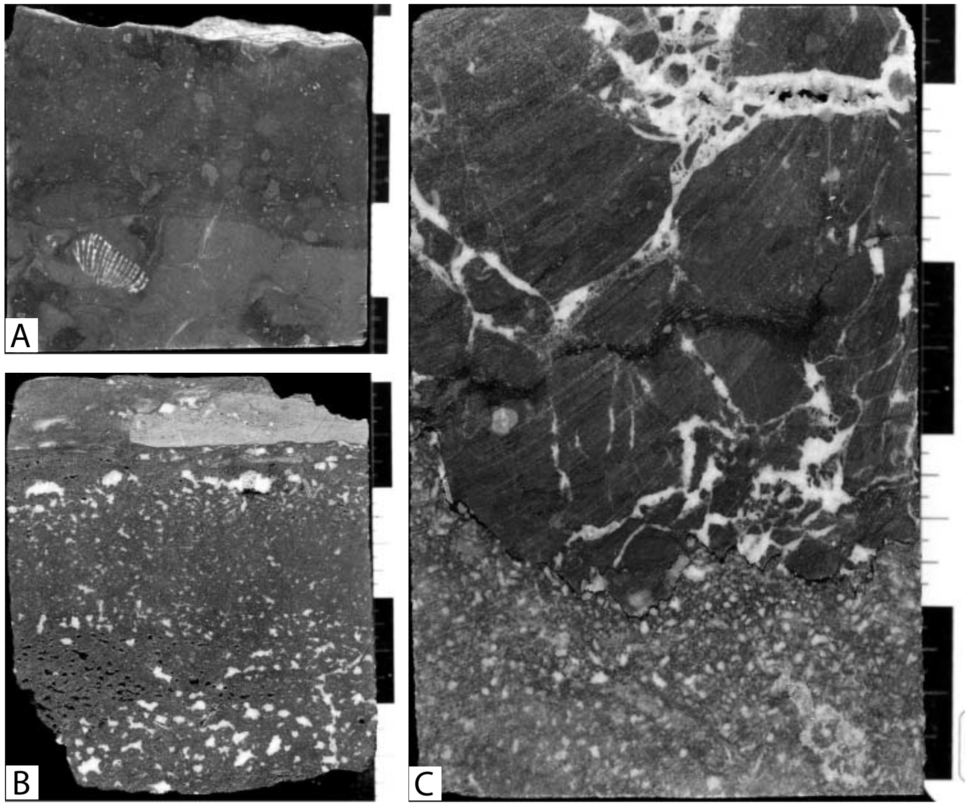

Figure 3. Rogers City-Dundee contacts. (A) Summit Petroleum Sturm 3 well, permit 41019, depth 3882 ft (1183.2 m). Rogers City and Dundee are both limestone. The contact is a bored, pyritized hardground, which is most easily distinguished by the color change. (B) Midwest Oil Productions Rousseau 1-12 well, permit 35426, depth 3946.5 ft (1202.9 m). Rogers City and Dundee are both dolomite. A large rip-up clast rests on the contact, below which porosity and replacive dolomite exist in keystone vugs. (C) Cronus Development Tow 1 well, permit 48086, depth 3196.5 ft (974.3 m). Rogers City and Dundee are both dolomite. The fine-grained Rogers City is separated by a stylotized contact from the coarse-grained Dundee. Note the abundant fractures filled with coarse saddle dolomite in the Rogers City. The scale, on the side of all three photos, is in inches.

article is to show that GSC estimates for the Dundee (undifferentiated) do not accurately represent the GSC for Rogers City and Dundee taken separately. As a result, we have subdivided the Dundee (undifferentiated) into Rogers City and Dundee to facilitate more reliable regional GSC estimates.

Subsurface stratigraphic subdivision has been accomplished with varying degrees of difficulty in different parts of the Michigan Basin in lower Michigan. The Dundee (undifferentiated) has been subdivided using various criteria by other workers, including a combination of wireline log signatures and core data in field-scale studies (Curran and Hurley, 1992), the presence of anhydrite in subregional studies (Gardner, 1974), and drill cuttings in regional studies (Cohee and Underwood, 1945). Here we present a methodology for the basinwide subsurface subdivision of the Dundee Limestone (undifferentiated) using wireline logs. This method combines most of the previous techniques with a few new ones, but its real value lies in the ability to differentiate Rogers City and Dundee in areas previously thought impossible without a core.

ROGERS CITY AND DUNDEE LIMESTONES

The primary Rogers City facies is nodular wackestone, which was deposited in an open-marine setting (Curran and Hurley, 1992). Compared to the relatively homogeneous Rogers City, the Dundee has a variety of primary sedimentary facies. The Dundee contains dolomitized sabkha-lagoonal facies and anhydrite deposits in the western part of the basin (Gardner, 1974). In the central and eastern basin, the Dundee was deposited along an eastward-dipping ramp in generally unrestricted open-marine conditions (Gardner, 1974; Luczaj et al., 2006). Common Dundee facies in these areas include crinoid grainstones, skeletal-peloidal grainstones and packstones, skeletal wackestones, and restricted-fauna mudstones and wackestones (Curran and Hurley, 1992). Shoal-water and more restricted facies occur at the top of the Dundee, across the basin, suggesting a regional relative sea level fall at the top of the formation. The Rogers City-Dundee contact is readily apparent in the core on the basis of a distinct pyritized and bored hardground (Figure 3). This contact has been interpreted

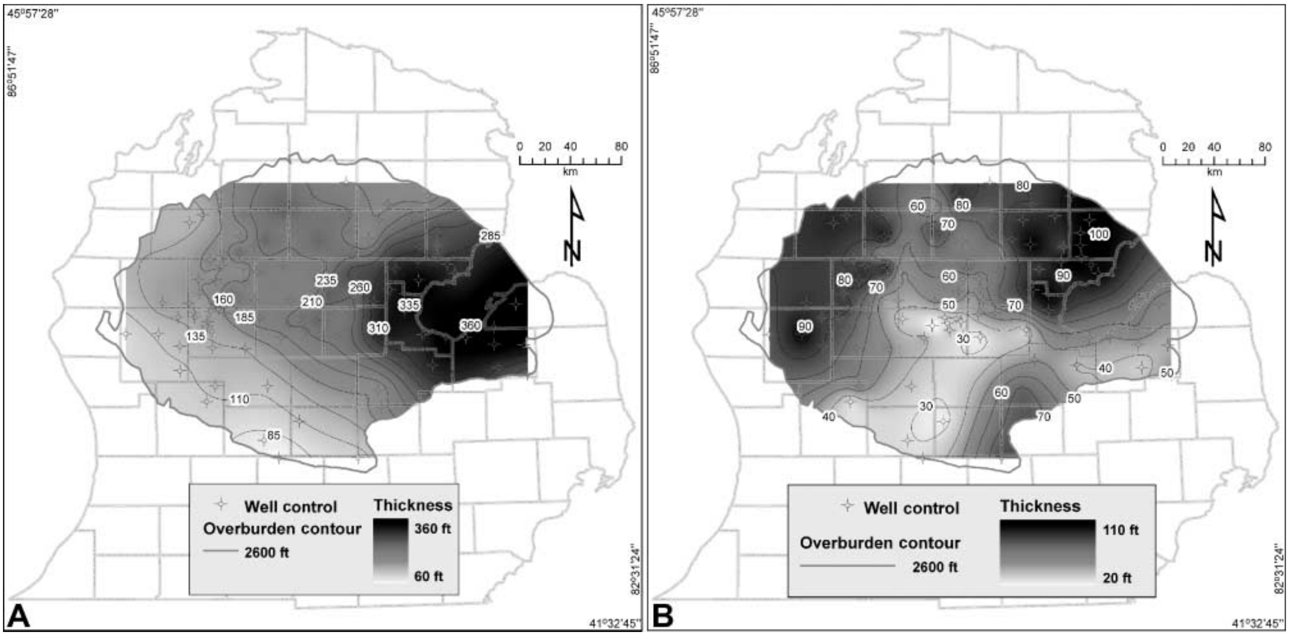

Figure 4. Isopach maps. (A) Isopach map of the Dundee. The Dundee thickens eastward toward the Middle Devonian depocenter, where its maximum thickness is greater than 350 ft (107 m). (B) Isopach map of the Rogers City. Thickness trends in the Rogers City are more variable than in the Dundee, and the Rogers City is commonly much thinner than the Dundee. The Rogers City is thinner in the central part of the basin compared to similar thicknesses in the eastern and western parts of the basin.

as a sequence boundary or flooding surface (Curran and Hurley, 1992).

In addition to facies and depositional environment, the Rogers City and Dundee differ in diagenetic alteration and gross lithology. The Rogers City is a massive, micritic limestone, except where dolomitized in the west-central part of the basin (Gardner, 1974). The Rogers City is dolomitized in a few places in the eastern part of the basin, including several noteworthy oil fields (e.g., Deep River and North Adams in Arenac County), but the occurrence of dolomite is much more common in the west-central part of the basin. The Dundee typically comprises both limestone and dolomite but may be entirely limestone or entirely dolomite (Ehlers et al., 1959). The origin of dolomite in both units has a long, controversial history. Proposed dolomitizing mechanisms in different areas of the basin include reflux (Gardner, 1974), syndepositional nonfracture related (Curran and Hurley, 1992), and hydrothermal fracture related (Barnes et al., 2005; Luczaj et al., 2006). Regardless of origin, dolomitization has had a profound effect on reservoir properties. The Rogers City has satisfactory reservoir quality only where it is dolomitized. In contrast, the Dundee has primary and secondary porosity in both limestone and dolomite (Cohee and Underwood, 1945).

Formation thickness is not directly related to reservoir quality but greatly impacts total GSC. Furthermore, formation thickness and depositional geometry are related, in part, to Michigan Basin subsidence patterns (Figure 4A). During the Middle Devonian, basin subsidence produced a narrow basin center (Howell and van der Pluijm, 1999). Not all thickness changes are attributable to simple thickening toward this depocenter. In the west-central part of the Michigan Basin, the Rogers City thins appreciably (Figure 4B). Shell banks (shoals) in the Dundee may explain this thinning (Gardner, 1974). Thus, at the regional scale, GSC in Rogers City and Dundee is controlled by variable lithology, reservoir quality, and formation thickness (Figure 5).

METHODS OF LITHOSTRATIGRAPHIC SUBDIVISION

A hierarchical procedure is used to differentiate the Rogers City and Dundee. The criteria are listed in order of priority: (1) the presence of anhydrite capping the Dundee, (2) a distinct break from essentially zero porosity in the Rogers City on a limestone-calibrated neutron porosity log to a more porous section in the Dundee, and (3) a distinct gamma-ray marker (Figure 6).

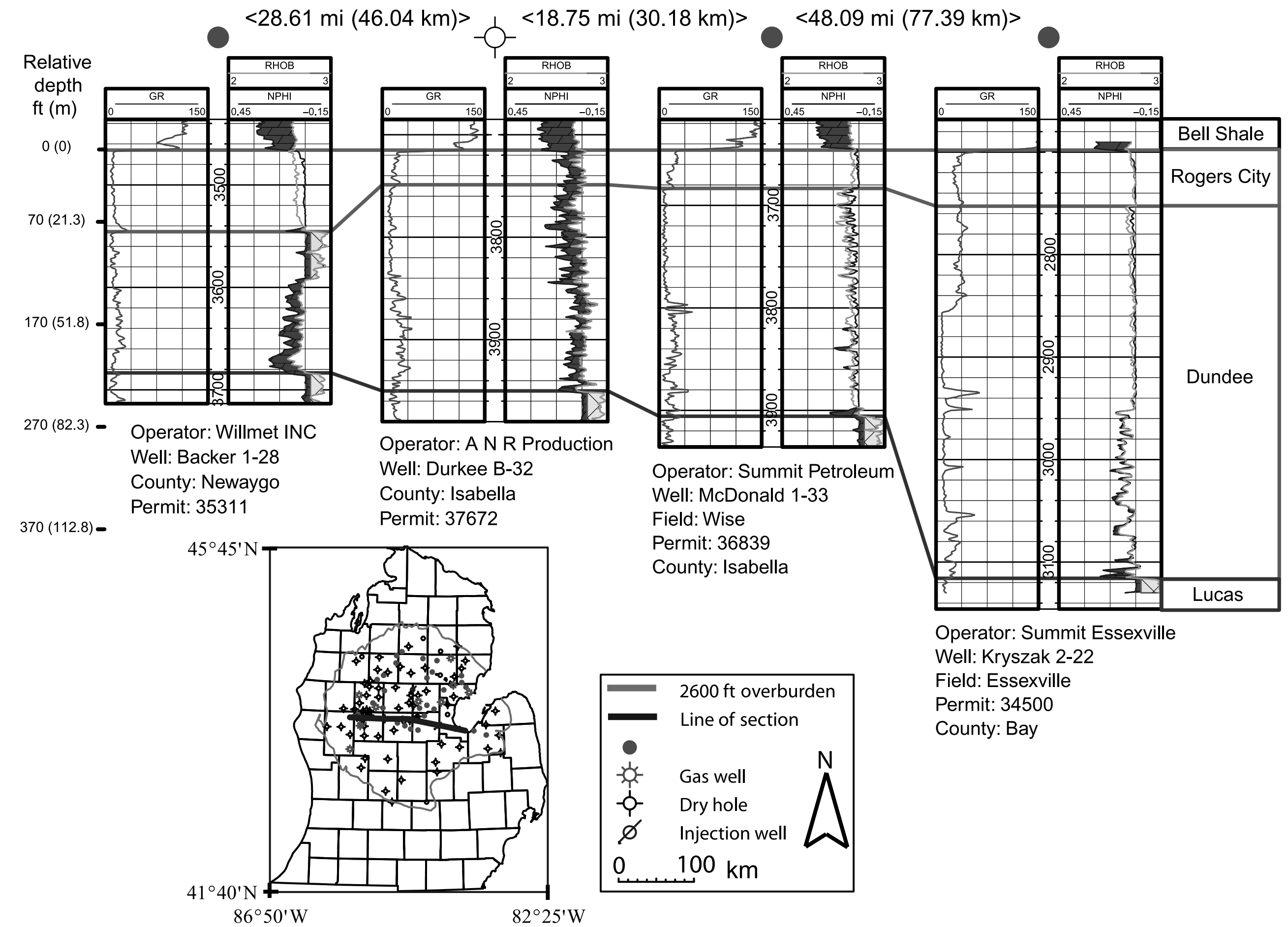

Figure 5. Regional cross section showing variability in lithology and thickness in the Rogers City and Dundee. Both units, but especially the Dundee, thicken toward the east. The Rogers City thins in the central part of the basin. Dolomite (shaded dark) is quite variable, while anhydrite (shaded light) in the Dundee is only present in the western part of the basin. GR = gamma ray; RHOB = bulk density; NPHI = neutron porosity.

Criterion 1 was first described by Gardner (1974), who defined his Rogers City Member as the massive carbonate above the Reed City anhydrite and below the Bell Shale. Gardner (1974) also recognized that his Rogers City Member could be mapped over much of the basin, but he acknowledged that this boundary is a difficult pick where the Reed City anhydrite is absent. The Rogers City Member and Reed City anhydrite terminology has been informally used (e.g., Luczaj et al., 2006) but further complicates the stratigraphy. Using the occurrence of anhydrite to subdivide Rogers City and Dundee is straightforward and can be used with great confidence where anhydrite is present (Figure 6A). Anhydrite is only present in the western part of the basin, however, so other methods are needed for much of the central and the entire part of the eastern basin.

In the absence of anhydrite, the Rogers City and Dundee can be distinguished using either a limestone-calibrated neutron porosity log (criterion 2) or a gamma-ray log (criterion 3) (Kirschner and Barnes, 2006). The grainy carbonate facies assemblage of the Dundee is typically porous, whereas the micritic Rogers City facies typically have little or no porosity. The contact between the two units is the sharp break from zero to measurable porosity, downward, on a neutron porosity log (Figure 6B). Subdivision using the gamma-ray marker is necessary only if porosity logs are unavailable or if the Rogers City has been dolomitized. The gamma-ray marker, or spike, likely results from high concentrations of clay or other organic-rich radioactive materials that accumulated during a depositional hiatus or sequence boundary between Dundee and Rogers City. The gamma-ray marker is most useful in the central part of the basin when Rogers City and Dundee are both dolomitized. The gamma-ray marker is less pronounced in the eastern part of the basin, but this area is rarely dolomitized, and the

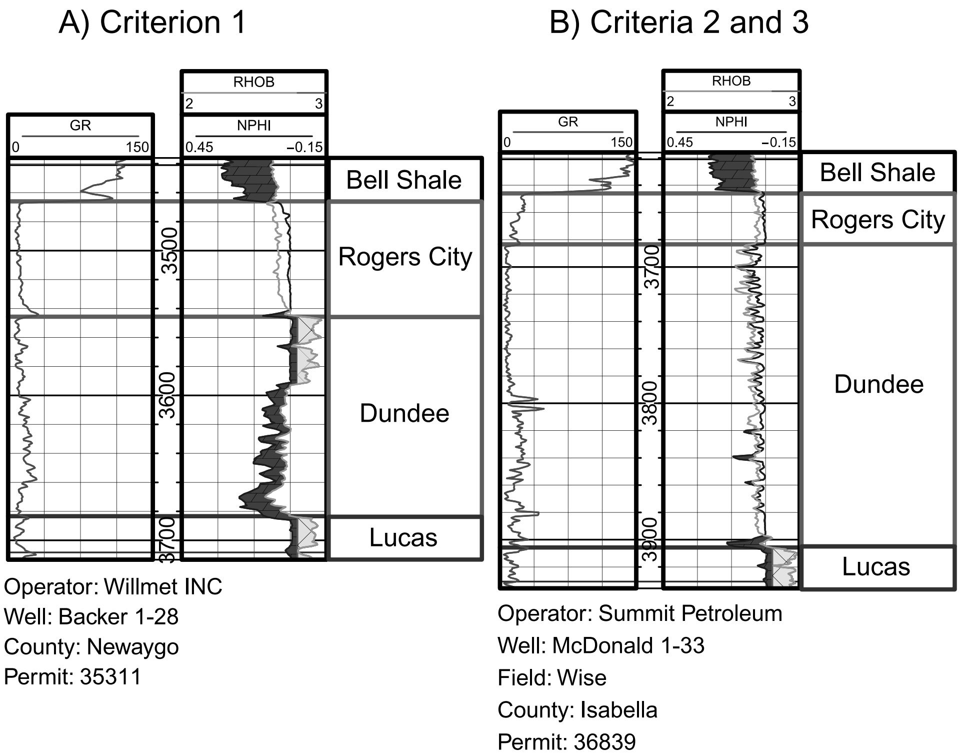

Figure 6. Formation subdivision criteria. (A) Criterion 1. The Rogers City is distinguished from the Dundee on the basis of an anhydrite layer (sometimes informally called the Reed City anhydrite) capping the Dundee. The dolomite directly overlying the anhydrite is probably part of the Dundee, but is quite thin and discontinuous. Therefore, the pick is made at the top of anhydrite, which is lightly shaded, instead of the dolomite. (B) Criteria 2 and 3. In the absence of anhydrite, the Rogers City and Dundee can be subdivided using the sharp increase in porosity downward on a neutron porosity (NPHI) log (2) or a marker on the gamma ray (GR) log (3). Criteria 2 and 3 are also both visible in panel A. RHOB = bulk density.

break in porosity on the neutron porosity log is easily distinguished. Criteria 2 and 3 were tested against available cores that cut the Rogers City-Dundee contact and are reliable indicators of the formation contact.

METHODS FOR GSC ESTIMATES

The GSC estimates were calculated from a total of 114 digital formation density-neutron porosity (FDC-CNL) logs from representative wells. The wells were classified as either predominately limestone or predominately dolomite (Figure 7). A dolomite lithology causes apparent porosity readings on a limestone-calibrated neutron porosity log, which must be corrected to true porosity using correction charts (Asquith and Gibson, 1982). The degree of error depends on the amount of porosity, but for simplicity, an average chart-determined value of seven porosity units was subtracted from the limestone-calibrated porosity log to correct apparent porosity to true porosity where the dominant lithology is dolomite. No correction was necessary if the lithology was predominantly limestone.

Statewide GSC estimates were calculated in the area where both units lie at sufficient burial depth. To compare how regional differences in lithology, thickness, and petrophysical properties affect GSC in the Rogers City and Dundee, estimates were also calculated for three geologically different areas of the basin represented by Arenac, Gladwin, and Osceola counties. Osceola County is in the west-central part of the basin, where the Rogers City is commonly dolomitized, the Dundee is ubiquitously dolomitized, and both formations are relatively thin. Gladwin County is in the central basin, where the Rogers City is always limestone, the Dundee has variable proportions of limestone and dolomite, and both formations are thicker than in the west-central basin. Arenac County is in the eastern basin where both formations are near their maximum thickness; however, the Dundee is almost three times as thick as the Rogers City, and dolomite occurs primarily in the Dundee.

The GSC can be calculated using the formula

$$\mathrm{GSC} = A_t^* h^* \phi^* \rho^* \xi \qquad (1)$$

where A_t is the total area in square meters, h is the formation thickness in meters, ϕ is the average porosity in percent, ρ is the density of supercritical CO_2 in metric tons per cubic meters, and ξ is the unitless storage efficiency factor (modified from U.S. Department of Energy [DOE], 2007). The total area is the surface area under consideration (e.g., a county or the area below

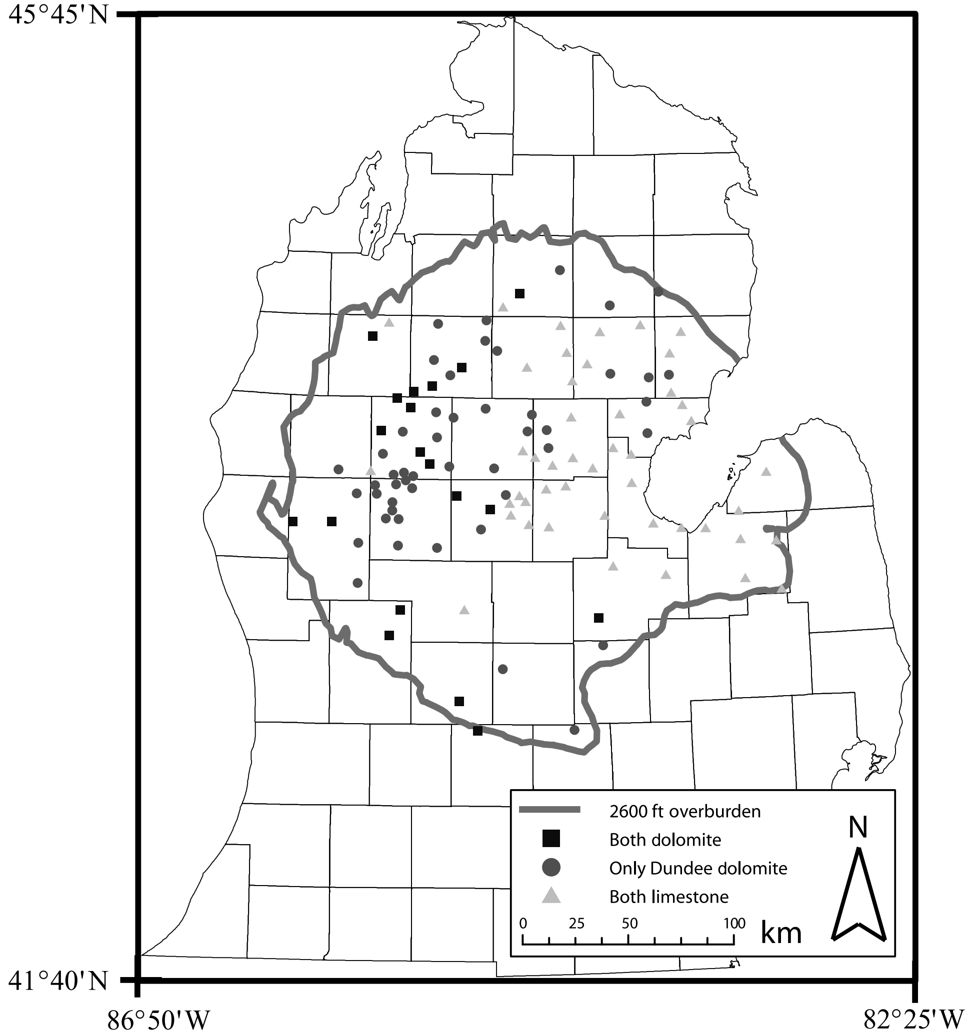

Figure 7. Representative wells (114 total). Squares are wells where the dominant lithology is dolomite in both Rogers City and Dundee. Circles are wells where the Dundee is mostly dolomite, whereas the Rogers City is limestone. Triangles are wells where Rogers City and Dundee are both limestone.

2600 ft [792 m]). Formation thickness and average porosity were calculated using digital logs. An average density of supercritical CO_2 of 0.7 t/m^3 was used for the depth range of Rogers City and Dundee in the Michigan Basin (see Barnes et al., 2009). The efficiency factor (ξ) reflects the fraction of total pore volume that is filled with CO_2, and ranges from 1 to 4% for a regional study on the basis of Monte Carlo simulations with a 15 to 85% confidence range (DOE, 2007). It may be useful to think of ξ as an uncertainty factor, which considers regional variation in reservoir properties and that not all pore space is available for geological sequestration. Generally, greater uncertainty or greater known variability in reservoir properties would correspond to the use of a low ξ factor. The ξ factor used for this study is discussed further below.

Porosity-permeability crossplots are used to define a porosity cutoff for a critical permeability (Lønøy, 2006). The relationship between porosity and permeability in the Rogers City and Dundee was determined by fitting trend lines to porosity and permeability data from three cored wells (Figure 8). The Rogers City and Dundee have variable pore types, however, especially in limestone versus dolomite reservoirs. Different pore types may have significantly different permeability values associated with the same porosity value (Lønøy, 2006), which helps explain why the correlation coefficient (R^2) values for porosity versus permeability trend lines in Figure 8 are low. Ideally, porosity cutoffs would be ascertained for all of the different pore types and then averaged to obtain the average porosity cutoff for the variety of pore types present, but no pore-type data were available for our analysis. Therefore, porosity cutoffs for Rogers City and Dundee were determined for each core using a critical permeability of 1 md (Table 1). The average porosity cutoffs for Rogers City and Dundee are 3.7 and 5.8%, respectively. The average of all the data yields a porosity cutoff of 4.8%

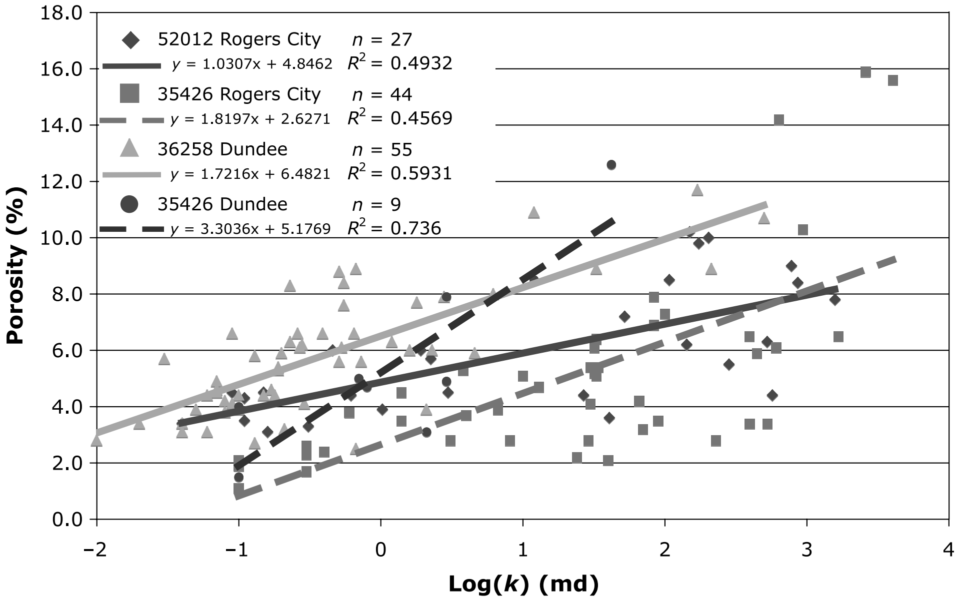

Figure 8. Porosity versus permeability relationships for Rogers City and Dundee. Different shapes show data points for porosity and permeability values from three different cores: (1) State Redding & Sparrow 1-29 HD1, permit 52012, core analyzed in the Rogers City (diamond) from 3883 to 3910 ft (1183.5 to 1191.7 m); (2) Midwest Oil Productions Thelma Rousseau 1-12, permit 35426, core analyzed in the Rogers City (square) from 3903 to 3948 ft (1189.6 to 1203.4 m) and in the Dundee (circle) from 3949 to 3958 ft (1203.7 to 1206.4 m); and (3) Oryx Energy Van Gaever & Lockwood 1, permit 36258, core analyzed in the Dundee (triangle) from 3529 to 3584 ft (1075.6 to 1092.4 m). The relationship between porosity and permeability was determined by fitting a trend line to each data set. The correlation coefficient, R^2, values are low because the pore type for each data point was unknown, which causes multiple porosity and permeability relationships to be evaluated by the same trend line.

for the Dundee (undifferentiated). These porosity cutoffs are not the best representation of either the Rogers City or Dundee, not to mention the Dundee (undifferentiated), because of the lack of pore-type data discussed above. Nonetheless, using porosity cutoffs supported by conventional core analysis data is far preferable to assuming that all porosity is suitable for CO_2 sequestration.

Choosing an efficiency factor is rather subjective. For a regional study, the ξ factor is influenced by the net to total area, net to gross thickness, and effective to total porosity ratio (DOE, 2007). Good well control permits the use of a higher efficiency factor because it provides reduced uncertainty and constrains lateral variability by delineating the net to total reservoir area. Estimates that assume average porosity and thicknesses for the entire formation oversimplify geological heterogeneity. A porosity cutoff characterizes the minimum effective porosity, which eliminates poor reservoir quality rock and further reduces uncertainty in net to gross thickness and the effective to total porosity ratio. The use of porosity cutoffs supported by conventional core analysis data, together with good well control, justifies the use of the maximum regional efficiency factor of 4% for this analysis.

Table 1. Porosity Cutoffs Determined from Core Data (Listed by Permit Number, See Figure 8), and Average Porosity Cutoffs for the Rogers City, Dundee, and Dundee (Undifferentiated)

Formation	Porosity Cutoff (%)
52012 (Rogers City)	4.84
35426 (Rogers City)	2.62
36258 (Dundee)	5.17
35426 (Dundee)	6.48
Average Rogers City	3.73
Average Dundee	5.83
Average Dundee (undifferentiated)	4.78

Formation thickness (h) and porosity (ϕ) were calculated for each representative well, using the porosity cutoffs presented above. Thus, h is the net formation thickness above the porosity cutoff, and ϕ is the average porosity above the cutoff instead of the true average porosity. These values were then averaged for (1) the entire study area, (2) Arenac County, (3) Gladwin County, and (4) Osceola County. The GSC estimates were calculated for each of the four areas. The GSC estimates cannot be compared, however, because each of the four areas has a different surface area (A_t). To compare the storage capacities of the different areas, a normalized GSC footprint was calculated using the formula

$$\text{GSC Footprint} = \text{GSC}/A_t = h^*\phi^*\rho^*\xi \qquad (2)$$

where GSC Footprint is in metric tons per square meters and all other variables are the same as previously defined (see equation 1). Table 2 shows the input parameters and GSC footprints for the Dundee (undifferentiated), Rogers City, and Dundee in each of the four areas.

DISCUSSION

Our procedures for the stratigraphic subdivision of the Dundee (undifferentiated) cannot guarantee exact picks of the Rogers City and Dundee boundary because lithofacies vary regionally, wireline log response may be variable, and supporting core data are limited. This is especially true when relying only on criterion 3, the gamma-ray marker. Either local dolomitization or tight facies in both Rogers City and Dundee may result in the uncertainty of the pick on the order of tens of feet in some places, but when criterion 1 or 2 is used, the uncertainty is probably less than a few feet. The impact of this uncertainty on geological sequestration calculations is small. Estimates of storage capacity are unchanged in areas where both formations are tight. Uncertainties in areas where both formations are dolomitized do affect storage capacity estimates for the Rogers City, but not the Dundee. For example, if 20 ft (6 m) is added to the top Dundee pick for the representative wells where criterion 1 or 2 does not apply, the statewide GSC of the Dundee remains roughly 1.88 Gt, but the GSC of the Rogers City approximately doubles to 0.25 Gt. Dolomite-related uncertainties affect the GSC of the Rogers City more than the Dundee because the Rogers City is only a reservoir where dolomitized and also has a lower porosity cutoff. Sparse well control and increasingly complicated geology cause log-pick uncertainties to increase toward the margins of the basin. This poses a significant problem for stratigraphic correlation in these areas but not for GSC studies because basin margin areas are generally unsuitable for geological sequestration because of shallow burial depth.

The subsurface subdivision of the Dundee Limestone (undifferentiated) into two petrophysically distinct units, Rogers City and Dundee, provides a much

Table 2. Input Parameters and GCS Footprints for the Statewide Study Area and Arenac, Gladwin, and Osceola Counties*

Study Area	State			Arenac			Gladwin			Osceola		
A_t (m^2)	41,189,150,793			952,879,716			1,336,655,889			1,483,491,944		
Formation	Dundee (Undifferentiated)	Dundee	Rogers City	Dundee (Undifferentiated)	Dundee	Rogers City	Dundee (Undifferentiated)	Dundee	Rogers City	Dundee (Undifferentiated)	Dundee	Rogers City
h (m)	19.9	15.9	2.5	40.2	32.8	2.0	19.3	16.2	0.06	16.0	10.1	5.9
ϕ (%)	9.4	10.2	4.6	9.7	10.7	2.8	10.1	11.0	1.6	7.8	8.5	6.7
GSC (Mt)	2150	1881	133	104	93	1.49	73	67	0.033	52	36	17
GSC Footprint (t/ha)	522	457	32	1089	978	16	548	500	0	348	242	112

*Input parameters include surface area (A_t), formation thickness (h), and average ϕ. The GSC is reported in million metric tons (Mt) and the GSC Footprint in metric tons per hectare (t/ha).

more defensible assessment of the GSC than without this subdivision. Arguably, a porosity cutoff reduces the need to differentiate these formations because estimates are made only for reservoir rocks. However, several additional advantages to differentiating the two formations exist. First, the Dundee is clearly identified as the primary sequestration target. Statewide GSC estimates are more than an order of magnitude greater for the Dundee than the Rogers City (Table 2). Initially, this result seems at odds with the Dundee (undifferentiated) production data because the Rogers City accounts for at least 25% of cumulative oil production (Wylie and Wood, 2005). The logical inference is that the Rogers City should have approximately 25% of combined Rogers City and Dundee GSC, but the relative GSC contribution of the Rogers City is really less than 6.5%. This paradox is easily explained by the nature of oil production in the Rogers City. Rogers City oil is only found in laterally discontinuous dolomite reservoirs. Regionally, most of the Rogers City is tight limestone and not a good reservoir rock.

Subdivision also confirms that the two formations are distinctly different and permits more geologically defensible GSC estimates caused by disparate petrophysical properties in the Rogers City versus the Dundee. The GSC for the Dundee (undifferentiated) is overestimated (by 7%) compared to individual GSC estimates for Rogers City and Dundee calculated separately. Overestimation occurs because of a lower porosity cutoff in the Rogers City compared to the Dundee, yet the Rogers City generally has very little net formation thickness above cutoff porosity. There is simply no way to accurately calculate GSC for the Dundee (undifferentiated) because the petrophysical properties of the Rogers City and Dundee are so different. Average petrophysical properties for the Dundee (undifferentiated) fail to characterize the GSC at the regional (statewide) scale and cannot even begin to capture county-scale variability.

Throughout most of lower Michigan, the Dundee is a potential geological sequestration target. The Rogers City is generally not a target, except in local dolomitized reservoirs. This point is best illustrated by examining GSC footprints in several counties: the Rogers City ranges from 0 t/ha in Gladwin County to 112 t/ha in Osceola County but typically has very little GSC (e.g., 16 t/ha in Arenac County). The relatively large Rogers City footprint in Osceola County is caused by a high frequency of wells where the Rogers City is dolomitized. The GSC footprint for the Dundee in Gladwin County is approximately double that in Osceola County, and the GSC footprint for Arenac County is double that for Gladwin County. In Arenac County, the Dundee stratigraphic section is thicker than that in counties to the west because the paleodepocenter of the Michigan Basin during the Middle Devonian was located near Arenac County. Although dolomite is important and does impact the GSC in the Dundee, most of the variability in the GSC is related to a simple thickening of the section from west to east across the basin.

CONCLUSIONS

The Middle Devonian Dundee (undifferentiated) Limestone formation in the Michigan Basin is a potential geological sequestration target. The Dundee (undifferentiated) can be subdivided in the subsurface, using wireline logs, into Rogers City and Dundee. The Dundee is an important geological sequestration reservoir, with a GSC estimated at 1.88 Gt. Conversely, statewide GSC estimates for the Rogers City total a mere 0.13 Gt. Subdividing the Dundee (undifferentiated) is important when estimating GSC because the petrophysical properties, thicknesses, and lithologies of Rogers City and Dundee are significantly different. Failure to subdivide these units in the course of a storage capacity analysis overestimates the GSC (2.15 Gt) in the Dundee (undifferentiated).

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