CO_2 Sequestration Assessment of the basal sandstone in Tennessee

SECARB Phase III Work Product 1.6.a

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Executive Summary

Geologic carbon sequestration is the permanent storage of CO_2 in deep underground geologic formations, which is preceded by the separation and capture of CO_2 at the point of emissions from a stationary source such as a coal-fired electric power plant. The United States Department of Energy's (DOE's) Office of Fossil Energy National Energy Technological Laboratory (NETL) is engaged in research and development of Carbon Sequestration Program technology. This report assesses potential geologic carbon dioxide (CO_2) storage capacity of the basal sandstone in Tennessee.

The Southeast Regional Carbon Sequestration Partnership evaluated the Basal Sandstone in Tennessee for potential to store commercial quantities of CO_2. This report expands upon the findings from the 2007 assessment of potential CO_2 storage reservoirs in the southeast United States (Smyth et al., 2007), which included an initial assessment of the basal sandstone capacity. These estimates are based on limited and generalized data sets, which are primarily from published literature (Smyth et al., 2007). In the 2007 report, the depth range for the basal sandstone was found to be 4,000 to 8,000 feet (ft) and the average thickness was 100 ft. The capacity estimate for the basal sandstone from the 2007 report was 2.5 gigatons (Gt) (metric) of CO_2.

Smyth et al (2007) recognized the need for a more accurate estimate of capacity for the geologic sinks. This report provides a site specific, detailed geologic investigation of the basal sandstone. In this report the CO_2 storage capacity of the basal sandstone in Tennessee is assessed using an average reservoir total porosity, gross formation thickness, and average storage reservoir depth and pressure. The methodology is based on the capacity assessment methodology for saline aquifers in the United States Department of Energy *2010 Carbon Sequestration Atlas of the United States and Canada*. Storage capacities are summarized in Table ES-1.

Table ES-1. Storage Capacity for the Basal Sandstone.

	CO_2 Storage Capacity			
	Trillion Standard Cubic Feet (Tscf)		Billion Metric Tons (Gt)	
Basal Sandstone	High Estimate P(90%)	Low Estimate P(10%)	High Estimate P(90%)	Low Estimate P(10%)
Zone 1	56.03	5.93	2.96	0.31
Zone2	18.16	1.92	0.96	0.10

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1.0 Introduction

This report assesses the carbon dioxide (CO_2) storage capacity for the basal sandstone in the United States Department of Energy's (DOE's) Southeast Regional Carbon Sequestration Partnership (SECARB) region. This material is based upon work supported by the Department of Energy National Energy Technology Laboratory under DE-FC26-04NT42590. The subject of this assessment, the basal sandstone, is a saline reservoir present in the Lower Cambrian section of central Tennessee (**Figure 1**). Reservoir properties for the basal sandstone are promising and it has the potential to be utilized as a storage reservoir for anthropogenic CO_2. This unit was included in a larger interval designated for waste disposal in deep injection wells in Humphreys and Maury Counties. The injection interval is composed of the lower part of the Knox Group to the Precambrian.

Overlying the basal sandstone are the multiple thick, impermeable units of the Conasauga Group. The Conasauga Group includes the Maynardville Limestone, the Nolichucky Shale, the Maryville Limestone, Rogersville Shale, Rutledge Limestone, Pumpkin Valley Shale, and the Conasauga Shale. The shaley units would serve as regional seals for the storage reservoir.

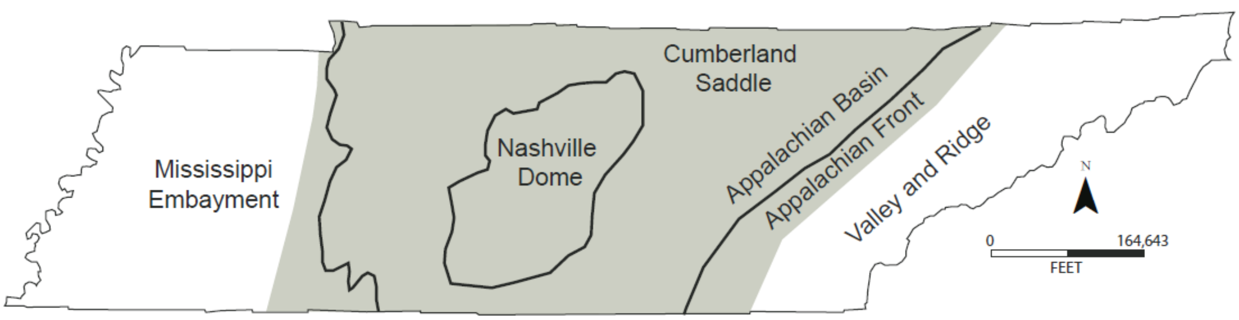

Figure 1. A map showing the major physiographic features in Tennessee. The area of the basal sandstone that was assessed for sequestration potential in Tennessee is shown in grey.

1.1 Study Methodology

The approach used to calculate the CO_2 storage capacity of the basal sandstone saline reservoir follows the capacity assessment methodology set forth by the DOE's Regional Carbon Sequestration Partnerships Capacity Estimation Subgroup (NETL, 2010). The DOE methodology provides a volumetric estimate for useable CO_2 storage capacity based on geographical area (A_t), gross formation thickness (h_g), total porosity (ϕ_{tot}) and CO_2 density (ρ). A storage coefficient (E_{saline}) is used to represent the fraction of the total pore volume that would be filled by CO_2. The efficiency factor (E_{saline}) incorporates a series of variables that limit the ability of injected CO_2 to occupy 100% of the pore space in a given formation, such as geologic heterogeneity, gravity or buoyancy effects, and limited sweep efficiency. The simplified DOE CO_2 storage capacity (G_{CO2}) equation for calculating effective CO_2 storage within a particular saline formation is as follows:

$$G_{CO2} = A_t * h_g * \phi_{tot} * \rho * E_{saline}$$

The terms used in this equation are discussed in **Table 1** below:

Table 1 Key Reservoir Parameters Used to Assess CO2 Storage Capacity

Parameters	Units	Description
G_{CO2}	M	Usable CO_2 storage capacity (M, is mass in metric tons).
A_t	L^2	Geographical area that defines the basin or region being assessed for CO_2 storage (L is length).
h_g	L	Gross thickness of saline formation for which CO_2 storage is assessed within the basin or region defined by A_t.
ϕ_{tot}	fraction	Average porosity of entire saline formation over thickness h_g.
ρ	M/L^3	Density of CO_2 at pressure and temperature representative of storage conditions.
E_{saline}	L^3/L^3	CO_2 storage efficiency factor that reflects the fraction of the total pore volume that is filled by CO_2.

When applied at a regional or basin level, the CO_2 storage efficiency coefficient (E_{saline}) incorporates inefficiencies in displacement, including volumetric displacement (E_v) and microscopic displacement (E_d) as discussed in **Table 2** below. In addition, the

CO_2 storage efficiency coefficient (E_{saline}) also incorporates the following three limitations on accessibility related to geologic heterogeneity, as presented in **Table 2**.

Table 2 Geologic Components of Regional CO_2 Storage Efficiency Coefficient

Term	Symbol	P10/P90 Values by Lithology	Description
		for Clastics	
Net to Total Area	$E_{An/At}$	0.2/0.8	Fraction of total basin or region area that has a suitable formation present.
Net to Gross Thickness	$E_{hn/hg}$	0.21/0.76*	Fraction of total geologic unit that meets minimum porosity and permeability requirements for injection.
Effective to Total Porosity	$E_{\phi e/\phi tot}$	0.64/0.77*	Fraction of total porosity that is effective, i.e., interconnected.
Displacement terms used to define the pore volume immediately surrounding a single well CO_2 injector			
Volumetric displacement efficiency	E_v	0.16/0.39	Combined fraction of immediate volume surrounding an injection well that can be contacted by CO_2 and fraction of net thickness that is contacted by CO_2 as a consequence of the density difference between CO_2 and *in situ* water.
Microscopic displacement efficiency	E_d	0.35/0.76	Fraction of pore space unavailable due to immobile *in situ* fluids

For this assessment, regional log data were used to identify the elevation of formation tops and to generate structure and thickness (isopach) maps. Formation tops data were also gathered from relevant literature with assessments of the Cambrian and Precambrian units as they occur in the area of interest. The sandstone porosity for the basal sandstone was determined from regional porosity log data and published values collected for the basal sandstone interval. Due to limited data availability in central Tennessee, default, national average values for P_{10} and P_{90} from Appendix B of the *National Carbon Sequestration Atlas* (2011) were used for the algorithm terms, net-to-total area $E_{An/At}$, net-to-gross thickness $E_{hn/hg}$, and effective-to-total porosity $E_{\phi e/\phi tot}$ terms (**Table 2**). Efficiency factors used for the capacity estimates are for clastics and are P_{90} = 5.4% and P_{10} = 0.56%.

2.0 The Basal Sandstone CO_2 Storage Capacity Assessment

2.1 Geology of the 'Basal Sandstone'

The study area is comprised of the central portion of Tennessee (**Figure 1**). Major geologic features in Tennessee include the Valley and Ridge province in the easternmost portion of the state. The Valley and Ridge geologic province is a northeast trending zone of intensely deformed sedimentary rocks where geologic storage options are limited due to extensive faulting. In the central portion of the state is the Nashville Dome (Central Basin), which is the southern extension of the Cincinnati Arch. West of the Nashville Dome is the Mississippi Embayment (**Figure 1**). **Figure 2** shows a generalized geologic map of the sediments exposed at the surface in Tennessee.

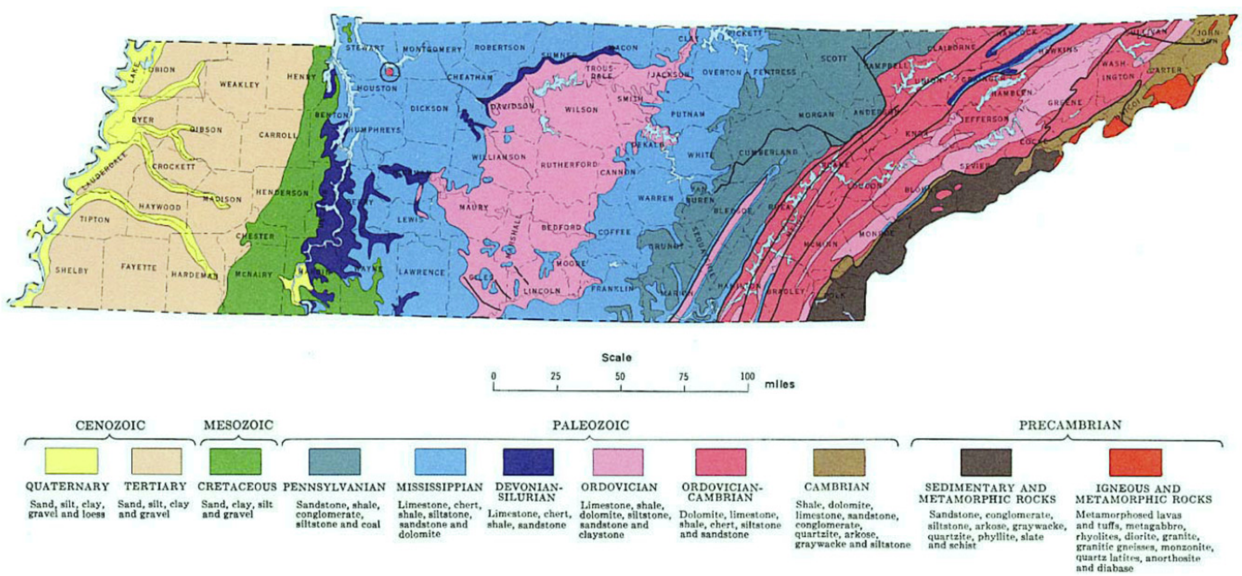

Figure 2. Generalized Geologic Map of Tennessee (Tennessee Division of Geology, 1970).

The basal sandstone in this study is defined as the sandstones which directly overlie the Cambrian unconformity. The basal sandstone is Cambrian in age and occurs below the Conasauga Group and its equivalents. Below the basal sandstone (**Figure 3**) is the Precambrian basement (Mulderink and Bradley, 1986) composed of very fine-grained sandstone, siltstone, shale, and igneous or metamorphic basement rocks (Lloyd and Reid, 1986).

As a part of a SECARB assessment of potential saline reservoirs for CO_2 (Smyth et al., 2007), the basal sandstone unit was informally correlated to the Mt. Simon sandstone, an aerially extensive sandstone unit immediately above the Precambrian unconformity in the Illinois and Michigan Basins. However, in an evaluation of potential saline storage reservoirs in Kentucky, the Kentucky Geological Survey states that the sandstone unit above the Precambrian unconformity south of the Rough Creek and Kentucky River Fault Systems is not equivalent to the Mt. Simon Sandstone. Therefore, the sandstone unit located above basement and below the Conasauga Group in southern Kentucky and into Tennessee is most likely not the Mt. Simon and is locally named ‘the basal sandstone’ (Parris et al., 2010).

Lloyd and Reid (1986) show the basal sandstone to be equivalent to the Lower Cambrian section of the Chilhowee Group in Tennessee. Although the basal sandstone is present throughout central and east Tennessee, due to the intense deformation of the subsurface strata in the Valley and Ridge province and uncertainty about facies changes and existing equivalents, the basal sandstone was only assessed for geologic storage west of the Valley and Ridge geologic province and east of the Western Highland Rim. The western region of Tennessee is not assessed in this report because very few wells penetrate the Cambrian interval, and the basal sandstone is likely to be thin or absent in this region (Whitaker et al., 1992; Parris et al., 2010).

The current study builds from the Smyth et al. (2007) assessment of the basal sandstone. For this report a more rigorous approach was adopted and the capacity estimates are more conservative compared to the Smyth et al. study (2007). For example, more logs were used in this study along with a more detailed log assessment. Additionally, an up to date approach for determining storage capacity was used (NETL, 2010).

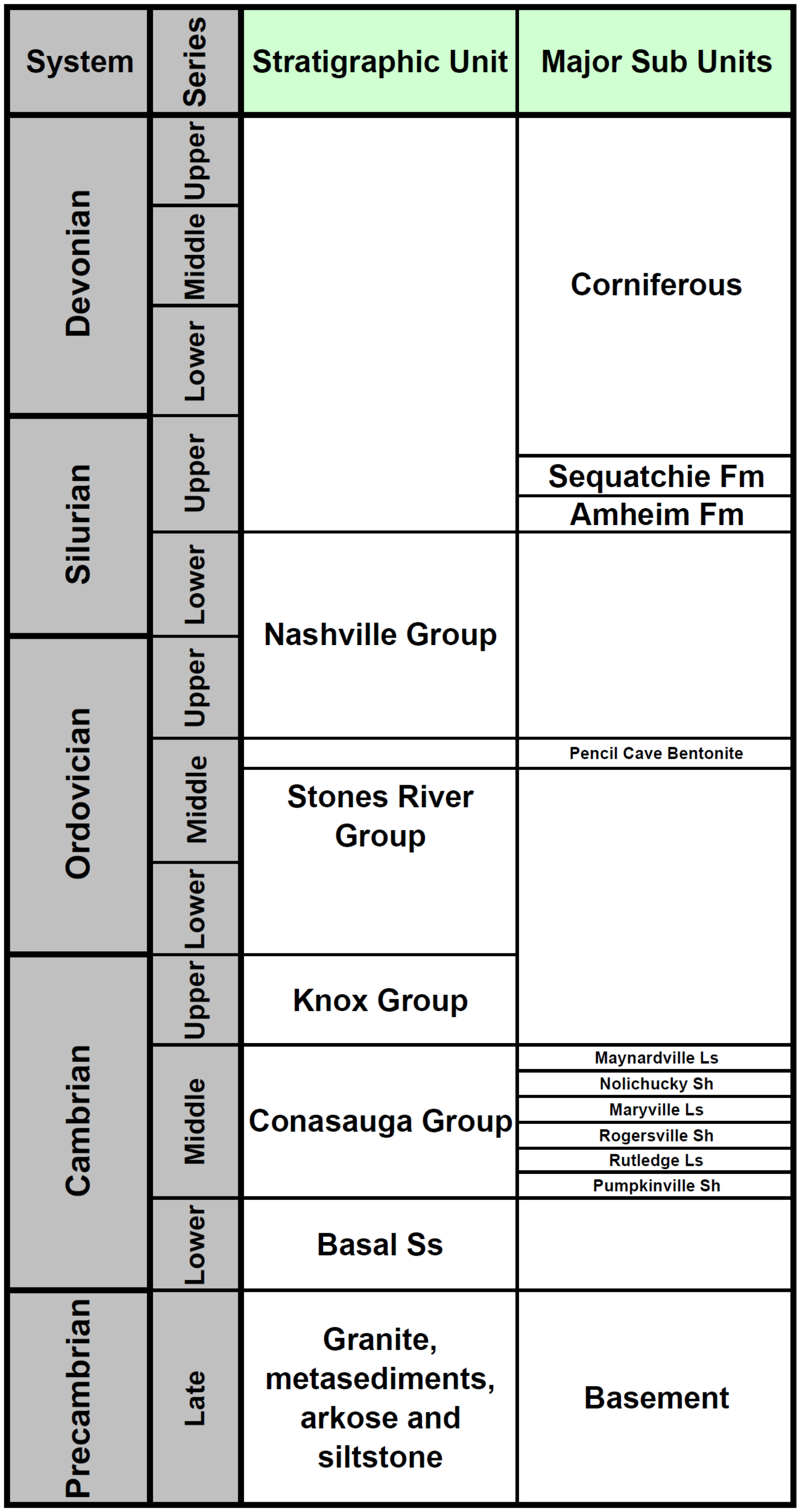

Figure 3. Stratigraphic Column (modified from Childs et al., 1984).

The basal sandstone occurs at depths from 5,000 ft to greater than 9,000 ft, placing it at a depth suitable for the sequestration of supercritical CO_2 (**Figure 4**). Data collected for this study indicates that the basal sandstone in central Tennessee ranges from 80 ft to greater than 200 ft (**Figure 5**). Mulderink and Bradley (1986) estimated thicknesses up to 700 ft, however, this was not observed in available data used to assess the basal sandstone for this study. The sandstone is a tan to light gray, fine- to coarse grained rock that is poorly sorted and well indurated with interbeds of dark gray to brown dolomite (Brahana et al., 1986). Minor carbonates found in the basal sandstone may be part of the overlying confining layer (Brahana et al., 1986). A structural cross section shows the log character of the basal sandstone and the overlying Conasauga Group as well as the structure of the Nashville Dome in central Tennessee (**Plate 1**).

The overlying Conasauga Group is composed of light- to medium-gray limestone with minor amounts of gray to green impermeable shale (Warner, 1972; Geraghty and Miller, 1978). Sedimentation cycles of the Conasauga Group represent a complex interplay between carbonate platform and intrashelf shale basin sedimentation along the early Paleozoic passive margin of the southern Appalachians (Glumac and Walker, 2000). Within the Conasauga Group, shale is the dominant lithology to the northwest (Kentucky and Tennessee) and gradually becomes more carbonate rich to the southeast (eastern Tennessee) (Glumac and Walker 2000). The Conasauga Group is regionally extensive with average thickness of 2,000 ft (Hardeman, 1966). Both the lithology and continuity of the Conasauga Group make it a good candidate for a confining unit for the basal sandstone.

Data collected from driller's records, resistivity logs, and gamma ray logs indicate that the limestone of the Conasauga Group contains increasing amounts of argillaceous material with depth (Brahana et al., 1986). The unit on which the basal sandstone rests is granitic basement. It is assumed that below the weathered surface of this Precambrian basement the rocks have very low effective porosity or permeability and very little water is thought to exist below the basal sandstone (Brahana et al., 1986). A type log shows the lower portion of the Knox Formation, the Conasauga Group, the basal sandstone, and the top of the Precambrian basement (**Figure 6**).

Vertical flow between the basal sandstone and any overlying aquifers is believed to be very limited because of the hydrologic characteristics of the Conasauga confining unit (Mulderink and Bradley, 1986). Additional data are needed to define adequately the hydrogeology and water quality of the basal sandstone (Mulderink and Bradley, 1986).

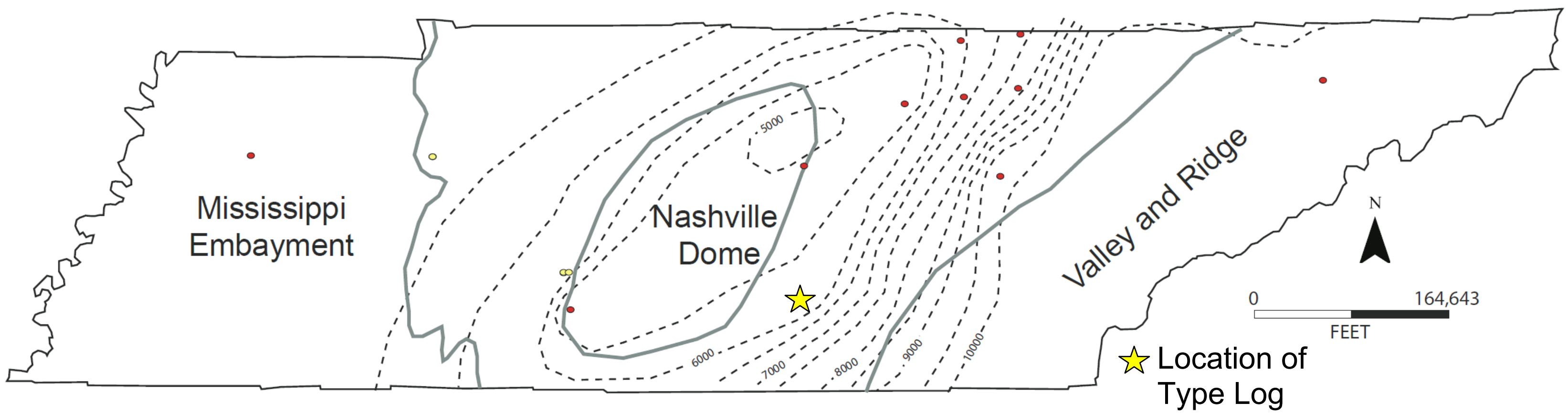

Figure 4. Depth in feet to the top of the 'Basal' sandstone in middle Tennessee. All circles represent the wells used in this assessment. The yellow circles represent wells used for waste injection. Contours are in feet.

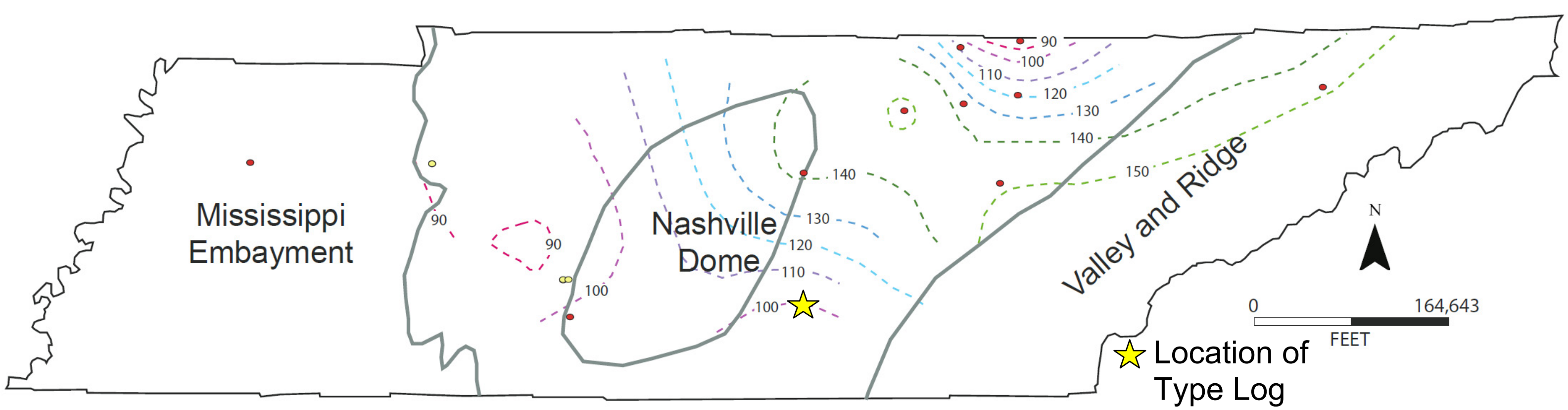

Figure 5. Isopach map of the basal sandstone in middle Tennessee. All circles represent the wells used in this assessment. The yellow circles represent wells used for waste injection. Contours are in feet.

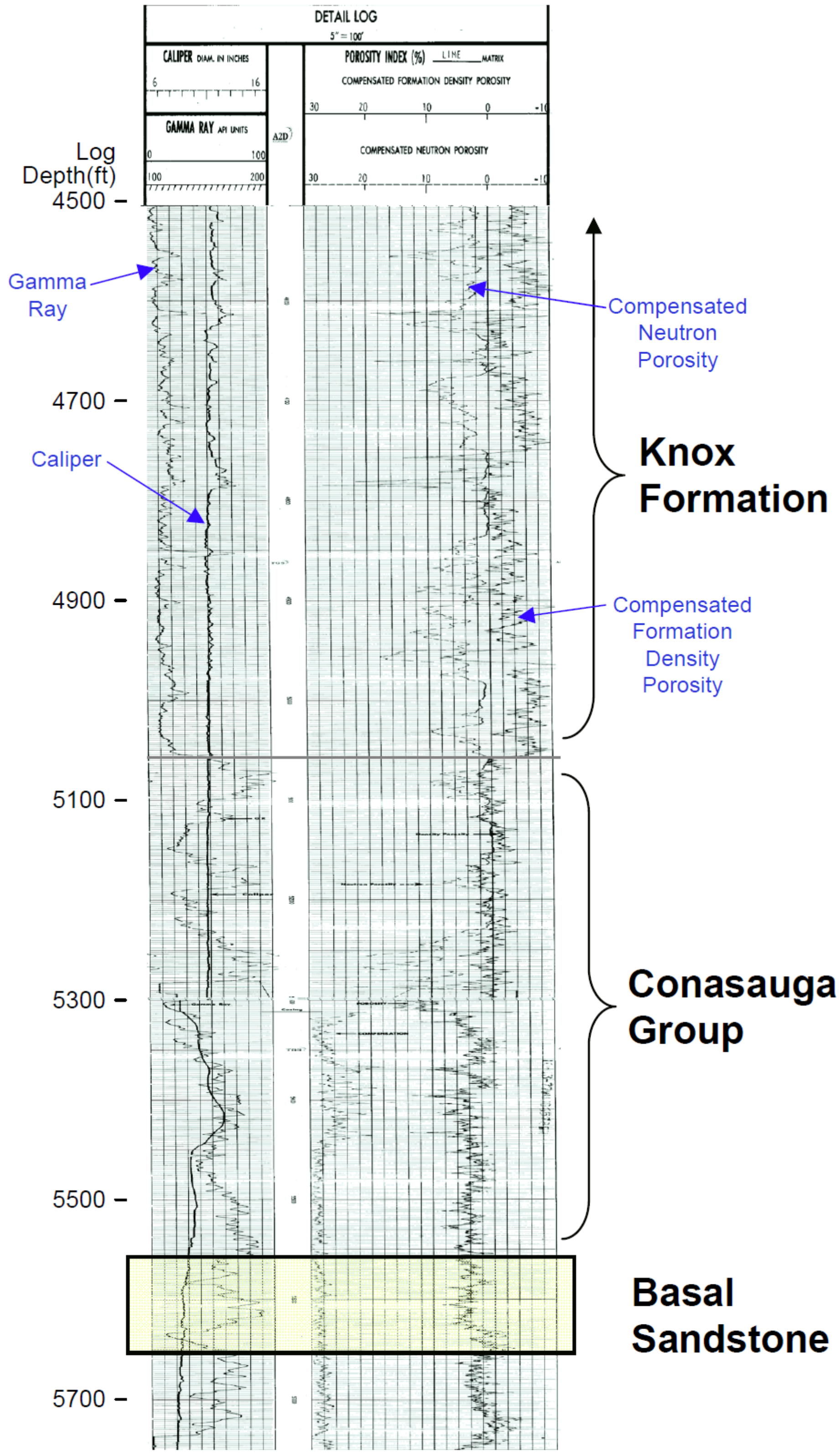

Figure 6. Type log for the basal sandstone, well #35 (API #:41-031-20001-0000).

The data set for this study consists of fourteen wells that penetrate the 'Basal Sandstone' in Tennessee (**Table 3**). These wells were drilled for energy or mineral exploration, or for deep waste disposal (**Figures 4 and 5**). Dissolved-solids concentrations reported in three water samples from the basal sandstone range from 38,500 to 201,800 mg/L (Brahana et al., 1986) (**Table 4**).

Table 3. Summary of selected wells that pass through the basal sandstone (modified from Brahana et al., 1986).

Well Number	Well Name	County	API	Depth to top of Basal Sand (ft)	Depth to top of Precambrian Basement (ft)	Thickness of Basal Sand	Porosity (%)
1	California Co. E. W. Beelar No.1	Giles	41055000010000	5570	5640	70	
17	Gordon Street Inc. R. Holden No.1	Rutherford	41149000010000	5530	5,560	30	
19	Atha and Indiana Farm Bureau Ketchen Coal Co. No.1	Scott	41151000030000	7395	NP		
20	Big Chief H. H. Taylor No.1	Gibson	41053000010000	6854	6,935	81	
21	Stauffer Chem. Co. Fee (disposal) No.1	Maury		6300	6,400	100	
22	DuPont, Old Hickory Plant Fee No. I	Davidson	41037000080000	5270	5,460	190	12
23	Ed Riley Oil Co. Louise Lanham No. 1	Morgan	41129000010000	7485	NP		
24	DuPont, New Johnsonville Fee No.2	Humphreys	41085000070000	7210	7,450	240	7.9
29	Amoco Prod. Co. J.J. Brothers No. 1	DeKalb	41041200010000	5045	5445	400	
32	Stauffer Chem. Co. Fee No.2	Maury	41119000650000	6330	6,420	90	
34	Monitor Petroleum Gernt Est. No.8	Fentress	41049200790000	6980	7,744	764	8 (7**)
35	Amoco Prod. Co. J.J. Brothers No. 1	Coffee	41031200010000	5654	NP		
38	Mobil Chemical Fee No. I	Maury		6328	6,403	75	
39	Ladd Petroleum Co. T. J. Kemmer No. I	Cumberland	41035200410000	9960	10,110	150	
259	Associated Oil and Gas Exploration Co., Sells #1	Pickett		3939.28	unknown	88.56	7**

*Porosity values were determined from available neutron-porosity logs except for values listed with **, which are the average thickness-weighted porosities of individual zones (%) taken from Lloyd and Reid, (1986).*

Table 4. Dissolved-solids concentrations in water from wells that pass through the basal sandstone (modified from Brahana et al., 1986).

Well Number	Location	County	Water-bearing unit	Dissolved solids concentration, in milligrams per liter
24	New Johnsonville Dupont	Humphreys	Conasauga Group - and Basal Sandstone	a 99,034*
21	Mount Pleaseant Stauffer Chemical Co.	Maury	Basal Sandstone	b 38,500
38	Mount Pleaseant Mobil Chemical Co.	Maury	Basal Sandstone	c 201,800

Data sources: a, Warner (1972); b, Geraghty and Miller (1978); c, Resources Services, Incorporated (1979).
** indicates neutralized iron salts, which are by-products of the inject wastes.*

The basal sandstone reservoir is characterized by inter-bedded sandstone and shale with an overall coarsening upwards trend. The type log (**Figure 6)** shows the basal sandstone interval with the increased porosity values in the upper part of the section and decreasing towards the lower part. The thin shaley inter-beds are also apparent in the type log, and can be seen at the top and middle of the interval.

The shale inter-beds increase in number and thickness towards the southeast in the study area. Reservoir simulations have demonstrated that in dominantly porous intervals shale inter-beds have been shown to act as baffles to the upward movement of CO_2. For example, reservoir simulations of other saline aquifer storage targets in the SECARB region (Riestenberg et al., 2008) demonstrate that shale inter-beds within a porous and permeable reservoir can act as baffles to the upward movement of CO_2, favorably limiting the upward migration of injected CO_2 within the reservoir.

Permeability and Porosity:

The basal sandstone is classified as a saline reservoir and the concentration of dissolved solids in water collected from three wells in the basal sandstone exceeds 10,000 mg/L (**Table 4**). There is a history of deep-well injection of wastes into wells penetrating the basal sandstone at New Johnsonville in Humphreys County and Mt. Pleasant in Maury County in western middle Tennessee (Mulderink and Bradley 1986) (**Figures 4 and 5**). Migration of injected fluids in the basal sandstone was observed in three of the deep waste injection wells in Humphreys and Maury Counties (**Figure 4 and 5**).

As noted by Brahana et al. (1986), these waste-injection wells are open to a thick stratigraphic section from the lower part of the Knox Group to the Precambrian, which would include the basal sandstone. Existing data from the three deep waste injection wells indicates that the injected fluids likely invaded the permeable zones throughout parts of the entire section, thus demonstrating that permeability in the basal sandstone is enough to support some amount of fluid storage. Unlike the waste-injection operations in this area of western middle Tennessee, well completions for CO_2 storage wells would confine the injected CO_2 to the target reservoir so that injected fluids do not migrate to other porous intervals by way of the wellbore. The multiple confining layers of the Conasauga Group would stop upward migration of CO_2 within the storage reservoir.

Available porosity and permeability data for the basal sandstone are limited, but some information is available. Tsouris et al (2002) reviewed information collected by the DuPont Corporation in 1969, which reported that the basal sandstone consisted of fine-grained sand with an average porosity of 9.2% (1.7-14.9%) and an average permeability of 15.9 millidarcy (md; range 0.1-132 md). These results were determined from basal sandstone samples collected from wells near the county line between Sumner and Davidson counties. Porosity data used for this report was determined from available neutron porosity logs that passed through the basal sandstone along with porosity values listed in a report by Lloyd and Reid (1986) (**Table 3**).

2.2 Basal Sandstone Reservoir Properties and Capacity Estimates

Estimating potential CO_2 storage capacity for the basal sandstone first requires estimating the total reservoir pore volume using a standard volumetric approach, then calculating the theoretical volume of CO_2 that can be stored in 100 percent of the available pore space, and finally, using CO_2 storage efficiency factors (E_{saline}) to generate low- and high-confidence storage capacity estimates. The following approach was used to estimate the CO_2 storage capacity for the upper basal sandstone.

Total Pore Volume = $\mathbf{A_t * h_g * \phi_{tot}}$

Where:

A_t is the reservoir area

h_g is the gross reservoir thickness

ϕ_{tot} is the total porosity of the gross interval (including shales)

To calculate the area and thickness for each saline reservoir, structure and isopach maps were created in the *Petra* geologic mapping and analysis software (IHS Inc). Structure and thickness maps were developed using data from a study by Brahana et al. (1986), "formation tops" data provided in the Information Handling Services (IHS) Energy database of U.S. oil and gas wells, and well logs acquired for this study. For this study the reservoir was divided into two zones of assessment. The Central Basin and Highland region falls roughly between 5,000 to 7,000 ft contours and is designated as **Zone 1** (**Figure 7**). The area between the 7,000 to 10,000 ft structure contours approximately coincides with the Cumberland Plateau region, which is designated as **Zone 2** (**Figure 7**). To find the total area for each reservoir, polygons were drawn on the structure maps for the area represented by Zones 1 and 2. The gross thickness for each saline reservoir was calculated by subtracting the top depth of the unit located immediately below the assessed formation from the top of the formation. Therefore, gross thickness of the basal sandstone was calculated by subtracting the top of the basal sandstone from the top of the Precambrian basement (see **Figures 4 and 5**), then the gross thickness for all the wells was averaged to give the average gross thickness for Zones 1 and 2. Net reservoir sand thickness was calculated using available neutron porosity and spontaneous potential-resistivity well logs. For the neutron-porosity logs, the basal sandstone was determined based on the negative deflection of the gamma ray curve (indicative of low clay content in the rock matrix) and the positive deflection of the porosity curves (indicative of an increase in pore space in the rock matrix). For the spontaneous potential-resistivity logs net sand thickness was determined based on negative deflection of the spontaneous potential (SP) from a positive SP baseline (indicative of high clay content to fine-grained rock matrix) and by corresponding low resistivity values (indicative of brine saturated porous rock).

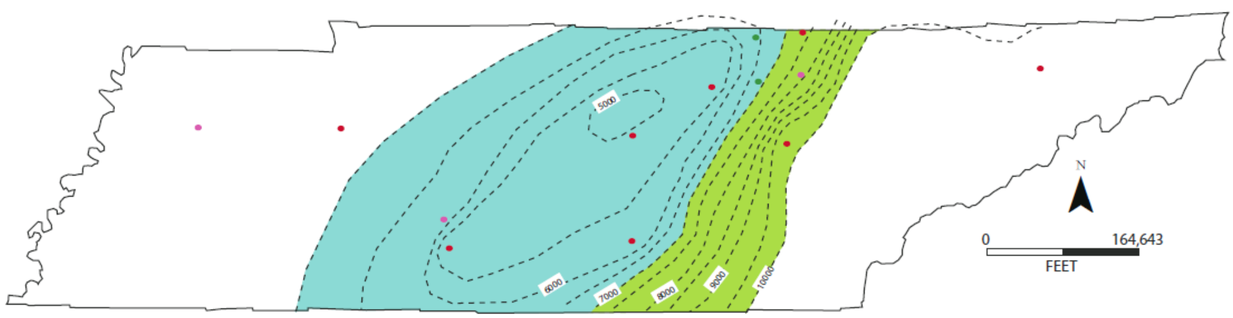

Figure 7. Outline of Zones 1 (in blue) and 2 (in green) used for the capacity assessment of the basal sandstone.

<u>Theoretical Maximum CO_2 Storage Capacity</u>

Theoretical maximum CO_2 storage volume assumes that 100% of the reservoir pore volume is occupied by CO_2. Theoretical maximum storage is calculated by applying an appropriate CO_2 formation volume factors based on the reservoir's estimated average native pressure and temperature conditions. The CO_2 formation volume factor (Bg_{CO2}) was calculated assuming normal temperature and pressure gradients. The temperature gradient used in this study is 1.85 °F per 100 feet plus 70 °F (ambient surface temperature) and the pressure gradient is 0.43 psi per foot.

The reservoir characteristics for the basal sandstone are listed below (**Table 5**). This data was collected from literature assessments of the basal sandstone in

Tennessee (Brahana et al., 1986; Mulderink and Bradley, 1986; and Tsouris et al, 2002).

Table 5. Reservoir Characteristics of the Basal Sandstone

Basal Sandstone	*Total Area (Mi2)*	*Avg Depth (ft)*	*Avg Gross Thickness (ft)*	*Avg Total Porosity (%)*	*Pore Volume (tcf)*	*Bg_{CO2} (res cf/scf)*	CO_2 Capacity (Tscf) (E=100%)
Zone 1	**14200**	**5978**	**112**	**7**	**3**	**0.00334**	**975**
Zone2	**4150**	**8314**	**128**	**8**	**1**	**0.00312**	**356**

2.3 Basal Sandstone Assessment Example Calculation

The updated DOE/NETL storage efficiency values recommended for saline reservoirs assessment methodology were used to estimate achievable CO_2 storage capacity from calculated total pore volume (Goodman, et al., 2011). A brief summary of the capacity methodology can be found in section 1.1.

Following is the calculation of practical CO_2 storage volume for basal sandstone in Tennessee. Using structure and isopach maps it was determined that within **Zone 1**, the basal sandstone covers an area of approximately 14,200 square miles and has an average gross thickness of 112 ft. A porosity value of 8.3% percent was calculated using the available porosity data collected from various sources (see section 2.2). A formation volume factor of 0.00334 reservoir cubic feet per standard cubic feet (res cf/scf) was estimated using regional temperature and pressure gradients. Storage capacities are also listed in **Table 6**.

*Theoretical Storage Volume in Standard Cubic Ft for **Zone 1** of the basal sandstone in central Tennessee:*

1) $A * h * \Phi / Bg_{CO2}$ **= (14,200 mi^2 * 2.79 x 10^7 ft^2 * 112 ft * 0.08) / (0.00334 res**

cf/scf)

= 1099 Tscf

Storage Efficiency and Practical CO_2 Storage Volume:

2) Low Case: P(10) = 1099 Tscf * 0.51% = 5.933 Tscf

High Case: P(90) = 1099 Tscf * 5.4% = 56.03 Tscf

Volume of Stored CO_2 Converted from Tscf to Billion Metric Tons (Gigatonne):

3) Low Case: P(10) = 10.99 Tscf * / 18.9 Mscf per metric ton= 0.31 Gt
High Case: P(90) = 10.99 Tscf * / 18.9 Mscf per metric ton = 2.96 Gt

Table 6. CO2 Storage Capacity Results

	CO_2 Storage Capacity			
	Trillion Standard Cubic Feet (Tscf)		Billion Metric Tons (Gt)	
Basal Sandstone	High Estimate P(90%)	Low Estimate P(10%)	High Estimate P(90%)	Low Estimate P(10%)
Zone 1	56.03	5.93	2.96	0.31
Zone2	18.16	1.92	0.96	0.10

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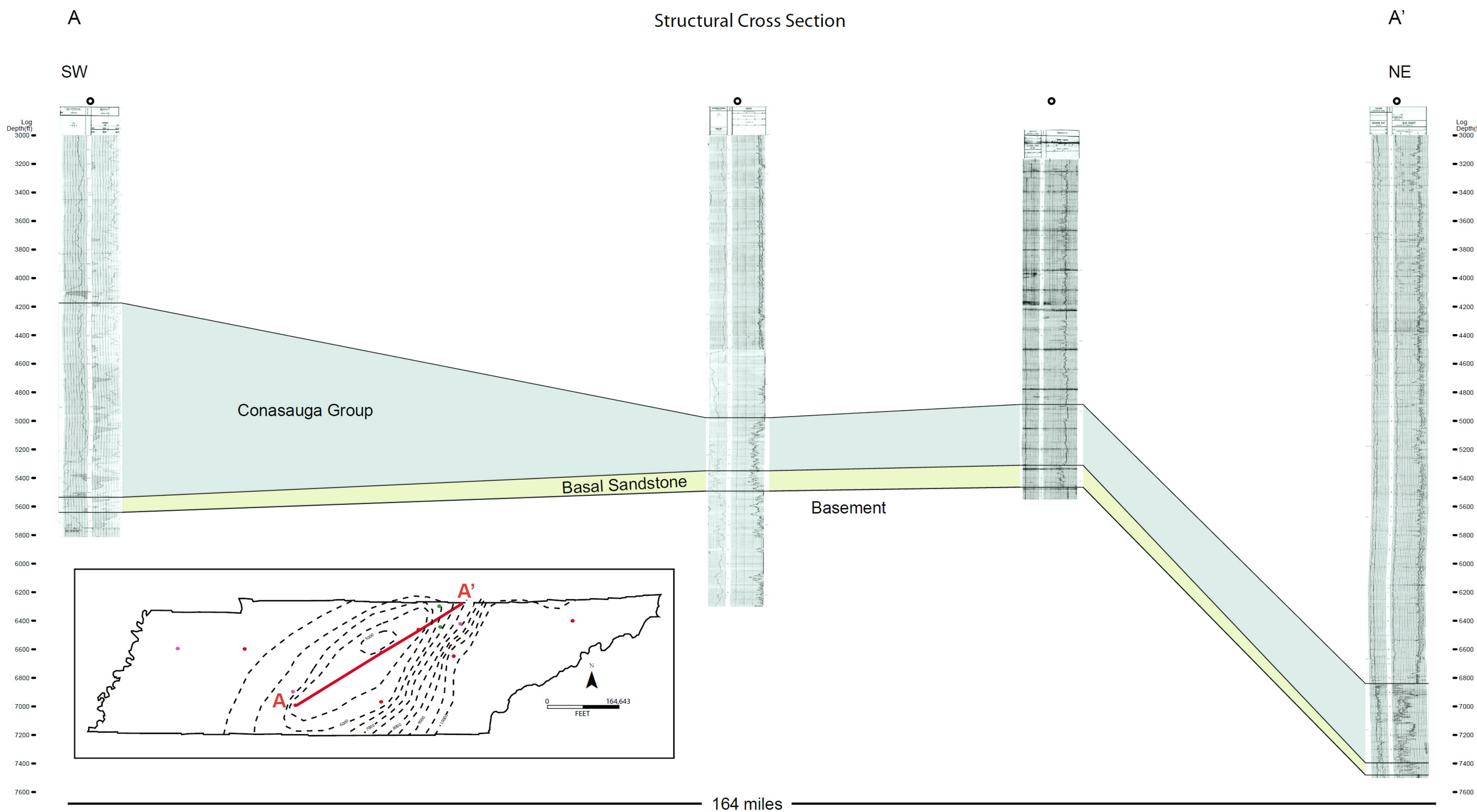

Plate 1. Southwest to Northeast structural Cross section showing the Conasauga Group and the basal sandstone in Tennessee