# Southeast Regional Carbon Sequestration Partnership

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## Abstract

Major efforts of the Bureau of Economic Geology (BEG) have been supplying Geographic Information Systems (GIS) data to support analysis of geologic storage potential of the Gulf Coast part of the SE Regional Sequestration Partnership region. Initial results submitted were geological characterization of Texas and Louisiana oil and gas reservoirs, highlighting those suitable for enhanced oil recovery (EOR). In response to evolving partnership needs, BEG then compiled and digitized additional brine aquifer data and created GIS data layers to add to the previously created brine formation data layers. BEG has also participated in partnership activities though presentations, reviews, meetings, and national $CO_2$ sequestration forums.

# Table of Contents

## List of Graphical Materials—Figures



## List of Graphical Materials—Tables

# Executive Summary

In support of the Southern States Energy Board's (SSEB) work to meet United States Department of Energy (DOE) objectives focusing on exploring solutions for the capture, transport, and storage of anthropogenic fossil fuel carbon dioxide ($CO_2$) emissions in the southeast region through the Southeastern Regional Carbon Sequestration partnership (SECARB), the Bureau of Economic Geology's (BEG) Gulf Coast Carbon Center (GCCC) completed two data sets: (1) data sets to be used for assessment of storage volumes available under a use-for-profit driver (2) data sets to be used to calculate volumes available for storage under cap-and-trade, regulatory, or other at-cost driver.

Major efforts include compilation of data to describe Texas, Louisiana, and Mississippi oil reservoirs suitable for use for storage plus enhanced oil recovery (EOR) and to assess how much $CO_2$ could be sold to support $CO_2$-EOR if capture-ready sources were available in this region. Additional layers have been compiled that can be used to calculate the approximate volumes of storage in brine-filled formations beneath these reservoirs. In addition, we began work identifying areas in the Appalachian and Piedmont physiographic provinces that have no potential for geologic storage, considering the potential for terrestrial storage in Texas, and inventorying volumes available for geologic sequestration elsewhere in the SECARB region.

## Methods and Sources of Data

Our methodology separates volumes of $CO_2$ that could be sold for EOR from volumes that could be stored as waste product. For this assessment, we first screened reservoirs for those that were likely to be economic targets. Other reservoirs, including abandoned reservoirs, gas reservoirs, or those which are not suitable for $CO_2$ miscible floods are, for purposes of this assessment, included in the volume of subeconomic brine-filled porosity. We first describe the methodology for quantifying economic targets, then the methods used for description of brine-filled formations.

There are three broad reservoir characteristics that can be applied as screening criteria to determine the feasibility of $CO_2$ EOR; minimum miscibility pressure (MMP), injectivity, and reservoir heterogeneity. The most critical detailed constraint for the applicability of miscible $CO_2$ EOR is MMP. Minimum miscibility pressure is a function of oil properties, reservoir temperature, reservoir pressure, and the purity of the injected $CO_2$. Other screening criteria include injectivity, which controls the rate at which $CO_2$ can be put into the reservoir, and storage capacity (described in terms of total porosity). Geologic heterogeneity affects both early $CO_2$ breakthrough and, thus, volume of $CO_2$ recycled. For determining candidate reservoirs, MMP was the only reservoir characteristic applied. No reservoirs were included as candidates for $CO_2$ EOR unless MMP was less than the initial reservoir pressure.

Several other reservoir properties are important to consider in screening and process design phases. Broadly speaking, oil viscosity, oil API-gravity, reservoir depth, reservoir oil saturation, and reservoir heterogeneity are among the most important. Cracoana (1982) suggested oil viscosity values of 1 centipoise (cp) or less and an API-gravity of greater than 40°. Stalkup (1984) suggested that reservoirs should have oil gravities greater than 27° API-gravity and should be no shallower than 2,500 ft (762 m). Others have suggested that API oil gravity should range between 11° and 30°. Both viscosity and API-gravity are constraints controlled by the minimum miscibility pressure. Residual oil saturation is primarily an economic screen, and values of 20 to 25% have been suggested by Stalkup (1984).

The approach to determining the best possible $CO_2$ EOR miscible flood candidates in the Gulf Coast region was to construct an oil reservoir database and develop a screening method. The database covers the states of Alabama, Mississippi, Louisiana, and Texas. Screening criteria were based on those of Holtz et al. (2001). Screening proceeded according to a decision tree, which allows choice of large reservoirs with miscible $CO_2$ flood potential as candidates (fig. 1).

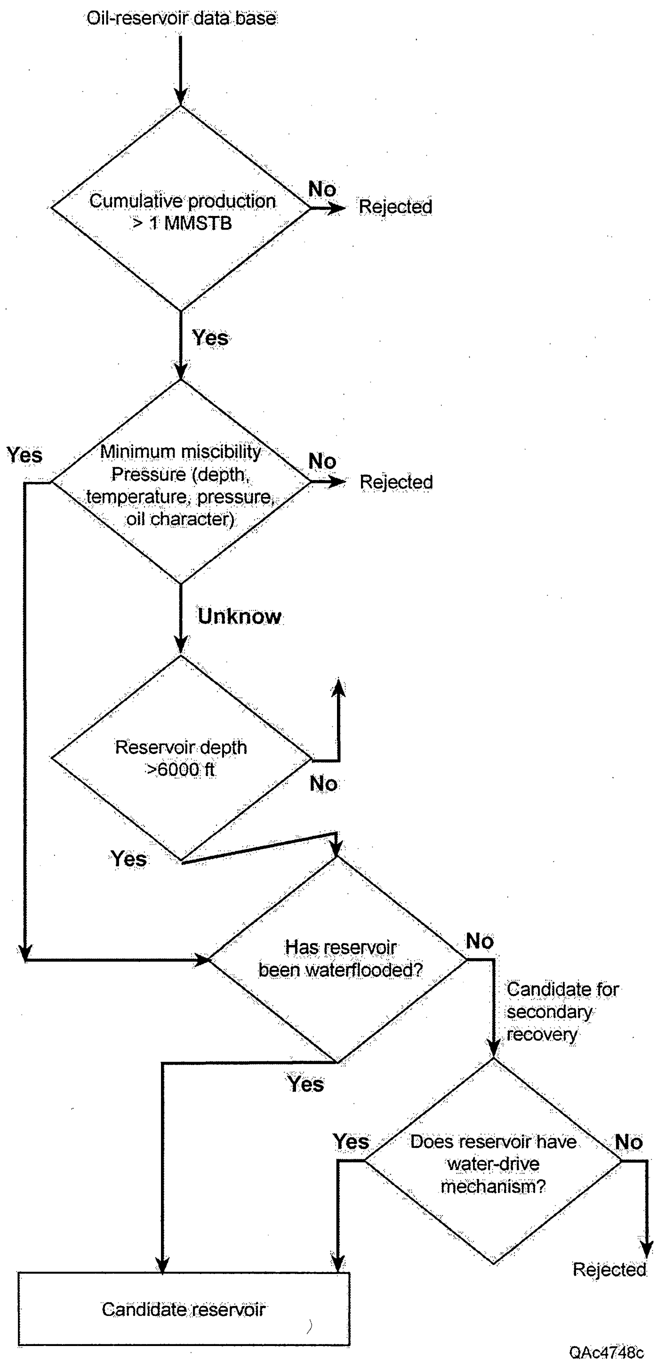


Figure 1. Decision tree for identifying gas-displacement-recovery candidate reservoirs.

General reservoir screening constraints were applied to cull out reservoirs that were not yet at the stage of their production life where $CO_2$ EOR would be the proper option. Reservoirs that are candidates for $CO_2$ EOR are those that are at an advanced stage of waterflooding or aquifer encroachment. At this production stage, most of the mobile oil has been produced, and the remaining significant volume of oil is residual oil that cannot be produced without EOR. To identify reservoirs at an advanced stage of production, screening constraints that were grounds for rejection from the candidate set included reservoirs

- that were not initially water driven,
- that were at an early stage of waterflooding, and
- that had not yet been waterflooded.

However, previous waterflooding was not applied as a requirement for large, deep reservoirs where vaporizing gas-drive miscibility can be achieved. The literature (SPE-EOR Field Reports [1982–1992]) shows that these reservoirs have had gas displacement EOR applied directly after primary production.

An extensive database that includes major oil reservoirs in Texas, Louisiana, Alabama, and Mississippi was developed for screening. An unpublished BEG Texas oil reservoir database was combined with Louisiana and Mississippi data from the TORIS database, as well as reservoir data on Mississippi from the Alabama Geologic Survey. Data for Texas reservoirs were generated by gathering engineering information from numerous sources, including the *Atlas of Major Texas Oil Reservoirs* (Galloway et al., 1983), *Atlas of Major Texas Gas Reservoirs* (Kosters et al., 1989) and hearings reports from the Railroad Commission of Texas. The database includes petrophysical and fluid characteristics and geological information, along with production information and location data. Reservoirs were grouped by plays. The Louisiana Geological Survey (LGS) provided field outlines and field names for Louisiana.

We first assess which reservoirs are most likely to be economic, then we estimate a minimum volume capacity using simplified assumptions for how much $CO_2$ could be stored. Finally we calculate the net usage, which is an estimated volume that an operator would need to purchase to recover the oil. This methodology was developed by Gulf Coast Carbon Center (GCCC) industry-academic collaborative as part of the match provided to SECARB.

## Estimating Minimum Miscibility Pressure

The key criterion to determining whether a $CO_2$ EOR flood is likely to be economic is miscibility of $CO_2$ in oil. Miscibility increases with depth and with oil gravity. Using available data and empirical equations, we determined the minimum miscibility pressure (MMP). Typically MMP is defined as the minimum pressure above which recovery of oil exceeds 90% in slim tube tests. Although this pressure is less than that required for complete miscibility, any further pressure increase will not significantly change final oil recovery.

A two-step approach has been taken to estimate a reservoir's MMP. First, the molecular weight of C5+ components of the reservoir oil must be determined. A correlation between oil API-gravity and C5+ oil molecular weight published by Lasater (1958) should be made (fig. 2). This correlation can be empirically determined by applying equation 1.

$$MW = \left(\frac{7864.9}{G}\right)^{\frac{1}{1.0386}} \qquad (1)$$

where MW = C+5 molecular weight, and

G = API oil gravity.

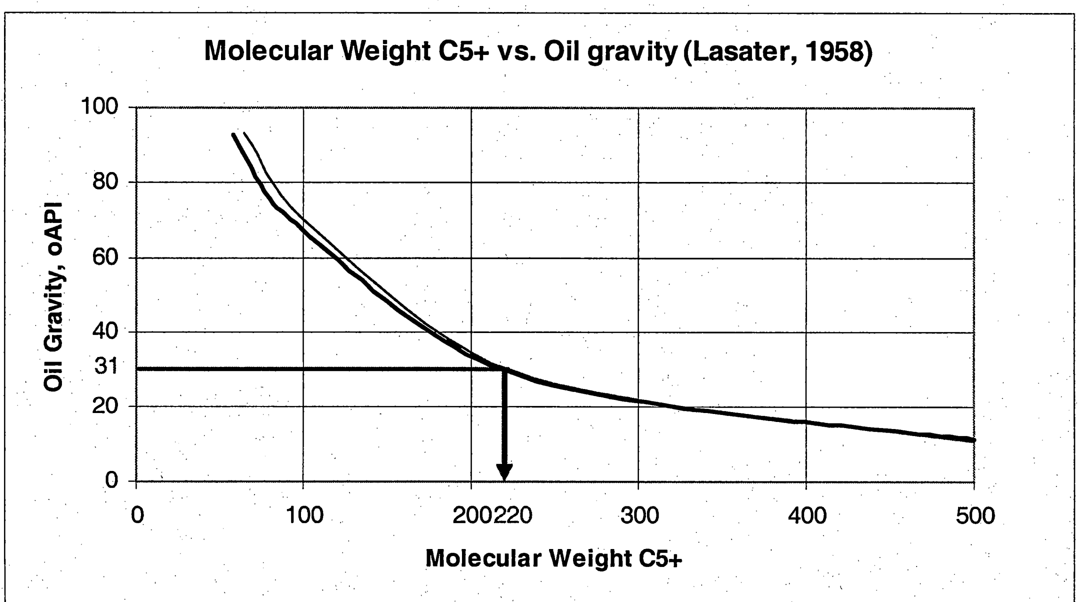


Figure 2. Correlation between oil gravity and the molecular weight of an oil's C+ 5 components.

Second, MMP from reservoir temperature and C5+ oil molecular weight must be determined. A relationship published by Holm and Josendahl (1982) and extended by Mungan (1981), which estimates MMP from molecular weight of the C5+ components of reservoir oil and reservoir temperature (fig. 3), was applied. This relationship was used by developing an equation through nonlinear multiple regression that allowed us to estimate MMP (Equation 2).

$$MMP = -329.558 + (7.727 * MW * 1.005^{T}) - (4.377 * MW) \qquad (2)$$

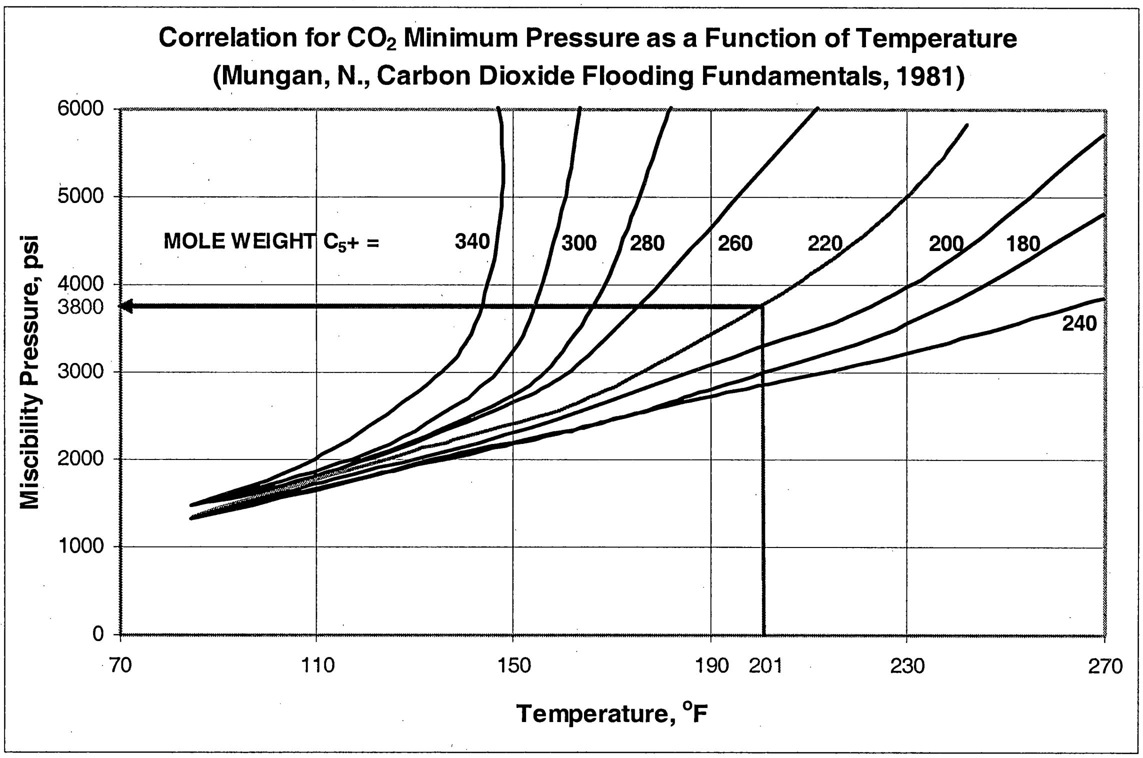


Figure 3. Nonlinear relationship between temperature and C+5 oil molecular weight and minimum miscibility pressure.

## Quick-Look Total $CO_2$ Storage Potential (CO2QLSP)

To accurately assess the capacity of a reservoir to store $CO_2$ one needs to compile reservoir properties and determine how much of the volume would be filled by $CO_2$ during an injection and how much would be bypassed. The quick-look approach is a spread sheet solution used when not enough data are available to calculate pore volume from reservoir parameters.

A quick-look $CO_2$ storage potential (capacity) can be obtained by analyzing cumulative production of an oil field. Here we assume that the pore volume represented by oil production is available in the reservoir for $CO_2$ storage. Stock-tank oil volumes are converted back to reservoir volumes, and resultant pore volumes are converted to the amount of $CO_2$ that could be put into that volume at initial reservoir conditions (Equation 3).

$$CO_2QLSP \text{ (metric tons)} = 0.05259 * N_p * B_{oi} / B_{CO2} \qquad (3)$$

where $N_p$ = Cumulative oil production (STB),

$B_{oi}$ = Oil formation volume factor (rbbl/STB), and

$B_{CO2}$ = $CO_2$ formation volume factor (RCF/SCF).

An empirical equation was derived to obtain $B_{CO2}$. Data for this equation were obtained from Jarrell et al. (2002). The equation is a set of statements and $2^{nd}$- and $3^{rd}$-order polynomials.

Often in a large reservoir database, oil formation volume factor is a data field that is not populated. To overcome this problem, we make assumptions and apply empirical equations. Oil formation volume factor can be estimated from an equation by Standing (1947) (Equation 4).

$$Bo = 0.972 + 0.000147F^{1.175} \qquad (4)$$

where $F = Rso(\frac{\gamma_g}{\gamma_o}) + 1.25T$

$$\gamma_o = \frac{141.5}{131.5 + API}$$

$\gamma_g$ = Gas specific gravity

API = oil API gravity

*Rso* = Solution gas-oil ratio

When applying this Standing correlation gas gravity and solution gas-oil ratio are needed, and when these parameters are not known an estimate can be made. In this report, we applied an average 0.75 gas gravity and used a second Standing correlation to estimate *Rso* (Equation 5).

$$Rso = \gamma_g \left(\frac{P}{18(10)^{Y_g}}\right)^{1.204} \qquad (5)$$

where Yg = 0.00091T – 0.0125API

T = Temperature, ($^oF$)

P = Pressure, (psi)

## Quick-Look Net Total $CO_2$ Usage Potential (CO2EORP)

For an economically driven $CO_2$ sequestration scenario focused on EOR, the most important parameter is amount of $CO_2$ that would be purchased from a source in order to recover additional oil. This is a different value than the volume stored because significant volume of $CO_2$ would be cycled to recover oil.

A quick-look method to determine the net $CO_2$ needed for a $CO_2$-enhanced oil recovery (EOR) project is based on reservoir cumulative production and $CO_2$ utilization rates, which are the amount of $CO_2$ used to recover a barrel of oil. First, a total $CO_2$ usage rate is applied, along with a recycle rate. For this quick-look method, original oil in place (OOIP) is estimated from cumulative production and primary + secondary recovery (Equation 6). Each reservoir is assumed to be close to its ultimate primary + secondary recovery. Furthermore, a basin-average primary + secondary recovery factor is applied. For the Gulf Coast, with its strong water-drive oil reservoirs, a 50% primary + secondary recovery factor is assumed.

$$OOIP = Np/ R_{ps} \qquad (6)$$

Target $CO_2$ EOR reserves are determined by applying a recovery factor, and the ultimate recovery factor from $CO_2$ EOR is taken as a percent of OOIP (Equation 7). EOR reservoir recovery is assumed to be 15% of the OOIP of each of the basins.

$$N_{CO2} = OOIP^* R_{CO2} \qquad (7)$$

The final step in calculating net $CO_2$ used in an EOR project is to apply utilization rates. Volume of $CO_2$ needed is obtained as a function of the total EOR volume target and net utilization rate (Equation 8). For Gulf Coast high-permeability sandstone reservoirs, the gross utilization rate was set at 4.5 MSCF/STB and the recycle rate at 2 MSCF/STB.

$$CO2\ EORP = N_{CO2}\,(U_{CO2T} - U_{CO2R}) \qquad (8)$$

where OOIP = Original oil in place (MSTB)

Np = Cumulative oil production (MSTB)

$R_{ps}$ = primary + secondary recovery

$N_{CO2}$ = Cumulative $CO_2$ EOR target

$R_{CO2}$ = Ultimate recovery factor from $CO_2$ EOR (% of OOIP)

$U_{CO2T}$ = Total $CO_2$ utilization (MSCF/STB)

$U_{CO2R}$ = CO2 utilization recycled (MSCF/STB)

CO2 EORP = Net $CO_2$ used in EOR project

## Waterflooded Reservoirs in Texas: Recovery Factors

To estimate average waterflood efficiency of Gulf Coast Tertiary sandstone reservoirs, we conducted a survey of major Texas oil reservoirs that have undergone secondary-recovery waterflood operations. Only those reservoirs that had undergone waterflood secondary recovery were included. Data were obtained from the *Atlas of Major Texas Oil Reservoirs* (Galloway et al., 1983). Non-Gulf-Coast reservoirs in Texas were also surveyed to establish a total range of possible values of waterflood recovery efficiency and to place Gulf Coast values of ultimate recovery in perspective. Recovery efficiency values were reported in percent of OOIP. Total range in recovery efficiency values was reported, as well as an average value, which was not weighted by OOIP of each reservoir, but which was considered equally on a reservoir-by-reservoir basis. However, the average value for the East Texas Woodbine play was weighted by OOIP value from East Texas field because it dominates the play and accounts for the bulk of the play's oil production.

Reservoirs were summarized primarily by depositional origin and secondarily by individual play. Principal producing Tertiary Gulf Coast plays in southeast Texas that have undergone waterflood secondary-recovery operations are from three plays: Yegua Deep-Seated Salt Domes, Frio Deep-Seated Salt Domes, and Frio Barrier/Strandplain Sandstone (Galloway et al., 1983). Play-average recovery efficiencies in these three plays range from 50.2 to 58.5%, with a total range for individual reservoirs from 28 to 61%. On the basis of these data, an average 50% recovery factor for waterflooded reservoirs in the Gulf Coast area is reasonable for averaging. One should remain aware that recovery efficiency is highly variable, depending on reservoir properties and the optimization of the flood engineering.

## Brine Storage Database Compilation

For the brine storage phase of the project, we focused on compiling, assessing, and digitizing published and compiled sources of data about distribution of potential sequestration targets in the subsurface. This approach was selected because (1) high-quality published data are abundant for the high-capacity target of the region and (2) compiling new data from primary subsurface data (for example, wireline logs, sample logs, seismic lines) for this complex subsurface geology over this large region would have required effort disproportionate with level of funding. We focused on two types of regions, those with significant to very large capacity in Gulf and Atlantic Coastal areas and those that could quickly be assessed to have little or no storage capacity. Some areas that probably have some- to good-capacity were deferred.

## Geographic Information System (GIS) Description

Reservoir and brine formation data were managed and mapped in a GIS system. Depending on original data type, different procedures of shapefile creation (digitization or analysis) were followed using ArcGIS software to arrive at the final package of shapefiles. All data are projected to Contiguous USA Albers Equal Area Conic parameters. This information is provided in .PRJ-files contained in the GIS_data folder. Metadata files are included in the GIS database to provide additional information about shapefiles. XML metadata files, which are stored as part of the shapefile in the GIS_data folder, can be viewed using ArcCatalog. Metadata have also been exported as HTML files that can be viewed using an Internet browser. Figure 4 shows a sample of the oil reservoir database developed from BEG, GCCC, and Louisiana Geological Survey (LGS) data.

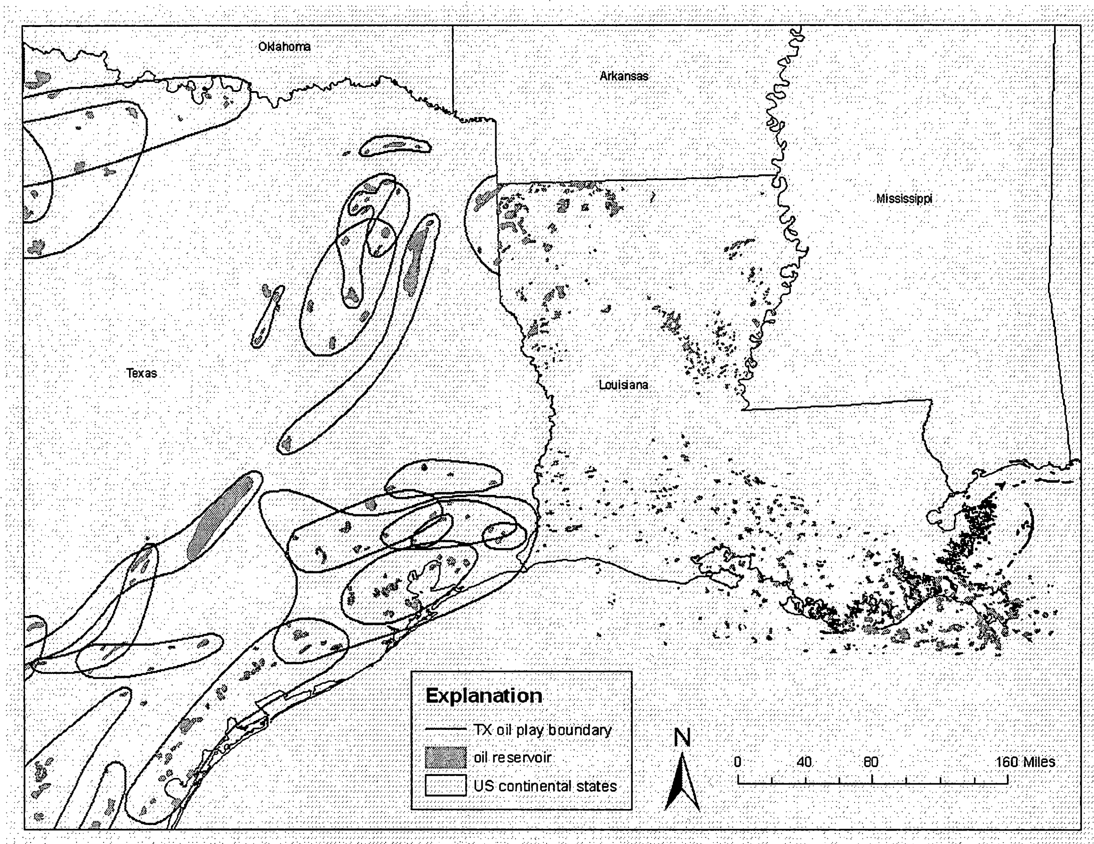


Figure 4. GIS data sample: distribution of oil reservoirs in Louisiana and major reservoirs and plays in Texas.

# Results and Discussion

## Gulf Coast Region Miscible Oil Reservoirs

The Permian Basin in West Texas has seen a long history of $CO_2$ enhanced oil recovery (EOR). More than 65 sandstone, limestone, and dolomite reservoirs have been subject to miscible $CO_2$ flooding in the last 30 years, and this economically viable, low-risk activity provides a prototype for beneficial use of large volumes of $CO_2$ with storage. However, the experienced gained has not been extended to the much more porous and permeable clastic depositional systems of the Gulf Coast. Proximity to possible anthropogenic $CO_2$ sources and the petrophysical character of these sandstones are just two of the attributes that are favorable for Gulf Coast formations.

Analysis shows that the miscible $CO_2$ EOR resource potential along the Texas Gulf Coast is 2.7 billion stock tank barrels (BSTB), and the total Gulf Coast potential, including Mississippi, Louisiana, and Alabama, is 4.5 BSTB. Results of this assessment indicate that mature Gulf Coast clastic oil reservoirs are a new, large potential target for $CO_2$ EOR when experience in the Permian Basin is retooled for this setting.

Six major groups of oil plays have been identified that contain candidates for $CO_2$ miscible displacement in the Gulf Coast (fig. 5). Oligocene and Eocene plays extend from central Louisiana, southwestward and parallel to the present-day coastline, all the way to the Mexican border. The Miocene play completely covers southern Louisiana and the Mississippi delta in a west-east trend. The Travis Peak-Hosston and the Cotton Valley-Smackover major plays extend from the east side of the Gulf Coast region, in south Alabama and the west Florida Panhandle, to East Texas, covering southern Alabama, southern Mississippi, northern Louisiana, and central east Texas. Finally, the Pennsylvanian play is found in central north Texas, east of the Texas Panhandle and northwest of Dallas-Fort Worth.

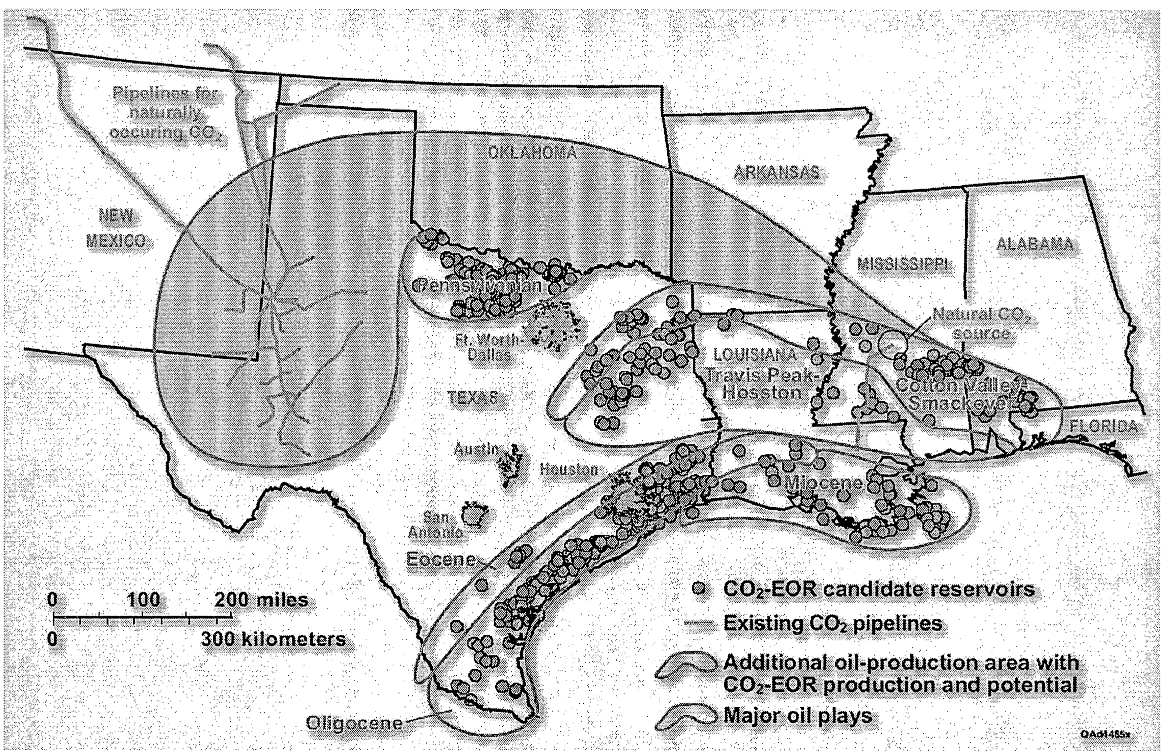


Figure 5. Map of $CO_2$ EOR Miscible Potential in the Gulf Coast.

The majority of the $CO_2$ EOR candidate reservoirs in southeast Texas are located along the Oligocene play. The large cumulative oil production of the biggest fields in this region comes from reservoirs in Frio deep-seated salt domes and Yegua salt-dome flanks. A major group of candidate reservoirs is located in northeast Texas, distributed along the west ends of the Travis Peak-Hosston and Cotton Valley Smackover plays. A third concentration of reservoirs is located in north Texas, bordering Oklahoma and following the Pennsylvanian oil reservoir play trends (Galloway et al., 1983). According to our analysis, Texas Gulf Coast $CO_2$ EOR resources (excluding the Permian Basin) add up to 3 billion stock tank barrels (BSTB).

In Louisiana, Miocene plays are located mainly in the Mississippi delta and along the coastline. The rest of the reservoirs are scattered throughout the state and are dispersed in different plays. The Bay Marchand reservoirs have been responsible for the largest cumulative oil production in Louisiana. According to the assessment, the state has1,500 million stock tank barrels (MMSTB) of $CO_2$ EOR resources.

In Mississippi, candidate reservoirs are located mainly along the Cotton Valley–Smackover plays. Only 10 other reservoirs can be found south of the major group in the Travis Peak–Hosston play. The Smackover Formation and the Tuscaloosa Group have provided the state with most of the cumulative oil production. Brookhaven is the largest candidate field in Mississippi and produces from the Tuscaloosa Group. The analysis for the state indicates 89 MMSTB of $CO_2$ EOR resource potential

In Alabama all the Gulf Coast candidate reservoirs are found in the Cotton Valley–Smackover play. Like in Mississippi, gross cumulative volumes have been produced from the Smackover Formation. The largest candidate field in the state is Citronelle, and it produces from the Rodessa Formation. Analysis for Alabama indicates 98 MMSTB of $CO_2$ EOR resource potential.

The largest potential and economic incentive for use for $CO_2$ to EOR is found in the Texas Gulf Coast, followed by Louisiana (fig. 6). The magnitude of the resources in the Texas Gulf Coast makes the Alabama and Mississippi results appear small; however, 187 MMSTB still represents a sizable resource to attract development of the use of $CO_2$ for EOR.

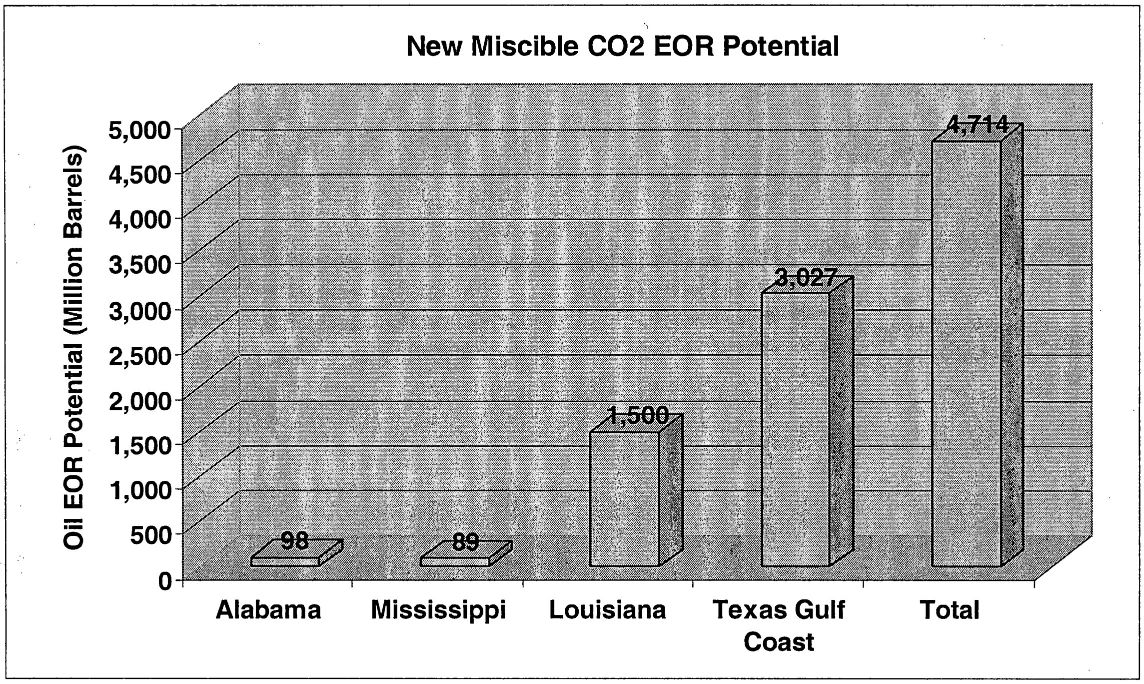


Figure 6. Bar graph of miscible $CO_2$ EOR resource potential in the Gulf Coast.

## $CO_2$ Storage Capacity Associated with Miscible $CO_2$ EOR

Use of $CO_2$ for EOR results in retention of large volumes of $CO_2$ in the reservoir. The volume of this storage is highly dependent on engineering practices and sequestration incentives or cost of $CO_2$. During oil production, $CO_2$ is produced with oil, and this produced $CO_2$ is generally separated from oil and brine, compressed, and cycled back into the reservoir to stimulate additional production. This cycled volume cannot be counted as part of the storage capacity. In current market conditions (high cost of $CO_2$), at the end of production, the $CO_2$ is usually produced as a commodity and used in another part of the field. In a future market, where storage of $CO_2$ has value, this $CO_2$ could be left in the reservoir at abandonment. In a quick-look method of estimating this capacity, we assume that the produced oil is replaced on a volume-for-volume basis by $CO_2$.

The estimated volume of storage at abandonment in EOR candidates is over 2,500 million metric tons (MMT) of $CO_2$ (fig. 7). The largest sequestration capacity in these economic EOR reservoirs is in Texas, with over 1,300 MMT of sequestration capacity. Louisiana also has a large capacity of over 1,100 MMT. Mississippi and Alabama account for smaller but significant volumes of sequestration capacity. These results indicate that Oligocene and Miocene oil reservoirs represent a large target for sequestering $CO_2$ at the end of $CO_2$ EOR.

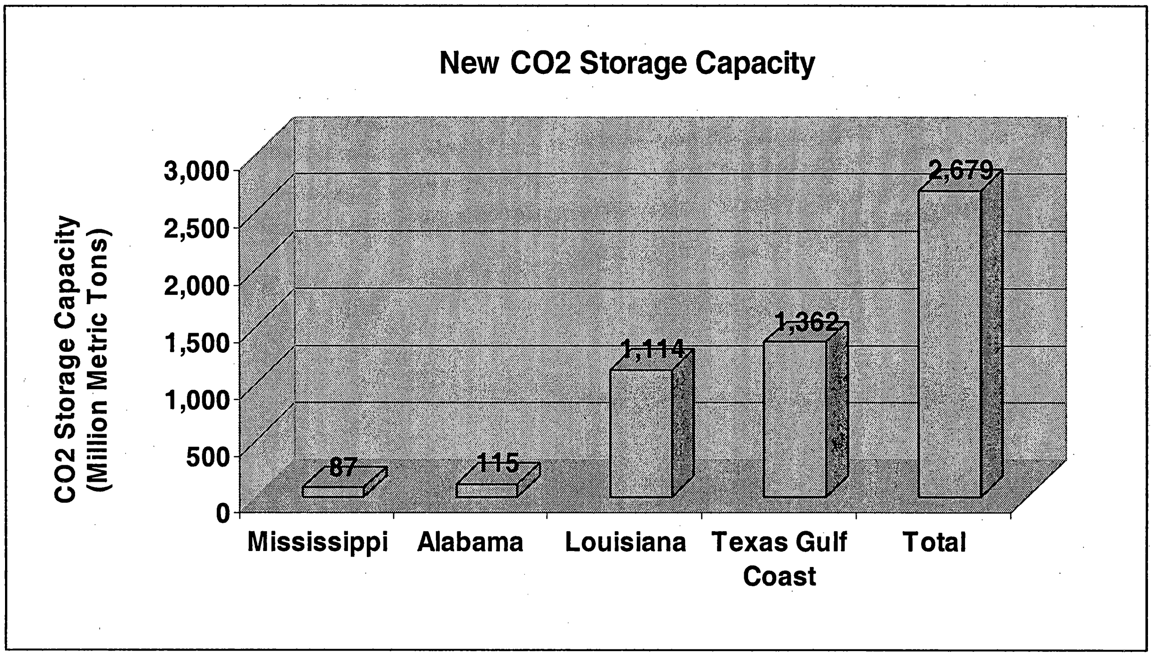


Figure 7. $CO_2$ sequestration capacity in miscible oil reservoirs along the Gulf Coast.

## Gulf Coast Region Brine Storage

The Gulf Coastal Plain is an attractive target for $CO_2$ sequestration because of the coincidence of $CO_2$ emitters (industrial and power-generation facilities) and potential sinks in a thick wedge of sand-rich sediment. Gulf Coast sandstones are also used extensively for underground injection of chemical and other wastes (Kreitler et al., 1988).

The coastal-plain physiographic regions of Texas, Louisiana, Mississippi, and Alabama are underlain by terrigenous, clastic, sedimentary units that dip gently and thicken substantially toward the center of the Gulf of Mexico Basin. Flat-lying carbonate sediments underlie onshore portions of the basin in Florida and the Yucatan Peninsula (Bryant et al., 1991). In this phase of the Southeast Regional Carbon Sequestration (SECARB) project, we compiled data needed to estimate the capacity of Tertiary-age, sandstone-rich sediments in onshore portions of the Gulf of Mexico Basin in Texas, Louisiana, and Mississippi.

Thickness and stratigraphic nomenclature are barriers to describing the options in $CO_2$-injection-target selection in the same format used in other parts of the onshore U.S. Because of the areal extent of the depositional basin, complex depositional environments, and stratigraphic complexities resulting from growth faulting, definition of rock- and hydro-stratigraphic units is complex and varies from researcher to researcher. We therefore have "lumped together" rather than "split" to assess capacity in this region. Number of possible sinks along the Gulf coast, total sand volume, and diversity of potential targets are all very large.

**Geologic History of the Gulf of Mexico**

Geologic evidence suggests that formation of the Gulf of Mexico (GOM) began in early Mesozoic (Late Triassic), and it continues to evolve today. Mesozoic history of the basin is relevant to this study because it provided the structural framework (fig. 8) upon which a huge volume of sediments have subsequently been deposited during Cenozoic time. The following section on Mesozoic geologic history of the GOM is summarized from Salvador (1991a, b). W. E. Galloway and other workers have published most extensively on Cenozoic deposits along the northwest and north edges of the GOM Basin. Many of their references can be accessed through a Web page sponsored by an industrial consortium: http://web.ig.utexas.edu/research/projects/gbds/gbds.htm.

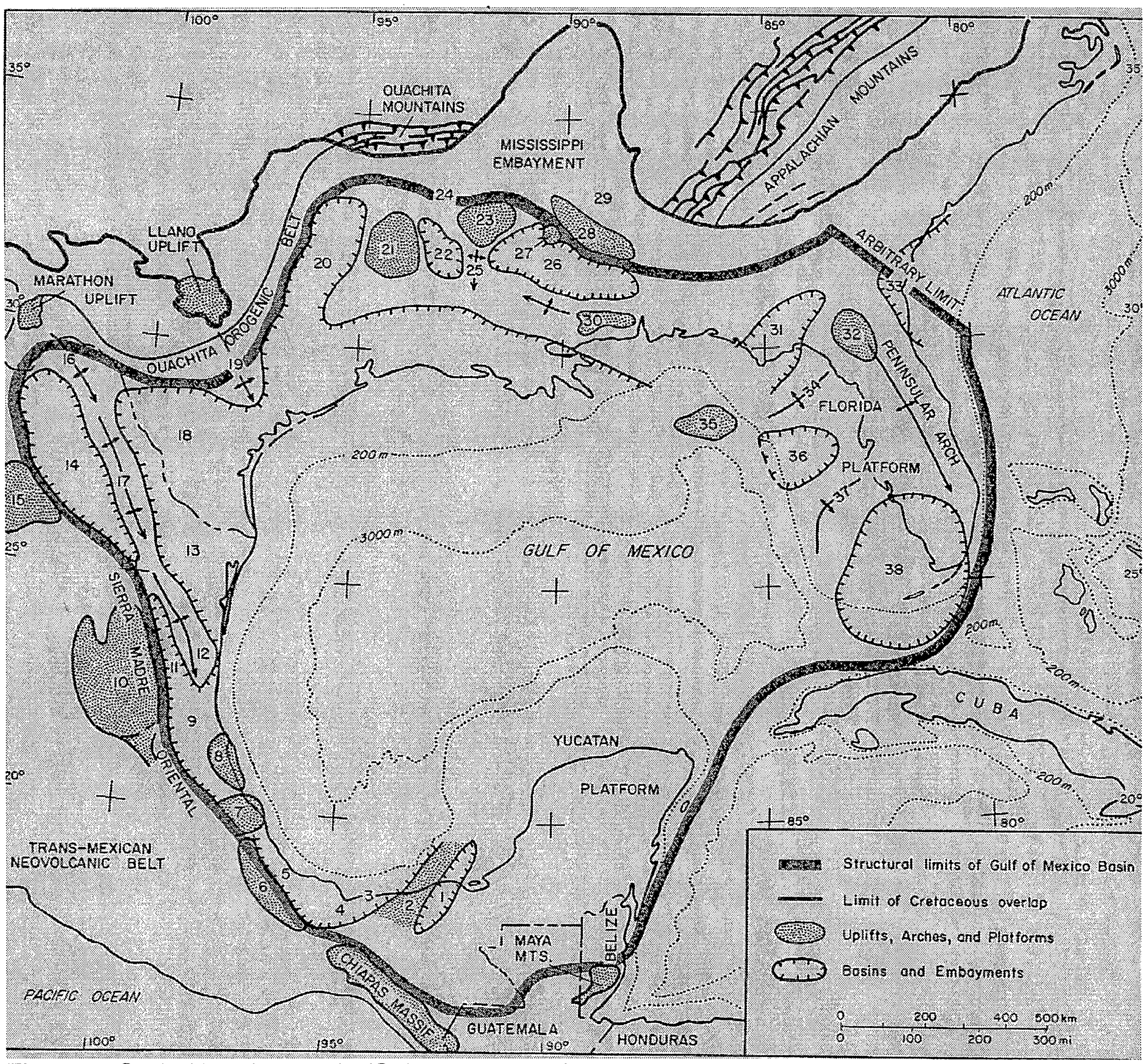

Figure 8. Gulf of Mexico Basin (Salvador, 1991a).

**Mesozoic Units**

Rifting associated with breakup of the supercontinent Pangea began in Late Triassic and continued during Early and Middle Jurassic time. Supporting evidence includes the presence of tensional deformation features (fracture networks and grabens) filled with Triassic red beds and associated volcanic rocks. Tensional features have been mapped around the periphery of the present-day GOM in eastern Mexico and the southeastern U.S. that create GOM marginal basins (for example, East Texas Basin [20 on fig. 8], Mississippi Interior Salt Basin [26 on fig. 8]).

Slow subsidence of continental crust, which was later to form shallower portions of the Gulf of Mexico, is inferred by the presence of extensive Middle to Late Jurassic evaporite deposits. Salt deposition was followed by seafloor spreading and formation of oceanic crust and continued extension of continental crust. The central, deepest part of the Gulf of Mexico Basin is underlain by Mesozoic-age oceanic crust, with no evidence of overlying evaporite formations. Structural highs, such as the Sabine and Monroe Uplifts and the Jackson Dome in Texas, Louisiana, and Mississippi, are thought to be remnant horsts from the early phases of crustal extension.

After cessation of seafloor spreading and emplacement of oceanic crust, the entire basin subsided, most likely as a result of thermal cooling, followed by sediment loading. Rapid subsidence resulted in regional transgression and flooding of surrounding continental areas. Early to Middle Cretaceous time was dominated by extensive shelf-carbonate deposition and reef buildup along the northwest, north, and northeast margins of the basin and on the Florida and Yucatan Platforms. Regional uplift of the North American continent resulted in widespread deposition of fine-grained terrigenous sediment, which ended major Cretaceous reef building and a carbonate depositional phase along the northwestern and northern portions of the basin, from northeastern Mexico to northern Louisiana. During the Cretaceous, sandstones were deposited in basins marginal to the Gulf of Mexico. The Paluxy and Woodbine Formations are examples of this type of sandstone, which previous assessment has shown are attractive targets for sequestration in the East Texas Basin (Hovorka et al., 2000). Generally correlative units, also attractive targets for sequestration, are found in the interior salt basins of Louisiana, Mississippi, and Alabama and include the Tuscaloosa and Eutaw Sandstones (Hovorka et al., 2000).

With the exception of some basinal areas (for example, East Texas Basin and the Rio Grande Embayment), subaerial erosion and formation of a regional unconformity occurred around the periphery of the Gulf Coast basin between the Middle and Late Cretaceous. Continued uplift of North America and worldwide lowering of sea level in Late Cretaceous time ended major carbonate deposition in all areas of the GOM Basin except for the Florida and Yucatan Platforms. Igneous activity occurred during this time in the Mississippi Embayment and along the Balcones Fault Zone in Texas.

The Cretaceous-Tertiary boundary is marked by a regional disconformity now known to be a result of meteoritic impact on the north edge of the Yucatan Platform (Hildebrand et al., 1991).

### Cenozoic units

Since the end of Cretaceous time (65 Ma), terrigenous deposition along the northwest and north edges of the Gulf of Mexico has resulted in basinward progradation of the shoreline. Galloway et al. (2000) estimated 240 to 290 km (150 to 180 mi) of lateral (eastern to southern) shift of the shoreline since the end of the Cretaceous. This tremendous volume of sediment was supplied along eight principal fluvial axes during four continental-scale phases of crustal uplift (Galloway et al., 2000) (fig. 9).

The weight of this thickness of sediments caused deformation of underlying, more ductile and buoyant shales and salt, resulting in development of extensional deformation styles of this region. Growth faults allowed blocks of sediment to rotate, accommodating additional volumes of sediment accumulation. Anticlines, turtle structures, and piercement diapirs formed where salt and shale were displaced upward. These structures segregate the Gulf Coast into blocks, forming traps for hydrocarbons in (1) fault-bounded compartments, (2) steeply dipping areas near salt domes, and (3) rollover structures (Halbouty, 1979; Winker et al., 1983). These structures also created leak points, where buoyant fluids have escaped to the surface.

Sand-rich facies include river-channel, delta-mouth-bar, barrier, slope-channel, and fan environments. Growth faulting created accommodation for accumulation of exceptionally thick sands. Episodes of relative sea-level rise flooded the area and caused widespread accumulation of clay shales. Complex interactions among sea level, coastal process, and sediment supply have led to complexity within this thick sedimentary package.

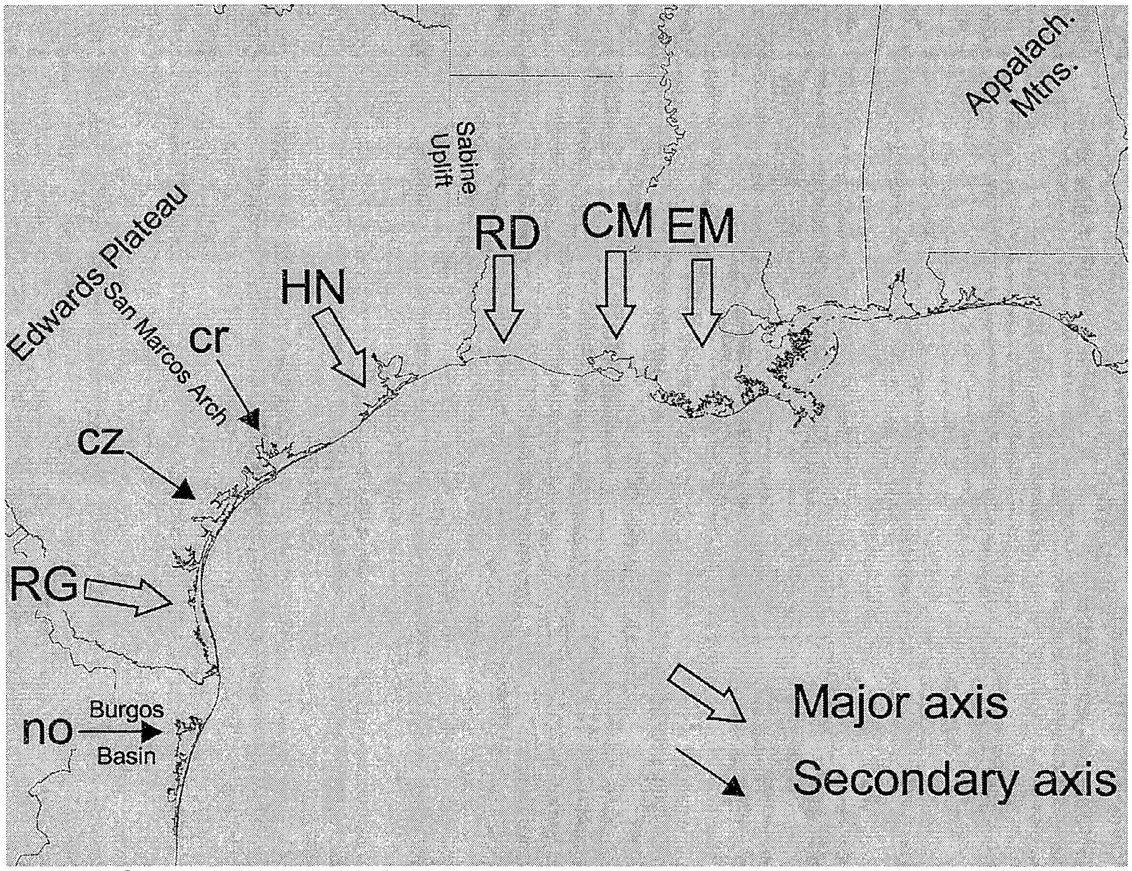

Figure 9. Structural features and major and secondary fluvial axes, along which sediments were deposited in the Gulf of Mexico basin: no = Norias, RG = Rio Grande, cz = Carrizo, cr = Corsair, HN = Houston, RD = Red River, CM = Central Mississippi, and EM = East Mississippi (Galloway et al., 2000).

Lower Tertiary (Paleocene and Eocene) sediments are divided into four main rock stratigraphic groups, which are, from oldest to youngest, Midway, Wilcox, Claiborne, and Jackson. Each of these groups contains numerous sand-rich geologic formations; however, names and stratigraphic boundaries of the component formations vary between, and sometimes within, states. For example, the basal formation of the Claiborne Group is called the Tallahatta Formation in Florida, Mississippi, and Kentucky, whereas in Louisiana and Arkansas, the same horizon is referred to as the Cane River Formation, and in Alabama it is called the Meridian Sand. In Texas, the basal unit of the Claiborne Group is the Carrizo Sand. Oligocene deposits overlying the Jackson Group include the Catahoula Tuff or Sandstone, Frio Formation, and Vicksburg Group. These lower-Tertiary-age groups of sediments are consistently recognized throughout the Gulf Coastal Plain (Hosman, 1996).

Units of upper Tertiary (Miocene and Pliocene) age have less consistent nomenclature and degree of differentiation between states. Miocene deposits in Texas and Louisiana are Oakville Sandstone (older) and Fleming Formation (younger). In Mississippi, Miocene deposits are Hattiesburg Clay (older) and Pascagoula Formation (younger), and in Alabama, Miocene deposits are undifferentiated. Gulf coast Pliocene-age deposits are called Goliad Sand in Texas, Foley and Citronelle Formations in Louisiana, and Citronelle Formation in Mississippi and Alabama (Hosman, 1996).

There is considerable inconsistency in stratigraphic nomenclature (both rock-stratigraphic and hydrostratigraphic) units along the northwestern and northern Gulf Coastal Plain (Salvador, 1991a). Lower Tertiary rock-stratigraphic or geologic unit names are fairly uniform throughout the Gulf Coastal Plain, except in some cases, a time synchronous unit composed of different facies may have different names between outcrop and shallow subsurface. For example, in the Houston and Rio Grande Embayment areas of the Texas Upper Oligocene, sediments are called Catahoula Tuff or Sandstone at and near the surface and Frio Formation in the subsurface.

To further complicate the picture, hydrostratigraphic (also known as hydrogeologic, aquifer, or geohydrologic) units incorporate water-bearing horizons of entire or partial groups of geologic units. For example, component geologic units of the Gulf Coast aquifer (GCA) of Texas are, from oldest to youngest, the Catahoula Formation, the Oakville Sandstone/Fleming Formation, the Goliad Formation, the Pleistocene formations—Willis Sand, Lissie Formation, and Beaumont Clay—and Quaternary terrace deposits and alluvium (Doering, 1935; Baker, 1979).

The three main aquifer subunits of the Gulf Coast aquifer in Texas are, from oldest to youngest, Jasper, Evangeline, and Chicot. According to Ashworth and Hopkins (1995), the oldest geologic unit in the Jasper aquifer subunit of the GCA is the Oligocene- to Miocene-age Catahoula Formation. However, some ambiguity exists about whether the Catahoula is a confining unit (see, for example, Baker, 1979) or a water-bearing unit in different areas of the GCA. This formation provides usable quantities of water "near" the outcrop, but it is a confining unit farther downdip. In fact, some workers identify subsurface equivalents of the Catahoula Formation as the Frio Clay (Galloway, 1977). Another geologic unit included in the Jasper aquifer in Texas is the undivided Oakville Sand/Fleming Formation, which overlies the Catahoula Formation. In a few wells in eastern Webb County in South Texas, Jasper aquifer wells also extend down into upper water-bearing sands of the Jackson Group.

**Potential for Storage in the Brine-Bearing Sandstones of the Gulf Coast**

Tertiary-age sediments of the Gulf Coastal Plain of Texas and Louisiana are composed of thick intervals of sand-rich sediment, separated by widespread marine shales that were deposited during regional transgressive flooding events (Galloway et al., 2000). The wedge of sand-rich deposits along the northern and northwestern Gulf of Mexico Basin extends downward to the top of Cretaceous (fig. 10). This stratigraphic horizon becomes too deep to be penetrated by many wells; mapping it seaward of ~160 km (~100 mi) inland from the coast would require interpretation of seismic and faunal data.

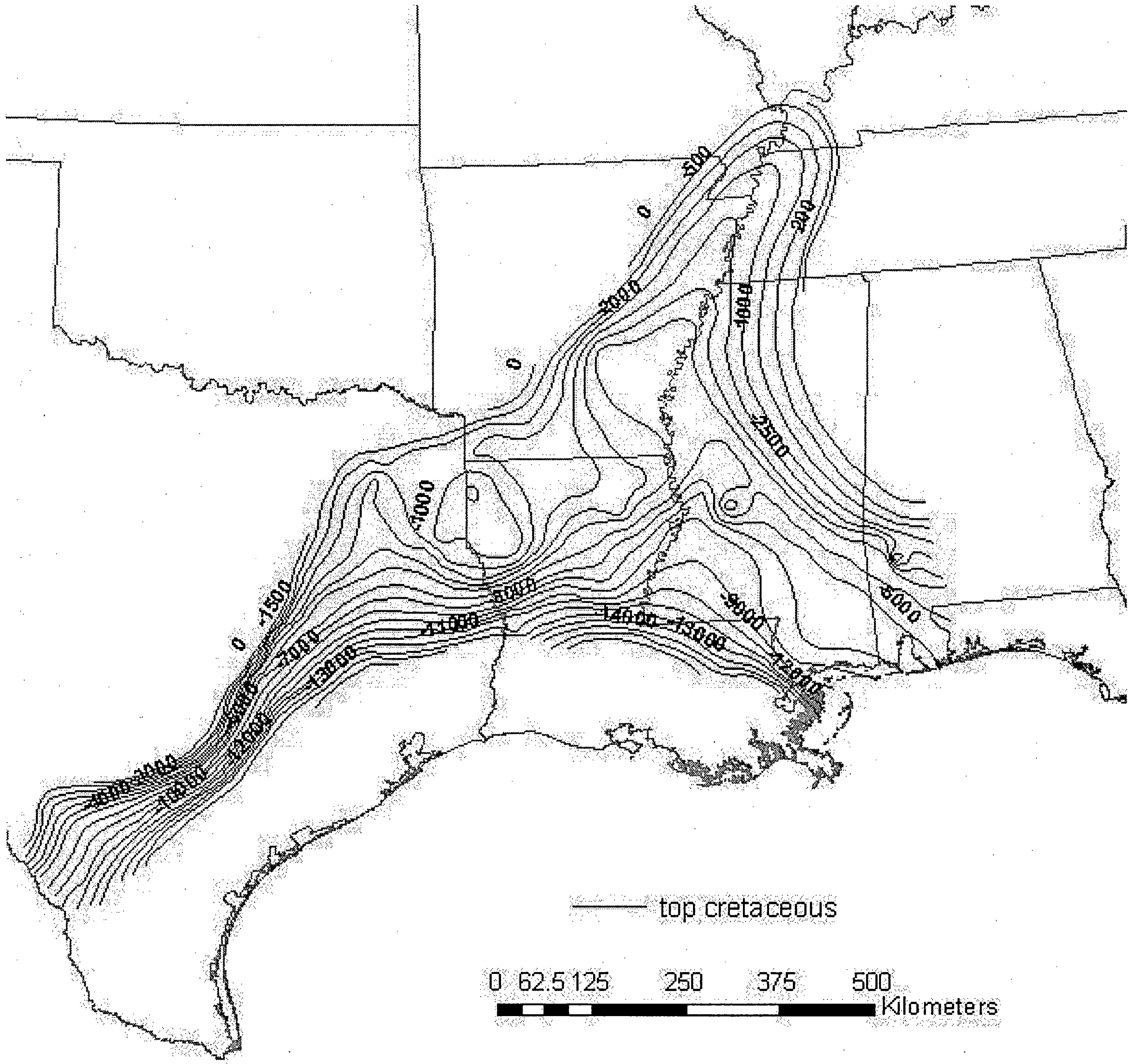


Figure 10. Base of Cretaceous in Gulf Coast. Data digitized from Hosman (1996). Contour interval is variable.

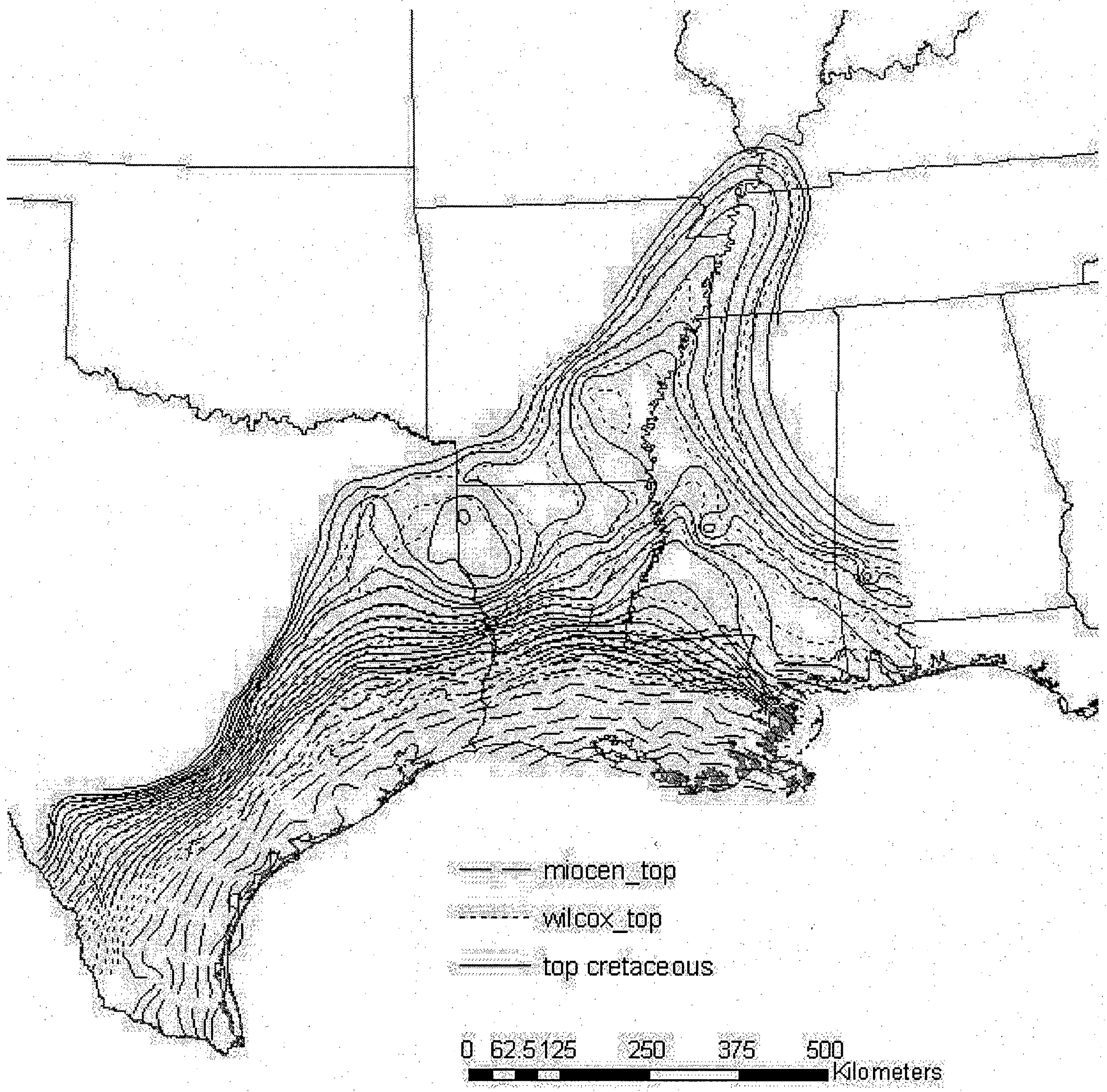


Figure 11. Units used to estimate thickness of the sedimentary wedge. Data digitized from Hosman (1996).

In order to estimate total thickness of sand in onshore Cenozoic sediments, we need to know depth to top and bottom of the younger (gulfward) geologic units deposited farther to the southeast and south in Texas and Louisiana. To fill in this gap, we digitized stratigraphic top and thickness contours (from Hosman, 1996) of units listed in table 1. Figure 11 shows schematically how we extended coverage to the edge of the continental margin. By using the base of the deepest unit for which data extend to the Gulf Coast shoreline and adding thicknesses of overlying units up to 800 m (2,400 ft) below ground surface (proxy for base of usable quality water), we can estimate thickness of the sedimentary wedge into which $CO_2$ can be injected along the Gulf Coastal Plain in Texas, Louisiana, and Alabama.

Table 1. Gulf Coast units provided for volume calculations

| Age | Stratigraphic unit | Mapped | Mapped |
|---|---|---|---|
| Base Cenozoic | Cretaceous deposits | Top | |
| Tertiary, Paleocene | Midway Group | Top | Thickness |
| Tertiary, Eocene | Wilcox Group | Top | Thickness |
| Tertiary, Eocene | Carrizo sand and Meridian sand member | Top | Thickness |
| Tertiary, Eocene | Cane River Formation and equivalents | Top | Thickness |
| Tertiary, Eocene | Sparta sand, Memphis sand, and Laredo Formation | Top | Thickness |
| Tertiary, Eocene | Cook Mountain Formation | Top | Thickness |
| Tertiary, Eocene | Cockfield and Yegua Formations | Top | Thickness |
| Tertiary, Eocene/Oligocene | Vicksburg and Jackson groups, undivided | Top | Thickness |
| Miocene | Miocene deposits | Top | Thickness |
| Pliocene | Pliocene deposits | Top | Thickness |

Thickness and stratigraphic complexity of the wedge make preparation of net-sandstone and net-porosity maps on a formation-by-formation basis an ambitious task. In order to estimate net sandstone volume of the entire wedge, we counted all sandstones in representative logs in regional cross-section sets (Dodge and Posey, 1981) of several hundred wells, from surface to 14,000 ft depth. We determined by inspection that variability in these data is large, but not vertically or laterally systematic, so it is meaningful to use bulk averages to characterize the system. The average percent sandstone in the Gulf Coast wedge onshore is 23%. Average porosity of these sandstones estimated from our database is 30%, and average permeability is more than 200 millidarcys (mD).

The net sandstone volume of the entire wedge includes oil reservoirs in which oil would be immiscible under $CO_2$ flood and oil and gas reservoirs that are or will be abandoned. Some workers seek these reservoirs as preferred $CO_2$ storage sites because the seal is known to have trapped buoyant fluids. We do not separately inventory this noneconomic storage because we have concern that the numerous well penetrations may have degraded the seal. We recommend instead using the deeper, brine-bearing formations (water leg of the reservoir), which typically have fewer penetrations, rather than the abandoned production interval itself. This concept of stacked storage is especially useful in a region with numerous high-quality sandstone-seal units to select from, as shown by the very large brine-filled volume.

## Appalachian and Piedmont Region Brine Storage

The Appalachian Mountains extend from Newfoundland to Alabama, roughly parallel to the Atlantic Coast of the United States. Except for a portion in Newfoundland, the mountain chain can be divided into three sections, northern, central, and southern. Sections of the southern and central Appalachians, which extend from Alabama to Roanoke, Virginia, and from Roanoke, Virginia, to New York, respectively, are discussed here. The southern and central Appalachians are subdivided longitudinally from northwest to southeast into the Appalachian Plateau, the Appalachian Valley and Ridge, and the combined Blue Ridge and Piedmont provinces (fig. 12). In the Appalachian Plateau, rocks are nearly flat lying (fig. 13). Strata of the valley and ridge are generally unmetamorphosed but are extensively folded and faulted—mostly folded in the southern segment, but folded and faulted in the central portion. The Blue Ridge and Piedmont are composed of crystalline rocks that have been extensively metamorphosed and fractured (Rogers, 1949; Shumaker, 1996).

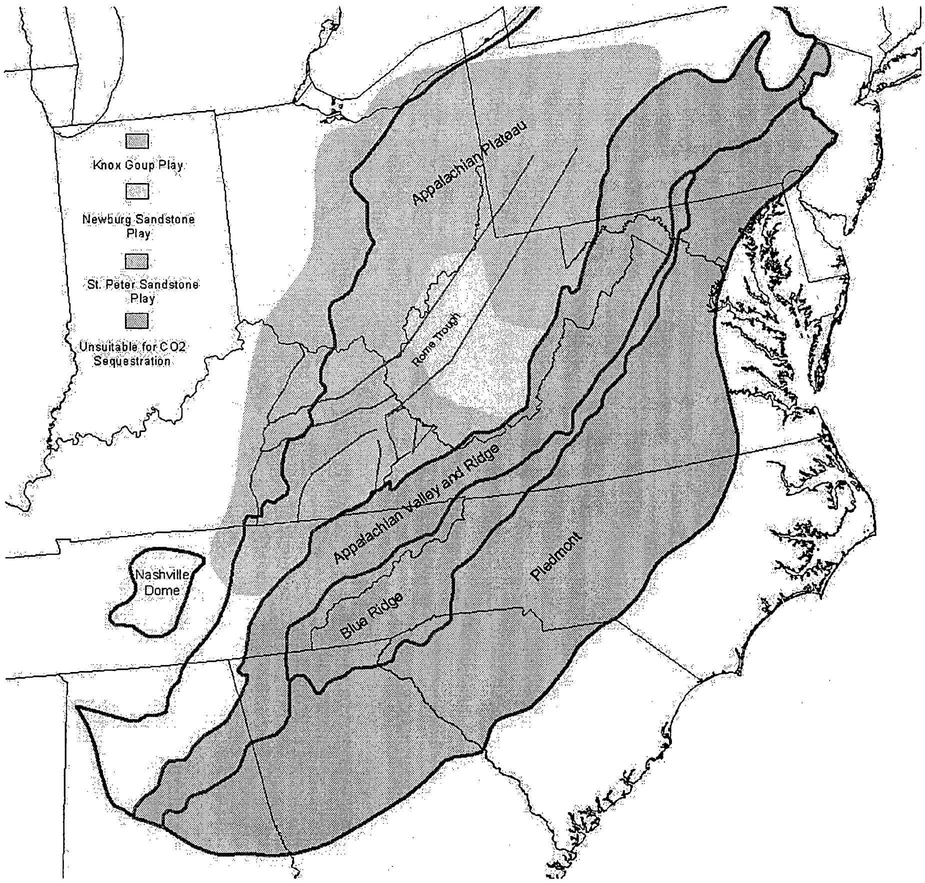


Figure 12. Physiographic provinces of the Appalachian Mountains; highlighted areas that are both unsuitable (Piedmont, Blue Ridge, and Valley and Ridge provinces) and suitable (portions of the Appalachian Plateau) for sequestration of greenhouse gasses. From Fenneman and Johnson (1946), Baranoski et al. (1996), Drahovzal and Noger (1995), Humphreys and Watson (1996), Patchen (1996), and Shumaker (1996).

The Appalachian Basin has undergone three different phases of mountain building since early Paleozoic time: the Taconic (Middle Ordovician), Acadian (Late Devonian), and Alleghenian (Pennsylvanian to Permian) orogenies. Prior to formation of the Appalachian Basin, the Grenville Orogeny (~900 Ma) and Iapetian rifting (~570 Ma) took place along a continental margin westward and parallel to what we currently know as the Atlantic coast of the United States. These earlier tectonic events influenced the stratigraphy and structural styles of subsequent tectonic events and the distribution of economic deposits found in the present-day Appalachians (King, 1959; Milici, 1996; Shumaker, 1996). For example, the Rome Trough is one of a series of grabens formed as part of the Eastern Interior Graben System. Shumaker (1996) suggested that this system represents a failed rift zone formed during Iapetian extensional tectonics. The Rome Trough is the location of one of several Appalachian Basin depocenters in which great thicknesses of Paleozoic sediments accumulated (Read, 1989).

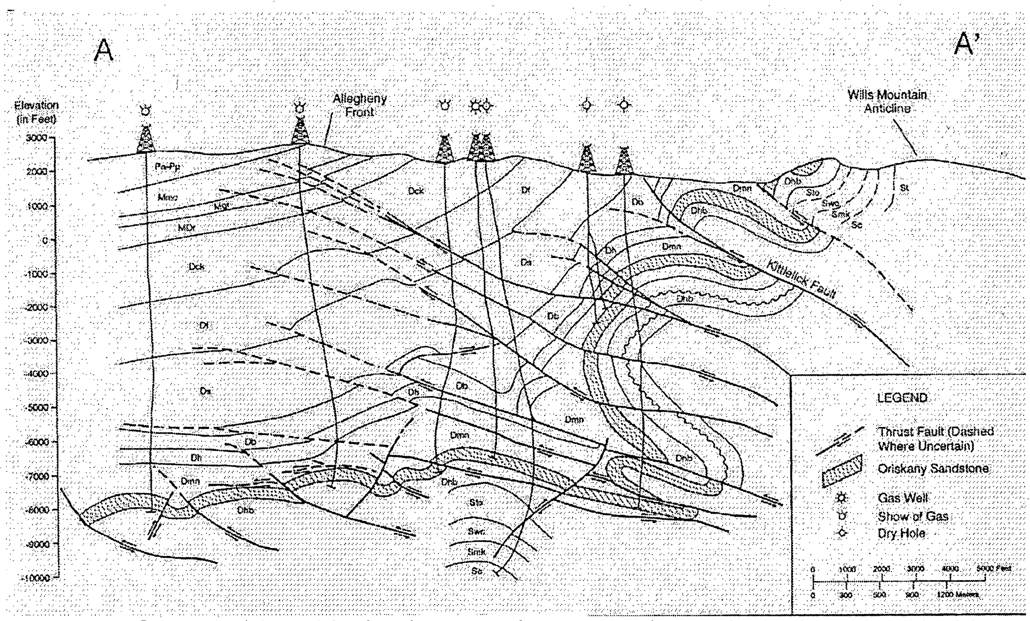


Figure 13. Cross section showing increase in structural complexity from Appalachian Plateau (A) to Appalachian Valley and Ridge (A'). Source: Figure Dos-14 in Harper and Patchen (1996).

**Blue Ridge and Piedmont**

Crystalline rocks of the Blue Ridge and Piedmont provinces have had a complex structural history, resulting from multiple episodes of plutonism, metamorphism, and deformation that occurred during continental collisions and rifting from Precambrian to early Mesozoic time (Rogers, 1949, 1972; King, 1959; King et al., 1960; Milici, 1996; Shumaker, 1996). In the late Paleozoic, Precambrian-age crystalline rocks were thrust westward over younger Paleozoic rocks, forming the Blue Ridge Mountains and resulting in extremely brittle deformation. As stated by Spencer (1972), fractures across most of the Blue Ridge province are widely spaced (~1 ft), but near major faults, fracturing becomes so intense that in some places individual crystals are shattered. Crystalline rocks of the Piedmont region are younger than those of the Blue Ridge and represent metasedimentary and granitic to ultramafic intrusive rocks accreted to the east edge of the North American continent in middle to late Paleozoic time (King, 1959; Milici, 1996). Unlike fractured carbonates of the Ordovician Knox Group, with its many feet of sedimentary cover, Blue Ridge and Piedmont rocks are exposed at the surface. Hence, brittle deformation and lack of overlying seal rule out rocks of the Blue Ridge and Piedmont provinces as greenhouse-gas repository sites.

### Valley and Ridge

As discussed in Shumaker (1996), the Grenville-age rocks present at the surface in the Blue Ridge form the basement underneath the Appalachian Plateau and Valley and Ridge provinces. Rocks comprising the valley and ridge are thought to represent an allochthonous block of Appalachian basin sediments thrust westward during continental collision (see, for example, Shumaker, 1996). Not only are strata in the valley and ridge province of the Central and Southern Appalachian Mountains folded and faulted, drilling has revealed the presence of complex buried structures, of which there is little to no surface expression. Less competent layers, such as shale, salt, and thinly bedded carbonates, which acted as décollement or detachment zones for large-scale thrust faults, contain soft-sediment deformation features (King, 1959; Spencer, 1972). Targeting horizons that have undergone such complex structural deformation as observed in the Appalachian Valley and Ridge (fig. 13) could require multiple drilling attempts and extensive characterization to assess capacity and permanence and, hence, become prohibitively expensive. However, repository horizons below $CO_2$ sources located within this physiographic province might be considered on a case-by-case basis. For example, if the subsurface structure underneath a particular power plant is reasonably well known, it might be less costly to drill in that location than to pipe the gas over adjacent valleys and ridges into a more distant and suitable area.

## Atlantic Seaboard Region Brine Storage

Along the Atlantic Seaboard, sedimentary rocks are shallow (<2,400 ft below surface) beneath most of the coastal plain so that injected $CO_2$ would be in a gas phase, and pore fluids are fresh so that injection would likely be limited by the Safe Drinking Water Act of 1974. Sedimentary rocks are found at sufficient depths (>2,400 ft below surface) only very near the Atlantic Coast. Pore fluids also become saline at about the same location, meeting the criterion for storage that the $CO_2$ be injected below potable water. The volumes that could be stored and the degree of separation of injected $CO_2$ from potable resources have not been assessed, and additional research is needed to determine whether there is an option for carbon capture and storage (CCS) at sites in this area. There may also be unassessed potential for mineral trapping by injection into large basalt bodies in the subsurface (depths >4,800 ft) of the continental margin of the southeastern U.S.

In South Carolina, the coastal plain consists of a seaward-dipping and seaward-thickening wedge of Cretaceous through Pleistocene sediments. Most stratigraphic units crop out in belts generally parallel to the coast, where they receive precipitation, which then infiltrates and flows downdip to recharge groundwater. South Carolina receives abundant rainfall, and a number of the shallow aquifers provide ample domestic and industrial water. This groundwater resource precludes use of the strata for waste storage.

The deeper portions of the eastern coastal plain are prospective because this area contains strata that are sufficiently deep, porous and permeable, and hydraulically isolated from fresh-water aquifers to make potential $CO_2$ sequestration targets. This area was identified to explore for a potential target for capture and storage of $CO_2$ from industrial activities in this region. However, depth to basement in eastern South Carolina is shallow, largely because of the Cape Fear Arch to the north (Manheim and Horn, 1968; Colquhoun et al., 1983; Aucott et al., 1987; Miller, 1990), which limits the area within South Carolina where aquifers are sufficiently deep to be candidates for $CO_2$ sequestration.

The subsurface of this area has been moderately characterized, but deep aquifers are poorly known because shallow aquifers generally provide sufficient water. There is very little potential for hydrocarbon production along coastal South Carolina, and because the state currently has laws prohibiting subsurface liquid waste disposal, there has been little subsurface research related to petroleum exploration or subsurface disposal of industrial liquid wastes.

Because the basement is so shallow in eastern South Carolina, the only potential candidate for $CO_2$ sequestration is the Upper Cretaceous Cape Fear Formation (fig. 14), which directly overlies the igneous/metamorphic basement in the region (Manheim and Horn, 1968; Colquhoun et al., 1983; Aucott et al., 1987; Miller, 1990). Farther south, in eastern Georgia, the depth to basement is greater, and, therefore, many of the data collected extend into this region. Note that the aquifer unit described later is referred to by several names in the literature: some call it Cape Fear Formation (Manheim and Horn, 1968; Aucott et al., 1987), others call it Middendorf Formation (Colquhoun et al., 1983), and other regional studies assign it a symbol, such as A4 or Unit E (Brown et al., 1979; Miller et al., 1986). Miller (1990), in his regional study, referred to this interval as the Black Warrior River aquifer.

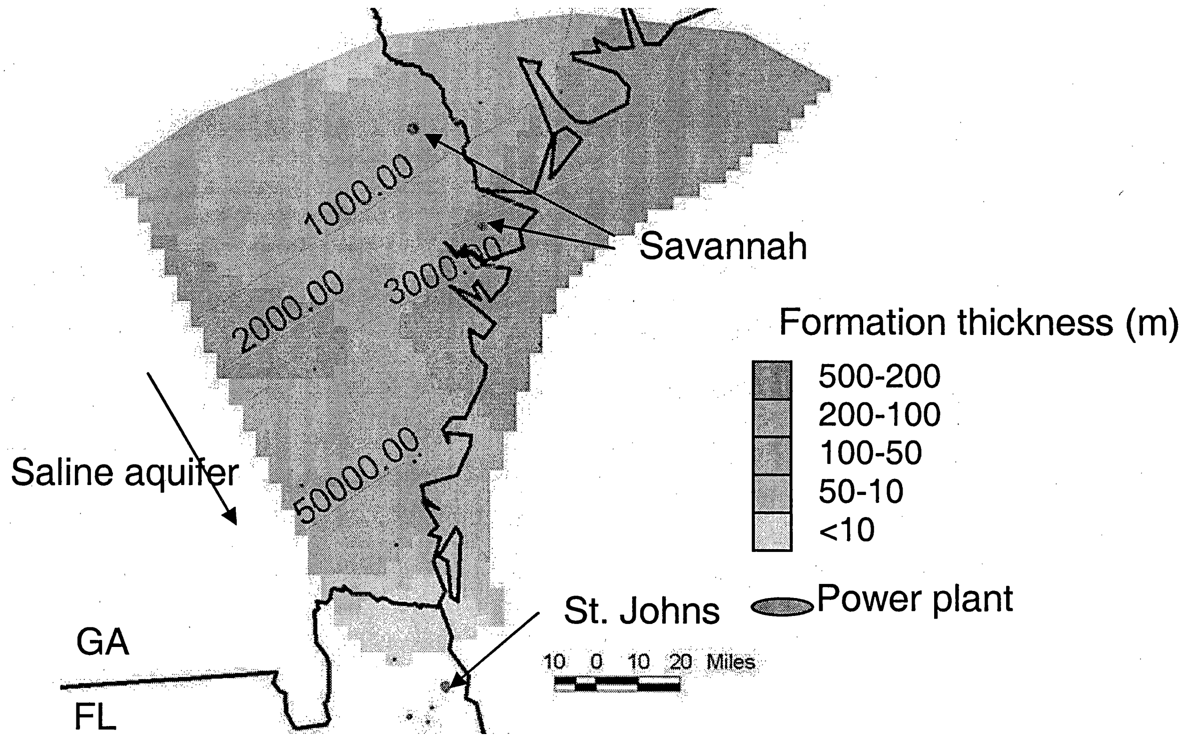


Figure 14. Coincidence of formation thickness and salinity (TDS in mg/L) in the Cape Fear Formation.

Another portion of the north-central Atlantic coastal plain where aquifers are sufficiently deep to be candidates for $CO_2$ sequestration is identified near the Atlantic shoreline in North Carolina and Virginia (Hovorka et al., 2000). The deep subsurface of this area has only been moderately studied because shallow aquifers generally provide sufficient water. There is very little potential for hydrocarbon production along the northern Atlantic coastal plain, and subsurface liquid waste disposal has been limited to shallow injection of secondarily treated wastewater (Maria Conicelli, U.S. Environmental Protection Agency, personal communication, 2000; Ching-Tzone Tienn, Maryland Department of the Environment, personal communication, 2000). However, a number of deep hydrocarbon exploration wells were drilled and analyzed, which provide valuable information on deep-aquifer properties (Anderson, 1948; Kasabach and Scudder, 1961; Maher and Applin, 1971; Trapp et al., 1984; Benson et al., 1985). A number of reports were generated to describe deep-aquifer properties as potential subsurface-waste disposal sites (Hansen, 1984). Regional aquifer analyses commonly include deeper horizons (Manheim and Horn, 1968; Brown et al., 1972; Trapp and Meisler, 1992).

Because the basement is relatively shallow in most of the north-central Atlantic coastal plain, the only regional candidate for $CO_2$ sequestration is the Lower Cretaceous Potomac Group, which is widely recognized as a major aquifer system in the northern Atlantic coastal-plain horizons (Manheim and Horn, 1968; Brown et al., 1972; Trapp and Meisler, 1992). The Potomac Group (fig. 15) directly overlies the igneous and metamorphic basement in most of the area of interest. However, there are some areas where the Potomac Group is underlain by sediments of Jurassic(?) age (Manheim and Horn, 1968; Brown et al., 1972). Several authors recognized an upper, middle, and lower Potomac aquifer (for example, Trapp and Meisler, 1992). GIS is based on the lower Potomac aquifer.

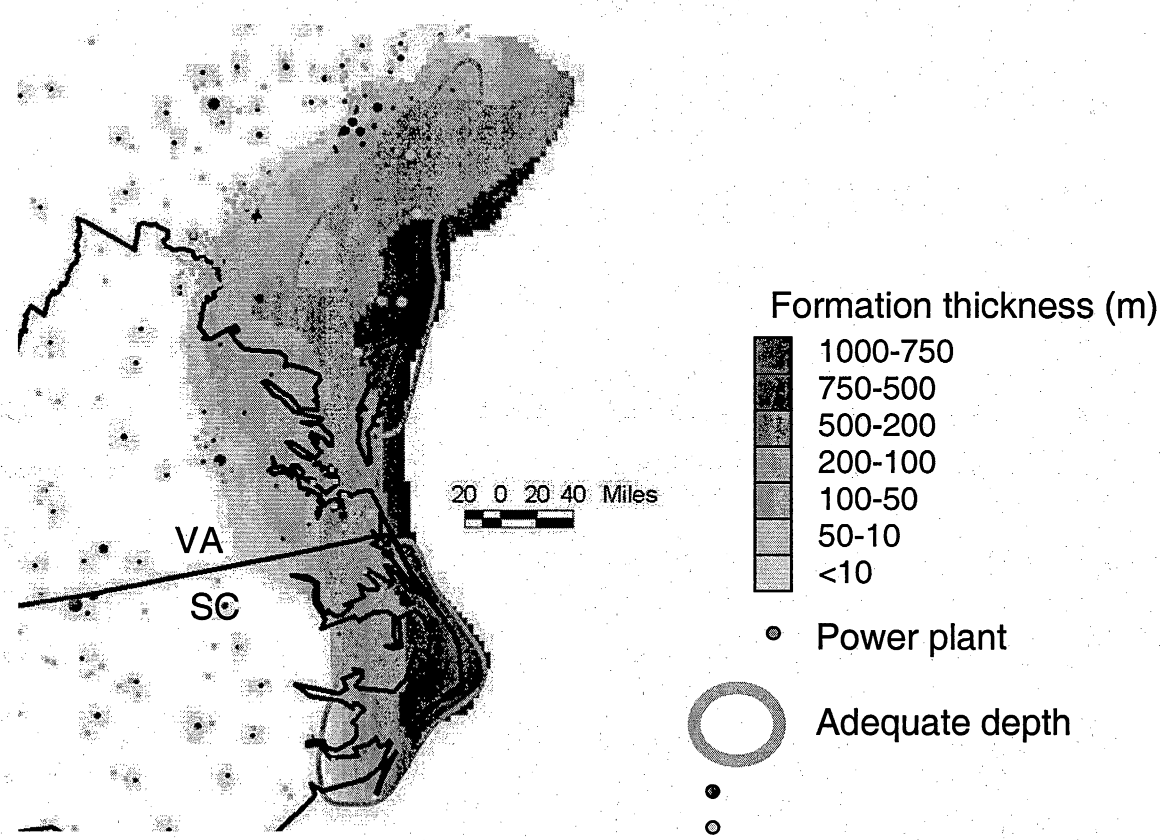


Figure 15. Location of thick lower Potomac Formation near the Atlantic coastline.

## Unassessed Areas (Mid-South Interior, Southern Georgia, Northern Florida, and Offshore Atlantic Wedge)

Three areas with moderate to good potential remain to be assessed in the SECARB region. These are southern Georgia to northern Florida, the Southeastern Mid-Continent, and the offshore Atlantic margin wedge. Sedimentary rocks become thicker and deeper in the south part of Georgia; therefore, this region may be attractive for geologic storage. Sandstones interfinger with carbonates of the Floridian aquifer. Assessment is needed to determine the distribution and depth of permeable units and the quality and distribution of seals. Data are available but must be compiled from diverse sources, integrated, and interpreted. The Southeastern Mid-Continent is underlain by a number of units that probably have geologic sequestration potential, including basal Cambrian sandstones and lower Paleozoic limestones, dolomites, and sandstones. Parts of the area (for example, the Knoxville Dome) are not suitable because here these units are too shallow and contain fresh water or they would host only gas-phase $CO_2$. Information gained elsewhere on injection into these units, for example at the Mountaineer project, will help to characterize potential of this region.

The U.S. sequestration program has not previously considered offshore storage; however it is considered a viable prospect in Europe and Japan, and for areas of the U.S. eastern seaboard with limited onshore capacity, it may be worthy of consideration. A thick wedge of sandstones and shales forms the continental shelf. Data are available for this volume from oceanographic research and from oil and gas exploration. Assessment of this area is recommended.

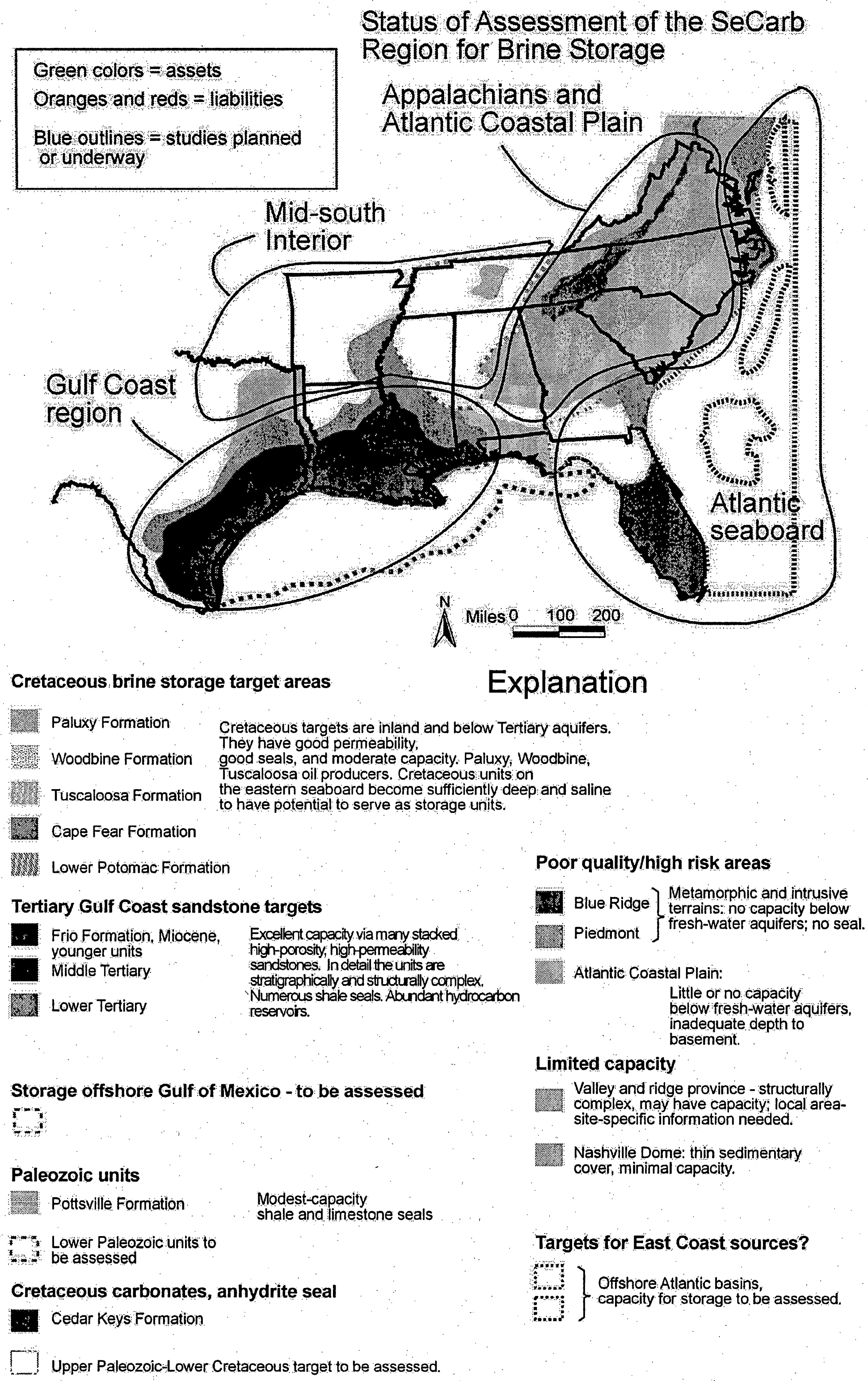


Figure 16. Overview of geologic storage potential of the SECARB region.

## Status of Terrestrial Storage Assessment, Texas

Management of terrestrial ecosystems can be used to mitigate greenhouse gases (GHG). To assess the potential for carbon sequestration in Texas, a baseline analysis of past land-use practices needs to be assembled. Changes in land use will need to be documented, and the baseline is set as land use prior to year 1990 for the Kyoto Protocol. Once past land-use practices have been established, future changes in land use can be documented and presented in the context of past practices, and the impact on carbon storage can be assessed.

The 1992 National Land Cover Data (NLCD) can serve as the baseline land use for Texas. Approximately 50% of the state is rangeland, most of which occurs in Railroad Commission of Texas Districts 7c and 8A. Although forests comprise only 15% of the state's land use, most occur in the east half of the state, with percentages of up to 54 percent in District 6. Agricultural areas are widespread throughout the state, with the exception of west Texas (Districts 7c and 8).

Data sources used to provide baseline information include NLCD, and National Agricultural Statistics Service (NASS) county-level tabular databases. National Resources Inventory data are collected by the National Resources Conservation Service (NRCS). Information on land classifications is available on NRI online at http://www.statlab.iastate.edu/survey/nri/est971nr.pdf. Information from the Farmland Mapping and Monitoring Program (FMMP) will also be collated. Full metadata, data collection details, and class descriptions are available online at ftp://ftp.consrv.ca.gov/pub/dlrp/FMMP/fmmp_meta.txt. A consistent land-use classification scheme will be used to document baseline land use and to assess changes in land use.

Estimates of above-ground biomass will be obtained from satellite imagery (Leaf Area Index, Normalized Difference Vegetation Index). Changes in above-ground biomass are evaluated and will be related to natural or anthropogenic processes where possible. Ground referencing will be used to validate satellite and air photo information. Below-ground biomass values will be estimated from species-specific rooting information and information on soil texture. Such estimates of below-ground biomass may be uncertain. Litter may also be a mechanism of carbon storage that will be examined.

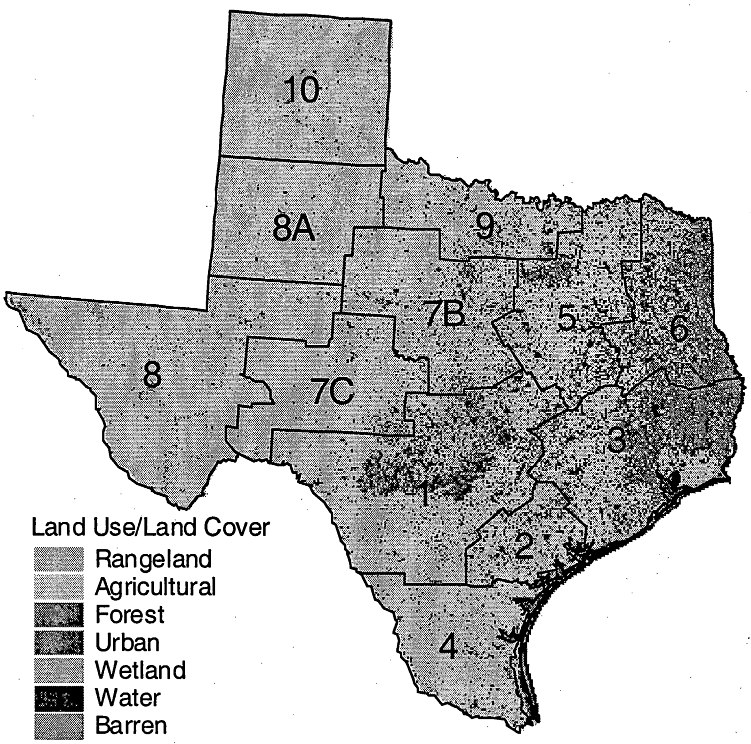


Figure 17. Railroad Commission of Texas district boundaries and National Land Cover Database (NLCD, 1992) land use/land cover.

Table 2. Calculated land use for regions of Texas divided by RRC districts. Districts 1–6 lie in the SECARB region and have much higher forest usage than the rest of the state.

| | *Land-Use Category Areas (%)* | | | | | | |
|---|---|---|---|---|---|---|---|
| *District* | *Rangeland* | *Agricultural* | *Forest* | *Urban* | *Wetland* | *Water* | *Barren* |
| 1 | 55.9 | 15.6 | 24.6 | 2.2 | 0.1 | 1.0 | 0.6 |
| 2 | 42.4 | 28.0 | 20.6 | 1.1 | 4.7 | 2.8 | 0.4 |
| 3 | 5.4 | 35.6 | 40.1 | 5.7 | 8.3 | 3.1 | 1.7 |
| 4 | 63.0 | 24.2 | 5.4 | 1.7 | 2.0 | 2.1 | 1.7 |
| 5 | 10.0 | 56.1 | 21.3 | 5.8 | 2.5 | 3.8 | 0.4 |
| 6 | 0.1 | 30.7 | 54.1 | 1.8 | 8.0 | 3.5 | 1.8 |
| 7B | 61.1 | 24.1 | 11.7 | 1.1 | 0.1 | 1.3 | 0.6 |
| 7C | 85.9 | 8.0 | 4.3 | 0.5 | 0.0 | 0.4 | 0.9 |
| 8 | 92.7 | 3.0 | 0.7 | 0.7 | 0.0 | 0.1 | 2.8 |
| 8A | 46.9 | 51.4 | 0.1 | 0.6 | 0.0 | 0.3 | 0.7 |
| 9 | 47.4 | 38.2 | 9.2 | 1.5 | 0.3 | 3.0 | 0.4 |
| 10 | 56.6 | 41.7 | 0.2 | 0.5 | 0.1 | 0.3 | 0.6 |
| Texas | 51.3 | 27.0 | 15.2 | 2.0 | 1.8 | 1.5 | 1.2 |

Rangeland: shrublands and grasslands
Agricultural: row crops, small grains, fallow, pasture/hay, orchards
Forest: perennial, evergreen, mixed
Urban: low- and high-density residential, transportation/industrial, urban grasses
Wetland: herbaceous and woody emergent wetlands
Water: open water
Barren: bare rock, quarries/open pit mines, transitional

## Conclusions

The most immediate and best-known potential for geologic storage of $CO_2$ in the SECARB region is in miscible oil reservoirs along the Gulf Coast. On a reservoir-by-reservoir basis, capacity of the subsurface is very well known, quality of the seal is proven, and cost of storage would be offset by $CO_2$ -EOR. $CO_2$ that could be stored as part of this economic activity measures 2,600 million metric tons. Very large volumes of $CO_2$ could be stored in the same area in brine-bearing sandstones with high-quality shale seals that would isolate $CO_2$ from underground sources of drinking water and not allow it to escape to the atmosphere.

Part of the SECARB region is underlain by rocks of the Blue Ridge and Piedmont physiographic provinces. The rocks are crystalline and metamorphic and have low potential for providing geologic environments for the storage component of CCS. Beneath the west part of the coastal plain, sedimentary rocks are shallow (<2,400 ft below surface) so that injected $CO_2$ would be in gas phase, and pore fluids are fresh so that injection would likely be prohibited. We rank the likelihood of locating suitable, secure, large-volume storage sites in the Blue Ridge, the Piedmont, and most of the Atlantic Coastal Plain very low.

On the Eastern Seaboard, sedimentary rocks are found at sufficient depths (>2,400 ft below surface) only very near the Atlantic Coast. Pore fluids also become saline at about the same location, meeting the criterion for storage that it occur below potable water. The volumes that could be stored and the degree of separation of injected $CO_2$ from potable resources have not been assessed, and additional research is needed to determine whether there is an option for CCS at sites in this area. That $CO_2$ could be stored offshore in the Atlantic Shelf sedimentary wedge is a possibility in need of additional investigation.

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