Geologic Framework for the National Assessment of Carbon Dioxide Storage Resources—South Florida Basin

By Tina L. Roberts-Ashby, Sean T. Brennan, Matthew D. Merrill, Madalyn S. Blondes, Philip A. Freeman, Steven M. Cahan, Christina A. DeVera, and Celeste D. Lohr

Chapter L of
Geologic Framework for the National Assessment of Carbon Dioxide Storage Resources

Edited by Peter D. Warwick and Margo D. Corum

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Editors' Preface

By Peter D. Warwick and Margo D. Corum

The 2007 Energy Independence and Security Act (Public Law 110–140) directs the U.S. Geological Survey (USGS) to conduct a national assessment of potential geologic storage resources for carbon dioxide (CO_2) and to consult with other Federal and State agencies to locate the pertinent geological data needed for the assessment. The geologic sequestration of CO_2 is one possible way to mitigate its effects on climate change.

The methodology that is being used by the USGS for the assessment was described by Brennan and others (2010), who revised the methodology by Burruss and others (2009) according to comments from peer reviewers, members of the public, and experts on an external panel. The assessment methodology is non-economic and is intended to be used at regional to sub-basinal scales.

The operational unit of the assessment is a storage assessment unit (SAU), composed of a porous storage formation with fluid flow and an overlying fine-grained sealing unit. Assessments are conducted at the SAU level and are aggregated to basinal and regional results. SAUs have a minimum depth of 3,000 feet (ft), which ensures that the CO_2 is in a supercritical state (and thus occupies less pore space than a gas). Standard SAUs have a maximum depth of 13,000 ft below the surface, a depth accessible with average injection pipeline pressures (Burruss and others, 2009; Brennan and others, 2010). Where geologic conditions favor CO_2 storage below 13,000 ft, an additional deep SAU is assessed.

The assessments are also constrained by the occurrence of relatively fresh formation water. Specifically, any formation water having a salinity less than 10,000 milligrams per liter (mg/L) total dissolved solids (TDS), regardless of depth, has the potential to be used as a potable water supply (U.S. Environmental Protection Agency, 2009). The U.S. Environmental Protection Agency (2008) has proposed the limit of 10,000 mg/L TDS for injection of CO_2. Therefore, the potential storage resources for CO_2 in formations where formation waters have salinities less than 10,000 mg/L TDS are not assessed (Brennan and others, 2010).

This report series contains geologic descriptions of each SAU identified within the assessed basins and focuses on the particular characteristics specified in the methodology that influence the potential CO_2 storage resource. Although assessment results are not contained in these reports, the geologic framework information will be used to calculate a statistical Monte Carlo-based distribution of potential storage space in the various SAUs following Brennan and others (2010). Figures in this report series show SAU boundaries and cell maps of well penetrations through the sealing unit into the top of the storage formation. Wells sharing the same well borehole are treated as a single penetration. Cell maps show the number of penetrating wells within one square mile and are derived from interpretations of incompletely attributed well data (IHS Energy Group, 2011; and other data as available), a digital compilation that is known not to include all drilling. The USGS does not expect to know the location of all wells and cannot guarantee the amount of drilling through specific formations in any given cell shown on cell maps.

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square foot (ft^2)	0.00002296	acre
square mile (mi^2)	2.59	square kilometer (km^2)
	Volume	
barrel (bbl), (petroleum, 1 barrel=42 gal)	0.1590	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
1,000 cubic feet (MCF)	28.32	cubic meter (m^3)
cubic meter (m^3)	6.290	barrel (petroleum, 1 barrel = 42 gal)

Abbreviations

CKLIZ	Cedar Keys/Lawson Injection Zone
CO_2	carbon dioxide
EPA	U.S. Environmental Protection Agency
mD	millidarcy
mg/L	milligrams per liter
SAU	storage assessment unit
TDS	total dissolved solids
UIC	underground injection control
USGS	U.S. Geological Survey

Geologic Framework for the National Assessment of Carbon Dioxide Storage Resources—South Florida Basin

By Tina L. Roberts-Ashby, Sean T. Brennan, Matthew D. Merrill, Madalyn S. Blondes, Philip A. Freeman, Steven M. Cahan, Christina A. DeVera, and Celeste D. Lohr

Abstract

This report presents five storage assessment units (SAUs) that have been identified as potentially suitable for geologic carbon dioxide (CO_2) sequestration within a 35,075-square-mile area that includes the entire onshore and State-water portions of the South Florida Basin. Platform-wide, thick successions of laterally extensive carbonates and evaporites deposited in highly cyclic depositional environments in the South Florida Basin provide several massive, porous carbonate reservoirs that are separated by evaporite seals. For each SAU identified within the basin, the areal distribution of the reservoir-seal couplet identified as suitable for geologic CO_2 sequestration is presented, along with a description of the geologic characteristics that influence the potential CO_2 storage volume and reservoir performance. On a case-by-case basis, strategies for estimating the pore volume existing within structurally and (or) stratigraphically closed traps are also discussed. Geologic information presented in this report has been employed to calculate potential storage capacities for CO_2 sequestration in the SAUs assessed herein, although complete assessment results are not contained in this report.

Introduction

This report is meant to provide geologic descriptions and basic reservoir characterization for storage assessment units (SAUs) identified within the South Florida Basin, in support of U.S. Geological Survey (USGS) Geologic Carbon Dioxide Storage Resources Assessment Team (2013a,b,c), which provide the results, data, and summary of a national assessment of carbon dioxide (CO_2) storage resources within the United States. The area assessed for CO_2 storage within the South Florida Basin and the surrounding region encompasses an area of approximately 22,447,911 acres and extends across the south-central and southern extents of the Florida peninsula (fig. 1). Although the South Florida Basin continues offshore toward its basin center to the southwest of peninsular Florida, this assessment was only conducted onshore and outward to the State-water boundary (fig. 1).

The South Florida Basin is located on the Florida Platform, a carbonate platform that can be more than 350 miles (mi) wide, extending from the shelf break off the east coast of Florida westward to the Florida Escarpment, a bathymetric and geologic feature that is more than 450 mi long that plunges from a depth of approximately 2,000 feet (ft) below sea level to more than 10,000 ft at the modern abyssal plain of the Gulf of Mexico (fig. 1; Hine and others, 2001; Scott, 2001). Together with the carbonate Bahama Platform, the Florida Platform was part of a larger "gigaplatform" during the Jurassic that extended from Mexico across the Gulf of Mexico to the Grand Banks of Newfoundland and is thought to have been one of the largest laterally continuous carbonate platforms in geologic history (Poag, 1991; Hine and others, 2001). The basement strata of the Florida Platform are composed of Precambrian and Cambrian igneous and metamorphic rocks, Ordovician to Devonian sedimentary rocks, and Triassic and Jurassic volcanic rocks whose depths increase from central-northern peninsular Florida to southern Florida (Milton, 1972; Arthur, 1988; Randazzo, 1997; Scott, 2001). Scientists believe that the igneous-metamorphic and sedimentary basement rocks were once attached to the African plate before rifting events associated with the breaking apart of the supercontinent Pangea in the Triassic or pre-Middle Jurassic(?) (Smith, 1982; Randazzo, 1997; Scott, 2001).

The Florida Platform has been subjected to multiple fluctuations in relative sea level throughout its history, with the highest levels occurring during the Late Cretaceous when a large majority of the platform was submerged (Randazzo, 1997). During the mid-Cretaceous, relative sea levels and paleo-environmental stresses, considered by many to be the result of worldwide oceanic anoxic events, affected sedimentation rates on the Florida Platform (Hine and others, 2001). Ultimately, sediment production and accumulation could not keep pace with tectonic subsidence that was occurring at that time, and the western portion of the Florida Platform became submerged (Hine and others, 2001). Regressive relative sea levels dominated the Tertiary, and by the Oligocene, relative sea levels were considerably less than modern-day sea levels, exposing much of the Florida Platform (Randazzo, 1997). Furthermore, during the Tertiary, the platform had an elevated eastern portion and a largely submerged western portion that was no longer suitable for major carbonate accumulation; therefore, the Florida Platform was transformed from a rim-type platform into a gently west-sloping ramp (Randazzo, 1997; Hine and others, 2001).

The South Florida Basin has a maximum sediment thickness of 15,000–17,000 ft and a center that is located offshore due west of Collier County (Pressler, 1947; Halley, 1985). The basin is positioned to the east of the Lower Cretaceous Reef trend, which generally runs parallel to the Florida Escarpment and continues into the Gulf of Mexico (fig.1; Halley, 1985). The South Florida Basin was subjected to differential subsidence and is part of the larger, regionally subsiding South Florida Embayment that includes the southeastern Gulf of Mexico, south Florida, and the Bahamas (Grinnell, 1976). The onshore part of the South Florida Basin, an emergent segment of the Florida Platform, and the Florida State waters represent about half of the entire basin (fig. 1; Applegate and Pontigo, 1984).

During the middle Jurassic through to about the middle Oligocene, shallow-water marine deposition was dominant in the South Florida Basin and sequences comprising carbonate and evaporite rocks were deposited in water typically less than about 300 ft deep (Halley, 1985; Scott, 2001). Organic-rich carbonate mud also accumulated during the intermittent occurrence of salinity-stratified interior lagoons (Halley, 1985). During this time, two important features affected sedimentation on the Florida Platform, including the South Florida Basin: the Suwannee Channel and Gulf Trough, together known as the Georgia Channel System (Miller, 1986; Huddlestun, 1993; Randazzo, 1997). The Suwannee Channel was a sedimentologic system positioned across northern Florida and southern Georgia through which the Suwannee Current flowed (fig. 1; Chen, 1965; Randazzo, 1997; Hine and others, 2001). The channel existed from Late Cretaceous to middle Eocene and connected the northern Gulf of Mexico to the Atlantic Ocean; the Gulf Trough existed from middle Eocene to middle Miocene (Randazzo, 1997; Hine and others, 2001). The position of and sediment-transporting current within the Georgia Channel System, together with high relative sea levels, prevented clastic sediments from encroaching down the Florida Platform and further contributed to a carbonate-dominated platform. During the late Oligocene, however, the channel system began to infill, possibly during relative sea level regression when river deltas were depositing sediments derived from the southern Appalachian Mountains due to renewed uplift and erosion within the orogenic system, marking the beginning of major clastic sediment deposition on the platform (Randazzo, 1997; Hine and others, 2001; Scott, 2001).

The South Florida Basin has been a target for petroleum exploration and production since the first discovery of oil within the Sunniland Formation in 1943 (Lloyd, 1996). Signs of hydrocarbons have been identified in several other geologic units within the basin; however, the Sunniland Formation is the only unit that has had commercial production to date, with a total of 14 existing or depleted oil fields (Palacas, 1978; Palacas and others, 1981; Applegate and Pontigo, 1984; Applegate, 1987; Winston, 1987; Lloyd, 1996; Pollastro and others, 2001). The most recently completed geologic assessments of undiscovered oil and gas resources conducted by the USGS present the history of hydrocarbon exploration and production in the South Florida Basin (Pollastro, 2001; Pollastro and others, 2001). The USGS estimates mean values of approximately 351 million barrels of oil, 1,658 billion cubic feet of gas, and approximately 75 million barrels of natural gas liquids that remain undiscovered in the South Florida Basin (Pollastro and others, 2001). Pore volumes associated with existing and depleted oil and gas fields may be available for the purpose of geologic CO_2 sequestration, with the additional possibility of uncharged traps that have yet to be delineated. Nonpetroleum-producing saline aquifers occur throughout the basin as well, with total dissolved solid (TDS) concentrations exceeding 10,000 milligrams per liter (mg/L). These aquifers could provide additional pore volume for CO_2 sequestration.

To date, at least two geochemically distinct hydrocarbon systems, separated by the massive Punta Gorda Anhydrite, have been recognized in the South Florida Basin that are each associated with unique source rocks and are confined to discrete stratigraphic intervals (Pollastro and others, 2001). This stratigraphic confinement of hydrocarbon systems is important to the potential of geologic CO_2 sequestration because it suggests the presence of several regional sealing units within the basin. The geographic extent of "regional" can vary from basin to basin within the United States. Within the South Florida Basin, "regional" is considered to be an area that typically extends across two or more counties. Regional seals are essential components to CO_2 storage sites, and their presence in hydrocarbon systems of the South Florida Basin suggests the potential for containment of CO_2 over long periods of time (that is, millennia) and a low risk of leakage from storage sites into overlying sources of drinking water or into the atmosphere (Wilson and others, 2003).

Multiple geologic units within the South Florida Basin meet the USGS criteria for conducting a regional assessment for CO_2 storage capacity and are for the most part confined to Jurassic and Cretaceous strata. The USGS-assessed reservoir units include (1) Pre-Punta Gorda SAU, (2) Sunniland Formation SAU, (3) Gordon Pass and Marco Junction Formations SAU, (4) Dollar Bay Formation SAU, and (5) Cedar Keys and Lawson Formations SAU (fig. 2).

In the following five sections, the depositional setting, distribution, and stratigraphy of each prospective SAU are presented. Key information that provides the basis for calculating the capacity of each SAU for buoyant and residual CO_2 storage (as described in Burruss and others, 2009; Brennan and others, 2010; Blondes and others, 2013), as well as information that relates to the reservoir characteristics for each unit, is also summarized. Such key input parameters include depth from surface; area; gross thickness; net-porous-interval thickness, or the portion of the SAU gross thickness that contains porous rock identified as being sufficient for CO_2 storage; porosity of the net-porous interval; and range of permeability for the entire SAU. Because the U.S. Environmental Protection Agency (EPA 2009, 2013) stipulates that aquifers used for CO_2 sequestration must contain groundwater with a TDS concentration greater than 10,000 mg/L, regional trends in groundwater quality for an assessed area are characterized, and the area fraction of the SAU that is available for CO_2 storage is estimated. All parameters were estimated using a combination of proprietary databases (such as IHS Energy Group, 2010, 2011 and Nehring Associates, Inc., 2010); public and nonproprietary databases and well-log repositories; and published literature, including isopachs, structure maps, and cross sections.

Finally, in order to differentiate between the pore volume contained within buoyant traps and that contained within residual traps for the various SAUs (see Brennan and others, 2010; Blondes and others, 2013), the pore volume enclosed within buoyant traps, which are analogous to stratigraphic and (or) structural hydrocarbon traps, is defined. For each SAU, (a) minimum and (b) most likely pore volumes enclosed within buoyant traps were constrained on the basis of (1) the sum of the cumulative oil and gas production and the known hydrocarbon reserve volume and (2) the minimum buoyant pore volume plus the estimated volume of undiscovered resources (see Brennan and others, 2010; Blondes and others, 2013). Because this method was applied to all SAUs, it is not discussed on a case-by-case basis. An upper boundary for enclosed pore volume was also determined for each unit, and methods for the various SAUs are discussed on a case-by-case basis. The information derived from the data sources and methods described in this report were used in accordance with the USGS Carbon Sequestration Assessment Methodology (Brennan and others, 2010; Blondes and others, 2013) to calculate the available storage space for CO_2 within each SAU.

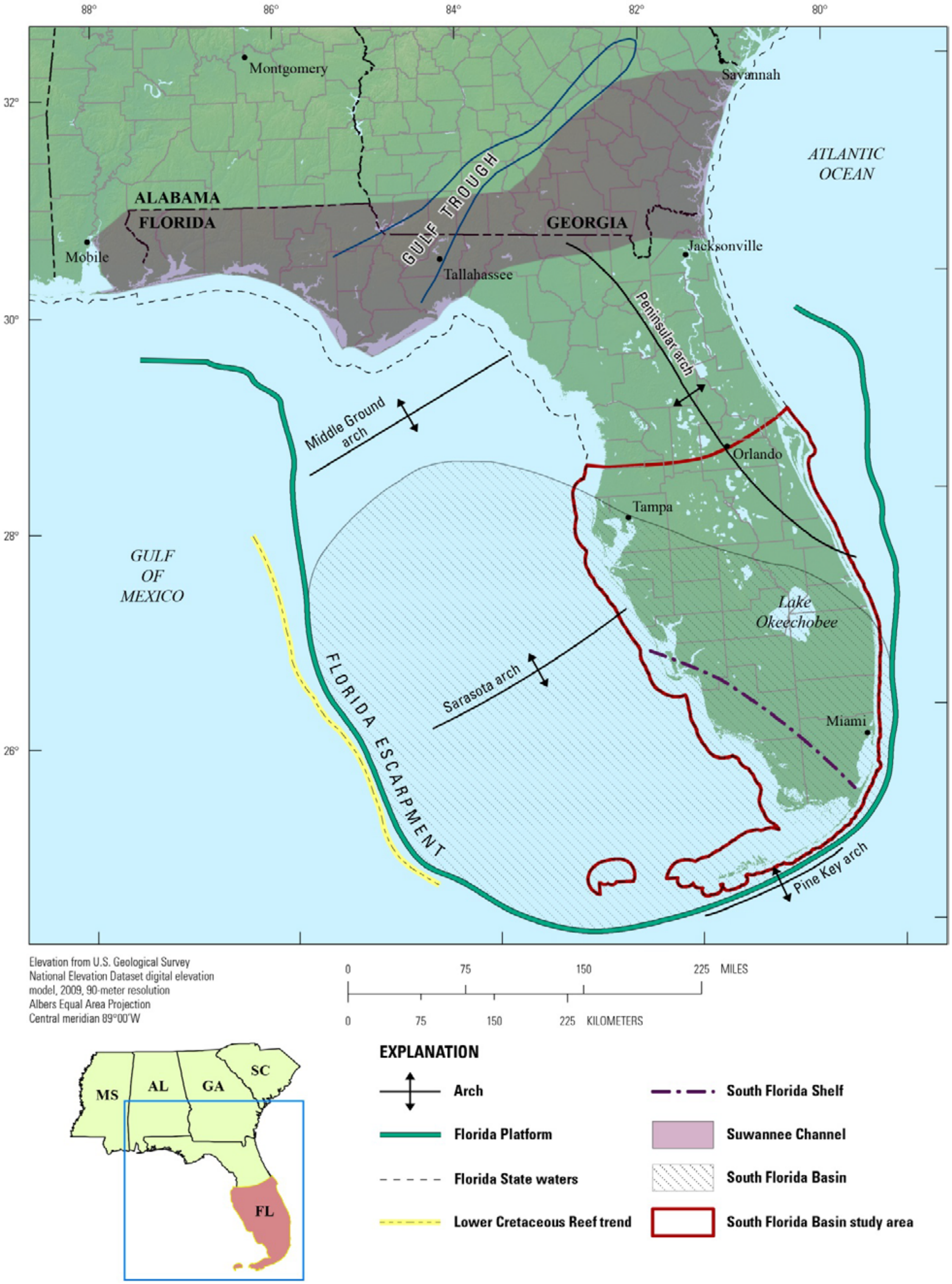

Figure 1. Geologic map of the South Florida Basin study area within the southeastern United States. Major structural features adapted from Grinnell (1976), Ferber (1985), Halley (1985), Huddlestun (1993), and Randazzo (1997). In the inset on the lower left, area shaded red is the South Florida Basin study area.

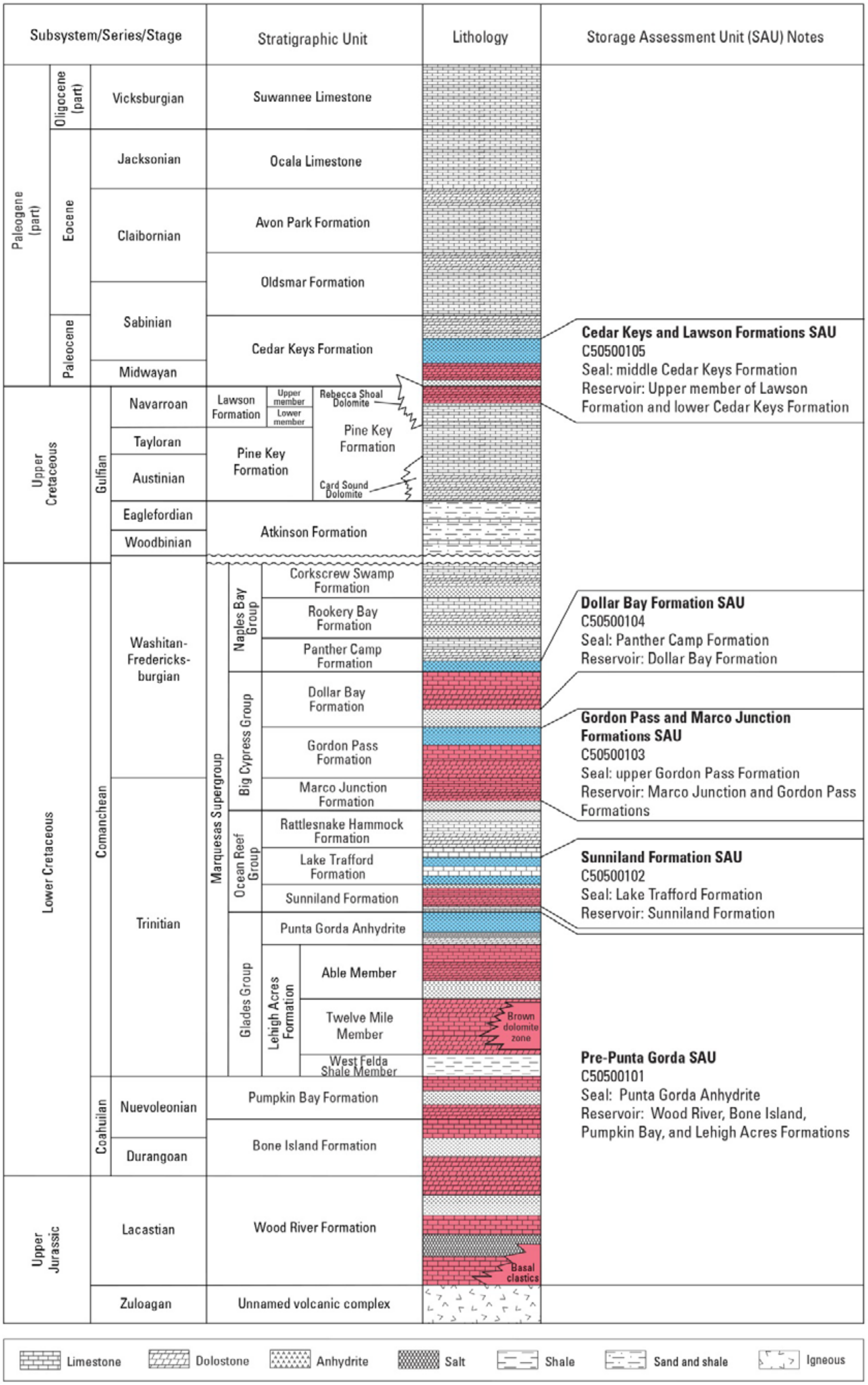

Figure 2. Stratigraphic column for the South Florida Basin study area. Storage assessment units consist of a reservoir (red) and regional seal (blue). Modified from Braunstein and others (1988), Pollastro and others (2001), and Faulkner and Applegate (1986).

Pre-Punta Gorda SAU C50500101

By Sean T. Brennan

The Pre-Punta Gorda SAU (fig. 3) is an Upper Jurassic to Lower Cretaceous composite assessment unit, with storage formations that include the Wood River, Bone Island, Pumpkin Bay, and Lehigh Acres Formations, and a seal that is composed of the Punta Gorda Anhydrite (fig. 2). The Upper Jurassic Wood River Formation is primarily composed of carbonate-rich deposits; however, the basal 100 to 150 ft of the formation contains approximately 100 ft of shale and arkosic sandstone (Braunstein and others, 1988; Pollastro and others, 2001). The overlying Lower Cretaceous Bone Island and Pumpkin Bay formations contain carbonates and evaporite strata and are overlain by the Lehigh Acres Formation (Pollastro and others, 2001). The Lehigh Acres Formation is divided into the basal West Felda Shale Member, overlain by the Twelve Mile Member and the Able Member. The West Felda Shale Member is a regionally persistent calcareous shale that is typically less than 100 ft thick in the South Florida Basin (Applegate and others, 1981). The Twelve Mile Member is a skeletal limestone (Winston, 1987) and contains the informal “Brown Dolomite Zone”, which has hydrocarbon staining (Applegate, 1987; Pollastro and others, 2001). The uppermost unit of the Lehigh Acres Formation, the Able Member, is composed primarily of anhydritic and argillaceous limestone. These storage formations are overlain by the Punta Gorda Anhydrite, the uppermost unit of the Glades Group (fig. 2; Pollastro and others, 2001), which is composed mainly of anhydrite, locally interbedded with limestone, dolomite, shale, and more rarely halite (Applin and Applin, 1965). The Punta Gorda Anhydrite is a regionally persistent, wedge-like unit, with thicknesses ranging from 200 ft in Hillsborough County, Florida to 2,100 ft in the Florida Keys (Applin and Applin, 1965). Isopachs of these formations were created using available formation-tops data and data interpreted from publically available geophysical logs provided by the Florida Geological Survey (IHS, 2010), which were then aggregated to estimate the average total thickness of the composite SAU, which ranges from 1,500 to 4,500 ft.

The extent of the Pre-Punta Gorda SAU, defined by the extent of the Punta Gorda Anhydrite, is approximately 20,709,000 acres. The depth to the top of the Lehigh Acres Formation is between 8,200 and 13,000 ft across the entire SAU, with an average depth of approximately 12,000 ft. The few water analyses obtained for this composite SAU indicate TDS values between 85,000 and 270,000 mg/L (Breit, 2002). These salinity values and the presence of thick evaporite units indicate that water salinity is likely well above 10,000 mg/L TDS for the entire SAU; therefore, 100 percent of the entire SAU is available for CO_2 storage.

The net-porous interval was determined by calculating a net-to-gross ratio from well logs for each unit of the composite SAU. These net-to-gross values were used to modify the isopachs of each formation in the composite SAU. These net-porous-thickness isopachs were aggregated into a single net-porous isopach for the entire SAU, which indicates an average net-porous thickness that ranges from 100 to 1,500 ft. Density and neutron porosity values from several wells in the SAU, along with values from literature sources (Applin and Applin, 1965; Applegate and others, 1981; Pollastro and others, 2001), were used to determine the range of porosity values for the net-porous intervals, which is between 9 and 15 percent. Because there is no petroleum production from within the SAU to date, and no published permeability values could be identified by the author during the assessment, analog values taken from SAUs identified within the Gulf Coast region (Roberts-Ashby and others, 2014) were used. Specifically, the Gulf Coast analogs considered during this assessment were the Smackover Formation SAUs (Buursink, 2014); the Sligo and Hosston Formations and Cotton Valley Group SAUs (Roberts-Ashby, 2014); the Rodessa Formation and James Limestone SAUs (Warwick, 2014); and the Washita and Fredericksburg Groups, Rusk Formation, and James Limestone SAUs (Brennan, 2014). Using these analogs, the permeability was estimated to be between 0.1 and 1,000 millidarcies (mD), with a most likely permeability of 15 mD. The buoyant trapping pore volume, based on these same analogs, was estimated to be between 0 and 200,000 million barrels, with a most likely value of 1,420 million barrels.

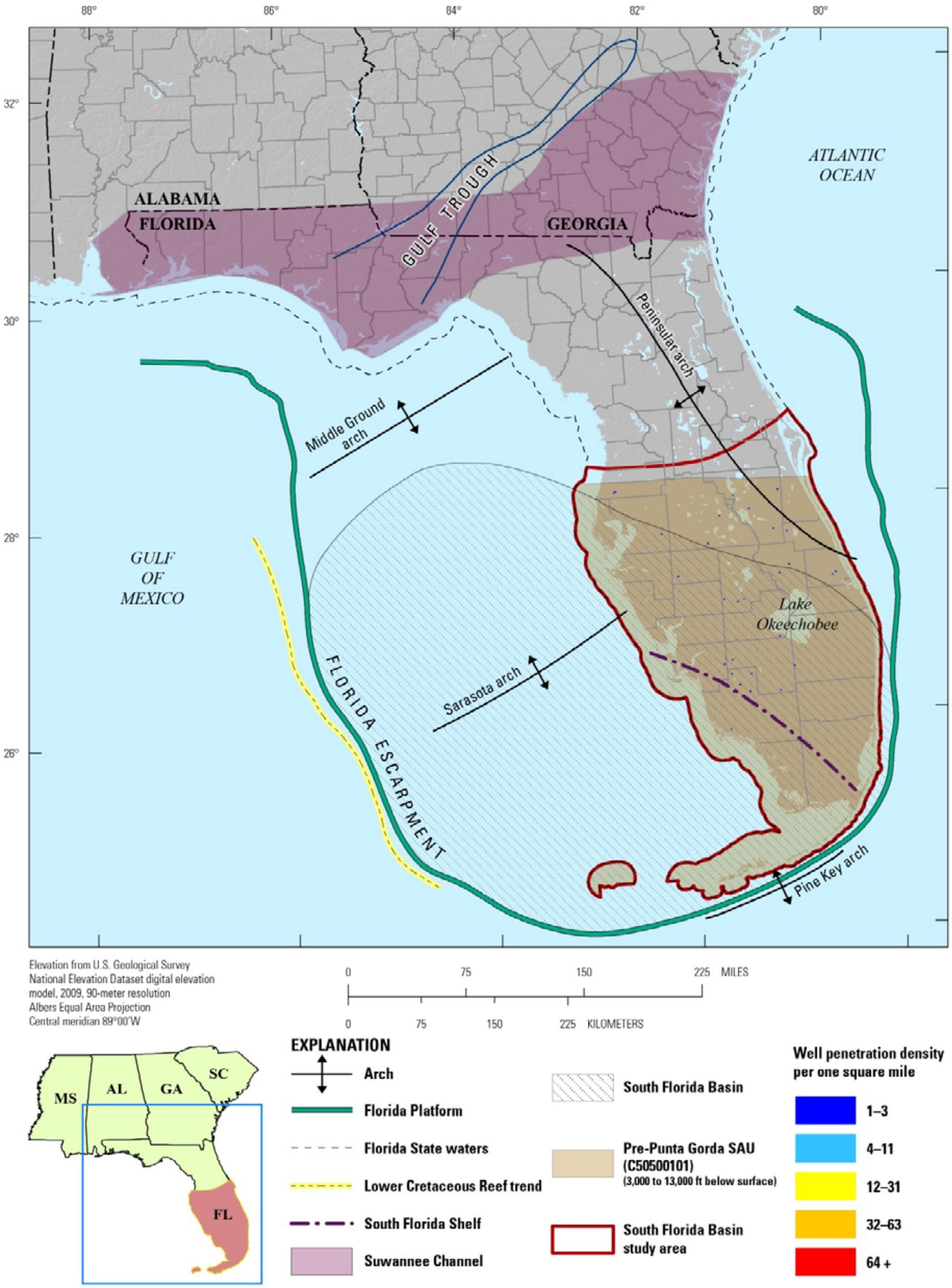

Figure 3. Map of the U.S. Geological Survey storage assessment unit (SAU) boundaries for the Pre-Punta Gorda SAU in the South Florida Basin. Grid cells (one square mile) represent counts of wells derived from ENERDEQ well database (IHS Energy Group, 2011) that have penetrated the reservoir-formation top.

Sunniland Formation SAU C50500102

By Tina L. Roberts-Ashby

The Lower Cretaceous Sunniland Formation is a predominantly carbonate unit within the South Florida Basin that forms a potential CO_2 storage reservoir within its petroleum-producing region, known as the Sunniland trend (figs. 2 and 4; Applegate and Pontigo, 1984; Roberts-Ashby and Stewart, 2012). The Sunniland Formation is composed of shallow-water marine deposits that accumulated on a very slowly subsiding platform subjected to cyclic sea level fluctuations, resulting in several carbonate-evaporite successions within the formation (Lane, 1994). The Sunniland trend is a slightly arc-like band within the South Florida Basin that is ≈145 mi long and 20 mi wide, where oil production activities have been concentrated to date within the Sunniland Formation (Applegate and Pontigo, 1984; Roberts-Ashby and Stewart, 2012). This region of the Sunniland Formation is also believed to contain the more highly porous intervals of the formation, which are composed of mound-like structures (30–100 ft thick) thought to be shallow-water bioherms, banks, shoals, and barrier beaches made of coarse fossil fragments (predominantly rudistids) and various seafloor debris that are located within the middle to upper parts of the Sunniland Formation (Mitchell-Tapping, 1986; Lane, 1994; Pollastro, 2001; Roberts-Ashby and Stewart, 2012). The basal, or lower, part of the Sunniland Formation is composed of a tight, organic-rich, micritic limestone of low porosity and permeability; this section of the formation contains the Sunniland Formation petroleum source rocks (Klopp, 1975; Pollastro, 2001). Updip and to the northeast of the porous, petroleum-producing trend, the Sunniland Formation thins and is partially replaced by low-porosity dolostone, and the porous bioclastic mounds transition laterally into low-porosity, miliolid-rich limestone; downdip and southwest of the trend, the upper section of the Sunniland Formation is composed of anhydrite (Grinnell, 1976; Applegate, 1983; Applegate and Pontigo, 1984; Lane, 1994). In the area of the potential CO_2 storage reservoir, the Sunniland Formation is overlain by the Lower Cretaceous Lake Trafford Formation, which is composed of carbonate-evaporite successions of anhydrite; fine dolostone; and micritic, skeletal limestone (Ferber, 1985; Halley, 1985). The Lake Trafford Formation contains thick (>30 ft), confining beds of anhydrite and overall has an average thickness of ≈130–170 ft. The low permeability of the overlying Lake Trafford Formation and the lateral decrease in permeability of the Sunniland Formation form the regional seal for the Sunniland Formation SAU.

One potential CO_2 storage reservoir is identified within the Sunniland Formation of the South Florida Basin that is between 3,000 and 13,000 ft subsurface depth—Sunniland Formation C50500102 SAU (fig. 4). The Sunniland Formation SAU encompasses an area of about 3,024,000 acres (±10 percent).

Although porosity within the Sunniland Formation petroleum reservoir is high, it is not limited to the isolated mounds, and the area of porous carbonate within the upper part of the formation is much larger than the area containing the producing oil fields (Beinert, 1976; Applegate and Pontigo, 1984; Mitchell-Tapping, 1987; Lloyd, 1996; Roberts-Ashby and Stewart, 2012). As such, the boundary of the Sunniland Formation SAU is not limited to the producing fields but is instead primarily defined by the area around the Sunniland trend, where the Sunniland Formation is known to be a porous carbonate reservoir rock with proven structural and stratigraphic trapping and a thick regional seal consisting of anhydrites within the Lake Trafford Formation (Applegate and Pontigo, 1984; Mitchell-Tapping, 1986; Lloyd, 1996; Roberts-Ashby and Stewart, 2012). Throughout the extent of the SAU, reservoir-top depths are greater than ≈10,000 ft, as seen in approximately 70 geophysical well logs. The rocks within the Sunniland Formation SAU deepen and thicken to the southwest (Klopp, 1975; Roberts-Ashby and Stewart, 2012), and on average are 230 to 270 ft thick, with a most likely thickness of 250 ft, as determined from the geophysical well logs.

Wave erosion common to shallow-water marine environments probably had a winnowing effect and created the porous and permeable reservoir carbonates of the Sunniland Formation, whereas in other areas, porosity within the formation has been enhanced by dolomitization resulting from periods of subaerial exposure (Applegate and Pontigo, 1984; Mitchell-Tapping, 1984; Pollastro, 2001).

Maximum porosities are found within the leached limestone of the Sunniland Formation (Mitchell-Tapping, 1984); however, porosity continues to be relatively high beyond the isolated mounds within the perimeter of the trend (Roberts-Ashby and Stewart, 2012). Average porosity in the porous intervals of the Sunniland Formation SAU range from 13 to 14 percent with a most likely porosity of 15 percent. Net-porous-interval thickness was estimated using geophysical logs for 70 wells located throughout the SAU, resulting in an average net-porous-interval thickness that ranges from 60 to 70 ft, with a most likely thickness of 65 ft. Average permeability in the Sunniland Formation SAU ranges from 0.01 to 400 mD, with a most likely permeability of 80 mD (Mitchell-Tapping, 1984; Nehring Associates, Inc., 2010).

Water sampled from six wells within the Sunniland Formation SAU indicates saline formation-waters, with TDS values well above 10,000 mg/L (Breit, 2002). Because groundwater within the Sunniland Formation SAU exceeds the 10,000 mg/L TDS lower limit emplaced by the EPA (EPA, 2010), 100 percent of the SAU is considered to be potentially suitable for geosequestration of CO_2.

In order to calculate the maximum buoyant pore volume within structural and stratigraphic closures for the Sunniland Formation SAU, the known closure areas from the highly productive regions located throughout the SAU were extrapolated and combined with upper bounds on regional reservoir thickness and porosity. The known closure areas were calculated by summing petroleum reservoir areas for the Sunniland Formation SAU (Nehring Associates, Inc., 2010). An assumption underlying this calculation is that there is potential for additional uncharged or undiscovered structural and stratigraphic closures outside of regions of historical hydrocarbon production.

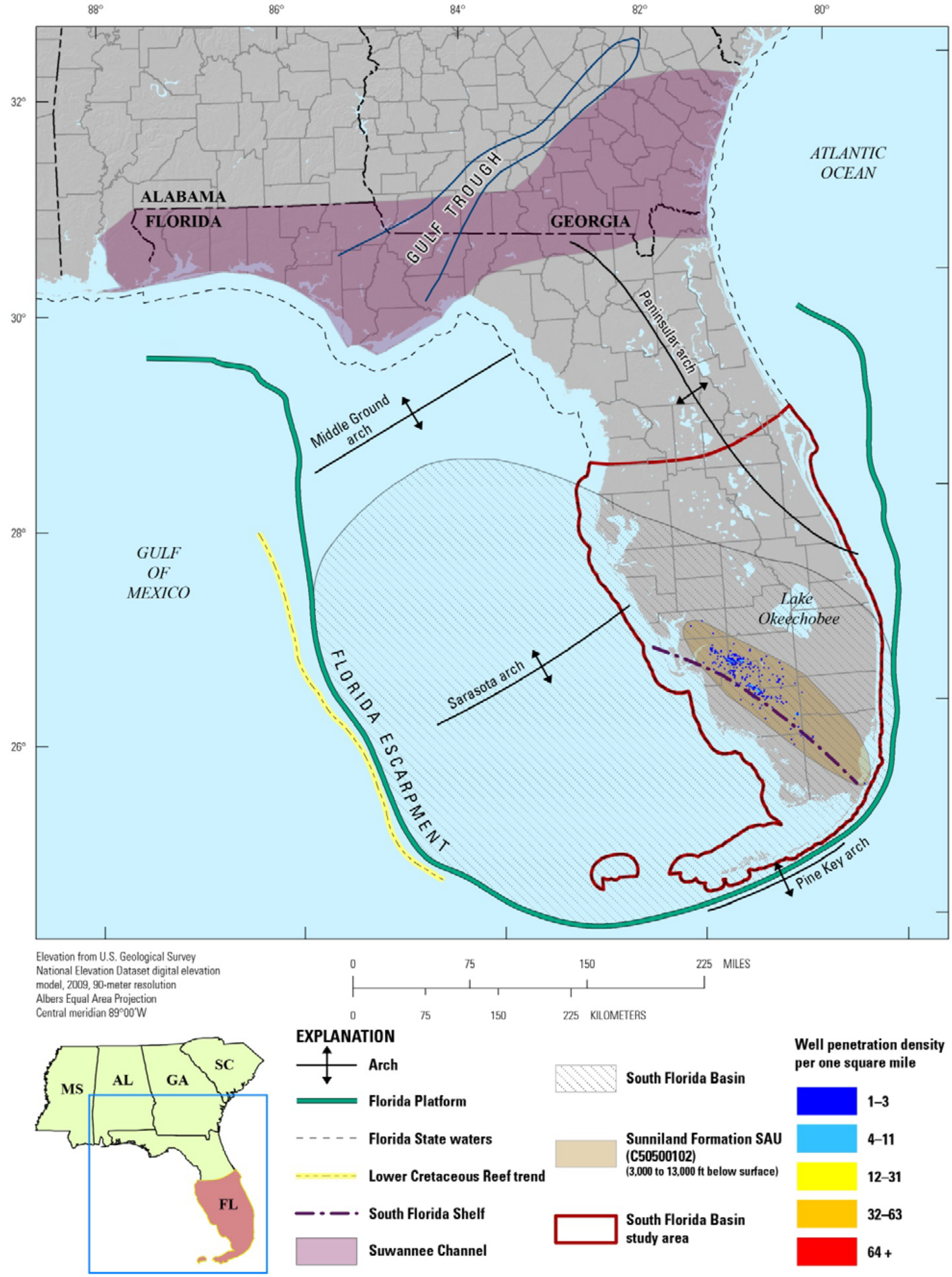

Figure 4. Map of the U.S. Geological Survey storage assessment unit (SAU) boundaries for the Sunniland Formation SAU in the South Florida Basin. Grid cells (one square mile) represent counts of wells derived from ENERDEQ well database (IHS Energy Group, 2011) that have penetrated the reservoir-formation top.

Gordon Pass and Marco Junction Formations SAU C50500103

By Matthew D. Merrill

The Marco Junction and Gordon Pass Formations are Early Cretaceous Albian-age shallow-marine carbonate and evaporite units in the Big Cypress Group, located in today's central and southern Florida (figs. 2 and 5). The sediments were deposited as distal back-reef chalky limestones and micrites (Winston, 1976; Amato and others, 1986). Changes in relative sea level in a restricted-marine environment increased salinity through evaporation, producing evaporite deposits of gypsum. Those gypsum deposits were later altered to anhydrite, and much of the original limestone from this interval has been altered to dolostone, the primary reservoir facies in these units. Work by Winston (1976), Mitchell-Tapping (1990), and Randazzo (1997) provide greater details on the depositional environment and post-depositional alteration recorded in these units.

The Gordon Pass and Marco Junction Formations SAU includes much of the onshore and State-waters extent of these formations (fig. 5). Boundaries extend northward from the Florida Keys to an east–west line near Tampa Bay. Both the Gordon Pass Formation and down-section Marco Junction Formation are reservoirs in this SAU; the seal is a thick regional anhydrite that marks the top of the Gordon Pass Formation. Interpolation and analysis of evaporite thicknesses from 35 wells were used to determine the extent of the seal thickness that is greater than 20 ft. In the northern part of the SAU, the 20-ft minimum-seal-thickness line serves as the northern boundary of the assessed area. In the east, south, and west, the SAU boundary extends to the State-water line. The SAU has an area of slightly more than 17 million acres. Within the SAU, the top of the Gordon Pass Formation reservoir ranges from 7,000 to 10,500 ft below the surface (IHS Energy Group, 2011).

Well-log analysis indicates the combined reservoir thickness is 500 to 1,000 ft, and the net-porous-interval thickness is 420 to 700 ft, with a most likely thickness of about 525 ft. Geophysical logs from wells located within the area of the SAU were used to identify the net-porous intervals, defined in this case as carbonate lithology with greater than 5 percent porosity, as inferred from neutron formation-density porosity logs. Data from the well logs suggest that a majority of the porous intervals are composed of dolostone. Lower Cretaceous formations of central and southern Florida, which occur at depths significantly deeper than the various aquifers used for potable water, contain water that is highly saline (>10,000 mg/L TDS; Breit, 2002); therefore, reservoirs should be available for CO_2 sequestration. Porosity data from Mitchell-Tapping (1990) indicate that average porosity values for the Dollar Bay Formation in the Big Cypress Group, a potential analog for the Gordon Pass and Marco Junction Formations (fig. 2), are between 8 and 18 percent; these values are similar to those inferred from well-log investigation and are used for this SAU. Analog permeability values, also from the Mitchell-Tapping (1990) investigation of the Dollar Bay Formation, span from 0.2 to 200 mD. Currently available maps and data reveal that structural features are not readily apparent in the Gordon Pass Formation or Marco Junction Formation, but this is assumed to be a result of lack of investigation. Debris mounds and low-relief reefs like those in the down-section Sunniland Formation are presumed to exist within this SAU; however, at a lesser magnitude and density. Additionally, research by Roberts-Ashby and Stewart (2012) show that porosity in the Sunniland Formation is not restricted to the reef mounds; this assumption has been extended to the Marco Junction Formation and Gordon Pass Formation reservoirs for the purposes of this assessment.

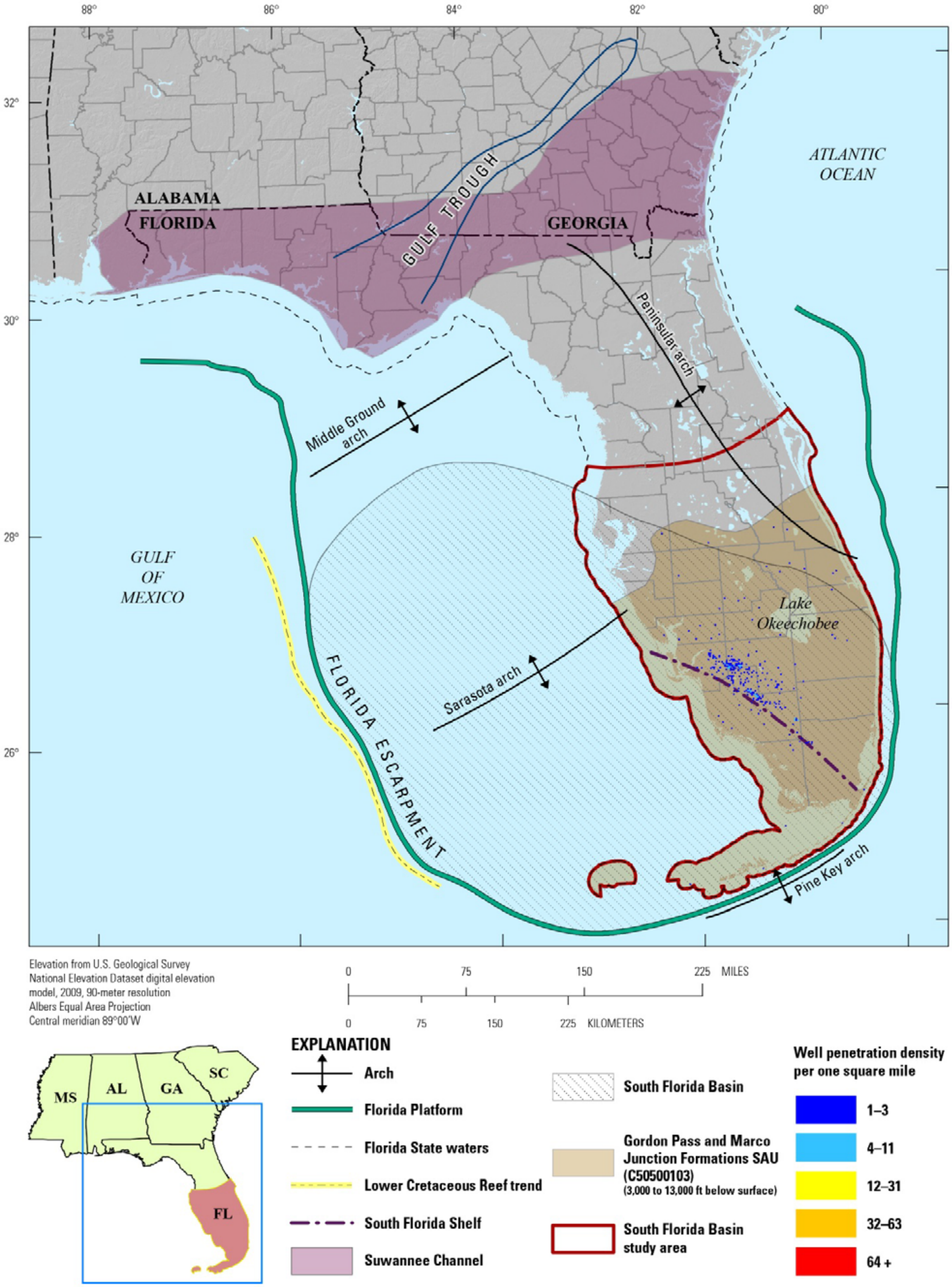

Figure 5. Map of the U.S. Geological Survey storage assessment unit (SAU) boundaries for the Gordon Pass and Marco Junction Formations SAU in the South Florida Basin. Grid cells (one square mile) represent counts of wells derived from ENERDEQ well database (IHS Energy Group, 2011) that have penetrated the reservoir-formation top.

Dollar Bay Formation SAU C50500104

By Matthew D. Merrill

The Lower Cretaceous Dollar Bay Formation (Big Cypress Group) is mainly composed of sequences of evaporites and carbonates that were deposited during sea level regressions and transgressions; locally they contain thin beds of calcareous shale, mudstones, salt, and lignitic material (figs. 2 and 6; Applin and Applin, 1965; Winston, 1971; Mitchell-Tapping, 1990; Pollastro and others, 2001). In some parts of the basin, the dominant lithology is limestone; however, dolostones produced by the variable alteration of these carbonates are potentially the most porous lithology (Pollastro and others, 2001). Variable dolomitization may be the result of differential cementation and conterminous and subsequent periods of changing pore fluid chemistry (Mitchell-Tapping, 1990). The Dollar Bay Formation was deposited in a tidal flat depositional environment resulting in mudstones and wackestones with intervening anhydrites, all of which overlay the anhydrites of the upper part of Gordon Pass Formation (Mitchell-Tapping, 1990), which seal the down-section Gordon Pass and Marco Junction Formations SAU C50500103.

Anhydrite and gypsum beds in the Panther Camp Formation (Naples Bay Group) are the proposed seals for the Dollar Bay Formation SAU. The SAU is restricted to a minimum continuous evaporite thickness of 20 ft in the Panther Camp Formation. Additional evaporite beds and low-permeability dolostone strata in the up-section Rookery Bay Formation could also provide secondary sealing. Thicknesses were observed through well-log investigation and then interpolated across the potential SAU area. Final SAU boundaries extend over much of southern Florida, with a northern boundary crossing from west to east: Sarasota, DeSoto, Hardee, Polk, Osceola, and Brevard Counties. The SAU stretches south of these counties and terminates along the State-water lines surrounding the Gulf Coast, Florida Keys, and Atlantic Coast of the State with an area of 16,085,000 acres (fig. 6).

Well data provided by the Florida Geological Survey and proprietary databases were used to determine depths and thicknesses for the SAU. The depth from surface to the reservoir formation in the SAU ranges from 7,000 to 10,000 ft (IHS Energy Group, 2011). Total thickness of the Dollar Bay Formation was determined from interpolation of well-log interval thicknesses picked from 34 wells. Thicknesses range from 200 to 500 ft, with a most likely thickness of 350 ft for the SAU. Analyses of neutron formation-density logs to determine the porosity of the reservoir provided potential thicknesses for the porous intervals within the total thickness of the formation. Well-log data obtained from nine wells were plotted and interpolated in ArcGIS, and histograms of the data layers were used to estimate net-porous-interval thickness resulting in a thickness range of 80 to 200 ft with a most likely thickness of 140 ft.

Porosity and permeability properties for Dollar Bay Formation reservoir rocks (Mitchell-Tapping, 1990) are the main sources of inputs chosen in this assessment. A likely range of inputs for porosity, mainly for porous dolostones, are between 8 and 18 percent. Permeability from the same sample set ranges from 0.2 to 200 mD. Water quality was not available for the Dollar Bay Formation; however, other Big Cypress Group reservoir formations stratigraphically below the Dollar Bay Formation are quite saline; data from Breit (2002) indicate that TDS contents of formation-water is over 100,000 mg/L.

Structural data for the reservoir are not widely available; therefore, any potential implications for CO_2 storage are not clear. As such, it is assumed that the structures and mounds present in the Sunniland Formation can serve as a general analog for what may occur in the Dollar Bay Formation. Oil and gas production in the Dollar Bay Formation is not currently active at a commercial scale; however, the USGS has assessed the formation as a potential source of undiscovered oil and gas resources (Pollastro, 2001; Pollastro and others, 2001).

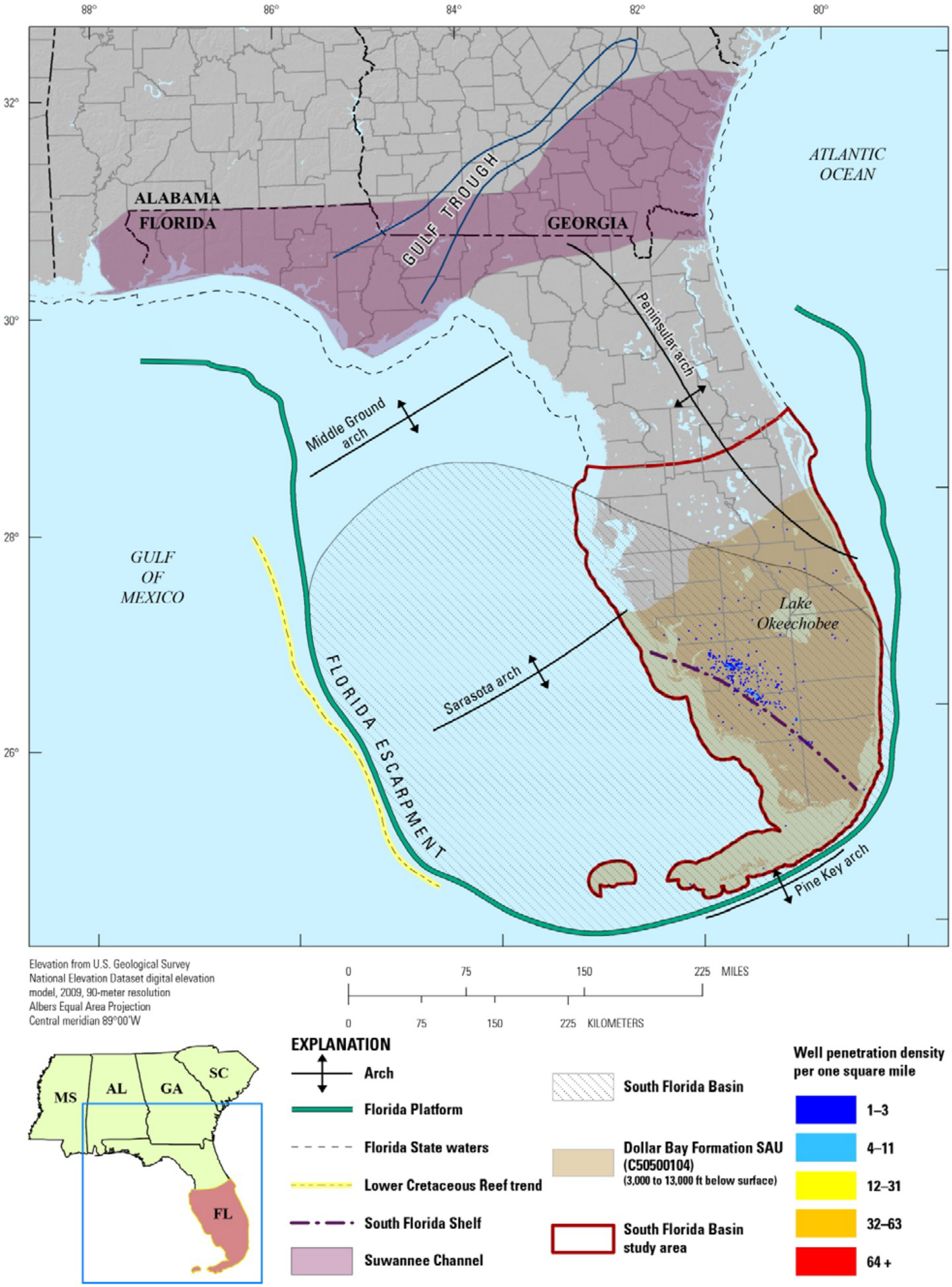

Figure 6. Map of the U.S. Geological Survey storage assessment unit (SAU) boundaries for the Dollar Bay Formation SAU in the South Florida Basin. Grid cells (one square mile) represent counts of wells derived from ENERDEQ well database (IHS Energy Group, 2011) that have penetrated the reservoir-formation top.

Cedar Keys and Lawson Formations SAU C50500105

By Tina L. Roberts-Ashby

Carbonate intervals within the Upper Cretaceous Lawson Formation and Paleocene Cedar Keys Formation form a potential CO_2 storage reservoir within the South Florida Basin that extends throughout south-central and southern Florida (figs. 2 and 7), identified here as the Cedar Keys and Lawson Formations SAU. The geologic units and reservoir properties of the Cedar Keys and Lawson Formations SAU directly correlate with the Cedar Keys/Lawson Injection Zone (CKLIZ) of Roberts-Ashby and others (2013). The Lawson Formation is assigned to the Navarroan Provincial Stage of the Upper Cretaceous and was deposited on a shallow, partly restricted marine shelf that had little to no terrigenous influence (fig. 2; Applin and Applin, 1967; Miller, 1986). Although some authors suggest that the Lawson Formation is restricted to the northern regions of Florida and that the Navarroan rocks of southern Florida are represented by the chalks of the Pine Key Formation, this author concurs with other researchers who have recognized the Lawson Formation throughout the Florida peninsula (Applin and Applin, 1967; Kaiser Aluminum and Chemical Corporation, 1971; Roberts-Ashby and others, 2013). The Lawson Formation has historically been separated into lower and upper members based upon lithologic and fossil-assemblage differences (Applin and Applin, 1967; Miller, 1986). The lower member of the Lawson Formation is largely composed of a soft chalk with low permeability and minor amounts of gypsum and anhydrite interbedded with thin lenses of chalky dolostone and dolomitic-chalk, mostly in the basal and upper portions of the member (Applin and Applin, 1967; Roberts-Ashby and others, 2013). The porosity and permeability in the upper member of the Lawson Formation is considerably higher, and in the area of the SAU, it is largely composed of an algal and rudistid biostrome that has undergone extensive diagenesis (Applin and Applin, 1944, 1967; Kaiser Aluminum and Chemical Corporation, 1971; Miller, 1986; Winston, 1994). The lithology of the upper member in the area of the SAU is mostly a coarsely crystalline dolostone with nodular and interbedded lenses of gypsum and anhydrite (Roberts-Ashby and others, 2013). The boundary that separates the two members is gradational, where the dolomitic lenses within the upper part of the lower member grade into the dolostones found in the basal part of the upper member (Roberts-Ashby and others, 2013). The Cedar Keys Formation overlies the Lawson Formation and is assigned to the Midwayan Provincial Stage of the Paleocene (fig. 2). The Cedar Keys Formation is a thick anhydrite and dolostone sequence thought to have been deposited in a regionally extensive tidal flat environment that had intermittent periods of open-marine conditions during the Paleocene, possibly continuing into the Eocene (Applin and Applin, 1967; Miller, 1986; Winston, 1995; Pollastro and others, 2001). Winston (1994) divides the Cedar Keys Formation into six subunits (units A–F) based on a detailed evaluation of anhydrite content; however, for this assessment, the Cedar Keys Formation was evaluated in a more simplified manner following that proposed in Roberts-Ashby and others (2013) for the CKLIZ, which presents three informal subunits: lower, middle, and upper Cedar Keys Formation. Within the area of the Cedar Keys and Lawson Formations SAU and the CKLIZ, the lower part of the Cedar Keys Formation is a porous dolostone with some thin interbedded and nodular anhydrite that has a porosity of at least 10 percent (Miller, 1986; Roberts-Ashby and others, 2013); this section of the Cedar Keys Formation forms the upper part of the porous reservoir interval within the Cedar Keys and Lawson Formations SAU and CKLIZ, as defined by Roberts-Ashby and others (2013). Within the confines of the SAU and CKLIZ, the middle Cedar Keys Formation is the section directly overlying the porous dolostone of the lower part of Cedar Keys Formation that consists of one or more thick (on average 650–985 ft) and laterally extensive anhydrite layers (Roberts-Ashby and others, 2013) that form a robust regional seal for CO_2 storage. The upper part of the Cedar Keys Formation is a porous, carbonate, reservoir-like interval that is not included in the Cedar Keys and Lawson Formation SAU or CKLIZ (fig. 2; Miller, 1986; Roberts-Ashby and others, 2013).

One potential CO_2 storage reservoir is identified within the Lawson and Cedar Keys Formations of the South Florida Basin between 3,000 and 13,000 ft subsurface depth—Cedar Keys and Lawson Formations SAU C50500105 (fig. 7). The Cedar Keys and Lawson Formations SAU encompasses an area of about 22,454,000 acres ($\pm$10 percent), which is slightly larger than the area defined for the CKLIZ due to the fact that the SAU boundary for this assessment extends all the way to the State-water boundary, and the CKLIZ study area did not.

The boundary of the Cedar Keys and Lawson Formations SAU is defined by the 3,000-ft and 13,000-ft reservoir-top depths interpreted from geophysical logs for more than 100 wells, and the presence of a thick (>50 ft) anhydrite seal within the middle Cedar Keys Formation (Roberts-Ashby and others, 2013). The rocks within the Cedar Keys and Lawson Formations SAU deepen to the south and southwest and on average are 500 to 800 ft thick with a most likely thickness of 700 ft, as determined from geophysical logs for over 100 wells (Roberts-Ashby and others, 2013).

Secondary, intercrystalline porosity dominates the upper member of the Lawson Formation and lower Cedar Keys Formation; however, some primary interparticle and intraparticle porosity is present within thin, localized limestone intervals of these units (Applin and Applin, 1944, 1967; Kaiser Aluminum and Chemical Corporation, 1971; Miller, 1986; Winston, 1994; Roberts-Ashby and others, 2013). Average porosity in the porous intervals of the Cedar Keys and Lawson Formations SAU ranges from 21 to 25 percent with a most likely porosity of 23 percent. Net-porous-interval thickness was estimated from geophysical logs for more than 100 wells resulting in an average net-porous-interval thickness that ranges from 160 to 240 ft, with a most likely value of 220 ft (Roberts-Ashby and others, 2013). Average permeability in the Cedar Keys and Lawson Formations SAU ranges from 0.1 to 430 mD, with a most likely permeability of 100 mD (Hickey and Wilson, 1982; Okwen, 2009).

The Cedar Keys and Lawson Formations serve as reservoirs for wastewater disposal, typically nonhazardous industrial or municipal waste, which is permitted by the Florida Department of Environmental Protection Underground Injection Control (UIC) program (Hickey and Wilson, 1982; Tampa Electric, 2011). Water sampled from wells that penetrate the Cedar Keys and Lawson Formations SAU indicate saline formation waters, with TDS values well above 10,000 mg/L (Hickey and Wilson, 1982; Breit, 2002). Because groundwater within the Cedar Keys and Lawson Formations SAU does not fall below the 10,000 mg/L TDS lower limit emplaced by the EPA (EPA, 2010), 100 percent of the SAU is considered to be potentially suitable for geosequestration of CO_2.

In order to calculate the maximum buoyant pore volume within structural and stratigraphic closures for the Cedar Keys and Lawson Formations SAU, upper bounds on regional reservoir thickness and porosity were used along with the Sunniland Formation SAU analog.

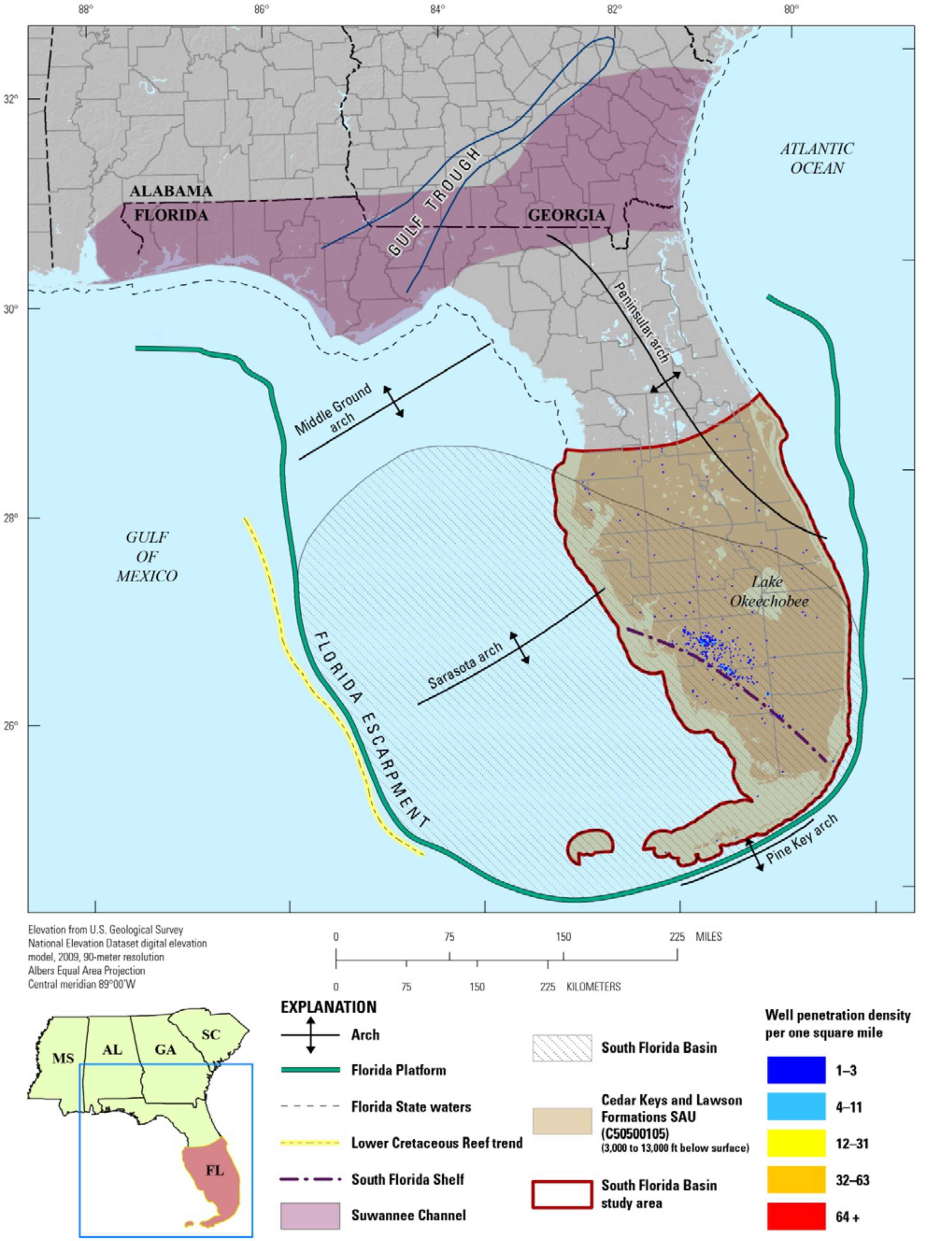

Figure 7. Map of the U.S. Geological Survey storage assessment unit (SAU) boundaries for the Cedar Keys and Lawson Formations SAU in the South Florida Basin. Grid cells (one square mile) represent counts of wells derived from ENERDEQ well database (IHS Energy Group, 2011) that have penetrated the reservoir-formation top.

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