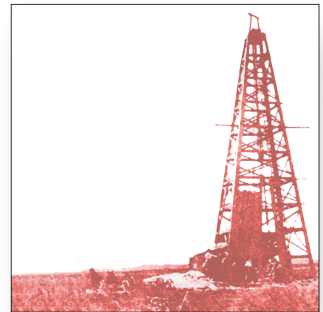
Chapter 2

Assessment of Undiscovered Conventional Oil and Gas Resources—Upper Jurassic–Lower Cretaceous Cotton Valley Group, Jurassic Smackover Interior Salt Basins Total Petroleum System, in the East Texas Basin and Louisiana-Mississippi Salt Basins Provinces



Click here to return to
Volume Title Page

By T.S. Dyman and S.M. Condon

Chapter 2 of

Petroleum Systems and Geologic Assessment of Undiscovered Oil and Gas, Cotton Valley Group and Travis Peak–Hosston Formations, East Texas Basin and Louisiana-Mississippi Salt Basins Provinces of the Northern Gulf Coast Region

By U.S. Geological Survey Gulf Coast Region Assessment Team

U.S. Geological Survey Digital Data Series DDS–69–E

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
P. Patrick Leahy, Acting Director

U.S. Geological Survey, Reston, Virginia: 2006

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1–888–ASK–USGS

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone:1–888–ASK–USGS

Suggested citation:
Dyman, T.S., and Condon, S.M., 2006, Assessment of undiscovered conventional oil and gas resources—Upper Jurassic–Lower Cretaceous Cotton Valley Group, Jurassic Smackover Interior Salt Basins Total Petroleum System, in the East Texas Basin and Louisiana-Mississippi Salt Basins Provinces: U.S. Geological Survey Digital Data Series DDS–69–E, Chapter 2, 48 p.

ISBN=1411309960

Contents

Plates

Figures

Tables

Assessment of Undiscovered Conventional Oil and Gas Resources—Upper Jurassic–Lower Cretaceous Cotton Valley Group, Jurassic Smackover Interior Salt Basins Total Petroleum System, in the East Texas Basin and Louisiana-Mississippi Salt Basins Provinces

By T.S. Dyman and S.M. Condon

Abstract

The Jurassic Smackover Interior Salt Basins Total Petroleum System is defined for this assessment to include (1) Upper Jurassic Smackover Formation carbonates and calcareous shales and (2) Upper Jurassic and Lower Cretaceous Cotton Valley Group organic-rich shales. The Jurassic Smackover Interior Salt Basins Total Petroleum System includes four conventional Cotton Valley assessment units: Cotton Valley Blanket Sandstone Gas (AU 50490201), Cotton Valley Massive Sandstone Gas (AU 50490202), Cotton Valley Updip Oil and Gas (AU 50490203), and Cotton Valley Hypothetical Updip Oil (AU 50490204). Together, these four assessment units are estimated to contain a mean undiscovered conventional resource of 29.81 million barrels of oil, 605.03 billion cubic feet of gas, and 19.00 million barrels of natural gas liquids.

The Cotton Valley Group represents the first major influx of clastic sediment into the ancestral Gulf of Mexico. Major depocenters were located in south-central Mississippi, along the Louisiana-Mississippi border, and in northeast Texas. Reservoir properties and production characteristics were used to identify two Cotton Valley Group sandstone trends across northern Louisiana and east Texas: a high-permeability blanket-sandstone trend and a downdip, low-permeability massive-sandstone trend. Pressure gradients throughout most of both trends are normal, which is characteristic of conventional rather than continuous basin-center gas accumulations. Indications that accumulations in this trend are conventional rather than continuous include (1) gas-water contacts in at least seven fields across the blanket-sandstone trend, (2) relatively high reservoir permeabilities, and (3) high gas-production rates without fracture stimulation. Permeability is sufficiently low in the massive-sandstone trend that gas-water transition zones are vertically extensive and gas-water contacts are poorly defined. The interpreted presence of gas-water contacts within the Cotton Valley massive-sandstone trend, however, suggests that accumulations in this trend are also conventional.

Introduction

The U.S. Geological Survey (USGS) is currently reassessing the undiscovered resource potential of 25 priority provinces in onshore areas of the United States that are estimated to contain 95 percent of the known and undiscovered petroleum resources. The National Oil and Gas Assessment (NOGA) Project particularly includes a reevaluation of continuous basin-center gas systems in these high-priority basins in order to accommodate changing views and new data since the last USGS assessment in 1995.

NOGA assessments are based on a total petroleum system–assessment unit approach. “A total petroleum system is a mappable hydrocarbon-fluid system with all of the essential elements and processes needed for oil and gas accumulations to exist, including the presence of source and reservoir rocks, hydrocarbon generation and migration, traps and seals, and undiscovered accumulations. An assessment unit is a mappable volume of rock within a total petroleum system that contains discovered and undiscovered fields that are relatively similar with respect to geology, exploration strategy, and risk characteristics” (Ahlbrandt, 2000, no page numbers). NOGA assessments are quantitative and probabilistic and are based on petroleum geologic and engineering data.

The purposes of this report are to (1) summarize the petroleum geology of the East Texas Basin and Louisiana-Mississippi Salt Basins Provinces, (2) identify and describe total petroleum systems and assessment units within the Upper Jurassic and Lower Cretaceous Cotton Valley Group, and (3) assess oil and gas resources for each assessment unit (fig. 1). For this assessment, the East Texas Basin and Louisiana-Mississippi Salt Basins Provinces (originally Provinces 5048 and 5049, respectively) have been combined as Province 5049.

Through the use of a total petroleum system approach, we analyze both source- and reservoir-rock potential for each assessment unit. The lower part of the Cotton Valley Group in east Texas, the Bossier Shale, will be assessed separately at a later date.

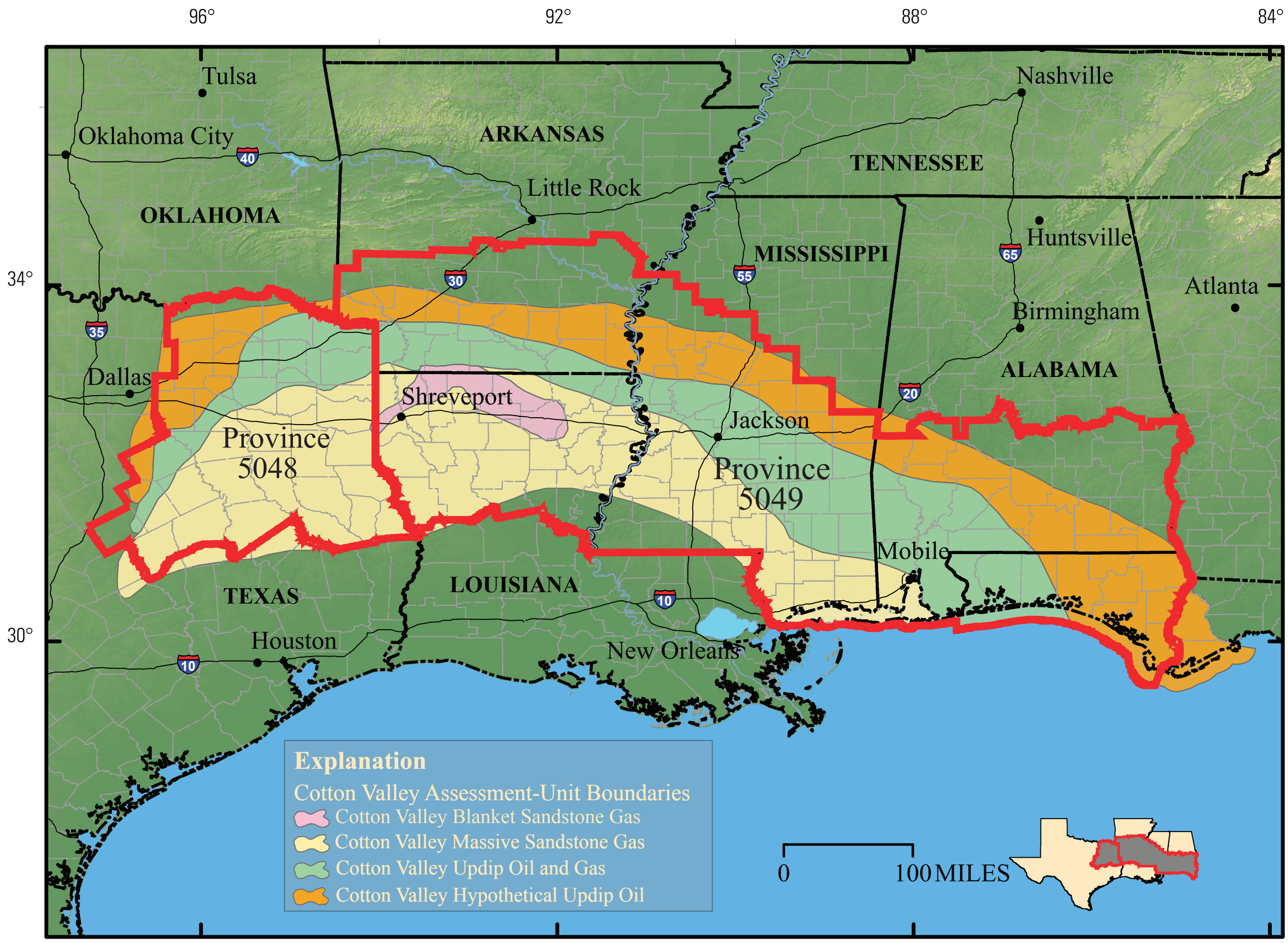


Figure 1. Map of the north-central coastal plain of the Gulf of Mexico, showing the four Cotton Valley Group assessment units (see color key) identified by us for this current assessment. In 1995, the U.S. Geological Survey (Schenk and Viger, 1996; Gautier and others, 1996) assessed three Cotton Valley Group plays. These were the Cotton Valley Blanket Sandstones Gas and Oil Play, identified in 1995 as a continuous-gas play, and the Cotton Valley Salt Basins Gas Play and the Cotton Valley Sabine Uplift Gas Play, identified as conventional-gas plays. Province 5048 is the East Texas Basin Province, and Province 5049 is the Louisiana-Mississippi Salt Basins Province; their boundaries are shown in red. Both provinces have been combined for this new assessment.

As part of the effort leading to the publication of the 1995 National Assessment of United States Oil and Gas Resources, Schenk and Viger (1996) identified one continuous-type basin-center gas play and two conventional-gas plays within the sandstone trend of the Cotton Valley Group in the East Texas Basin and Louisiana-Mississippi Salt Basins Provinces (figs. 2, 3). This assessment is an update of part of that work.

Acknowledgments

We acknowledge the helpful manuscript reviews of Debra Higley, James Otton, and Katharine Varnes. The U.S. Geological Survey Gulf Coast Region Assessment Team is composed of T.S. Dyman, S.M. Condon, R.R. Charpentier, T.A. Cook, T.R. Klett, M.D. Lewan, R.M. Pollastro, C.J. Schenk, and J.W. Schmoker. We recognize C.E. Bartberger for his work on the geologic and production characteristics of the Cotton Valley Group. Many thanks to Mary Eberle, for numerous improvements to the manuscript. This report summarizes information in Bartberger and others (2002).

Data Sources and Digital Maps

Cotton 1.ai

Interpretations, conclusions, maps, and resource estimates presented in this report are based on data from published literature, geologic and engineering data in both publicly available and proprietary databases, and conversations with industry personnel. Well and reservoir history and production information were compiled from digital data files of IHS Energy Group (PI/Dwights PLUS on CD-ROM) (PI/Dwights

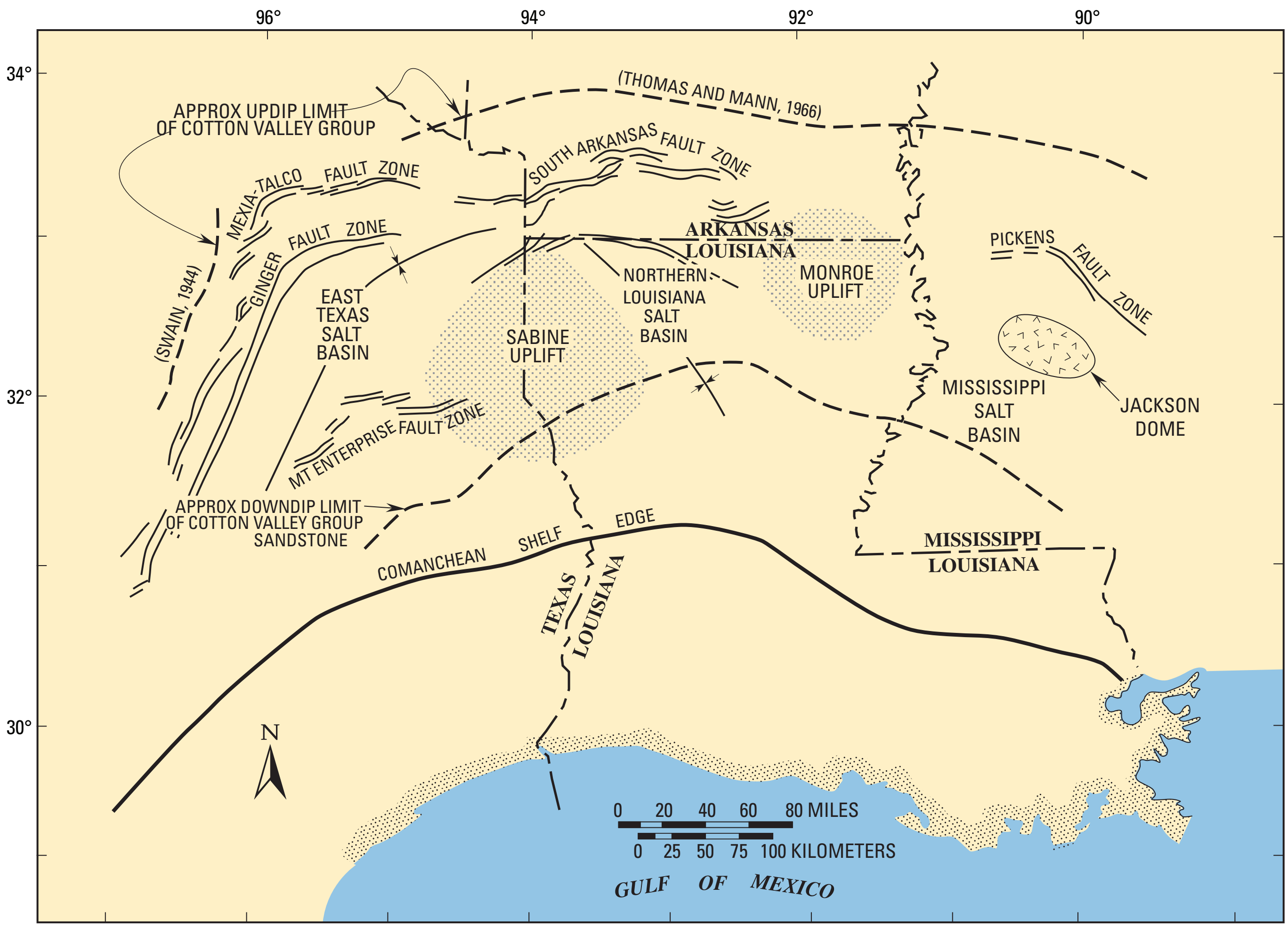


Figure 2. Index map of the north-central coastal plain of Gulf of Mexico (modified from Dutton and others, 1993, with additions from Thomas and Mann, 1966, and Swain, 1944), showing major tectonic features. The Sabine and Monroe uplifts were not positive features during deposition of Cotton Valley Group sediments. Cotton Valley depocenters (fig. 7) were located across the entire region from east Texas to Alabama. Salt movement in the East Texas Basin and northern Louisiana Salt Basin was contemporaneous with deposition of Cotton Valley Group clastic sediments. The Cotton Valley Group is an entirely subsurface sequence of strata with approximate updip limits shown here.

PLUS is a trademark of Petroleum Information/Dwights, d.b.a. IHS Energy Group).

IHS Energy Group data were current as of April 2001. Information queries resulted in data subsets including (1) wells that report a formation top for the Upper Jurassic–Lower Cretaceous Cotton Valley Group, (2) wells that report formation tops for the Upper Jurassic Smackover Formation, and (3) wells that report oil and/or gas production from the Cotton Valley Group. These data were then imported into ArcView GIS (geographic information system) desktop software (version 3.2) by Environmental Systems Research Institute, Inc. (ESRI), and displayed in map formats. Other map data, such as the distribution of environments of deposition of the Cotton Valley Group, were scanned from the published literature, imported into ArcView, and registered to a digital base map. GIS layers of these data were made by tracing over the scanned images with ArcView drawing tools.

Contour maps were constructed by using thickness and depth files consisting of longitude, latitude, and either the thickness of the Cotton Valley Group and associated units or the depth below sea level of the top of the Cotton Valley. These files were then read into EarthVision software (Dynamic Graphics, Inc., EarthVision Work Flow Manager, version 7), gridded, and contoured. Preliminary versions of each map were examined for data errors. Incorrect data were removed from the data sets or corrected, and maps were replotted. This process was repeated until all obvious errors were removed. A particular data problem was noted in east Texas where 152 wells (and one well in Louisiana) identified the top of the Cotton Valley Group at a lower depth than the top of the Bossier Shale. Calculations of the Cotton Valley thickness and subsea depth were affected by this data anomaly, and these wells were removed from the data sets. Contour maps were then imported into ArcMap (ESRI), added to other layers

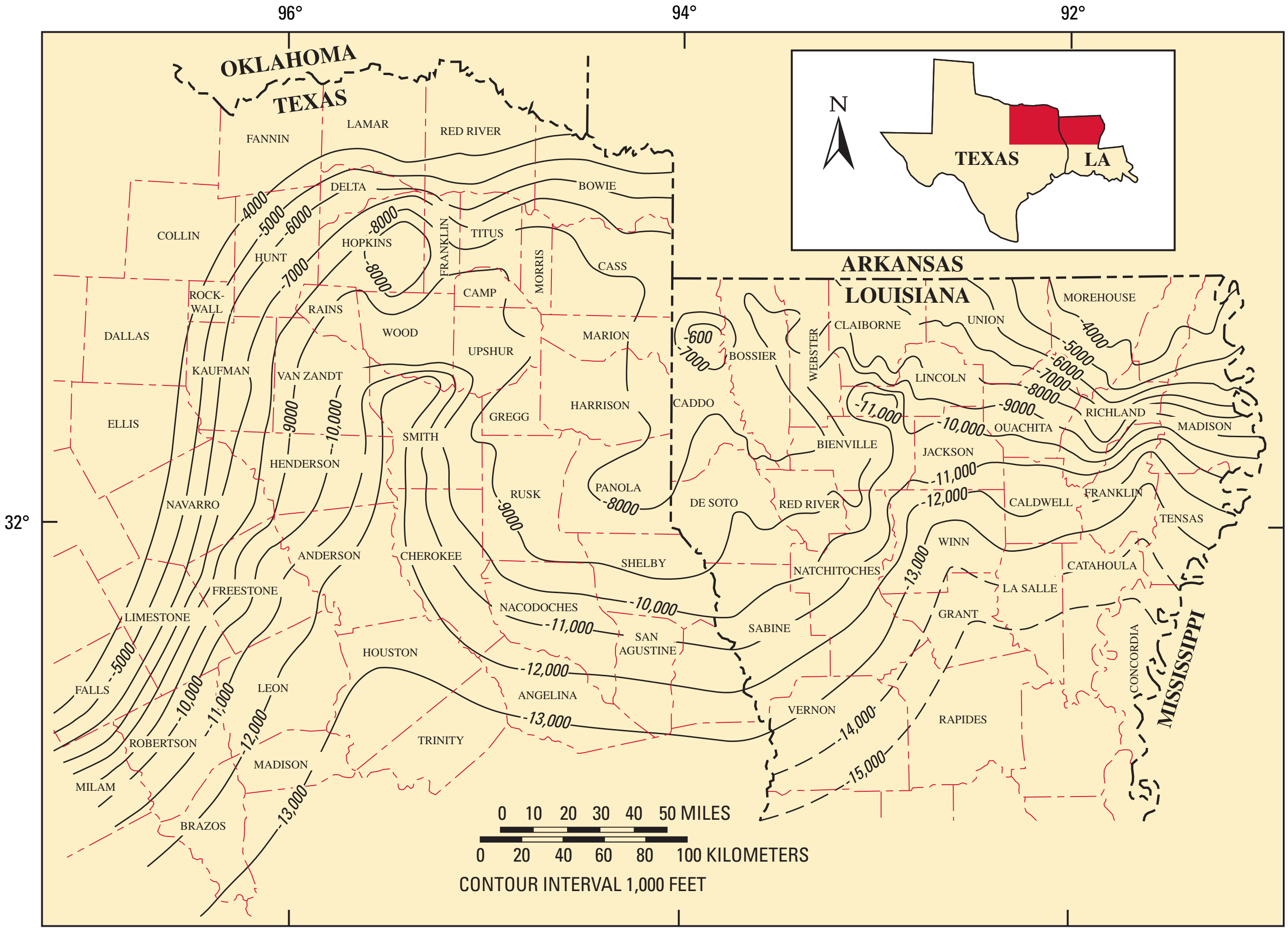


Figure 3. Generalized structure contours on top of Cotton Valley Group sandstones across northeast Texas and northern Louisiana (modified from Finley, 1984).

(such as a base-map layer), and lastly exported to Adobe Illustrator (version 10.0) for final preparation as plates and figures in this report. Because of the proprietary nature of the database, the exact locations of wells could not be shown. Instead, the map area was divided into cells, 0.5 mi on a side (four cells per square mile), and within each cell, the appropriate data from all wells were summarized at the center point of that cell. This technique allows us to show the general distribution and density of control points without revealing the proprietary locations of individual wells. Each plate is referenced in the text of this report where needed, and hotlinks are provided for quick reference.

Oil and gas field data for discovered fields used in this assessment were compiled from the "Significant Oil and Gas Fields of the U.S." database by NRG Associates (1999). The NRG database includes field and reservoir identification and location, geologic characteristics of each reservoir, and total recoverable petroleum volumes for oil and gas fields that exceed 3 billion cubic feet (BCF) of gas and 0.5 million barrels of oil (MMBO) or greater. These data are commercially available through NRG Associates.

Geologic Setting of Cotton Valley Group

The Upper Jurassic and Lower Cretaceous Cotton Valley Group consists of sandstone, shale, and limestone and underlies much of the northern coastal plain of the Gulf of Mexico from east Texas to Alabama (fig. 2; pl. 1). Cotton Valley strata form a sedimentary wedge that thickens southward toward the Gulf of Mexico from a zero edge in southern Arkansas, central Mississippi, southern Alabama, and east Texas (pl. 2). Depth to the top of the Cotton Valley ranges from about 750 ft subsea near the updip zero edge to >15,000 ft subsea along the southern margins of the East Texas Basin and Louisiana-Mississippi Salt Basins Provinces (figs. 2, 3; pl. 3). In southeastern Mississippi, the top of the Cotton Valley Group occurs at nearly 20,000 ft subsea. The greatest thickness of Cotton Valley rocks penetrated exceeds 5,000 ft in southeastern Mississippi (Moore, 1983). The downdip limit of the Cotton Valley Group in the Gulf Coast region has not yet been identified by drilling.

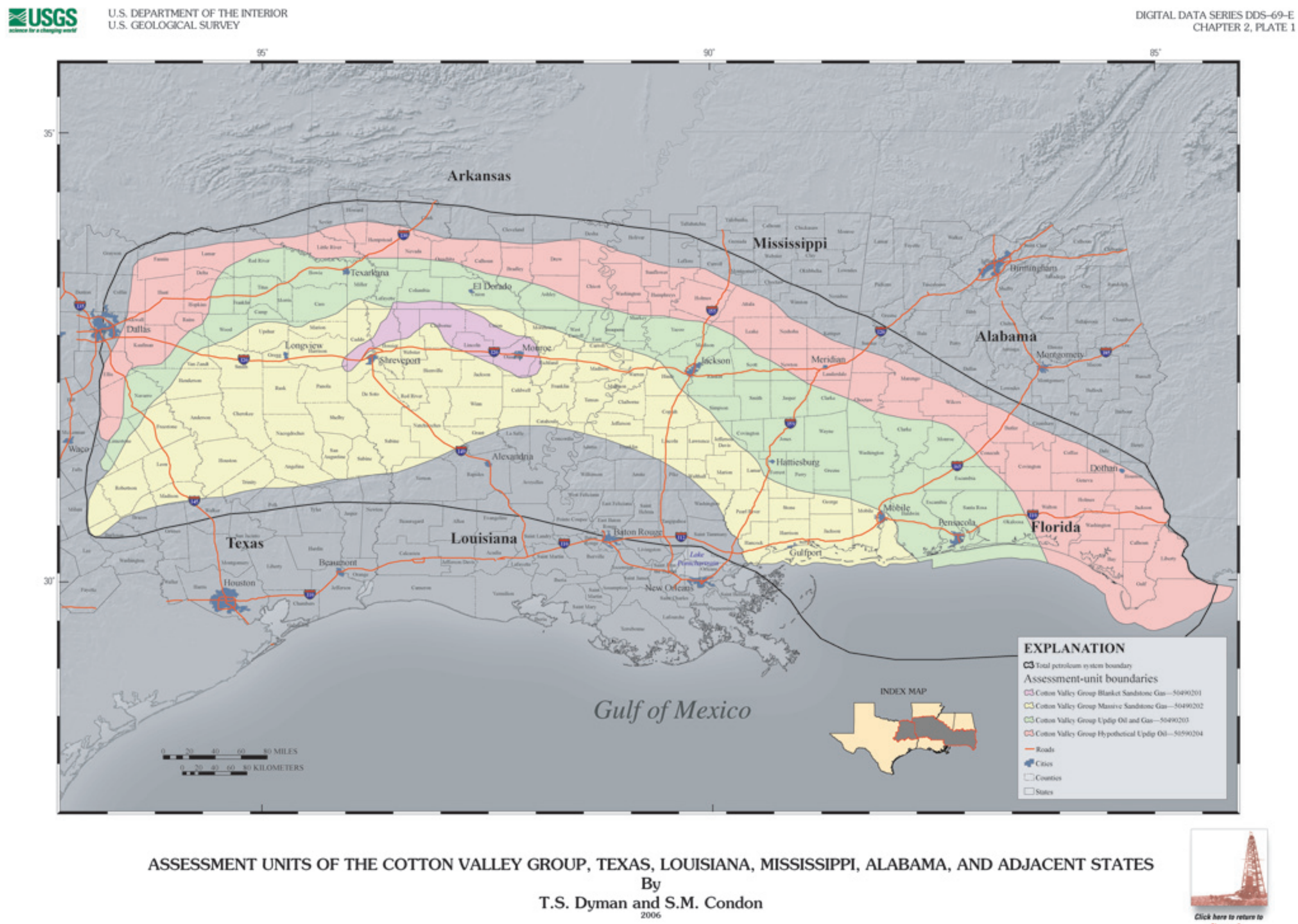


Plate 1. Assessment units of the Cotton Valley Group. This map shows the four assessment units of the upper part of the Cotton Valley Group (exclusive of the Bossier Shale) on a detailed base map. The assessment units are as follows: Cotton Valley Blanket Sandstone Gas, number 50490201; Cotton Valley Massive Sandstone Gas, number 50490202; Cotton Valley Updip Oil and Gas, number 50490203; Cotton Valley Hypothetical Updip Oil, number 50490204. The assessment units were defined by plotting the locations of all wells that have tops reported for the Cotton Valley Group and by plotting the distribution of wells that produce gas or oil from the Cotton Valley. The well-distribution plots are shown on plates 3–5. Then a map (fig. 8) showing a classification of Cotton Valley reservoir type based on properties of the producing intervals was used to define areas of blanket sandstones and massive sandstones. The blanket-sandstone assessment unit differs from the massive-sandstone assessment unit by having higher porosity and permeability values (see text for a more detailed description of the differences between the two units). The Cotton Valley Updip Oil and Gas Assessment Unit has reservoir properties similar to those of the Cotton Valley Massive Sandstone Gas Assessment Unit, but occurs in a shallower, updip structural position and produces both gas and oil. The blanket- and massive-sandstone assessment units also have some oil production, but gas is the major product. The Cotton Valley Hypothetical Updip Oil Assessment Unit was defined as the area that is updip from the Cotton Valley Updip Oil and Gas Assessment Unit but that also includes both the Cotton Valley Group and the underlying Smackover Formation. The rationale for defining this area was that both the potential source rock (Smackover) and the potential reservoir (Cotton Valley) needed to be present to delineate a hypothetical assessment unit; however, no production has been reported from this area to date. The source of well production and formation data used to define the four assessment units is IHS Energy Group (PI/Dwights PLUS, a trademark of Petroleum Information/Dwights, d.b.a. IHS Energy Group).

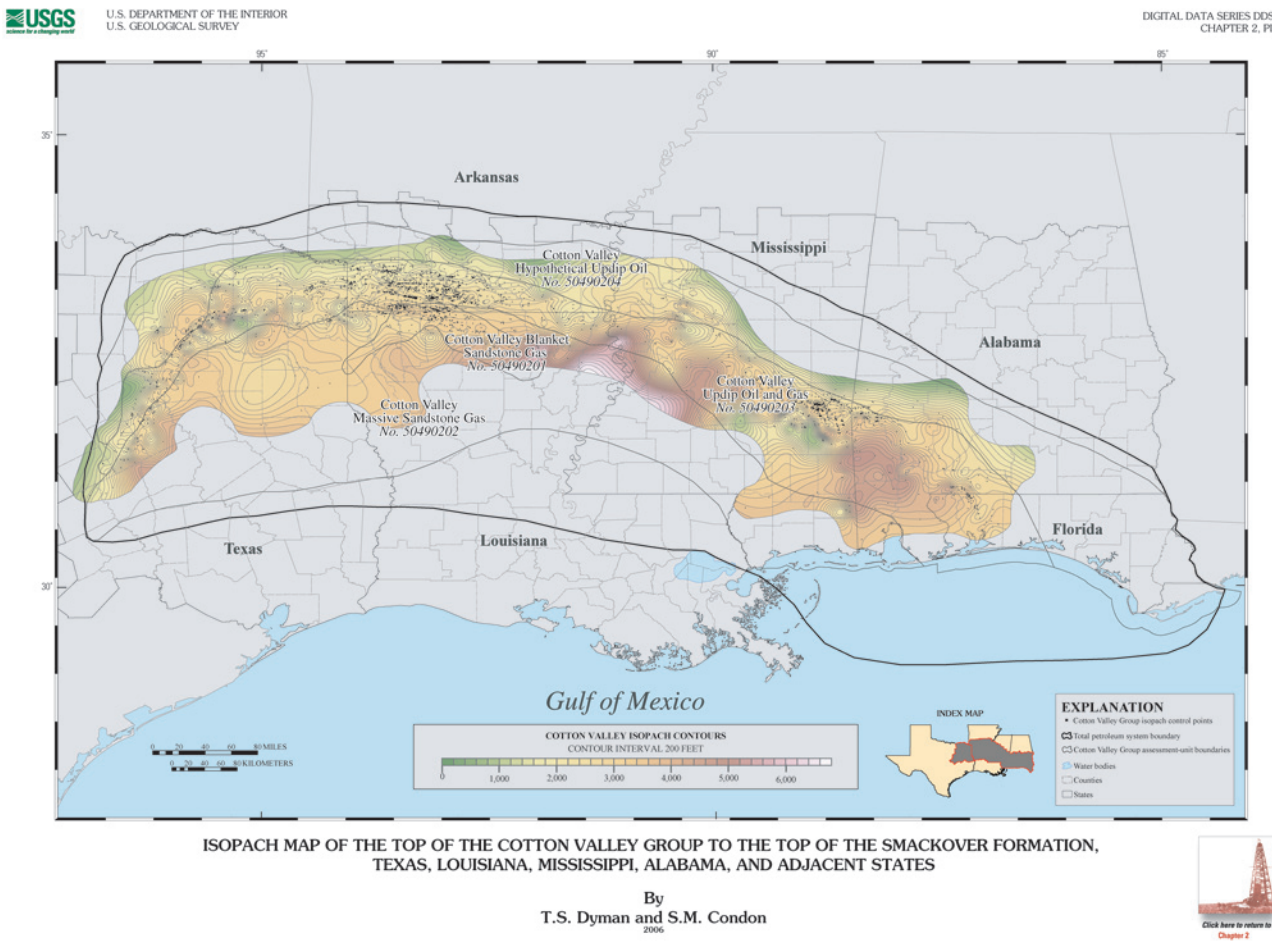


Plate 2. Isopach map of the interval from the top of the Cotton Valley Group to the top of the Smackover Formation interval. This isopach map shows the thickness of the interval from the top of the Cotton Valley Group to the top of the underlying Smackover Formation. It was necessary to contour this expanded interval, instead of just the upper part of the Cotton Valley Group, because of the limited availability of data. Ideally, just the part of the Cotton Valley Group above the Bossier Shale would have been contoured, but there are few Bossier picks in the database, and many of the Bossier picks are not at a consistent stratigraphic break (J.L. Ridgley, oral commun., 2002). Data for units below the Bossier, such as the Haynesville or Buckner Formations, are also limited on a regional basis. The Smackover Formation has abundant formation-tops data available on a regional level. The map was produced by first subtracting the values of the top of the Cotton Valley Group from those of the top of the Smackover Formation. This procedure resulted in a data set of 3,429 values for which latitude-longitude locations were available. The data were then gridded and contoured in the EarthVision software package (Dynamic Graphics, Inc., EarthVision Work Flow Manager, version 7), and the contours were exported into ArcMap (ESRI). The thicknesses in the data set range from 12 to 6,644 ft, although most are <5,500 ft. As noted above, some wells, especially in east Texas, record the top of the Cotton Valley as being below the top of the Bossier. These wells were excluded. After filtering out obviously erroneous data, a total of 3,390 wells were used for the map. In general, the map shows a downdip (southward) thickening of the interval; thickest areas are in (1) the southern part of the study area in Texas, (2) along the border between Louisiana and Mississippi, and (3) in southwestern Alabama along the border with Mississippi. The region with the thickest unit is in the central part of the map, which reflects input of sediment from the ancestral Mississippi River.

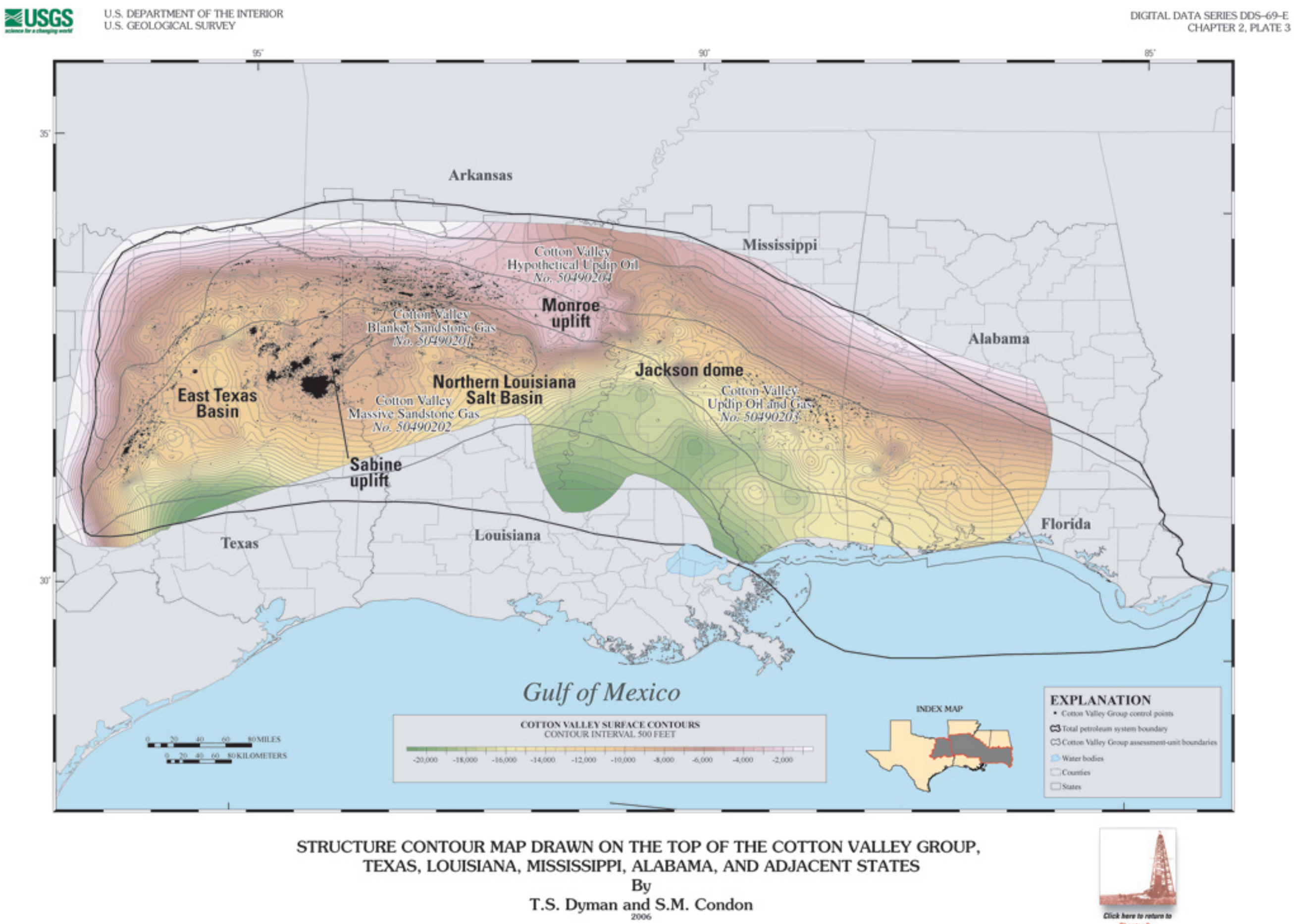


Plate 3. Structure contour map drawn on the top of the Cotton Valley Group. This map shows the structural configuration on the top of the Cotton Valley Group in feet below sea level. The map was produced by calculating the difference between a datum at the land surface (the elevation at either the kelly bushing or the ground surface) and the reported depth of the Cotton Valley Group. This procedure resulted in a data set of 10,687 wells for which latitude-longitude locations were available. The data were gridded and contoured in the EarthVision software package and exported to ArcMap. The elevation values range from 983 to 20,600 ft below sea level. Some data were examined in areas where "bull's-eyes" were evident, and some were found to be in error, but others just indicated small anticlines. After deleting the wells with obvious data problems, a total of 10,504 wells were used to generate the map. The map shows a gradual southward deepening of the top of the Cotton Valley Group; basins and domes are superimposed on the general trend. From west to east, some of the major features are (1) the East Texas Basin, (2) the Sabine uplift on the border between Texas and Louisiana, (3) the northern Louisiana Salt Basin, (4) the Monroe uplift in northeast Louisiana, and (5) Jackson dome in Mississippi. The deepest area that has relatively good data control is in southwestern Mississippi.

The Cotton Valley Group represents the first major influx of terrigenous clastic sediments into the coastal region of the Gulf of Mexico following continental rifting in Late Triassic time (Salvador, 1987; Worrall and Snelson, 1989). Earlier sedimentary deposits in the region (fig. 4) include Upper Triassic nonmarine red beds of the Eagle Mills Formation, the thick evaporite sequence of the Middle Jurassic Werner Formation (anhydrite) and Middle and Upper Jurassic Louann Salt, and the nonmarine Upper Jurassic Norphlet Formation. Following a major regional marine transgression across the region, regressive carbonates of the Upper Jurassic Smackover Formation were deposited and capped by red beds and evaporites of the Upper Jurassic Buckner Formation (fig. 4). Terrigenous clastic rocks of the Haynesville Formation overlie the Buckner in northern Louisiana and Mississippi. The marine Bossier Shale, the lowermost formation of the Cotton Valley Group (figs. 4, 5), was deposited conformably on the Gilmer Limestone and Haynesville Formation.

Louann Salt became mobile as a result of sediment loading and associated basinward tilting during Smackover Formation carbonate deposition. Salt mobility increased with the influx of Cotton Valley Group clastic sediments (McGowen and Harris, 1984), and numerous salt structures developed in the region.

The Sabine uplift is a broad, low-relief, basement-cored arch separating the East Texas Basin from the northern Louisiana Salt Basin (fig. 2). With vertical relief of about 2,000 ft (fig. 3), the Sabine uplift has an area of closure of >2,500 mi^2 (Kosters and others, 1989). Isopach data across the uplift indicate that it was a positive feature during deposition of the Jurassic Louann Salt, but primary uplift occurred in the late mid-Cretaceous (101–98 Ma) and early Tertiary (58–46 Ma) (Laubach and Jackson, 1990; Jackson and Laubach, 1991) (pl. 3). The Sabine uplift has been a focal area for hydrocarbon migration in the northern coastal plain of the Gulf of Mexico for the past 60 m.y.

Cotton Valley Group Stratigraphic Nomenclature

Since the first well was drilled in 1927 into Cotton Valley strata in northern Louisiana, informal stratigraphic nomenclature developed as numerous Cotton Valley oil and gas fields were discovered and described across the region through the 1940s. The proliferation of stratigraphic names is due to complex local facies differences in northern Louisiana and also to variability in Cotton Valley depositional systems across the northern coastal plain of the Gulf of Mexico. Terminology established by Swain (1944) was used until Cotton Valley stratigraphy was revised by Thomas and Mann (1963) and Mann and Thomas (1964). Most subsequent published reports, including the classic work of Collins (1980), used the Mann-Thomas stratigraphic terminology. Refinements to that terminology have been contributed by Coleman and Coleman (1981) and Eversull (1985).

Cotton Valley Group lithofacies and associated stratigraphic nomenclature in northern Louisiana are shown in figures 5 and 6. The basal formation of the Cotton Valley Group is the Bossier Shale, a dark-gray, calcareous, fossiliferous, marine shale ranging in thickness from 250 to 2,000 ft (Montgomery, 2001). In east Texas, isolated turbidite sandstones occur within the Bossier Shale (Collins, 1980). Overpressured gas currently is being produced from these sandstones in a rapidly developing new play (PI/Dwights Drilling Wire, Jan. 3, 2000; Exploration Business Journal, 2nd quarter, 2000). Completely encased in marine shale, these gas-charged sandstones might represent a basin-center gas accumulation.

The Bossier Shale grades upward into middle and upper Cotton Valley Group sandstones and shales. Sandstones consist of stacked barrier-island, offshore-bar, strand-plain, and fluvial-deltaic units referred to as the Terryville massive-sandstone complex in northern Louisiana by Coleman and Coleman (1981). In east Texas, the stratigraphically equivalent unit is called the Cotton Valley sandstone and consists of braided-stream, fan-delta, and wave-dominated deltaic sandstones (Wescott, 1983; Coleman, 1985; Dutton and others, 1993). Across the Cotton Valley hydrocarbon-productive trend in east Texas and northern Louisiana, the Terryville Sandstone or Cotton Valley sandstone averages about 1,000–1,400 ft in thickness (Finley, 1984; Presley and Reed, 1984; pl. 2). Sand deposition was interrupted in Early Cretaceous time by a regional transgressive event marked by deposition of Knowles Limestone (figs. 5, 6). In updip areas of east Texas and south Arkansas, the Knowles Limestone pinches out, and clastic rocks of the Travis Peak Formation and equivalent Hosston Formation directly overlie Cotton Valley Group sandstones (figs. 4, 5, 6). Saucier (1985) interpreted the Knowles Limestone as the uppermost formation of the Cotton Valley Group, but Coleman and Coleman (1981) included the stratigraphically higher Calvin Sandstone and Winn Limestone within the Cotton Valley Group (figs. 5, 6).

Cotton Valley Group Depositional Systems

Terryville Massive Sandstones

From east Texas to Mississippi, stacked barrier-island, strand-plain, and fluvial-deltaic sandstones—known as the Cotton Valley Group sandstone or Terryville Sandstone (fig. 5)—are associated with several depocenters. Cotton Valley Group depocenters and paleogeography across northern Louisiana are described by Coleman and Coleman (1981), who subdivided the Terryville Sandstone into four depositional “events” separated by widespread shale breaks (Roman numerals refer to the four depositional events in fig. 6). Moore (1983) compiled paleogeographic reconstructions of Cotton Valley Group sandstone deposition across south-central Mississippi. Paleogeographic reconstructions have not been

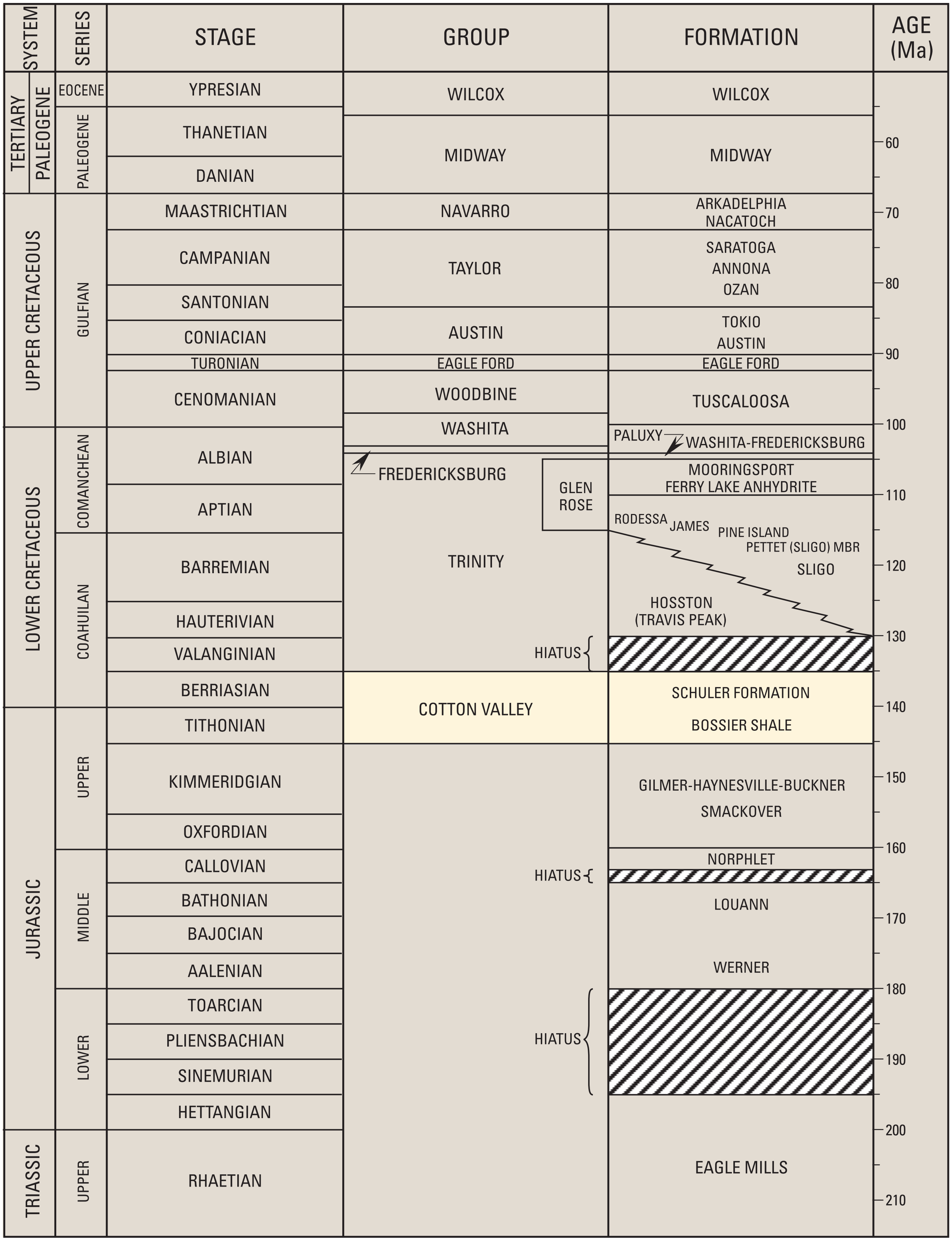


Figure 4. Chronostratigraphic section of northern Louisiana (modified from Shreveport Geological Society, 1987). Subdivisions of the Cotton Valley Group are shown in figure 5.

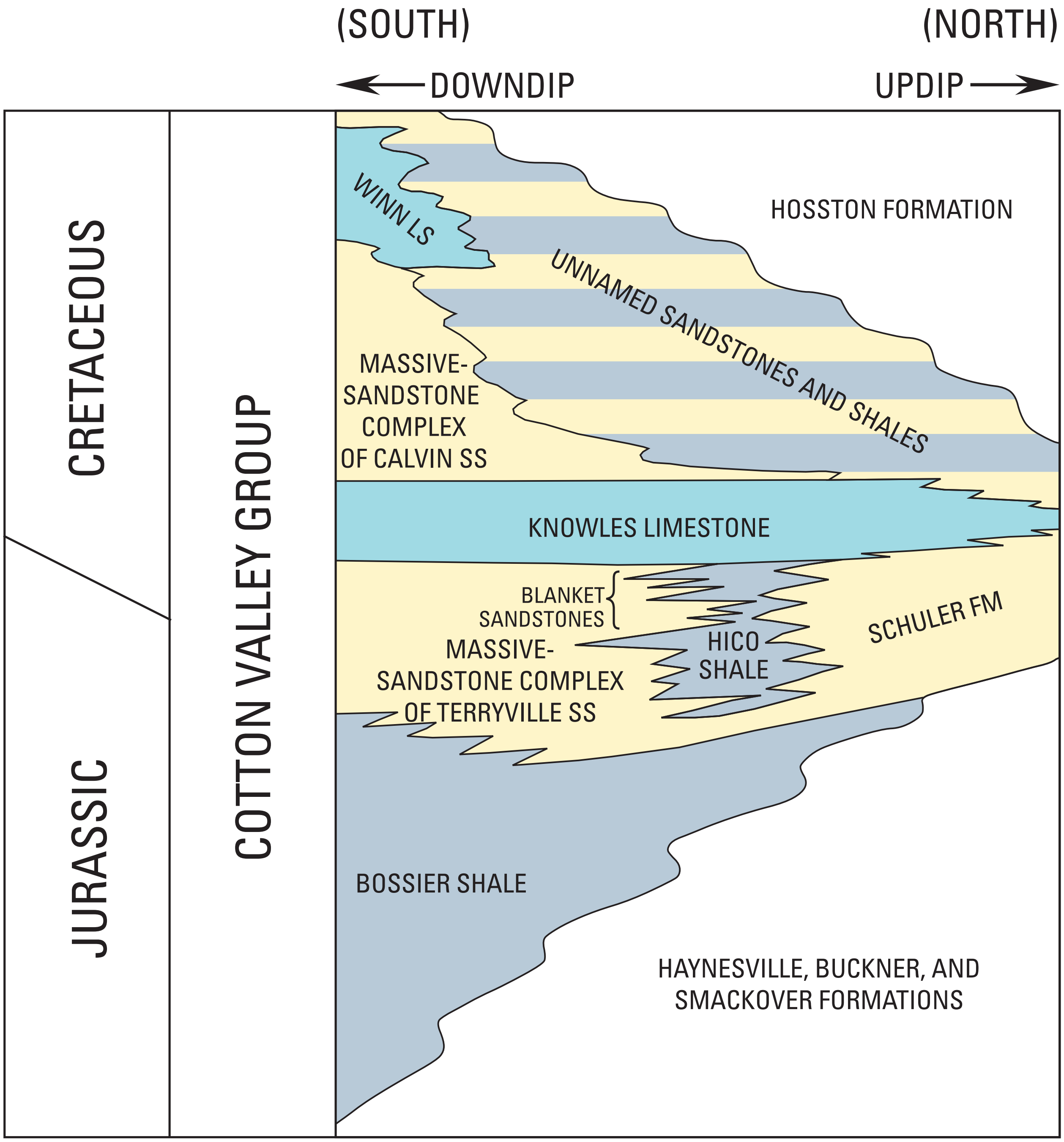


Figure 5. Generalized chart, showing sedimentary facies and stratigraphic nomenclature of the Cotton Valley Group (patterned units) in northern Louisiana (from Bartberger and others, 2002).

published for the East Texas Basin, but McGowen and Harris (1984) and Wescott (1985) provided data from which basic paleogeographic maps can be constructed. Figure 7, based on data integrated from these various workers, is a regional paleogeographic map of upper Cotton Valley depositional systems (equivalent to Terryville IV of Coleman and Coleman, 1981) across the northern coastal plain of the Gulf of Mexico from east Texas to Mississippi.

As shown in figure 7, Cotton Valley Group fluvial-deltaic depocenters were located in present-day northeast Texas, south-central Mississippi, and along the Louisiana-Mississippi border. The system along the Louisiana-Mississippi border represents the ancestral Mississippi River. Large volumes of sand delivered to the marine environment by this system were transported westward by longshore currents, producing an extensive, east-west–oriented barrier-island or strand-plain

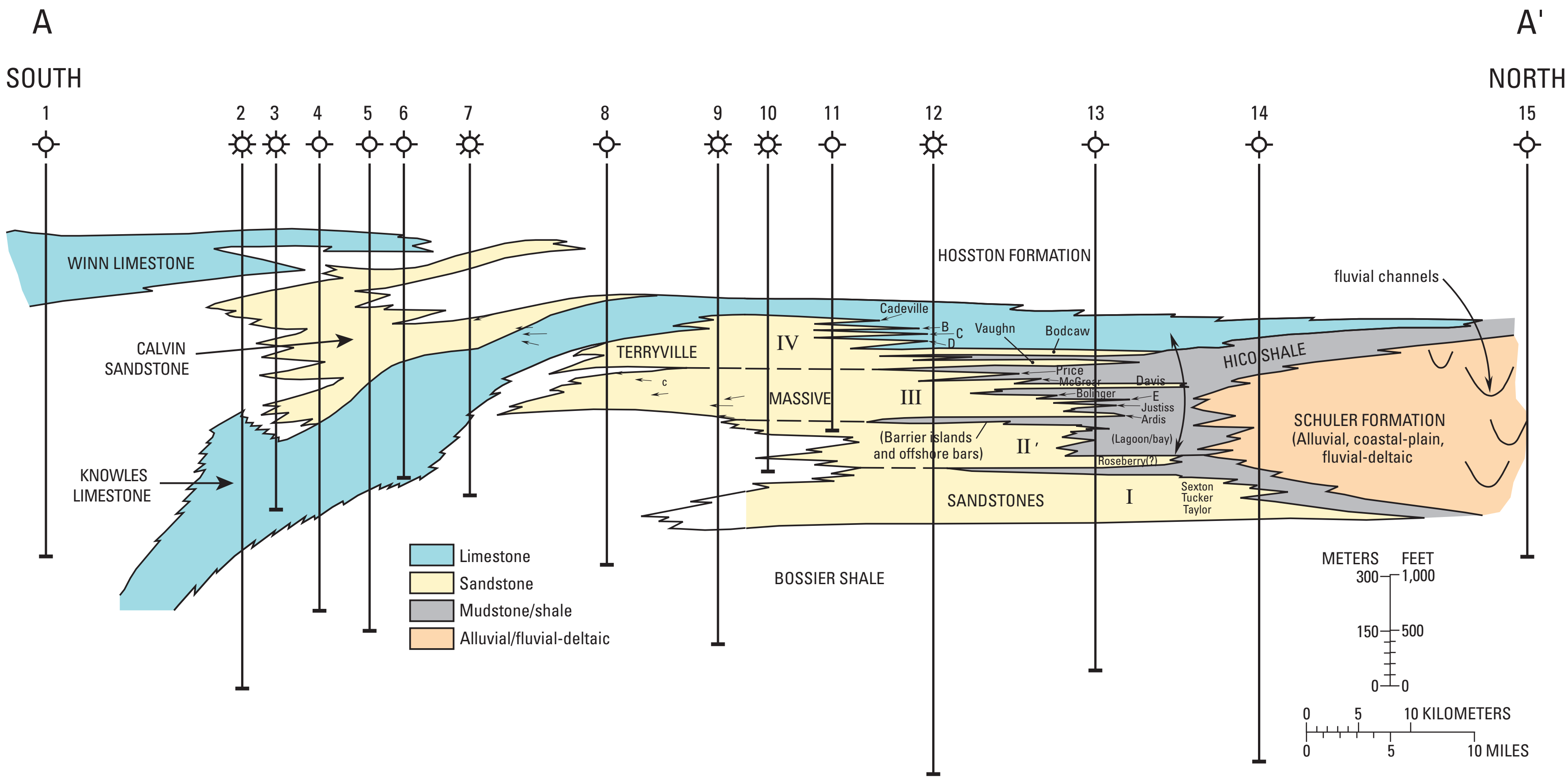


Figure 6. North-south stratigraphic cross section (from Bartberger and others, 2002, modified from Coleman and Coleman, 1981; no datum identified in original figure), showing stratigraphic nomenclature and environments of deposition of the Cotton Valley Group across northern Louisiana based on data from 15 wells located in figures 7 and 8. Curved, double-pointed arrow indicates stratigraphic range of blanket sandstones. Roman numerals refer to Terryville Sandstone depositional events identified by Coleman and Coleman.

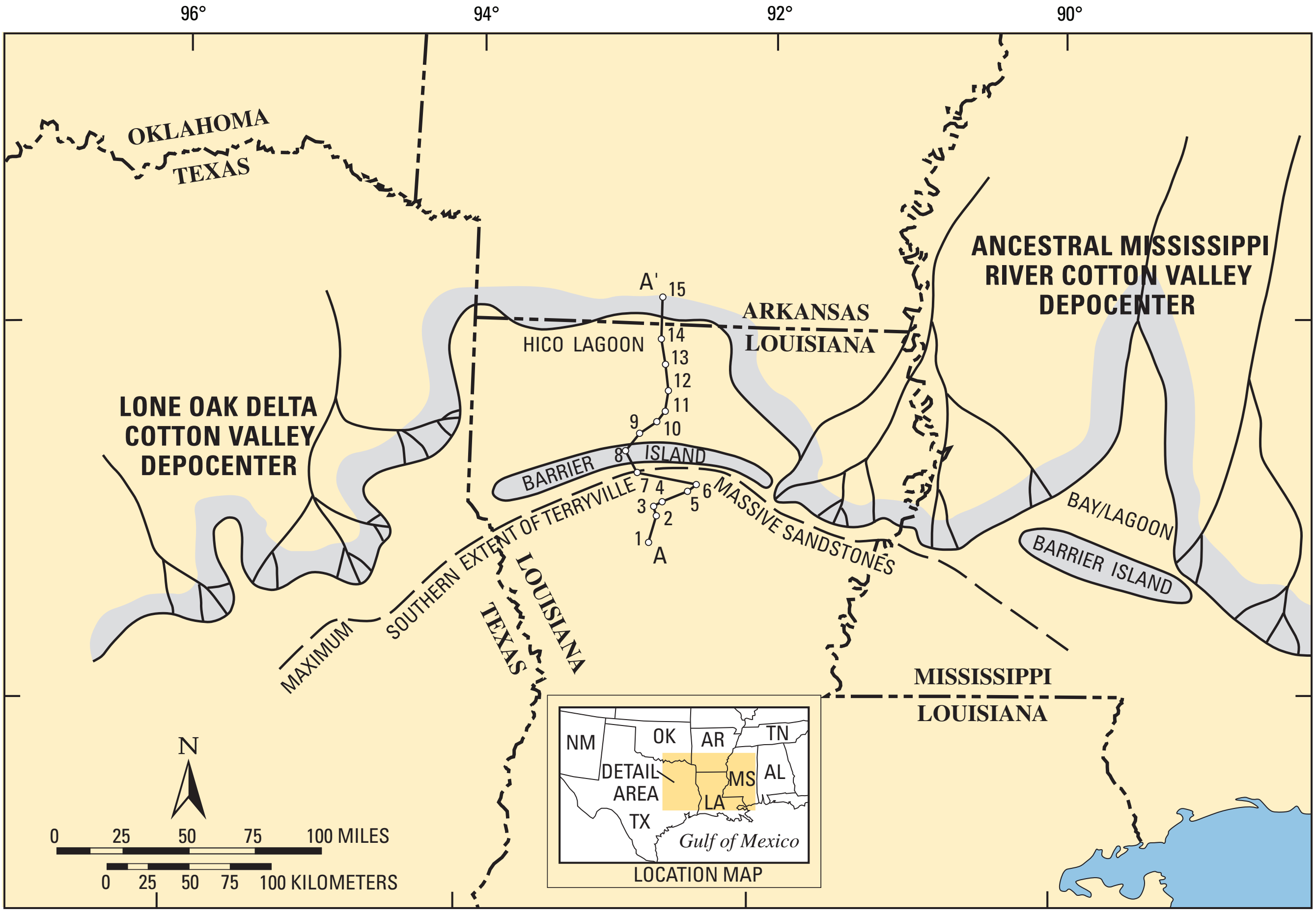


Figure 7. Regional paleogeographic map, showing sedimentary environments during deposition of the uppermost Cotton Valley Group sandstones (Terryville IV sandstone of Coleman and Coleman, 1981). Map synthesized from data of Thomas and Mann (1966), Coleman and Coleman (1981), Moore (1983), McGowen and Harris (1984), Wescott (1985), and Eversull (1985). The map also shows the locations of the numbered wells identified in the north-south stratigraphic cross section (fig. 6) of the Cotton Valley Group across northern Louisiana.

complex (Thomas and Mann, 1966). Vertical stacking of barrier-island/strand-plain sands through time resulted in accumulation of the Terryville Sandstone massive-sandstone complex (figs. 6, 7). The east-west–oriented barrier-island complex across northern Louisiana sheltered a lagoon to the north from open-marine waters to the south (Thomas and Mann, 1966). The Hico Shale accumulated in the lagoon while fluvial and coastal-plain sandstones and shales of the Schuler Formation were deposited in continental environments north of the lagoon (figs. 6, 7; pls. 4, 5). A similar, but smaller lagoon associated with barrier islands formed from longshore-transported sands in south-central Mississippi (Moore, 1983). In east Texas, during the earliest phase of Cotton Valley sandstone deposition, small fan deltas developed along the updip margin of the East Texas Basin (McGowen and Harris, 1984; Wescott, 1985; Black and Berg, 1987). According to McGowen and Harris (1984), fan-delta deposition persisted through the time of Cotton Valley deposition along the western margin of the East Texas Basin, where fan-delta deposits characterize most of the Cotton Valley sandstone interval. Along the northern flank of the East Texas Basin, in the region of the present-day Sabine uplift (fig. 2), a mature drainage system developed as fan deltas prograded basinward and evolved into a wave-dominated deltaic system. Lower Cotton Valley sandstones deposited in this delta system are referred to informally as the Taylor sandstone, according to Wescott (1985). Taylor sand deposition was terminated by a local transgressive event followed by delta progradation and development of a more elongate, fluvial-dominated system in the upper part of the Cotton Valley (fig. 7). This progradational package was referred to as the Lone Oak delta by Kast (1983).

Blanket Sandstones of Northern Louisiana

In northern Louisiana, at least 20 distinct tongues of sandstone extend landward from barrier-island deposits of the Terryville Sandstone massive-sandstone complex (for example, Bodcaw Tongue of Terryville Sandstone and Vaughn Tongue of Terryville Sandstone; fig. 6). They thin northward before pinching out into lagoonal facies of the Hico Shale (pl. 6). Some of these sandstones have limited geographic extent and cover only part of the lagoon, whereas others extend across most or all of the lagoon and interfinger with landward

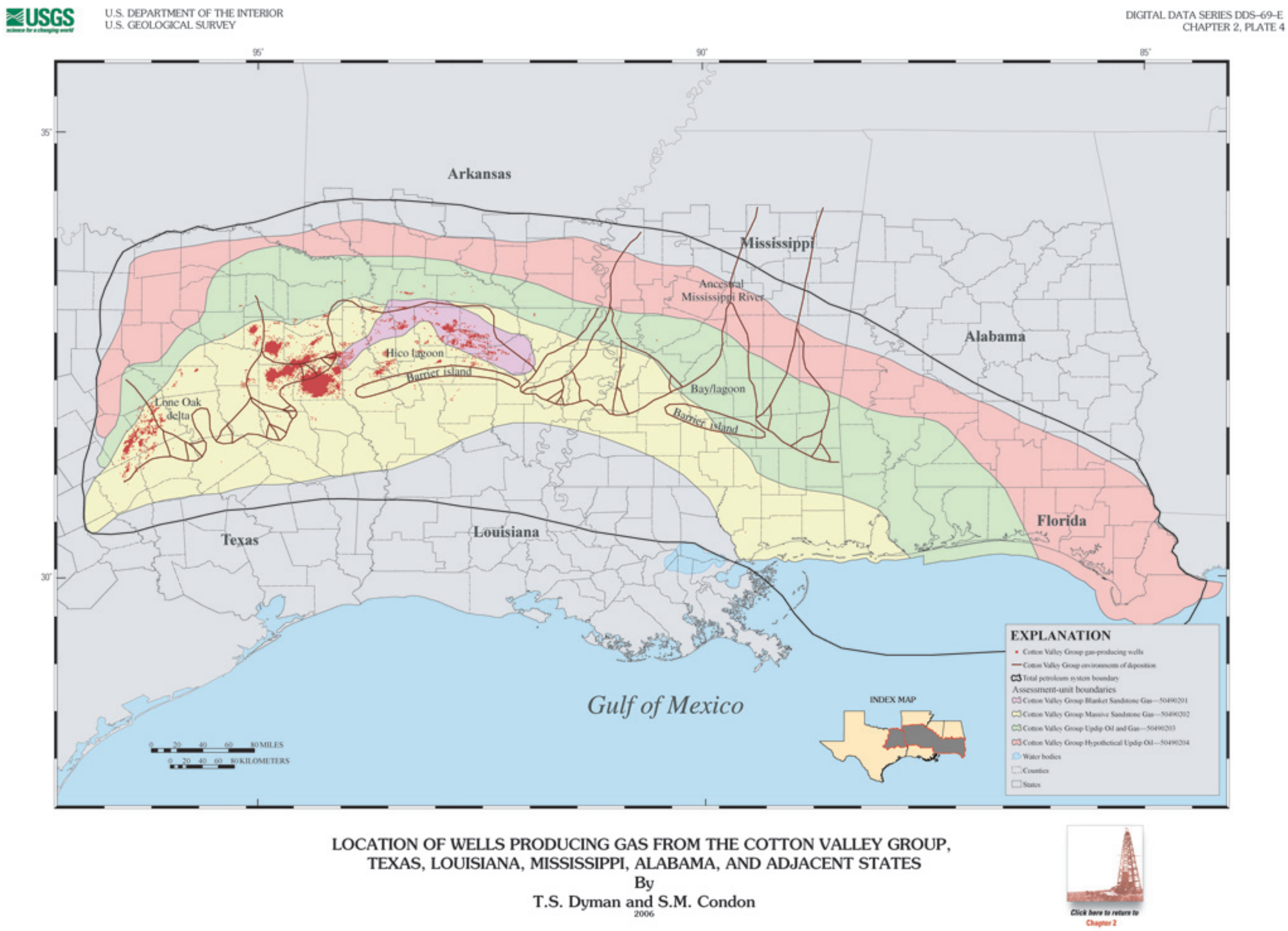


Plate 4. Location of wells producing gas from the Cotton Valley Group. This map shows the distribution of wells reporting gas production from the Cotton Valley Group (exclusive of the Bossier Formation). Data were retrieved from the PI/Dwights PLUS production database by querying the field variable named "Producing Zone and Product Code." The map shows 7,899 wells, most of which are along the west side of the East Texas Basin, on the Sabine uplift, and in the northern Louisiana Salt Basin (pl. 3). Assessment-unit boundaries for the Cotton Valley Group are also shown, as well as regional depositional environments of the upper Cotton Valley sandstones (fig. 7). In east Texas, most of the production has been updip from or lateral to the main deltaic lobes in the massive-sandstone assessment unit. In northern Louisiana, the bulk of the gas production has been from the blanket-sandstone assessment unit, in the Hico lagoon depositional setting. This synthesis of regional depositional environments is modified from Bartberger and others (2002) (see fig. 7 in this report).

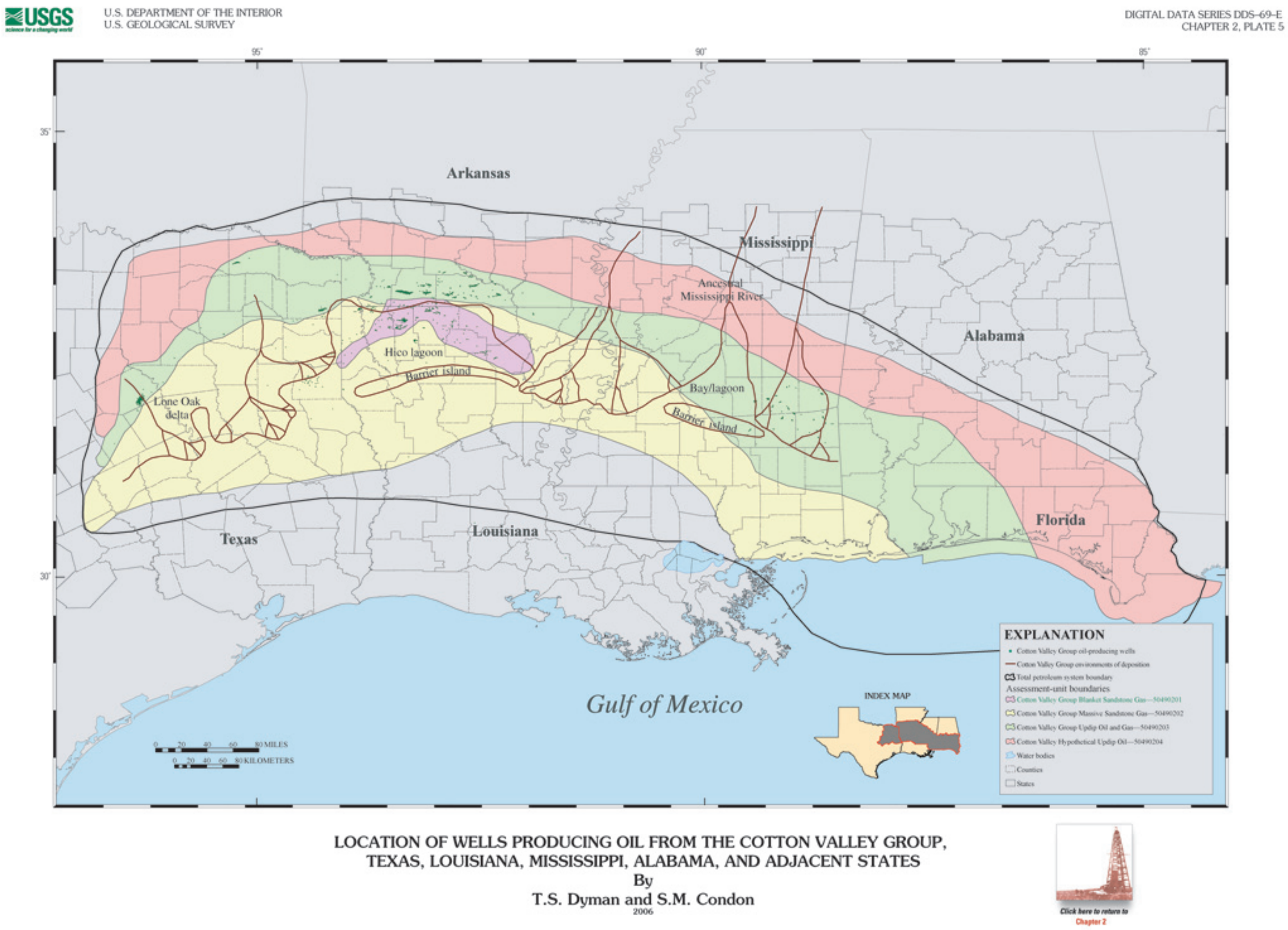


Plate 5. Location of wells producing oil from the Cotton Valley Group. This map shows the distribution of wells reporting oil production from the Cotton Valley Group (exclusive of the Bossier Formation). The map shows the location of 1,523 wells that have reported oil production. Although there is scattered oil production in east Texas, most of the Cotton Valley wells that produce oil are located in northern Louisiana, southern Arkansas, and southeastern Mississippi. Assessment-unit boundaries for the Cotton Valley are also shown, as well as regional depositional environments of the upper Cotton Valley Group sandstones (fig. 7). Oil has been produced from the Hico lagoon area and landward of the Hico lagoon in Louisiana and Arkansas as well as on a delta lobe in Mississippi. The synthesis of regional depositional environments is modified from Bartberger and others (2002) (see fig. 7 in this report).

continental deposits of the Schuler Formation (Coleman and Coleman, 1981; Eversull, 1985). These transgressive blanket sandstones were derived from Terryville barrier islands and transported landward into the Hico lagoon during periods of relative sea-level rise and/or diminished sediment supply (Coleman and Coleman, 1981; Eversull, 1985). These transgressive sandstones have significantly better porosity and permeability than the Terryville massive sandstones from which they were derived and have been prolific producers of oil and gas from structural, stratigraphic, and combination traps that were discovered during the 1940s, 1950s, and 1960s across northern Louisiana (Collins, 1980; Bebout and others, 1992). Referred to informally as "blanket" sandstones (Eversull, 1985), these transgressive deposits can be correlated across northern Louisiana (fig. 6) and were given informal names by operators during drilling in the 1940s and 1950s (Sloane, 1958; Thomas and Mann, 1963; Eversull, 1985).

Sandstone-thickness trends led Eversull (1985) to identify two groups of blanket sandstones. Geographically more extensive sandstones of the first group span most of the Hico lagoon deposits and commonly interfinger with continental deposits of the Schuler Formation. These sandstones generally are 30–70 ft thick and can reach a thickness of 140 ft toward the south, where they merge with barrier-island sandstones of the Terryville Sandstone massive-sandstone complex. Blanket sandstones of the second group generally are <30 ft thick, have limited geographic extent, and most commonly occur in the eastern part of the Hico lagoon section that is proximal to the fluvial-deltaic source. These sandstones pinch out northward into shales of the Hico lagoon. Transgressive blanket sandstones of both groups collectively have significantly greater porosity and permeability than barrier-island sandstones of the Terryville massive-sandstone complex to the south (Collins, 1980; Bebout and others, 1992).

Framework of the Total Petroleum System

The petroleum assessment of the Cotton Valley Group was conducted by using a total petroleum system model. A total petroleum system includes all of the important elements of a hydrocarbon fluid system needed to develop oil and gas accumulations, including source and reservoir rocks, hydrocarbon generation, migration, traps, seals, and discovered and undiscovered hydrocarbon accumulations. A total petroleum system is mappable and may include one or more assessment units. An assessment unit (AU) is a mappable volume of rock within a total petroleum system that encompasses discovered and undiscovered fields that share similar geologic characteristics and economics. Each assessment unit may include similar reservoir rocks, geology, exploration characteristics, and risk. Reservoir-rock elements include lithology, depositional environments, and postdepositional diagenetic alteration. Source-rock elements include organic richness, levels of thermal maturation, and timing of hydrocarbon generation and migration (U.S. Geological Survey World Energy Assessment Team, 2000).

Whether undiscovered hydrocarbon accumulations are conventional or continuous is important in USGS assessments and determines the methodology used. An assessment unit may support either discreet (conventional) or continuous-type (unconventional) oil and/or gas accumulations (Schmoker, 1996). Continuous-type gas accumulations generally occur throughout a large area; they are not significantly affected by hydrodynamic influences and lack well-defined downdip water contacts. Continuous-gas assessment units are treated as a separate category in NOGA and are assessed through the use of a specialized methodology (Schmoker, 1996). All of the assessment units identified in this report were assessed as conventional.

Source Rocks

Sassen and Moore (1988) demonstrated that Smackover Formation carbonate mudstones constitute the major hydrocarbon source rock that has charged the various reservoirs in Mississippi and Alabama. Wescott and Hood (1991) identified the Bossier Shale as the major hydrocarbon source rock in east Texas. Presley and Reed (1984) suggested that gray to black shales that are interbedded with Cotton Valley Group sandstones, as well as the underlying Bossier Shale, are the probable source for gas in Cotton Valley sandstone reservoirs. Dutton (1987) suggested that the most likely sources for hydrocarbons in Travis Peak Formation reservoirs in east Texas (which overlie the Cotton Valley Group) are laminated, lime mudstones of the lower member of the Upper Jurassic Smackover Formation and prodelta and marine shales of the Bossier Shale (fig. 5). Coleman and Coleman (1981) stated that "hydrocarbons were generated from neighboring source beds." We support a Smackover component for Cotton Valley hydrocarbons, particularly for oil-bearing reservoirs in the northern part of the region (Lewan, 2002). Because of the fluid behavior and complex history of gases in the region, multiple source rocks and oil sources may have contributed to Cotton Valley accumulations.

The Jurassic Smackover Interior Salt Basins Total Petroleum System (pl. 7) is defined to include source rocks of both Upper Jurassic Smackover Formation carbonates and calcareous shales and Upper Jurassic and Lower Cretaceous Cotton Valley Group organic-rich shales (fig. 4). The Smackover Formation is a well-established source rock over much of the northern coastal plain of the Gulf of Mexico, but little information has been published on source rocks for hydrocarbons produced specifically from Cotton Valley reservoirs in northern Louisiana and east Texas. In studying the overlying Travis Peak Formation in east Texas, Dutton (1987) showed that shales interbedded with Travis Peak sandstone reservoirs were deposited in fluvial-deltaic settings

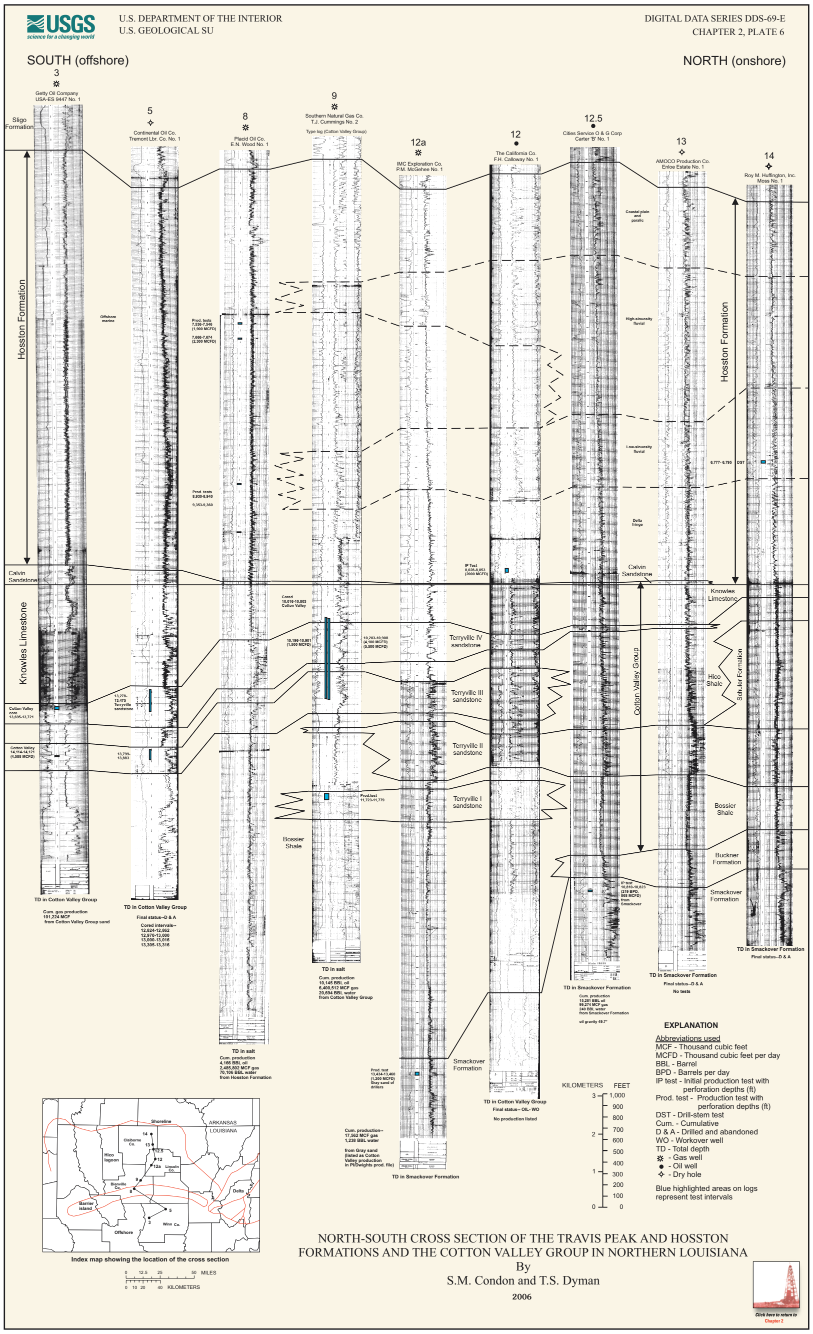


Plate 6. North-south stratigraphic cross section, showing correlated electric logs of the Cotton Valley Group and adjacent formations, northern Louisiana. This cross section extends from northern to central Louisiana and is based on a cross section published by Coleman and Coleman (1981). We were not able to find all of the logs for the wells shown. Some of the logs of Coleman and Coleman (1981) are not available either commercially or in the collection of well logs in the microfiche library maintained by the U.S. Geological Survey in Denver, Colorado. Logs from two additional wells were added to the cross section to fill gaps in the original. Appendix 2 presents a complete list of wells in the cross section. Good-quality logs were scanned, imported into CorelDraw (version 6.0), and correlated by using the top of the Cotton Valley Group as a datum. The cross section shows the downdip transition from continental rocks, through the Hico Shale, and into the blanket and massive sandstones of the Cotton Valley Group. The marine shale of the Bossier Formation is shown at the base of the Cotton Valley, and some wells also penetrated older units as deep as the Smackover Formation. The interpretation shown here differs slightly from that shown by Coleman and Coleman (1981), mainly in extending some of the massive-sandstone complex (Terryville Sandstone) farther south than before. This interpretation was based on production tests and core reported from the Cotton Valley in the southern two wells where Cotton Valley was previously not recognized. Blue highlighted areas on logs represent test intervals.

where organic matter commonly is oxidized and not preserved. Because measured values of total organic carbon (TOC) in Travis Peak shales are generally <0.5 percent, these shales are considered to have been only minor hydrocarbon source rocks for the Jurassic Smackover Interior Salt Basins Total Petroleum System, in accordance with the results of source-rock total organic carbon studies by Tissot and Welte (1978).

Burial History

In a study of diagenesis and burial history of the Travis Peak Formation in east Texas, Dutton (1987) reported that measured vitrinite reflectance (Ro) values for Travis Peak shales generally range from 1.0 to 1.2 percent. Such values indicate that Travis Peak rocks have passed through the oil window (Ro = 0.6–1.0 percent) and are approaching the level of onset of dry-gas generation (Ro = 1.2 percent) (Dow, 1978). A maximum Ro of 1.8 percent was measured in the deepest sample from a well in Nacogdoches County, Texas. Despite the thermal maturity levels reached by Travis Peak shales, the small amount and gas-prone nature of organic matter in these shales preclude generation of oil, although minor amounts of gas might have been generated (Dutton, 1987). Any such gas could have migrated into both Travis Peak and Cotton Valley reservoir rocks.

In the absence of actual Ro measurements, values of Ro can be estimated by plotting burial depth of a given source-rock interval versus time in conjunction with an estimated paleo-geothermal gradient (Lopatin, 1971; Waples, 1980). Dutton (1987) presented burial-history curves for tops of the Travis Peak Formation, Cotton Valley Group, Bossier Shale, and Smackover Formation by using seven wells on the crest and western flank of the Sabine uplift. The burial-history curves show total overburden thickness through time and use present-day compacted thicknesses of stratigraphic units. Sediment compaction through time was considered insignificant because of absence of thick shale units in the stratigraphic section. Loss of sedimentary section associated with mid-Cretaceous and mid-Eocene erosional events was also accounted for in the burial-history curves.

Dutton (1987) provided justification for using the average present-day geothermal gradient of 2.1 °F/100 ft for the paleo-geothermal gradient for the five northernmost wells. Paleo-geothermal gradients in the two southern wells probably were elevated temporarily because of proximity to the area of initial continental rifting. Dutton (1987) used the crustal extension model of Royden and others (1980) to estimate values for elevated paleo-geothermal gradients for these two wells for the 80-m.y. interval following the onset of rifting in the early Mesozoic. Dutton then reverted to the present-day gradient for the past 100 m.y.

By using estimated paleo-geothermal gradients in conjunction with burial-history curves, Dutton (1987) found that calculated values of Ro for Travis Peak Formation shales agree well with measured values. Because of this agreement, Dutton (1987) used the same method to calculate Ro values of shales for tops of the Cotton Valley Group, Bossier Shale, and Smackover Formation in east Texas. Estimated Ro data for the Bossier and Smackover in the seven wells range from 1.8 to 3.1 percent and from 2.2 to 4.0 percent, respectively, suggesting that these rocks reached a stage of thermal maturity in which dry gas was generated. Under the assumption that high-quality, gas-prone source rocks occur within these two formations, both of them could have generated gas now found in overlying Cotton Valley and Travis Peak reservoirs.

No regional source-rock thermal maturity analysis is known for the Cotton Valley Group in northern Louisiana. Scardina (1981) presented burial-history data for the Cotton Valley Group, but included no information on geothermal gradients or thermal history of rock units. Present-day reservoir temperatures in low-permeability Cotton Valley sandstones of east Texas and low-permeability massive sandstones of the Terryville Sandstone in northern Louisiana are in the 250 to 270 °F range (Finley, 1986; White and Garrett, 1992). It is likely that source rocks in the Bossier Shale and Smackover Formation in northern Louisiana underwent a thermal history relatively similar to their stratigraphic counterparts in east Texas and, therefore, are sources for Cotton Valley gas in northern Louisiana (fig. 8). Herrmann and others (1991) presented a burial-history plot for Ruston field in the Cotton Valley blanket-sandstone trend in northern Louisiana. They suggested that gas was derived locally from lower Smackover lime mudstones and Bossier shales. Their burial-history plot shows that the onset of generation of gas from Smackover and Bossier source rocks at Ruston field occurred at about 80 and 45 Ma, respectively. As already noted in this report, the Sabine uplift has been a positive feature for the past 60 m.y. (Kosters and others, 1989; Jackson and Laubach, 1991). Therefore, it would have been a focal area for gas migrating from source rocks in Smackover, Bossier, and Cotton Valley strata in east Texas and northern Louisiana.

Timing of Hydrocarbon Generation

Sassen and Moore (1988) conducted a detailed geochemical study of source rocks in the Smackover Formation of the Mississippi Salt Basin (fig. 2); the study included total organic carbon (TOC) analyses, Rock-Eval pyrolysis, and thermal alteration index (TAI) analyses on core samples. They determined that crude oil migrated vertically from the Smackover and charged overlying Cotton Valley Group and younger reservoirs. Subsequent cracking of oil in upper Smackover reservoirs resulted in the formation of gas, condensate, and bitumen. Major gas fields of the Smackover trend in Mississippi are remnants of former crude oil accumulations that emanated from the lower Smackover source-rock facies.

Lewan (2002) predicted the timing of oil and gas generation for the Jurassic Smackover Interior Salt Basins

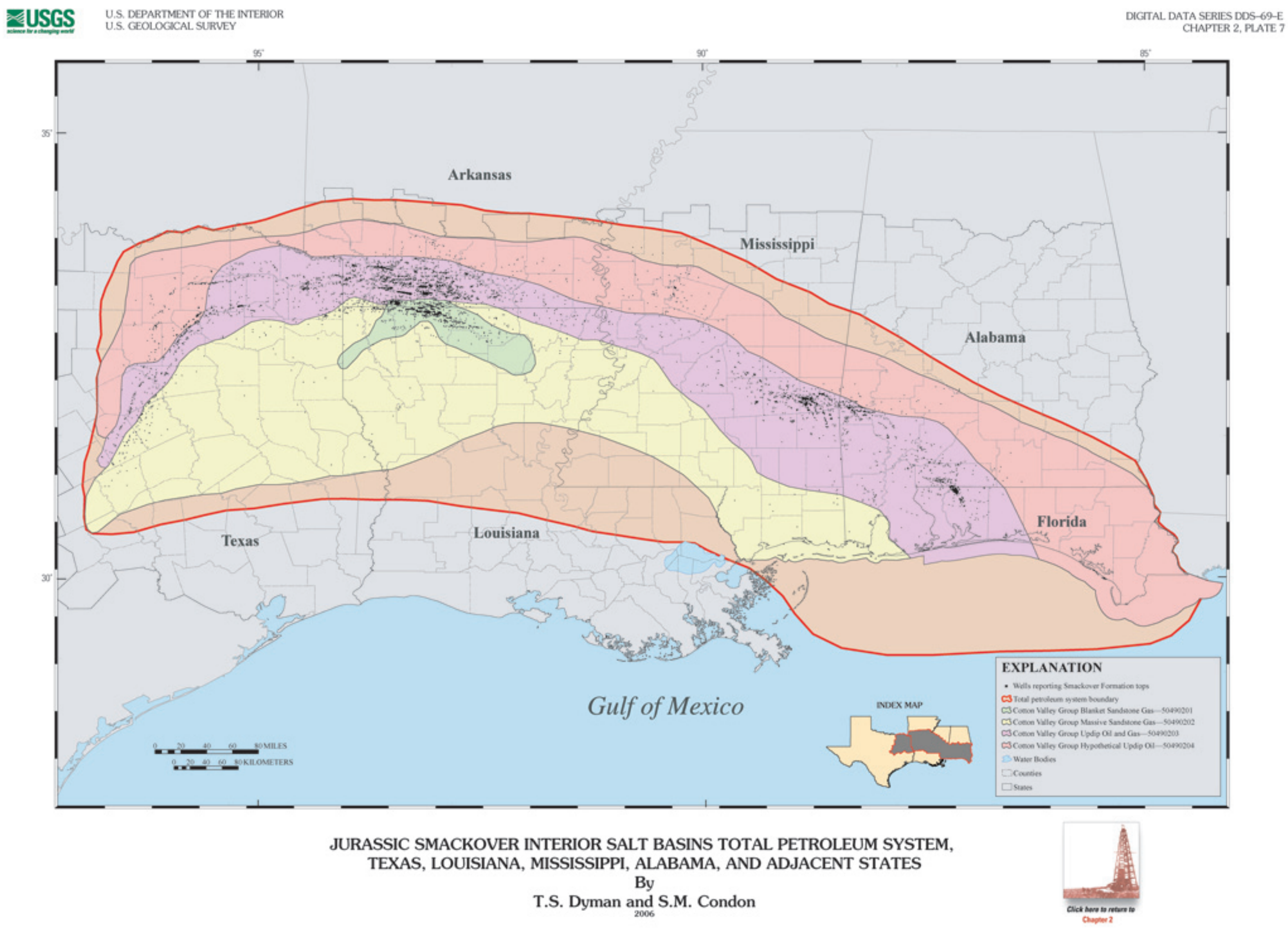


Plate 7. Jurassic Smackover Interior Salt Basins Total Petroleum System. This map shows the extent of the Jurassic Smackover Interior Salt Basins Total Petroleum System and the four assessment units of the Cotton Valley Group. The boundary of the total petroleum system was drawn to include all wells that reported the presence of the Smackover Formation; these are shown on the map. Wells reporting Smackover tops are arrayed in an arcuate pattern extending from east Texas to the northwestern part of the Florida Panhandle. Over this entire area there are 6,764 wells that report Smackover tops. The wells are clustered in east Texas, northwestern Louisiana, southern Arkansas, and southeastern Mississippi; they straddle the State line between Alabama and Florida. The Smackover is present in areas south of the clusters, but the formation is buried deeply in the subsurface and has not been reached by drilling in most areas. Depths of the Smackover reported in the database range from 1,394 to 23,554 ft. The southern boundary of the total petroleum system was drawn at a facies change in the Smackover from a shelf facies on the north to a deeper marine-basin facies to the south (Salvador, 1987).

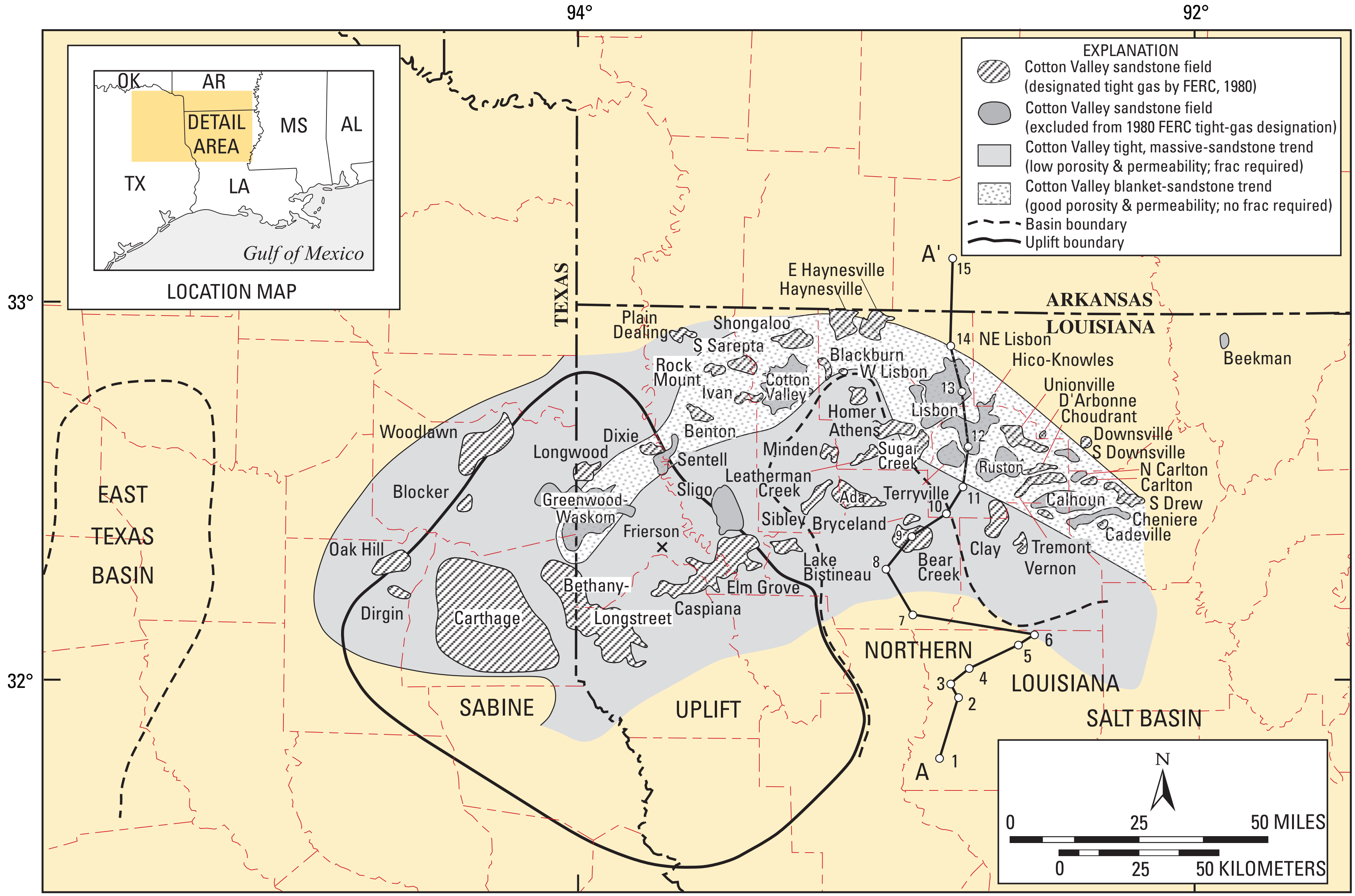


Figure 8. Map of northeast Texas and northern Louisiana (modified from Collins, 1980, and White and others, 1992), showing major fields that have produced hydrocarbons from Cotton Valley Group sandstones. Two different productive trends (only approximately equivalent to the similarly named assessment units described in this report) are recognized on the basis of the reservoir properties and resulting producing capabilities of Cotton Valley sandstone reservoirs. Fields excluded from "tight-gas" designation by the Federal Energy Regulatory Commission (FERC) in 1980 are shown in darker gray shading. The abbreviation "frac" indicates "fracture-stimulation treatment." The map also shows the locations of the numbered wells identified in the north-south stratigraphic cross section (fig. 6) of the Cotton Valley Group across northern Louisiana. X, Frierson field from Sonnenberg (1976).

Total Petroleum System by using kinetic parameters derived from hydrous pyrolysis experiments. According to Lewan, oil generation from source rocks in the Smackover Formation in the northern coastal plain of the Gulf of Mexico started at 121 ± 12 Ma and ended at 99 ± 16 Ma. On the basis of these age data, Smackover oil generation was complete prior to the tectonic activity associated with the Sabine uplift (94–89 Ma) and Monroe uplift (75–66 Ma). Gas generation from the cracking of Smackover oil in the northern Gulf Coast region started at 52 ± 19 Ma and culminated in the northwestern part of the Mississippi Salt Basin between 56 and 20 Ma (fig. 2). Lewan also noted that the large time interval (about 47 m.y.) between oil generation from Smackover source rocks (about 99 Ma) and gas generation (about 52 Ma) coincided with the major tectonism that formed the Sabine and Monroe uplifts. The abundance of Smackover-sourced oil along the northern rim of the Gulf of Mexico and the abundance of gas on the uplifts can be explained by this series of events.

Reservoir Rocks

In Louisiana, significant differences in reservoir properties between transgressive blanket sandstones to the north and massive, barrier-island sandstones to the south define two different hydrocarbon-productive trends within the Cotton Valley Group sandstones (fig. 8). Cotton Valley blanket sandstones have significantly higher porosity and permeability than the Terryville Sandstone massive sandstones to the south (table 1). Eversull (1985) reported that Cotton Valley blanket sandstones are more mature and better sorted. She attributed these superior reservoir properties to high-energy reworking during transgressive depositional events.

Coleman (1985) reported that blanket sandstones in northern Louisiana exhibit an increase in calcite cement and clay content northward toward their pinchout edges. Superior reservoir properties developed because (1) clays inhibited precipitation of quartz overgrowths and (2) secondary porosity was generated through widespread dissolution of calcite cement. Absence of detrital-clay grain coatings in the high-energy barrier-island sandstones of the Terryville Sandstone massive-sandstone complex to the south, however, permitted widespread precipitation of quartz cement as syntaxial overgrowths, resulting in nearly complete occlusion of porosity (Sloane, 1958; Coleman and Coleman, 1981). Whatever the cause of porosity differences, the blanket sandstones generally have sufficient porosity and permeability for gas or liquids to flow during open-hole drill-stem tests (DSTs) and to produce gas without fracture-stimulation treatment (Collins, 1980; Bebout and others, 1992). Terryville massive sandstones to the south and west, however, have such poor reservoir properties that they generally do not flow gas or liquids during DSTs and they require massive hydraulic-fracture treatments before commercial production can be obtained.

Abnormal Pressures

Pore or reservoir pressure is often reported as a fluid-pressure gradient (FPG) in pounds per square inch per foot (psi/ft). A normal FPG is 0.43 psi/ft in freshwater reservoirs and 0.50 psi/ft in reservoirs with very saline waters (Spencer, 1987). Pore pressures as high as 0.86 psi/ft have been encountered in Cotton Valley Group reservoirs in northeast Louisiana (fig. 9 and table 2). Multiple FPG values for a particular gas field in figure 9 and table 2 refer to gradients calculated for different, stacked blanket-sandstone reservoirs penetrated in that field. Across northern Louisiana, the highest reported FPGs are 0.84 and 0.86 psi/ft (Cheniere and Calhoun fields, fig. 9 and table 2) and occur in the southeast part of the trend. Gradients generally decrease to nearly normal values of 0.43–0.50 psi/ft in the northwest. This regional pattern is in general agreement with reservoir-pressure data for northern Louisiana summarized by Coleman and Coleman (1981) (fig. 10). The heavy dashed line in figure 10 shows a modification of the pressure boundary of Coleman and Coleman (1981) to include the 0.63-psi/ft gradient in Hico-Knowles field and the 0.67-psi/ft gradient in Tremont field (fig. 9 and table 2; Bartberger and others, 2002). Most Cotton Valley

Table 1. Comparison of two productive trends of Cotton Valley Group sandstones in east Texas and northern Louisiana.
[Data from Shreveport Geological Society (1946, 1947, 1951, 1953, 1958, 1963, 1980, 1987), Collins (1980), Nangle and others (1982), Finley (1984, 1986), Bebout and others (1992), and Dutton and others (1993). Abbreviations: TSTM, too small to measure; Sw, water saturation as a decimal fraction; MCFD, thousand cubic feet of gas per day]

Parameter	Blanket sandstone	Massive sandstone
Porosity in percent	10 to 19 (average = 15)	6 to 10
Permeability in millidarcies	1.0 to 280 (average = 110)	0.042 (east Texas) 0.015 (northern Louisiana)
Open-hole drill-stem test results	Wells flow gas and/or liquids	Wells generally do not flow gas or liquids
Stimulation treatment	No treatment necessary for commercial production	Massive hydraulic fracturing required to achieve commercial production
Initial gas flow rates (in MCFD)	500 to 25,000 (average = 5,000)	Prestimulation: TSTM to 300 Poststimulation: 500 to 2,500
Sw in productive zones	<0.40	Can be as high as 0.60
Gas/water contacts	Short, well-defined transition zones and gas-water contacts	Long transition zones with poorly defined gas-water contacts
Formation damage	Possible	Commonly severe

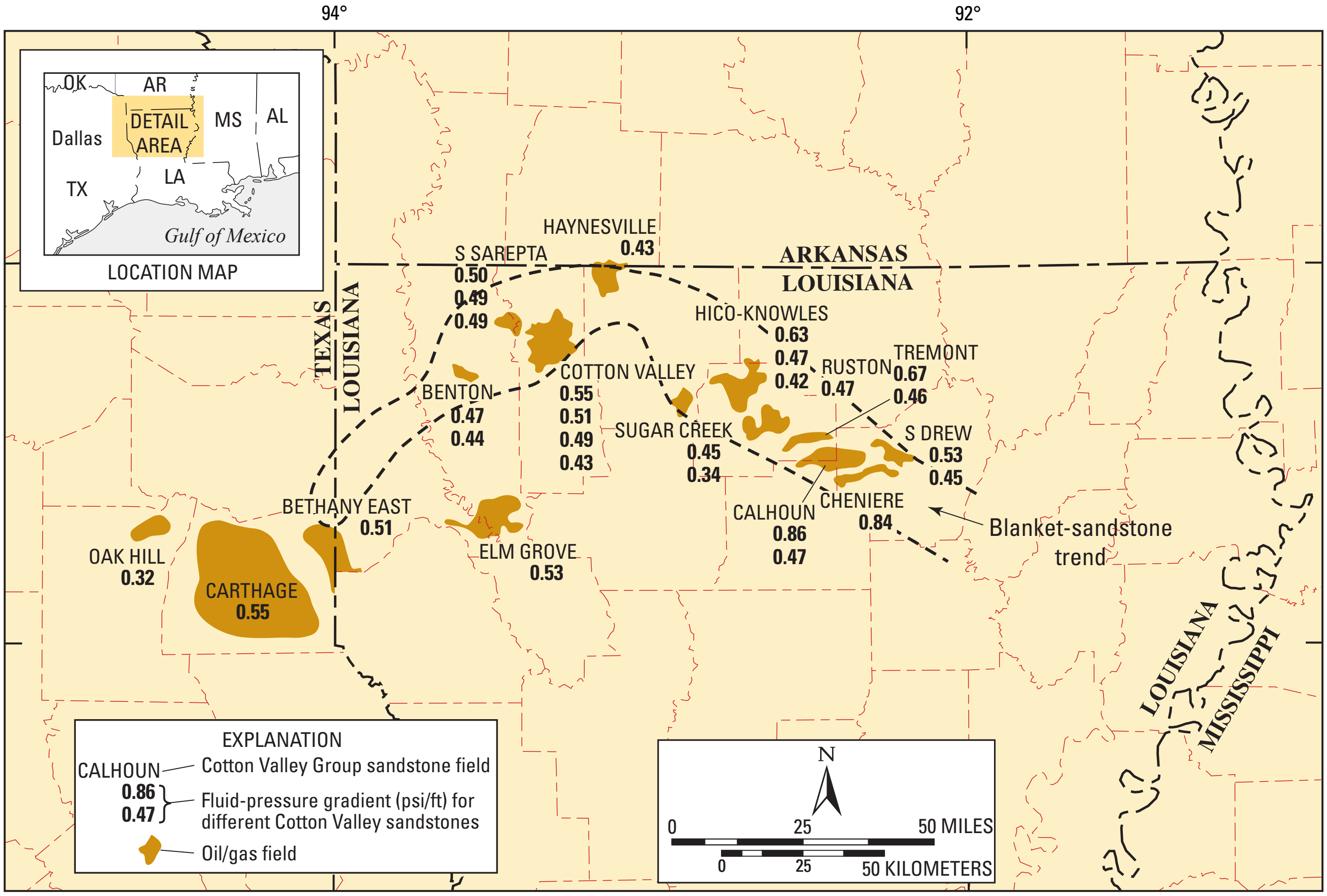


Figure 9. Map of northeast Texas and northern Louisiana, showing fluid-pressure gradients (in psi/ft) calculated from shut-in pressures in Cotton Valley Group sandstone reservoirs. Multiple pressure-gradient values for a particular gas field refer to gradients calculated for different, stacked blanket-sandstone reservoirs penetrated in that field. Shut-in-pressure data for Louisiana fields shown in table 2 in which BHP refers to bottom-hole pressure and FPG refers to final pressure gradient.

sandstone reservoirs, especially in the massive-sandstone trend across northwestern Louisiana and east Texas, are normally pressured, as shown in figure 9 and table 2.

Diagenesis

Understanding reservoir mineralogy of Cotton Valley Group sandstones is critical to successful wireline-log analysis and design of fracture-stimulation treatments. Considerable attention has been devoted to the study of diagenetic patterns of Cotton Valley sandstones, especially in the low-permeability massive-sandstone trend. Focusing on those sandstones in east Texas, Wescott (1983) reported that Cotton Valley sandstones are very fine grained, well-sorted quartz arenites and subarkoses. Principal cements include monocrystalline quartz, calcite, clays, and iron oxides. In unraveling the complex diagenetic history of these sandstones, Wescott (1983) interpreted two major diagenetic sequences. The most common sequence is as follows:

1. formation of clay coatings, primarily chlorite, on framework grains, partially covering grains
2. precipitation of syntaxial quartz overgrowths on quartz grains
3. dissolution of unstable grains, especially feldspar
4. precipitation of clays, primarily illite and chlorite and minor kaolinite
5. precipitation of calcite cement in both relict primary pores and secondary pores
6. large-scale replacement of grains and cements by calcite, resulting in poikilotopic texture in which a few relict quartz grains are “floating” in calcite.

In the other, less-common diagenetic sequence, which occurs primarily in cleaner, coarser-grained sandstones, calcite cementation developed early and progressed to yield a fabric showing widespread replacement of grains by calcite.

Wescott (1983) identified three general Cotton Valley Group sandstone types based on primary depositional texture and resulting diagenetic characteristics. He found that clean, well-sorted sands deposited in high-energy environments (type I) are nearly completely cemented by quartz and/or calcite, have little or no porosity or permeability, and have poor reservoir potential. Preservation of primary intergranular porosity results from the presence of authigenic chlorite grain coatings (Hall

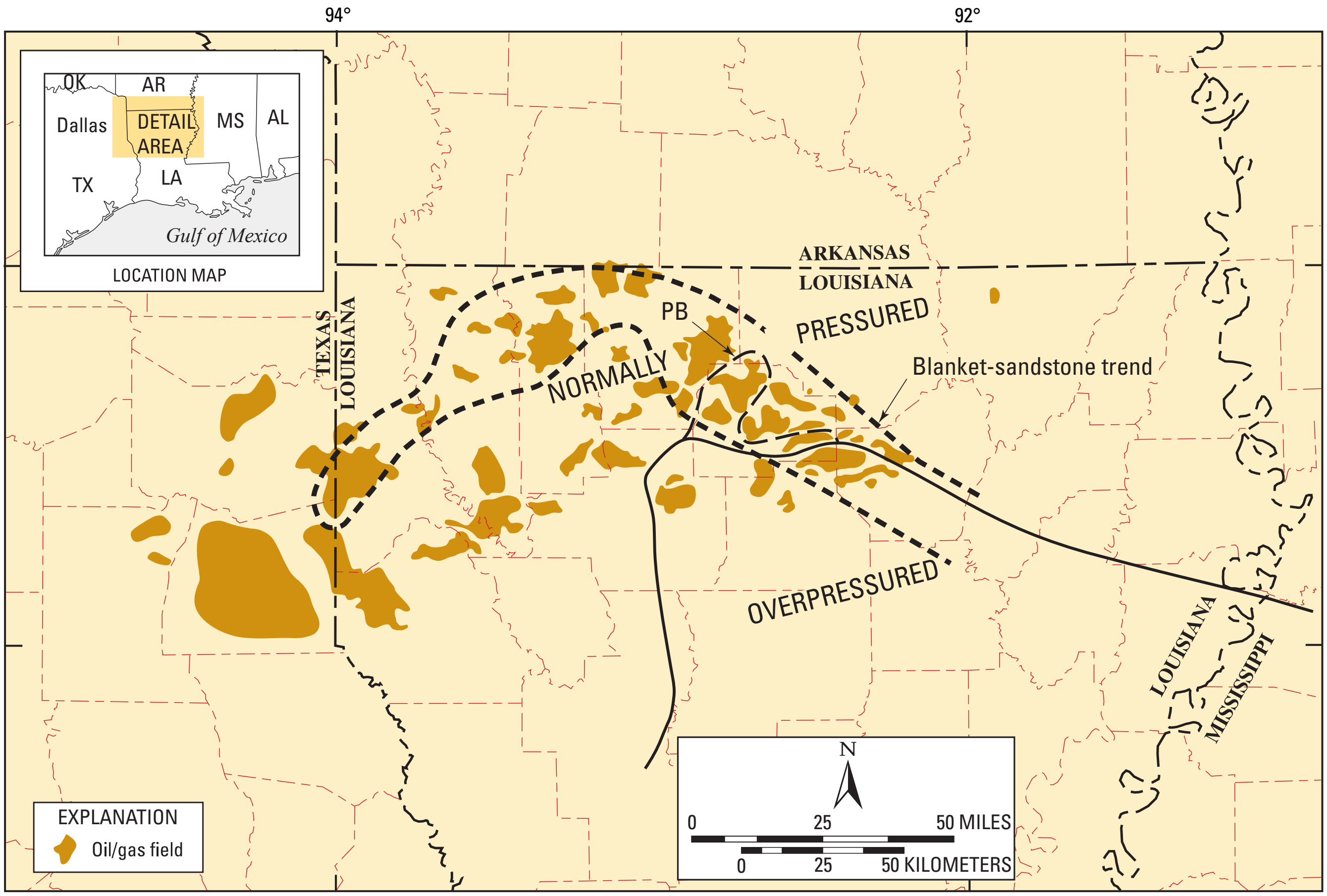


Figure 10. Map of northeast Texas and northern Louisiana (modified from Coleman and Coleman, 1981), showing geographic distribution of abnormally high pressures in Cotton Valley Group sandstone reservoirs. Long-dashed line (labeled PB) is the modification of the pressure boundary of Coleman and Coleman (1981) to include the 0.63-psi/ft fluid-pressure gradient in Hico-Knowles field and 0.67-psi/ft gradient in Tremont field as shown in figure 9 and documented in table 2. Comparison of this map with that in figure 8 shows that the boundary between overpressure and normal pressure cuts across the two productive trends of Cotton Valley sandstones.

and others, 1984). Nucleation of quartz overgrowths generally was inhibited by clays in sands deposited in lower-energy environments where abundant detrital clays remained (type II). Permeability is generally low in most clay-bearing sandstones, even though abundant microporosity is associated with these clays. The highest porosities occur in type III sandstones, which developed abundant secondary porosity due to dissolution of unstable grains and calcite cement. Hall and others (1984) reported that dissolution of unstable grains is often incomplete and secondary pores generally are poorly interconnected. These type III sandstones also have poor permeability and require fracture stimulation to produce gas commercially.

The Bodcaw Tongue of the Terryville Sandstone at Longwood field (figs. 6, 8) on the east flank of the Sabine uplift in northern Louisiana (Russell and others, 1984) is virtually identical diagenetically to Cotton Valley Group sandstones in east Texas (Wescott, 1983). Like Wescott (1983), Russell and others (1984) reported that the development of quartz overgrowths was inhibited by the presence of clays. The volume of pore-filling clays is so large that permeability is still low despite the presence of high microporosity. Also, as in east Texas, the best reservoir sandstones have little clay and developed abundant secondary porosity through dissolution of unstable grains and cement. Similar diagenetic patterns in northern Louisiana were also reported for Cotton Valley sandstones at Frierson field by Sonnenberg (1976) and for the lowermost part of the Terryville Sandstone (the informal Taylor sandstone) at Terryville field by Trojan (1985). In addition to authigenic constituents reported in east Texas and northern Louisiana, Trojan (1985) also found small amounts of authigenic pyrite in Taylor sandstone samples taken at Terryville field. Pyrite occurs as small silt-size clusters (framboids) and is volumetrically the least abundant authigenic mineral reported by Trojan (1985). Its presence is significant, however, because it affects formation resistivity values on wireline logs.

Porosity and Permeability

Cotton Valley Group blanket sandstones have porosities and permeabilities that range from 10 to 19 percent and 1 to

Table 2. Geologic and production data for Cotton Valley (CV) fields in east Texas and northern Louisiana.

[Data primarily from Shreveport Geological Society Reference Reports, Bebout and others (1992), and Pate and Goodwin (1961). Abbreviations: FERC, Federal Energy Regulatory Commission; Struct, structural trap; Strat, stratigraphic trap; Comb, combination structural and stratigraphic trap; A, anticline; FA, faulted anticline; FC, facies change (sandstone pinch-out); N, structural nose; FN, faulted structural nose; MCFD, thousand cubic feet per day; BOPD, barrels of oil per day; BCPD, barrels of condensate per day; BWPD, barrels of water per day; BHT, bottom hole temperature (°F); BHP, bottom hole pressure (psi); FPG, fluid-pressure gradient (psi/ft); Sw, water saturation (decimal). Drive mechanism—SG, solution gas; PD, pressure depletion; GC, gas-cap expansion; WD, water drive]

Name of field producing from CV ss	FERC termed "tight" for CV ss?	Trapping mechanism for field	Date field discov-ered	Date of CV well discovery and specific CV ss that was productive	Depth of perforations in discovery well for specific CV ss (ft)	Initial production for specific CV ss				Gas:oil ratio (GOR)	Porosity (%)	Nonstressed permeability (mD)		BHT (°F)	BHP (psi)	FPG (psi/ft)	Sw	Depth to gas-water contact (GWC) or oil-water contact (OWC)	Drive mecha-nism	Shreveport Geological Society Reference Report (volume: page)
						MCFD	BOPD	BCPD	BWPD			AV.	MAX.							
Ada-Sibley		Comb (FA, FC)	1936	1954: CV	9,900															I: 93; I: 189
Athens		Struct (FA)	1941	1948: Vaughn	8,500–8,544	10,500		254		41,338:1										II: 385; III-2: 41; IV: 197
				1949: "B"	8,464–8,494	12,000		156		76,923:1										
				1950:Bodcaw	8,148–8,186	694		2		347,000:1										
				1951: "D"	8,145–8,170	3,370		208		16,201:1										
Bayou Middlefork		Struct (A)		1953: Bodcaw	7,764	191	210													
Bear Creek–Bryceland		Struct (A)	1937	1966: CV	10,700															I: 97; V: 114
Beekman	No	Comb (N, FC)	1942	1942: CV	3,700–3,711	1,500	35		28	42,800:1										II: 391
Benton		Struct (A)	1944	1944: "D"	8,001–8,040	3,280		164		20,000:1	18	136		190	3,765	0.47	0.17	GWC @ –7,818		II: 395; VII: 44
				1945: Bodcaw	8,137–8,148	1,306	127			10,286:1	14	85		190	3,725	0.44		OWC @ –7,876		
Blackburn		Comb (N, FC)	1953	1953: Bodcaw	8,717	1,301		54		24,092:1										
E. Blackburn			1959																	
Cadeville			1955		9,700															
Calhoun	No	Struct (FA)	1948	1948: "D"	9,500	814		22		37,000:1	17				4,000	0.47			SG,PD	No SGS report
		Comb (FA, FC)		1957: Cadeville	9,121–9,124	4,779		1,148		4,162:1	15		2,132		8,201	0.86	0.05		SG,PD	Pate & Goodwin, 1961
Carlton		Struct (A)	1953	1953: Bodcaw																
N. Carlton	No	Comb (A,FC)		1964: Purdy	8,950															No SGS report
				1965: CV ?	9,470															
Cartwright			1960																	
Caspiana		Comb (N, FC)		1975: Cotton Valley	8,500															
Cheniere	No	Comb (N, FC)	1962	1962: Cadeville	9,682–9,697	4,401		528		8,335:1					8,188	0.84				v: 120
				1963: CV "A"	9,603–9,609	1,230		8		153,750:1										
Choudrant		Struct (A)	1946	1946: "D"	9,097–9129	4,732		211		21,000:1	19	250						Separate GWCs in 2 "D" ss		II: 409; III-2: 55
Clay		Struct (A)		1952: CV	9,700															No SGS report
Cotton Valley	No	Struct (A)	1922	1937: Bodcaw	8,170 TD (OH)	5,323		455		11,700:1	16	121	775	231	4,000	0.49	0.15	GWC @ –8,420	WD	II:413; VI:63
				1937: Davis	8,521–8,551 (OH)	4,800		400		12,000:1	15	280			4,368	0.51	0.10		GC	
				1938: "D"	8,502–8,532	1,020	1,200				18	150			3,926	0.43				
				1949: Justiss	9,050						16	34			4,700	0.55	0.22		GC	
				"C"																
				Taylor																
D'Arbonne			1947	1947: Bodcaw	8,157	4,100		88		46,590:1										
Dixie			1929																	
Downsville			1948																	
S. Downsville	No	Struct (A)	1961	1961: Vaughn	8,900															No SGS report
S. Drew		Strat (FC)	1972	1972: "D"	9,061–9,069	2,560				85,000:1	12	20		200	4,850	0.53	0.40	3 GWCs in "D" ss	GC	VI: 116
				1976: Vaughn	9,525–9,531	873		15		58,200:1	10	8		200	4,250	0.45	0.40		GC	
Elm Grove		Struct (FA)		1973 Cotton Valley	7,768						8	1		247	4,154	0.53	0.45			
Greenwood-Waskom	No		1924																	
Haynesville		Struct (A)	1921	1944: Taylor	8,835–8,920		373								3,870	0.43				I: 119; III-1, 18
				1945: Camp	7,980–8,004		264													
E. Haynesville			1945	1949: Tucker	8,588–8,600	2,898		276		10,500:1										II: 435; III-2: 63
Hico-Knowles	No																			
Hico		Struct (FA)	1946	1946: Vaughn	8,525–8,556	8,240		121		68,100:1	17				3,686	0.42		Multiple GWCs	PD	I:125; III-2: 75
				1946: Bodcaw	8,287–8,345	892		41		21,649:1	18				4,061	0.47			PD	
				1949: Feazel-McFearin	8,914–8,929	2,880		308		9,350:1	15				5,616	0.63				

Table 2. Geologic and production data for Cotton Valley (CV) fields in east Texas and northern Louisiana—Continued.

Name of field producing from CV ss	FERC termed "tight" for CV ss?	Trapping mechanism for field	Date field discovered	Date of CV well discovery and specific CV ss that was productive	Depth of perforations in discovery well for specific CV ss (ft)	Initial production for specific CV ss				Gas:oil ratio (GOR)	Porosity (%)	Nonstressed permeability (mD)		BHT (°F)	BHP (psi)	FPG (psi/ft)	Sw	Depth to gas-water contact (GWC) or oil-water contact (OWC)	Drive mechanism	Shreveport Geological Society Reference Report (volume: page)
						MCFD	BOPD	BCPD	BWPD			AV.	MAX.							
Knowles		Struct (A)	1945	1945: Vaughn	8,700–8,750	5,212		139		37,500:1					3,500	0.40				III-2: 82
				1946: Bodcaw	8,630–8,670	8,516		158		53,900:1										
				1948: McCrary	8,912–8,924	6,762		761		8,886:1										
				1953: Feasel-McFearin	8,996–9,008	7,000		275		25,450:1										
Homer			1919																	
Ivan			1952																	
Lake Bistineau			1916																	
Leatherman Creek		Struct (FA)	1975	1975: Cotton Valley	10,400–10,800						12	1					0.30		PD	VI: 70
Lisbon	No	Struct (FA)	1936	1939: Vaughn	8,444–8,464	5,000		61		82,000:1	17	150					0.35		PD	I: 143
				1940: Burgess-Simmons	8,766–8,806	1,993		160		12,458:1	14	40							PD	
NE Lisbon		Comb (N, FC)	1941	1942: Burgess-Simmons	8,502–8,525	510		17		30,000:1										I: 169
				1943: Bodcaw	7,790–7,816	19,000					17	196								
Longwood		Strat (FC)	1927	1948: Bodcaw	8,350															
Minden			1957																	
Monroe			1916																	
W. Monroe			1957																	
Plain Dealing			1946																	
Rocky Mount			1959																	
Ruston	No	Comb (A,FC)	1943	1948: "D"	8,796–8,806	6,500		56		24,000:1	18	100		210	4,100	0.47	0.23	GWC in Vaughn ss	PD	I: 185; III-2: 87; VI: 108
				1949: Bodcaw	8,707–8,730	4,263		195		21,860:1	19	150							PD	
				1949: Vaughn	8,809–8,838	7,995		390		20,501:1									PD	
				1949: "D"	8,674–8,706	8,250													PD	
				1949: Bodcaw	8,760–8,810	15,500													PD	
				1951: Feazel (Davis)	9,468–9,476	1,062		50		21,240:1	18	80							PD	
S. Sarepta		Comb (FA,FC)	1949	1949: Bodcaw	8,710	2,160		173		12,485:1	17	265			4300	0.49	0.14		PD	
				1949: Savis	9,000						13	75			4,500	0.50	0.15		PD	
				1949: Ardis	9,150						12	50			4,525	0.49	0.14		GC	
Sentell	No	Comb (N, FC)	1951	1951: Bodcaw	8,320	25,500		455		56,043:1	16	50								No SGS report
Shongaloo			1921																	
Sligo	No		1922																	I: 193
Sugar Creek		Struct (FA)	1930	1957: Bodcaw	8,724–8,730	5,000		210		23,810:1					3,972	0.46				I: 213; VI: 126
				1957: Vaughn	8,780–8,795	2,850		48.5		58,763:1					2,955	0.34				
				1958: "D"	7,917–7,925	21,000		896		23,437:1										
				1962: "D"	7,686–7,693	3,200		112		28,571:1										
				1962: McFearin	8,003–8,008	2,800		168		17,500:1										
				1979: Price	9,462–9,474	520														
Terryville	No	Comb (N, FC)	1954	1954: "D"	9,203–9,227	3,739		277		13,514:1	10	125						GWC in "D" ss	WD	V: 196
				1957: "C"	9,169–9,182	1,030		38	29	27,105:1										
				1959: "C"	9,049–9,053		133													
				1962: McGrary	9,354–9,362	4,000		300		13,333:1										
Tremont		Comb (N, FC)	1944	1944: Bodcaw	9,060–9,080	2,235		97		23,000:1					4,200	0.46				I: 219; VI: 133
				1971: Davis	9,633–9,706	1,145		144		7,951:1	14	34		217	6,519	0.67	0.15		PD	
Unionville		Strat (FC)	1950	1950: Vaughn	8,550															
				1950: Davis	8,700															
Vernon		Strat (FC)		1967: Cadeville	10,900															

280 mD (millidarcy), respectively (tables 1, 2). Porosity and permeability data are not readily available for all productive blanket sandstones in Cotton Valley fields. However, sufficient data are available from several blanket-sandstone reservoirs within a dozen fields across northern Louisiana to highlight the widespread distribution of relatively high-quality reservoir sandstones across the Cotton Valley blanket-sandstone trend (fig. 11). Data shown in figure 11 are derived primarily from field reports published by the Shreveport Geological Society and from White and others (1992). Multiple values of porosity and permeability for a given field in figure 11 represent measured values for separate, stacked blanket-sandstone reservoirs within that field. Average porosity and permeability are 15 percent and 115 mD, respectively, for Cotton Valley blanket sandstones, calculated from data in figure 11.

Relatively high porosity and permeability of blanket sandstones are reflected in (1) the ability of these sandstones to flow gas and/or liquids on open-hole DSTs and (2) high initial gas production rates (fig. 12) from these sandstones in production tests without use of massive hydraulic fracture-stimulation treatments. Multiple values of initial flow rates for a given field shown in figure 12 indicate rates from different stacked blanket sandstones producing in that field. Across the blanket-sandstone trend, as shown in figure 12, initial production rates range from 510 MCFD (thousand cubic feet per day) to 25,500 MCFD and average about 5,000 MCFD.

Cotton Valley Group sandstones in the massive-sandstone trend (fig. 8; table 1) have significantly poorer reservoir properties than those in the blanket-sandstone trend. Massive Cotton Valley sandstones have sufficiently low permeability that they generally do not flow gas or liquids during open-hole DSTs, and they require fracture-stimulation treatment to obtain commercial rates of gas production (Collins, 1980). Commercial gas production from these sandstones was not achieved until the 1970s when technological advances in massive hydraulic fracturing occurred together with higher gas prices from deregulation. Consequently, development of Cotton Valley fields in the Cotton Valley massive-sandstone

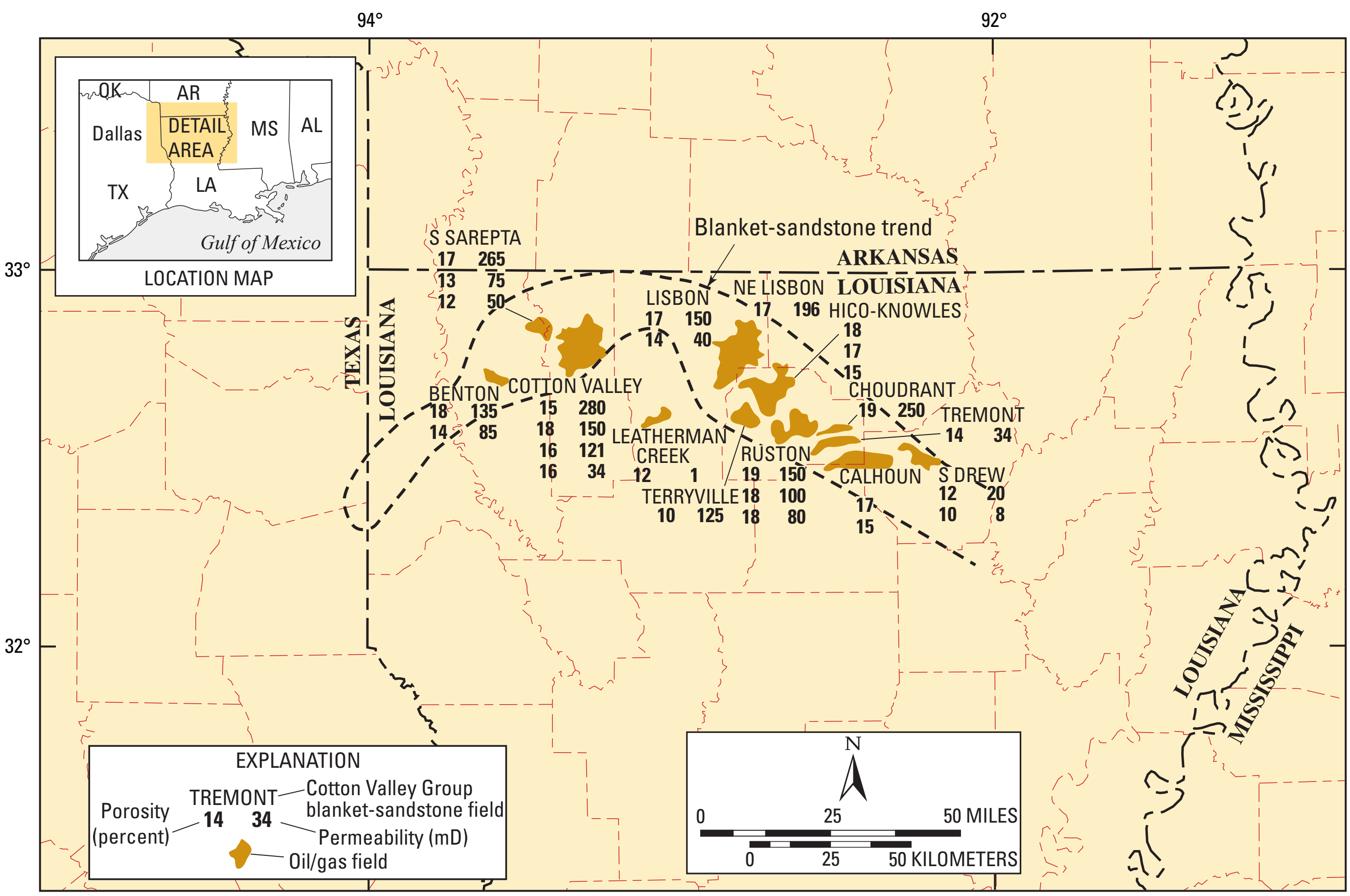


Figure 11. Map of northeast Texas and northern Louisiana, showing measured values of porosity and permeability in Cotton Valley Group blanket sandstones. Porosity and permeability data are documented in table 2. Multiple values of porosity and permeability for a given field represent measured values for separate, stacked blanket-sandstone reservoirs in that field.

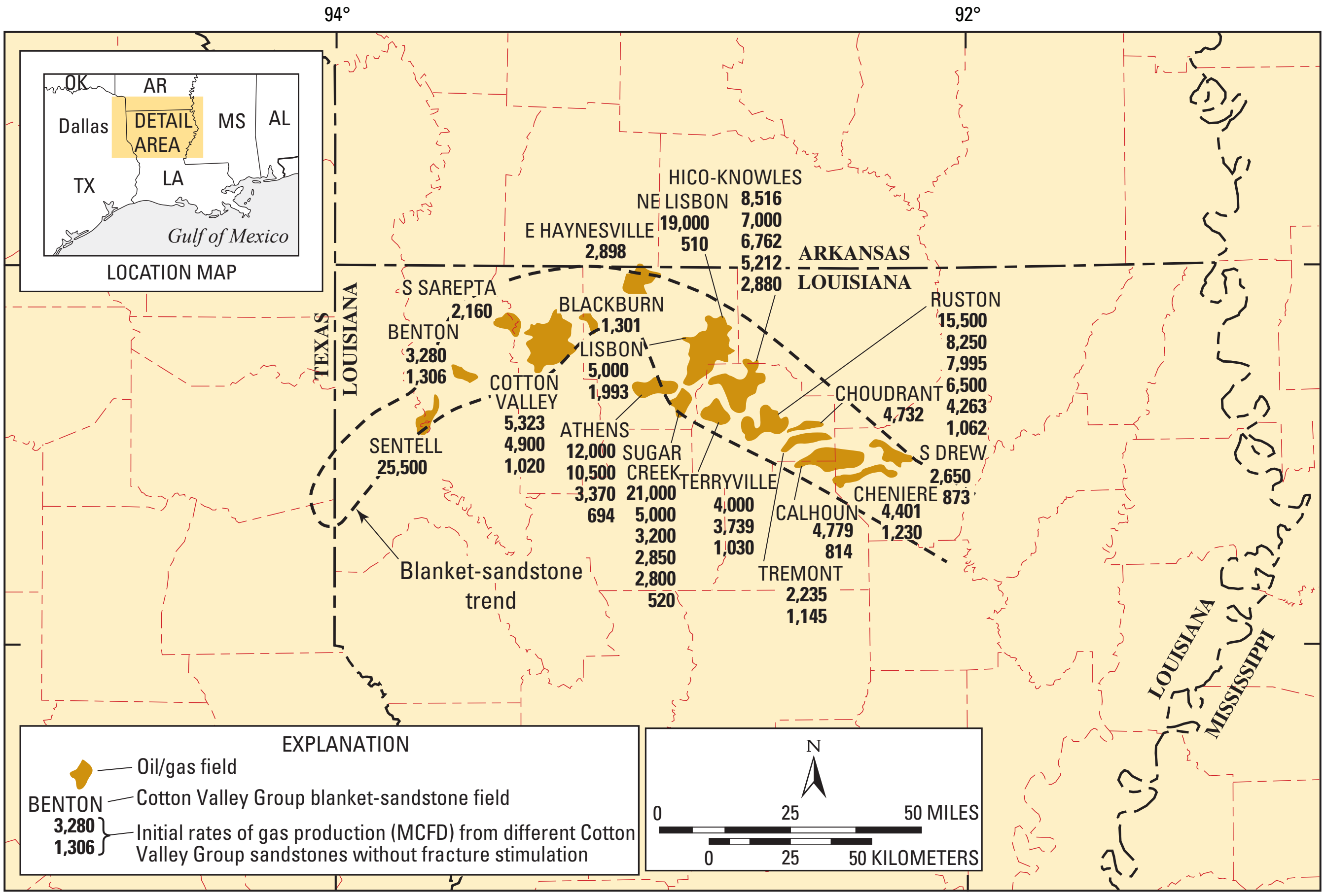


Figure 12. Map of northeast Texas and northern Louisiana, showing initial rates of gas production in thousands of cubic feet of gas per day (MCFD) from Cotton Valley Group blanket sandstones. Multiple values of initial flow rates for a given field represent rates from different stacked blanket-sandstone reservoirs producing in that field. All rates are from blanket sandstones, which do not require fracture-stimulation treatment for commercial production.

trend did not occur until the late 1970s and 1980s when they were designated as “tight” by the Federal Energy Regulatory Commission (FERC). Development drilling in Elm Grove and Caspiana Cotton Valley fields in northern Louisiana continues at the time this report is being written (Al Taylor, Nomad Geosciences, oral commun., April 2000; see also Bartberger and others, 2002). One consequence of such recent development of fields in the Cotton Valley massive-sandstone trend is that less published information is available on characteristics of these fields than on older fields in the blanket-sandstone trend.

Gas-Water Contacts

The presence or absence of gas-water contacts is important in defining whether an assessment unit includes conventional fields (gas-water contacts present) or continuous-type fields (gas-water contacts absent).

Blanket-Sandstone Trend

The Cotton Valley Group blanket-sandstone trend was assessed as a continuous-gas accumulation in the USGS 1995 National Assessment of United States Oil and Gas Resources (Schenk and Viger, 1996). Owing to the presence of abundant gas-water contacts across this area, we have redefined this blanket-sandstone trend as part of a conventional-gas assessment unit.

Gas-water contacts have been reported in seven fields within the blanket-sandstone trend across northernmost Louisiana (fig. 13) (Bartberger and others, 2002). Because of relatively high porosity and permeability in blanket sandstones, gas-water contacts are sharp. Separate gas-water contacts for individual, stacked blanket sandstones have been identified in Hico-Knowles and Choudrant fields (fig. 8, table 2). The seven fields for which gas-water contacts have been described are widely distributed across the blanket-sandstone trend (fig. 13). Because of the relatively uniform distribution of high-permeability Cotton Valley sandstone reservoirs that have conventional shale seals in fields across the blanket-

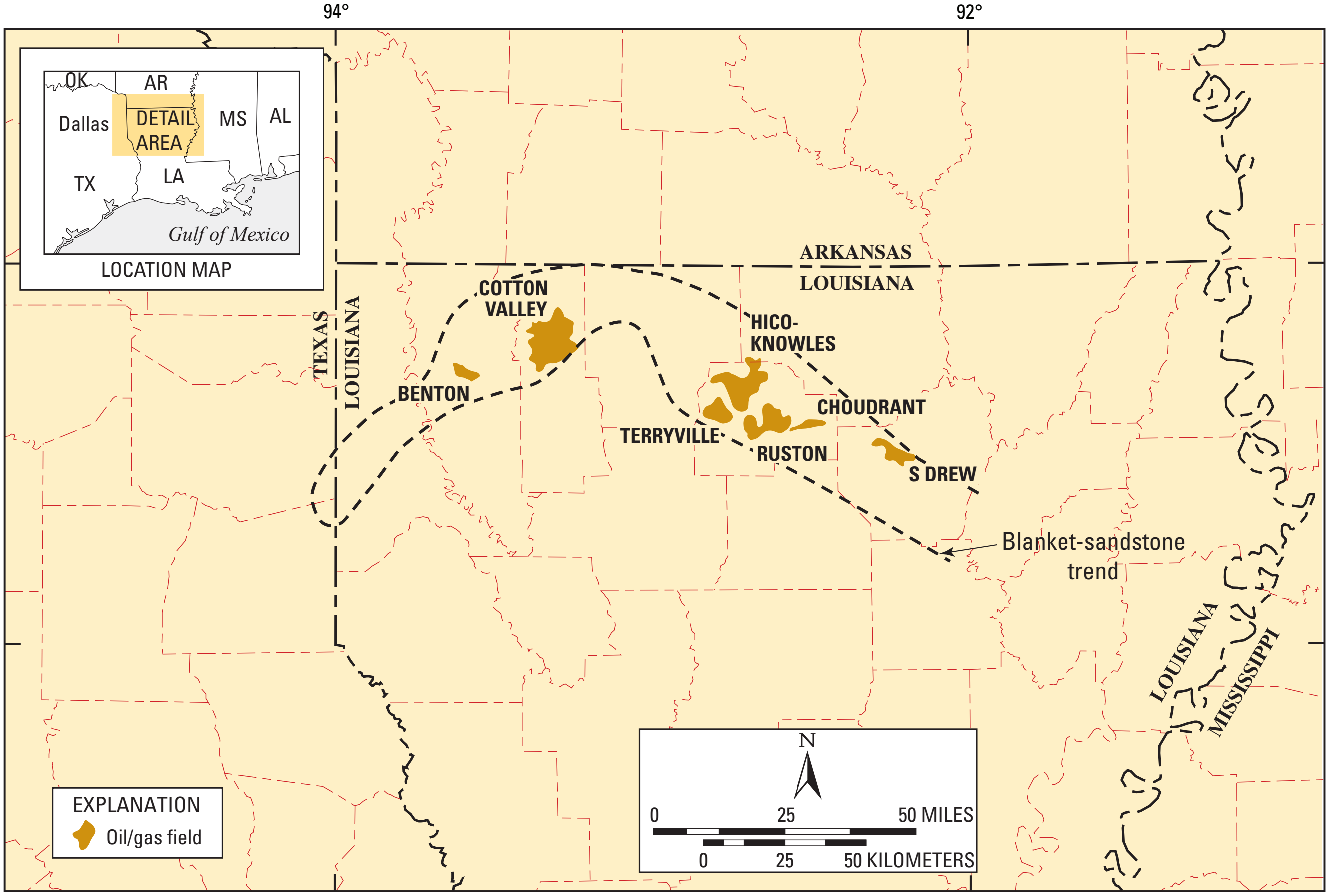


Figure 13. Map of northeast Texas and northern Louisiana, showing those fields that are productive from Cotton Valley Group sandstones and that have gas-water contacts identified and reported in the public literature. The presence of gas-water contacts in these fields suggests that they are conventional-gas accumulations. See table 2 for sources of information on gas-water contacts.

sandstone trend, it is likely that all Cotton Valley fields in this trend have well-defined gas-water contacts similar to those documented in the seven fields shown in figure 13. For these reasons, the blanket-sandstone trend has been interpreted as a conventional assessment unit in this report.

Massive-Sandstone Trend

Evaluating the presence or absence of gas-water contacts in the low-permeability massive-sandstone trend of the Terryville Sandstone is more difficult. No reference to specific gas-water contacts in massive sandstones of the Cotton Valley Group in any Cotton Valley gas field has been found in the published literature. Nangle and others (1982) and Dutton and others (1993), however, made general statements indicating that gas-water contacts are present in fields across the Cotton Valley massive-sandstone trend.

Both water- and gas-charged sandstones have been reported in the middle and upper Cotton Valley Group interval in some fields, although Taylor sandstone occurrences in the lower part of the Cotton Valley interval produce gas in all major Cotton Valley fields in the massive-sandstone trend. Along with the Taylor sandstone, most of the upper part of the Cotton Valley sandstone interval produces gas in some fields, such as Carthage field (fig. 8), according to Al Brake (BP, oral commun., 2000; see also Bartberger and others, 2002). Other fields such as Woodlawn and Blocker (fig. 8), however, produce gas only from lower Cotton Valley Taylor sandstone and from a few sandstones in the uppermost Cotton Valley section. Intervening middle and upper Cotton Valley sandstones are reportedly water bearing. The presence of individual gas-bearing and water-bearing sandstone intervals that are separated by conventional shale seals suggests the presence of gas-water contacts and is more indicative of conventional-gas accumulations than of continuous-gas accumulations.

Our evaluation of DST and production-test data from Cotton Valley Group sandstones in the massive-sandstone trend revealed that few dry holes penetrate Cotton Valley sandstones on the flanks of those fields. No flanking dry holes were found that tested water without gas, thereby implying existence of a gas-water contact for a particular field. Likewise, a detailed examination of test data from all wells within and flanking Oak Hill and Elm-Grove/Caspiana fields (fig. 8) in the massive-sandstone trend revealed no flanking dry holes that tested water without gas.

Initial rates of gas production from wells on the flanks of Cotton Valley Group fields in the low-permeability massive-sandstone trend, however, generally are lower than for crestal wells, as illustrated for Caspiana field in figure 14. Also, as shown for Caspiana field in figure 15, the ratio of initial daily rate of water production (in BW—barrels of water) to initial daily rate of gas production (in MMCFG—millions of cubic feet of gas) in terms of BW/MMCFG is significantly higher in flank wells. Initial rates of gas production from crestal wells commonly range from 1,000 to >4,000 MCFD, and the ratio of initial rate of water to gas generally is <200 BW/MMCFG and often below 100 BW/MMCFG (figs. 14, 15). Initial rates of gas production from flank wells generally are <1,000 MCFD, and water production initially is significantly higher, usually in the 300–600 BW/MMCFG range and sometimes >1,000 BW/MMCFG (fig. 14). These data suggest a decrease in gas saturation and an accompanying increase in water saturation in Cotton Valley sandstones from crestal wells to flank wells, and that a commercial limit to gas production has been reached in the flanking wells, although gas-water contacts have not been encountered.

Corroborating these suggestions is the experience of Al Taylor (Nomad Geosciences, oral commun., 2000; see also Bartberger and others, 2002) who reported the presence of vertically extensive gas-water transition zones in Cotton Valley Group sandstone fields in the massive-sandstone trend. Gas saturation of sandstone reservoirs decreases along the flanks of these low-permeability Cotton Valley gas fields while water saturation simultaneously increases (fig. 16). A long gas-water transition zone is developed along the margin of the field. Wells that are low in the transition zone, on the edges of Cotton Valley fields in the massive-sandstone gas trend, exhibit low initial rates of gas production and high initial rates of water production, as shown by some flank wells at Caspiana field (figs. 14, 15). Hyperbolic declines in rates of gas production in conjunction with lower gas saturations of reservoir sandstones in these transition-zone wells result in such low rates of gas production that these wells become noncommercial (Al Taylor, Nomad Geosciences, oral commun., 2000). Commercial limits of gas production are reached before gas-water contacts can be encountered by development drilling.

In summary, Cotton Valley Group blanket sandstones across northern Louisiana have sufficiently high porosity and permeability that gas accumulations exhibit short gas-water transition zones and have sharp gas-water contacts. Gas fields in this trend have clearly defined lateral productive limits, beyond which wells produce water only. However, sandstones in the low-permeability Cotton Valley massive-sandstone trend across northern Louisiana, the Sabine uplift, and East Texas Basin display long gas-water transition zones with poorly defined gas-water contacts. Productive limits of fields in this trend are difficult to define on the basis of data from production tests or wireline logs. In conjunction with long gas-water transition zones, structural dips are gentle on the flanks of these gas accumulations. As development drilling progresses down the flank of one of these fields through the long gas-water transition zone, gas saturations in the sandstone reservoir decrease and water saturations increase. Eventually gas saturations become sufficiently low that, in terms of ultimate cumulative gas production, wells become marginally commercial to noncommercial at a structural position still within the transition zone above the gas-water contact. Consequently, development wells on the flanks of these gas accumulations generally have not encountered gas-water contacts. If drilling and completion costs were hypothetically reduced to zero, causing even the smallest amount of gas recovery to be commercial, development drilling could progress down the full length of transition zones, and gas-water contacts probably would be encountered. The progressive increase in water saturation with depth within these low-permeability Cotton Valley gas fields, therefore, suggests that poorly defined gas-water contacts are present below the depth at which wells become noncommercial. On the basis of the presence of long gas-water transition zones and the limits to gas saturation, we have defined reservoirs in the massive-sandstone trend as part of a conventional-gas assessment unit.

Traps and Seals

Many fields that produce from the Cotton Valley Group and Travis Peak Formation in east Texas, Louisiana, and Mississippi are in structural or combination traps that are associated with Louann Salt structures. Salt structures range from small, low-relief salt pillows to large piercement domes (McGowen and Harris, 1984; Kosters and others, 1989). Early discoveries in the blanket-sandstone trend were in anticlinal traps associated with salt structures. Subsequent discoveries came from more complex and subtle traps, including (1) combination traps with blanket sandstones pinching out across anticlines or structural noses and (2) stratigraphic traps with blanket sandstones pinching out on regional dip (Pate, 1963; Coleman and Coleman, 1981).

Numerous smaller structural highs on the Sabine uplift in the form of domes, anticlines, and structural noses provide traps for hydrocarbon accumulations, including many gas fields in Cotton Valley Group sandstones. The origins of these smaller structures also have been attributed to salt deformation and small igneous intrusions, as summarized by Kosters and others (1989). Because the Louann Salt is thin across the Sabine uplift, Kosters and others (1989) suggested that most of the smaller structures across the Sabine uplift developed in association with igneous activity.

Seals are most commonly lagoonal facies of the Hico Shale in updip positions. In the downdip massive- and blanket-sandstone trends, seals are primarily marine shales. Gas in wave-dominated deltaic (Taylor) sandstones in northern Louisiana reportedly is sealed by marsh and lagoonal shales (CER Corporation and S.A. Holditch & Associates, 1991).

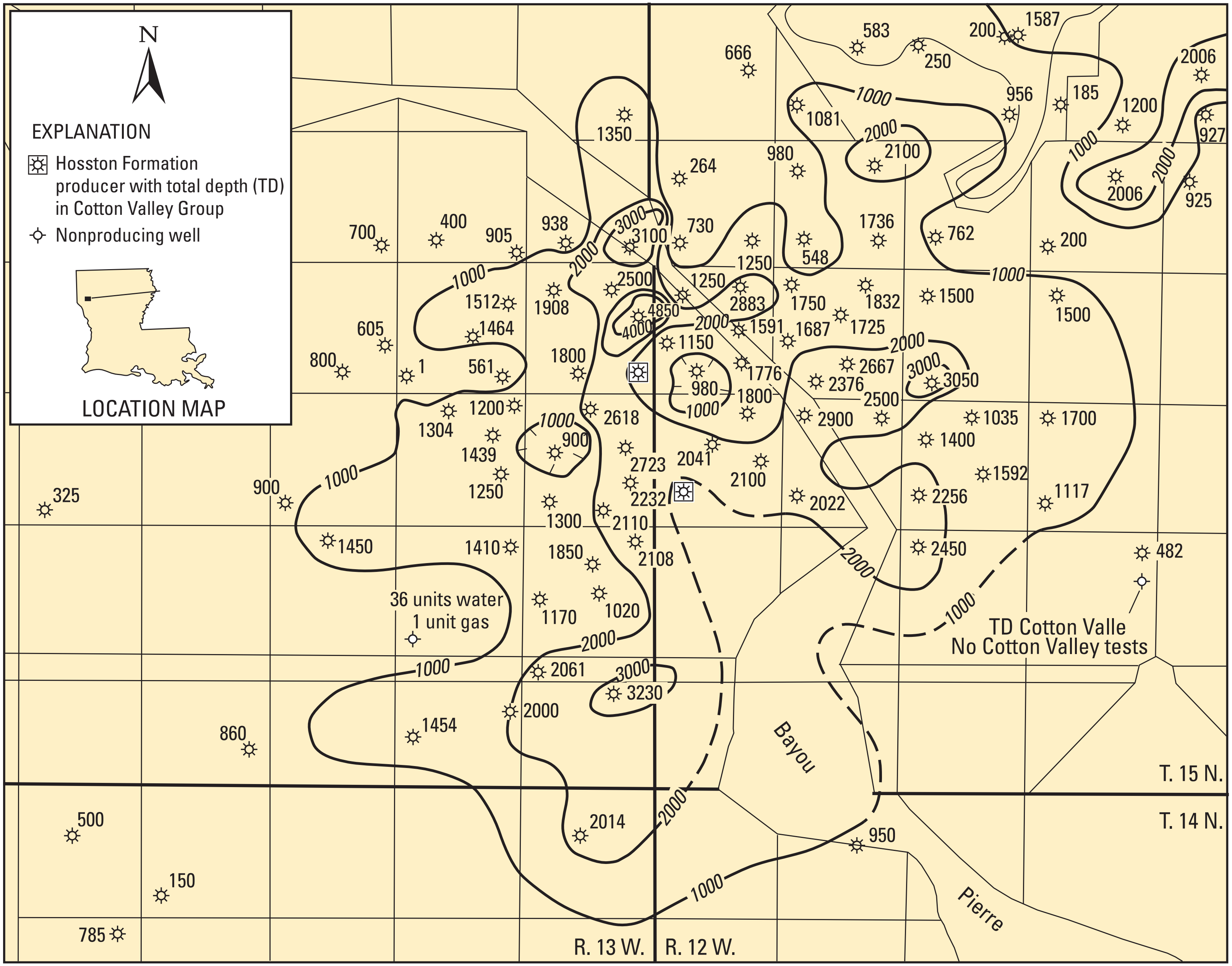


Figure 14. Map of Caspiana field (location in fig. 8) in northwest Louisiana in the low-permeability massive sandstones of the Cotton Valley Group, showing initial rate of gas production in thousands of cubic feet of gas per day (MCFD) from Cotton Valley sandstone reservoirs. Data from IHS Energy Group (2001, petroROM, version 3.43). Contour interval is 1,000 MCFD. Map shows general decrease in initial rates of gas production from center to flank of field.

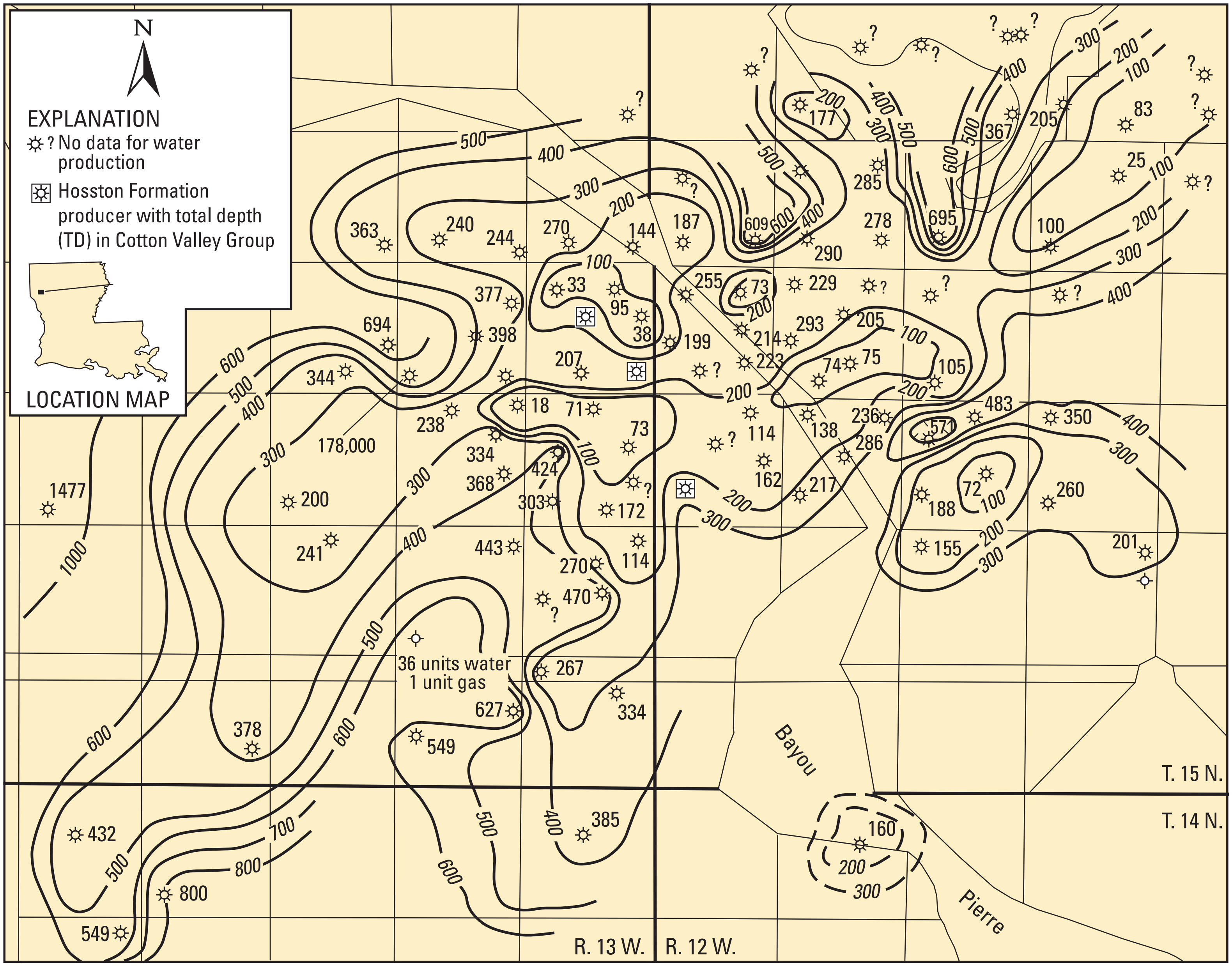


Figure 15. Map of Caspiana field (location in fig. 8) in northwest Louisiana in the low-permeability massive sandstones of the Cotton Valley Group, showing ratio of initial daily production rate of water in barrels of water (BW) to initial daily production rate of gas in millions of cubic feet of gas (MMCFG) from Cotton Valley Group sandstones. Data from IHS Energy Group (2001, petroROM, version 3.43). Contour interval is 100 BW/MMCFG. Mapped data show a significant progressive increase in the ratio of initial production rates of water to gas from crest to flanks of field.

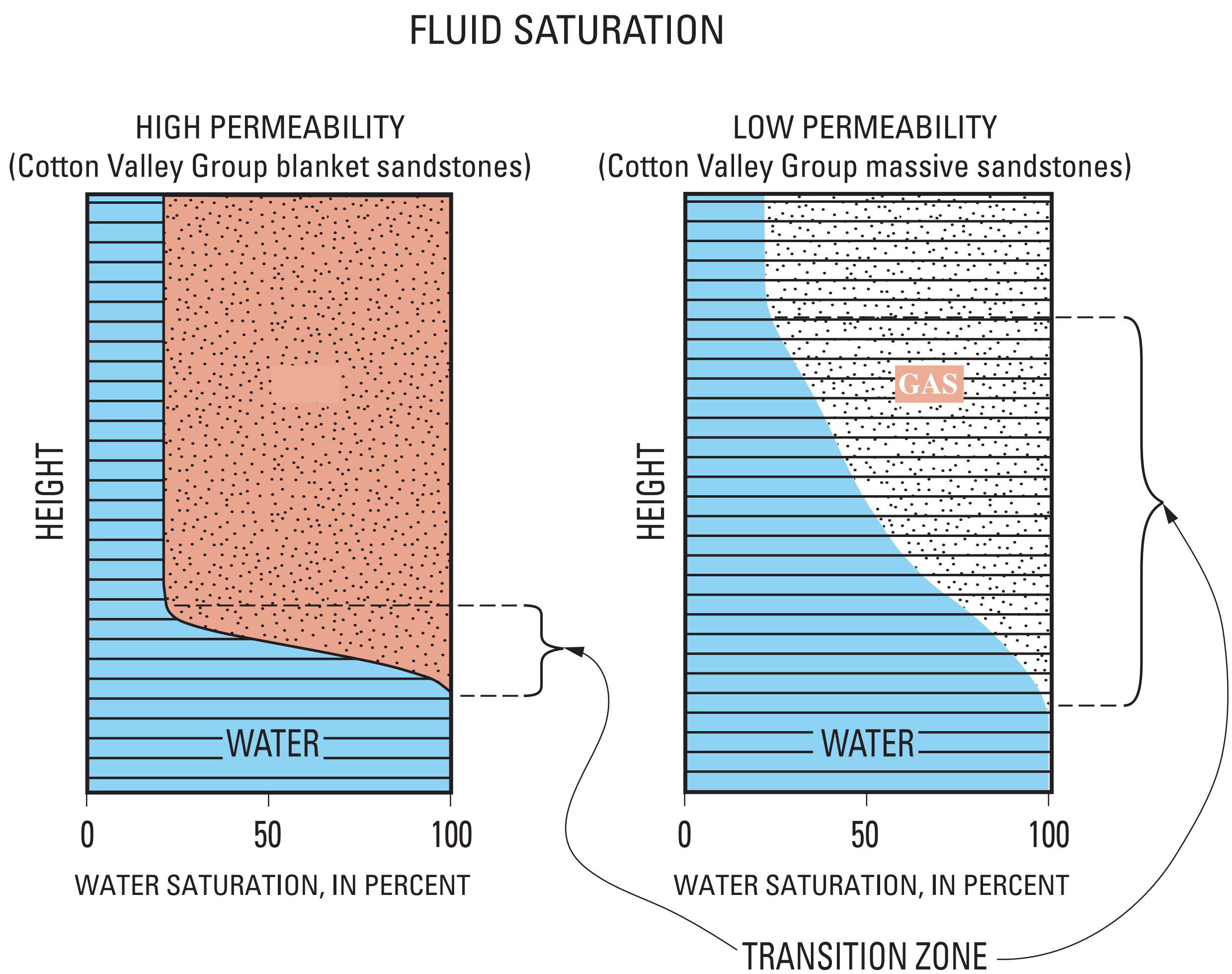


Figure 16. Schematic diagrams of gas-water transition zones in high- and low-permeability reservoirs (modified from Levorsen, 1967).

Exploration History

Commercial gas production was established in 1937 from high-porosity and -permeability Cotton Valley Group blanket-sandstone reservoirs across northern Louisiana and continued through the early 1960s. Gas flowed from blanket sandstones at commercial rates without artificial stimulation. By the early 1960s, the high-porosity blanket-sandstone play matured, and exploratory drilling waned. Low-porosity, low-permeability massive-sandstone wells to the south in Louisiana and to the west on the Sabine uplift in northwestern Louisiana and east Texas flowed gas at rates of <1,000 MCFD (thousand cubic feet of gas per day) and were not commercial when gas was selling at $0.18/MCF in the 1960s (Collins, 1980).

In the 1970s, gas production from low-permeability massive sandstones of the Cotton Valley Group became commercial in part as a result of technical advances in massive hydraulic-fracturing techniques. At Bethany field (fig. 8) on the Sabine uplift in east Texas in 1972, Texaco successfully used massive hydraulic fracturing to increase production rates out of low-permeability Cotton Valley sandstones from 500 MCFD to a sustained rate of 2,500 MCFD and 30 BCPD (barrels of condensate per day) (Jennings and Sprawls, 1977). In conjunction with development of improved stimulation technology, price deregulation through the Natural Gas Policy Act (NGPA) of 1978 spawned a dramatic increase in drilling for gas in low-permeability Cotton Valley sandstones (Bruce and others, 1992). In 1980, the Federal Energy Regulatory Commission (FERC) officially classified low-permeability Cotton Valley sandstones as “tight gas sands,” qualifying them for additional price incentives. Production from low-permeability Cotton Valley massive sandstones surged. At Carthage field in east Texas (fig. 8), for example, production from Cotton Valley sandstones increased from 2.2 BCFG (billion cubic feet of gas) in 1976 to 70.9 BCFG in 1980 (Meehan and Pennington, 1982). Cotton Valley sandstones have been designated as “tight” gas sandstones by FERC over a large area of northern Louisiana and northeast Texas (fig. 8; Dutton and others, 1993).

Productive Trends

Two productive Cotton Valley Group sandstone trends are identified on the basis of reservoir properties that are controlled primarily by variations in depositional environment and diagenetic alteration. Reservoir properties in turn govern gas-production characteristics, including both initial rate of gas production and whether hydraulic-fracture treatments are necessary to achieve commercial production rates. Table 1 summarizes these and other key parameters that distinguish Cotton Valley Group blanket- and massive-sandstone reservoir trends. Data presented in table 1 were derived from the variety of sources identified in the table headnote; much of the information comes from a series of reports by the Shreveport Geological Society (Reference Reports published by Shreveport Geological Society, 1946, 1947, 1951, 1953, 1958, 1963, 1980, 1987; see also Bartberger and others, 2002). Detailed

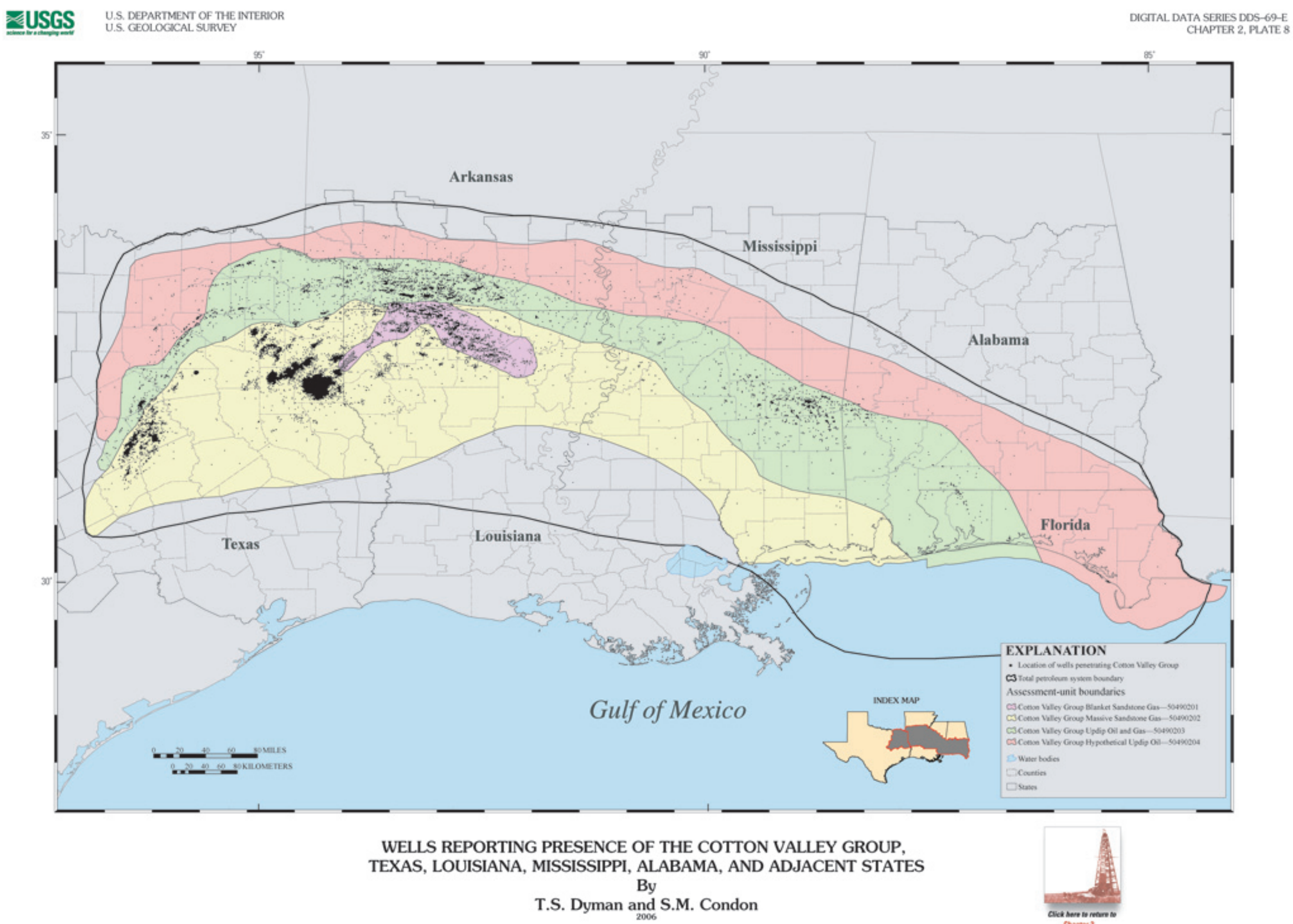


Plate 8. Wells reporting the presence of the Cotton Valley Group. This map shows the distribution of wells that have a reported occurrence of the Cotton Valley Group. The data plotted were the result of a simple database query, but are dependent on whether the operator of the well reported a Cotton Valley top that was then entered into the database. It is likely that some wells that penetrated the Cotton Valley do not have reported Cotton Valley tops, but the number of such wells is unknown. This map shows the locations of 14,189 wells for which locations are available in the database. There are four distinct clusters of Cotton Valley wells shown on the map: (1) in east Texas along the west side of the East Texas Basin, (2) in east Texas along the east side of the East Texas Basin (southwestern Sabine uplift), (3) in northern Louisiana and southern Arkansas, and (4) in southeastern Mississippi. Reported depths in the IHS database range from 802 to 21,020 ft. Assessment-unit boundaries for the Cotton Valley Group are also shown on this map to indicate the distribution of Cotton Valley wells within each assessment unit.

information was obtained from those reports on >20 Cotton Valley oil and gas fields in northern Louisiana, including data on porosity, permeability, initial production rates, gas-water contacts, and fluid-pressure gradients (FPGs) (table 2).

Most of the significant fields across northern Louisiana and northeast Texas from which Cotton Valley Group sandstones produce gas are shown in figure 8. Plate 8 shows the distribution of wells that penetrate the Cotton Valley Group in the province. The area shown in figure 8 is part of the larger region shown in figure 4 within which Cotton Valley sandstones were designated as “tight” gas sandstones by Federal Energy Regulatory Commission (FERC) in 1980.

Cotton Valley Group Assessment Units, Jurassic Smackover Interior Salt Basins Total Petroleum System

Assessment-Unit Definitions and Boundaries

Cotton Valley Blanket Sandstone Gas Assessment Unit (AU 50490201)

This assessment unit lies entirely within the boundary of the Jurassic Smackover Interior Salt Basins Total Petroleum System. It has a mature drilling record (pls. 4, 5) and gas and oil fields that exceed the minimum size (3 BCFG and 0.5 MMBO). It is located downdip from the Cotton Valley Updip Oil and Gas Assessment Unit. Nine fields exist above the minimum size to classify the Cotton Valley Blanket Sandstone Gas Assessment Unit as a confirmed assessment unit (appendix 1). The estimated median undiscovered field size is 6 BCFG. The median number of undiscovered gas fields above the minimum size is estimated to be two. The assessment unit is defined by the presence of transgressive blanket sandstones (now part of the Cotton Valley Group) deposited along the coastal system in northern Louisiana and a small part of east Texas, updip from lower-permeability massive sandstones of the Cotton Valley Massive Sandstone Gas Assessment Unit (pls. 4, 5). The southern boundary of the Cotton Valley Blanket Sandstone Gas Assessment Unit is located where low-permeability massive-sandstone fields require fracture-stimulation treatment because of the lower average permeability of the massive-sandstone system. This assessment unit has a probability of 1.0 that one undiscovered field of greater than the minimum size exists (appendix 1). Drilling depths range from about 6,900 to 9,800 ft for both undiscovered oil and gas fields. The assessment unit covers an area of about 3,136 mi^2.

Cotton Valley Massive Sandstone Gas Assessment Unit (AU 50490202)

This assessment unit has a moderate drilling record (pls. 4, 5) and the presence of gas fields exceeding the minimum size (3 BCFG and 0.5 MMBO). It is downdip from the Cotton Valley Blanket Sandstone Gas Assessment Unit and the Cotton Valley Updip Oil and Gas Assessment Unit. Forty-four gas fields have been discovered above the minimum size to classify the Cotton Valley Massive Sandstone Gas Assessment Unit as a confirmed assessment unit (appendix 1). The median undiscovered field size is 18 BCFG. The median number of undiscovered gas fields above the minimum size is 18. The assessment unit is defined by the presence of massive low-permeability sandstones (now part of the Cotton Valley Group) south of the coastal system in north-central Louisiana and east Texas, eastward into central Mississippi and southern Alabama, and downdip from blanket sandstones of the Cotton Valley Blanket Sandstone Gas Assessment Unit (pl. 5). The southern boundary of the assessment unit is placed at the limit of commercial gas production. Producing wells in the Cotton Valley Massive Sandstone Gas Assessment Unit require fracture-stimulation treatment because of low average permeability. The assessment unit lies entirely within the boundary of the Jurassic Smackover Interior Salt Basins Total Petroleum System. This assessment unit has a probability of 1.0 that one undiscovered field of greater than the minimum size exists (appendix 1). Drilling depth ranges from about 8,000 to 20,000 ft for undiscovered gas fields. The assessment unit covers an area of about 42,269 mi^2.

Cotton Valley Updip Oil and Gas Assessment Unit (AU 50490203)

This assessment unit has a mature drilling record (pls. 4, 5) and the presence of oil and gas fields exceeding the minimum size (0.5 MMBO or 3 BCFG). It is downdip from the Cotton Valley Hypothetical Updip Oil Assessment Unit. Thirty-two oil and gas fields exist above the minimum size to classify the Cotton Valley Updip Oil and Gas Assessment Unit as a confirmed assessment unit (appendix 1). The estimated median undiscovered oil field size is 1.7 MMBO. The estimated median undiscovered gas field size is 6 BCFG. The median number of undiscovered oil fields above the minimum size is 12, and the median number of undiscovered gas fields above the minimum size is 2. The updip assessment-unit boundary occurs at the northern limit of known fields of the minimum size in northeast Texas, southeastern Oklahoma, northern Louisiana, central Mississippi, central Alabama, and the western part of the Florida Panhandle (pls. 4, 5). The southern assessment-unit boundary is developed where producing fields become primarily gas fields of the blanket-sandstone and massive-sandstone assessment units.

The assessment unit lies entirely within the boundary of the Jurassic Smackover Interior Salt Basins Total Petroleum System. It is confirmed and has a probability of 1.0 that one undiscovered field exists above the minimum size (appendix 1). Drilling depths range from 3,000 to 19,000 ft for both undiscovered oil fields and undiscovered gas fields. The assessment unit covers an area of about 30,825 mi^2.

Cotton Valley Hypothetical Updip Oil Assessment Unit (AU 50490204)

The existence of this assessment unit is based on a modest record of drilling and the presence of oil shows updip from the confirmed Cotton Valley Updip Oil and Gas Assessment Unit (pl. 5). No fields occur above the minimum size to confirm this assessment unit. The updip boundary is placed at the outcrop belt of Cotton Valley Group rocks in northeast Texas, southeastern Oklahoma, northern Louisiana, central Mississippi, central Alabama, and the westernmost part of the Florida Panhandle (pl. 5). The assessment unit lies entirely within the boundary of the Jurassic Smackover Interior Salt Basins Total Petroleum System. The southern assessment-unit boundary is defined by the occurrence of producing fields of the confirmed Cotton Valley Updip Oil and Gas Assessment Unit. Reservoir rocks deteriorate updip where nonmarine facies dominate and thermal maturities are lower than in the main producing trends farther south. Potential drilling depths range from 2,000 to 11,800 ft. The assessment unit covers an area of about 32,128 mi^2.

Assessment Results

Table 3 is a summary of the assessment results for the four conventional Cotton Valley Group assessment units by resource type (for example, crude oil, natural gas, and natural gas liquids). The total estimated mean undiscovered conventional-gas resource for the four Cotton Valley Group assessment units in the Jurassic Smackover Interior Salt Basins Total Petroleum System is 605.03 billion cubic feet (BCF); the range is 1,279.03 BCF (F5) to 144.03 BCF (F95), where F5 represents a 1 in 20 chance and F95 represents a 19 in 20 chance of the occurrence of at least the amount specified. This resource includes both nonassociated gas in gas fields and associated gas in oil fields. Only 26.81 BCF of the total mean estimated resource value (605.03 BCF) represents associated gas in oil fields. The largest undiscovered conventional gas resource was estimated for the Cotton Valley Massive Sandstone Gas Assessment Unit, which has a mean resource

Table 3. Assessment results for Cotton Valley Group reservoirs within Jurassic Smackover Interior Salt Basins Total Petroleum System (504902).

[MMBO, million barrels of oil; BCFG, billion cubic feet of gas; MMBNGL, million barrels of natural gas liquids; MAS, minimum accumulation size assessed (MMBO or BCFG); Prob., probability (including both geologic and accessibility probabilities) of at least one accumulation equal to or greater than the MAS; Accum., accumulation. Results shown are fully risked estimates. For gas accumulations, all liquids are included as NGL (natural gas liquids). F95 represents a 95 percent chance of at least the amount tabulated. Other fractiles are defined similarly. Fractiles are additive under the assumption of perfect positive correlation. Shading indicates not applicable. Totals do not reflect rounding]

Code and accumulation type	MAS	Prob. (0-1)	Total undiscovered resources											
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
504902	**Undiscovered conventional resources in Cotton Valley Group reservoirs within the Jurassic Smackover Interior Salt Basins Total Petroleum System**													
Oil accums.	0.5	1.00	9.20	26.81	61.14	29.81	7.57	23.41	58.22	26.81	0.35	1.14	3.05	1.34
Gas accums.	3.0						136.46	515.29	1,220.81	578.22	3.93	15.30	39.31	17.66
Total		1.00	9.20	26.81	61.14	29.81	144.03	538.69	1,279.03	605.03	4.28	16.44	42.36	19.00
50490201	**Cotton Valley Blanket Sandstone Gas Assessment Unit**													
Oil accums.	0.5	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gas accums.	3.0						4.54	13.89	31.85	15.54	0.22	0.68	1.66	0.78
Total		1.00	0.00	0.00	0.00	0.00	4.54	13.89	31.85	15.54	0.22	0.68	1.66	0.78
50490202	**Cotton Valley Massive Sandstone Gas Assessment Unit**													
Oil accums.	0.5	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gas accums.	3.0						127.40	487.62	1,157.23	547.25	3.58	14.22	36.65	16.42
Total		1.00	0.00	0.00	0.00	0.00	127.40	487.62	1,157.23	547.25	3.58	14.22	36.65	16.42
50490203	**Cotton Valley Updip Oil and Gas Assessment Unit**													
Oil accums.	0.5	1.00	9.20	24.42	51.44	26.70	7.57	21.43	49.17	24.02	0.35	1.04	2.58	1.20
Gas accums.	3.0						4.52	13.78	31.73	15.43	0.13	0.40	0.99	0.46
Total		1.00	9.20	24.42	51.44	26.70	12.09	35.21	80.90	39.45	0.48	1.45	3.57	1.66
50490204	**Cotton Valley Hypothetical Updip Oil Assessment Unit**													
Oil accums.	0.5	0.56	0.00	2.39	9.70	3.11	0.00	1.98	9.05	2.80	0.00	0.09	0.47	0.14
Gas accums.	3.0						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		0.56	0.00	2.39	9.70	3.11	0.00	1.98	9.05	2.80	0.00	0.09	0.47	0.14

of 547.25 BCF and a range of 1,157.23 BCF (F5) to 127.40 BCF (F95).

The total estimated mean undiscovered conventional–crude-oil resource for the Cotton Valley Group in the Jurassic Smackover Interior Salt Basins Total Petroleum System in the Louisiana-Mississippi Salt Basins Province is 29.81 million barrels (MMBO); the range is 61.14 MMBO (F5) to 9.20 MMBO (F95). The largest undiscovered conventional–crude-oil resource was estimated for the Cotton Valley Updip Oil and Gas Assessment Unit, which has a mean resource of 26.70 MMBO and a range of 51.44 MMBO (F5) to 9.20 MMBO (F95) (table 3).

The total estimated mean undiscovered conventional–natural-gas-liquids resource for the Cotton Valley Group in the Jurassic Smackover Interior Salt Basins Total Petroleum System in the Louisiana-Mississippi Salt Basins Province is 19.00 million barrels of natural gas liquids (MMBNGL); the range is 42.36 MMBNGL (F5) to 4.28 MMBNGL (F95) (table 3).

Conclusions

1. The Jurassic Smackover Interior Salt Basins Total Petroleum System is defined for this assessment to include both Upper Jurassic Smackover Formation carbonates and calcareous shales and Upper Jurassic and Lower Cretaceous Cotton Valley Group organic-rich shales. The Jurassic Smackover Interior Salt Basins Total Petroleum System includes four conventional Cotton Valley Group assessment units: Cotton Valley Blanket Sandstone Gas (AU 50490201), Cotton Valley Massive Sandstone Gas (AU 50490202), Cotton Valley Updip Oil and Gas (AU 50490203), and Cotton Valley Hypothetical Updip Oil (AU 50490204).

2. Together, these four assessment units are estimated to contain a mean undiscovered conventional resource of 29.81 million barrels of oil, 605.03 billion cubic feet of gas, and 19.00 million barrels of natural gas liquids.

3. The Cotton Valley Group represents the first major influx of clastic sediment into the ancestral Gulf of Mexico. Major depocenters were located in south-central Mississippi, along the Louisiana-Mississippi border, and in northeast Texas. Sands supplied by the ancestral Mississippi River drainage along the Louisiana-Mississippi border were swept westward by longshore currents, creating an east-west–oriented barrier-island or strand-plain system across northern Louisiana that isolated a lagoon to the north. More than 1,000 ft of stacked barrier-island sands accumulated as the Terryville Sandstone massive-sandstone complex. Periodic transgressive events reworked these barrier-island sands, transporting them northward into the lagoon where they were further reworked to become transgressive sandstones. These transgressive sandstones laterally pinch out into Hico lagoonal shales and can be correlated across northern Louisiana. They are referred to informally as blanket sandstones.

4. Two major Cotton Valley Group sandstone-reservoir trends are identified on the basis of reservoir properties and associated characteristics of gas production. Transgressive blanket sandstones across northern Louisiana have porosities ranging from 10 to 19 percent and permeabilities from 1 to 280 mD. These sandstones flow gas and/or liquids during open-hole DSTs and do not require fracture-stimulation treatment to produce gas at commercial rates. Fields that produce from these sandstone reservoirs were developed from the 1940s through the 1960s. Cotton Valley massive sandstones, located to the south of the blanket sandstones, extend westward across the Sabine uplift into east Texas. Massive sandstones exhibit porosities ranging from 6 to 10 percent and permeabilities of generally <0.1 mD. Designated as low-permeability (tight) gas sandstones by the Federal Energy Regulatory Commission (FERC), these reservoirs commonly do not flow gas or liquids during DSTs, and they require fracture-stimulation treatments to achieve commercial rates of production. Gas production from these sandstones in east Texas and northern Louisiana was not established until the mid-1970s when advances in massive hydraulic-fracture techniques occurred in conjunction with a significant increase in gas prices as a result of price deregulation.

5. Porosity and permeability of Cotton Valley Group sandstones are controlled by diagenetic properties, which in turn are governed by depositional environment. Although diagenetic patterns and mineralogy are complex, high-energy, clean sandstones generally are cemented by authigenic quartz and/or calcite and have poor reservoir properties. In lower-energy sandstones, clay coatings on quartz grains inhibited development of quartz overgrowths, resulting in preservation of primary porosity. High clay content, however, generally imparts poor permeability to these sandstones. The best reservoir sandstones are those that have undergone development of significant secondary porosity from dissolution of calcite cement and unstable framework grains.

6. Cotton Valley Group sandstones in northeast Louisiana exhibit abnormally high reservoir pressures with fluid-pressure gradients of >0.55 psi/ft. The boundary between the overpressured area on the east and the normally pressured area to the west cuts across both the permeable blanket-sandstone trend and the low-permeability massive-sandstone trend such that overpressures occur within both reservoir trends. Within the blanket-sandstone trend, where pressure data are more abundant, some Cotton Valley fields are overpressured, whereas adjacent fields are normally pressured. Also, within certain fields, some of the stacked blanket sandstones are overpressured, whereas others are normally pressured. Such compartmentalization of overpressured reservoirs in proximity to normally pressured ones, rather than development of overpressure on a regional scale, suggests that these blanket-sandstone fields are conventional-gas accumulations rather than continuous-gas accumulations. Also, the occurrence of normally pressured reservoirs across the trend of the Cotton Valley massive-sandstone reservoirs does not support the presence of a basin-center, continuous-gas accumulation.

7. Gas found in Cotton Valley Group sandstone reservoirs is thought to be derived primarily from Jurassic Smackover Formation source rocks deposited as lime muds and secondarily from interbedded Cotton Valley marine shales and underlying marine shales of the Bossier Shale. These source rocks are thought to have been buried to sufficient depths relative to the regional geothermal gradient to have generated dry gas during the past 60 m.y. Timing of gas generation and migration is favorable because it postdates development of the Sabine uplift, associated smaller structures on and flanking the Sabine uplift, and salt structures in the East Texas Basin and northern Louisiana Salt Basin.

References Cited

Ahlbrandt, T.S., 2000, Introduction, *in* U.S. Geological Survey world petroleum assessment 2000—Description and results: U.S. Geological Survey Digital Data Series DDS–60, version 1.0, 4 CD-ROMs.

Bartberger, C.E., Dyman, T.S., and Condon, S.M., 2002, Is there a basin-center gas accumulation in Cotton Valley sandstones, Gulf Coast Basin, U.S.A.?: U.S. Geological Survey Bulletin 2184-D, 38 p.; available at URL http:/geology.cr.usgs. gov/pub/bulletins/b2184-d/ (last accessed 30 September 2005).

Bebout, D.G., White, W.A., Garrett, C.M., Jr., and Hentz, T.F., 1992, Atlas of major central and eastern Gulf Coast gas reservoirs: Austin, Tex., University of Texas, Bureau of Economic Geology, 88 p.

Black, C.E., and Berg, R.R., 1987, Fan-delta reservoirs in the Lower Cotton Valley Group (Jurassic), Kildare field, northeast Texas: Gulf Coast Association of Geological Societies Transactions, v. 37, p. 35–42.

Bruce, P.L., Hunter, J.L., Kuhlman, R.D., and Weinheimer, D.D., 1992, New fracturing techniques reduce low-permeability gas sand completion problems: Oil and Gas Journal, v. 90, no. 41, p. 72–76.

CER Corporation and S.A. Holditch & Associates, eds., 1991, Staged field experiment no. 3—Application of advanced technologies in tight-gas sandstones—Travis Peak and Cotton Valley Formations, Waskom field, Harrison County, Texas: Gas Research Institute Report 91/0048, 253 p.

Coleman, J.L., Jr., 1985, Diagenesis of Cotton Valley sandstone (Upper Jurassic), east Texas—Implications for tight-gas formation pay recognition—Discussion: American Association of Petroleum Geologists Bulletin, v. 69, no. 5, p. 813–815.

Coleman, J.L., Jr., and Coleman, C.J., 1981, Stratigraphic, sedimentologic and diagenetic framework for the Jurassic Cotton Valley Terryville massive sandstone complex, northern Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 31, p. 71–79.

Collins, S.E., 1980, Jurassic Cotton Valley and Smackover reservoir trends, east Texas, north Louisiana, and south Arkansas: American Association of Petroleum Geologists Bulletin, v. 64, no. 7, p. 1004–1013.

Dow, W.G., 1978, Petroleum source beds on continental slopes and rises: American Association of Petroleum Geologists Bulletin, v. 62, no. 9, p. 1584–1606.

Dutton, S.P., 1987, Diagenesis and burial history of the Lower Cretaceous Travis Peak Formation, east Texas: Austin, Tex., University of Texas, Bureau of Economic Geology, Report of Investigations No. 164, 58 p.

Dutton, S.P., Clift, S.J., Hamilton, D.S., Hamlin, H.S., Hentz, T.F., Howard, W.E., Akhter, M.S., and Laubach, S.E., 1993, Major low-permeability sandstone gas reservoirs in the continental United States: Austin, Tex., University of Texas, Bureau of Economic Geology, Report of Investigations No. 211, 221 p.

Eversull, L.G., 1985, Depositional systems and distribution of Cotton Valley blanket sandstones in northern Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 35, p. 49–57.

Finley, R.J., 1984, Geology and engineering characteristics of selected low-permeability gas sandstones—A national survey: Austin, Tex., University of Texas, Bureau of Economic Geology, Report of Investigations No. 138, 220 p.

Finley, R.J., 1986, An overview of selected blanket-geometry, low-permeability gas sandstones in Texas, *in* Spencer, C.W., and Mast, R.F., eds., Geology of tight-gas reservoirs: American Association of Petroleum Geologists Studies in Geology No. 24, p. 69–85.

Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1996, 1995 national assessment of United States oil and gas resources—Results, methodology, and supporting data: U.S. Geological Survey Digital Data Series 30, Release 2, 1 CD-ROM.

Hall, C.D., Janks, J.S., and Ladle, G.H., 1984, Sedimentology and diagenesis of the Cotton Valley sandstone in the Amoco No. 1 Cullers well, Rusk County, Texas, *in* Presley, M.W., ed., The Jurassic of east Texas: Tyler, Tex., East Texas Geological Society, p. 127–140.

Herrmann, L.A., Lott, J.A., and Davenport, R.E., 1991, Ruston field—U.S.A., Gulf Coast Basin, Louisiana, *in* Beaumont, E.A., and Foster, N.H., eds., Treatise of petroleum geology—Structural traps, Volume V: Tulsa, Okla., American Association of Petroleum Geologists, p. 151–186.

IHS Energy Group, 2001, PI-Dwights WHCS [Well History Control System] (through April 2001): Available from IHS Energy Group, Denver, CO 80112.

Jackson, M.L.W., and Laubach, S.E., 1991, Structural history and origin of the Sabine Arch, east Texas and northwest Louisiana: Austin, Austin, Tex., University of Texas, Bureau of Economic Geology, Geological Circular 91-3, 47 p.

Jennings, A.R., and Sprawls, B.T., 1977, Successful stimulation in the Cotton Valley sandstone—A low-permeability reservoir: Journal of Petroleum Technology, v. 29, no. 10, p. 1267–1276.

Kast, J.A., 1983, Depositional environments of Schuler Formation (Cotton Valley sands), Upshur County, Texas [abs.]: American Association of Petroleum Geologists Bulletin, v. 67, no. 3, p. 493.

Kosters, E.C., Bebout, D.G., Seni, S.J., Garrett, C.M., Jr., Brown, L.F., Jr., Hamlin, H.S., Dutton, S.P., Ruppel, S.C., Finley, R.J., and Tyler, N., 1989, Atlas of major Texas gas reservoirs: Austin, Tex., University of Texas, Bureau of Economic Geology, 161 p.

Laubach, S.E., and Jackson, M.L.W., 1990, Origin of arches in the northwestern Gulf of Mexico Basin: Geology, v. 18, p. 595–598.

Levorsen, A.I., 1967, Geology of petroleum: San Francisco, W.H. Freeman and Co., 724 p.

Lewan, M.D., 2002, New insights on timing of oil and gas generation in the central Gulf Coast interior zone based on hydrous-pyrolysis kinetic parameters: Gulf Coast Association of Geological Societies Transactions, v. 52, p. 607–620.

Lopatin, N.V., 1971, Temperature and geologic time as factors of carbonification (in Russian): Izvestiya Akademii Nauk SSSR, Seriya Geologischeskaya, no. 3, p. 95–106.

Mann, C.J., and Thomas, W.A., 1964, Cotton Valley Group (Jurassic) nomenclature, Louisiana and Arkansas: Gulf Coast Association of Geological Societies Transactions, v. 14, p. 143–152.

McGowen, M.K., and Harris, D.W., 1984, Cotton Valley (Upper Jurassic) and Hosston (Lower Cretaceous) depositional systems and their influence on salt tectonics in the East Texas Basin: Austin, Tex., University of Texas, Bureau of Economic Geology, Geological Circular 84-5, 41 p.

Meehan, D.N., and Pennington, B.F., 1982, Numerical simulation results in the Carthage Cotton Valley field: Journal of Petroleum Technology, v. 34, no. 1, p. 189–198.

Montgomery, S., 2001, East Texas Basin Bossier gas play: Petroleum Frontiers (published by IHS Energy Group, Denver, CO 80112), v. 17, no. 2, 64 p.

Moore, T., 1983, Cotton Valley depositional systems of Mississippi: Gulf Coast Association of Geological Societies Transactions, v. 33, p. 163–167.

Nangle, P., Fertl, W.H., and Frost, E., Jr., 1982, What to expect when logging the Cotton Valley trend: World Oil, v. 195, no. 5, p. 175–195.

NRG Associates, 1999 [includes data current as of Dec. 1998], The significant oil and gas fields of the U.S.: Colorado Springs, Colo., NRG Associates Inc. (database available from NRG Associates, Inc., P.O. Box 1655, Colorado Springs, CO 80901, U.S.A.).

Pate, B.F., 1963, Significant north Louisiana Cotton Valley stratigraphic traps: Gulf Coast Association of Geological Societies Transactions, v. 13, p. 177–183.

Pate, B.F., and Goodwin, R.N., 1961, Calhoun field, Jackson, Lincoln, Ouachita Parishes, Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 11, p. 197–201.

Presley, M.W., and Reed, C.H., 1984, Jurassic exploration trends of east Texas, *in* Presley, M.W., ed., The Jurassic of east Texas: Tyler, Tex., East Texas Geological Society, p. 11–22.

Royden, L., Sclater, J.G., and Von Herzen, R.P., 1980, Continental margin subsidence and heat flow—Important parameters in formation of petroleum hydrocarbons: American Association of Petroleum Geologists Bulletin, v. 64, no. 2, p. 173–187.

Russell, B.J., Jr., Sartin, A.A., and Ledger, E.B., 1984, Depositional and diagenetic history of the Bodcaw Sand, Cotton Valley Group (Upper Jurassic), Longwood field, Caddo Parish, Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 34, p. 217–228.

Salvador, A., 1987, Late Triassic–Jurassic paleogeography and origin of Gulf of Mexico Basin: American Association of Petroleum Geologists Bulletin, v. 71, no. 4, p. 419–451.

Sassen, R., and Moore, C.H., 1988, Framework of hydrocarbon generation and destruction in eastern Smackover trend: American Association of Petroleum Geologists Bulletin, v. 72, no. 6, p. 649–663.

Saucier, A.E., 1985, Geologic framework of the Travis Peak (Hosston) Formation of east Texas and north Louisiana, *in* Finley, R.J., Dutton, S.P., Lin, Z.S., and Saucier, A.E., eds., The Travis Peak (Hosston) Formation—Geologic framework, core studies, and engineering field analysis: Austin, Tex., University of Texas, Bureau of Economic Geology, contract report prepared for the Gas Research Institute under contract no. 5082-211-0708, 233 p.

Scardina, A.D., 1981, Tectonic subsidence history of the North Louisiana Salt Basin: Baton Rouge, La., Louisiana State University, M.S. thesis, 103 p.

Schenk, C.J., and Viger, R.J., 1996, East Texas Basin and Mississippi-Louisiana Salt Basins Provinces, Region 6—Gulf Coast, geologic framework, *in* Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995 national assessment of United States oil and gas resources—Results, methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS–30, Release 2, 1 CD-ROM.

Schmoker, J.W., 1996, Method for assessing continuous-type (unconventional) hydrocarbon accumulations, *in* Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995 national assessment of United States oil and gas resources—Results, methodology, and supporting data: U.S. Geological Survey Digital Data Series 30, Release 2, 1 CD-ROM.

Shreveport Geological Society, 1946, Reference report on certain oil and gas fields of north Louisiana, south Arkansas, Mississippi, and Alabama: Shreveport Geological Society Reference Volume I, 333 p.

Shreveport Geological Society, 1947, Reference report on certain oil and gas fields of north Louisiana, south Arkansas, Mississippi, and Alabama: Shreveport Geological Society Reference Volume II, 503 p.

Shreveport Geological Society, 1951, Reference report on certain oil and gas fields of north Louisiana, south Arkansas, Mississippi, and Alabama: Shreveport Geological Society Reference Volume III, no. 1, 42 p.

Shreveport Geological Society, 1953, Reference report on certain oil and gas fields of north Louisiana, south Arkansas, Mississippi, and Alabama: Shreveport Geological Society Reference Volume III, no. 2, 109 p.

Shreveport Geological Society, 1958, Reference report on certain oil and gas fields of north Louisiana, south Arkansas, Mississippi, and Alabama: Shreveport Geological Society Reference Volume IV, 204 p.

Shreveport Geological Society, 1963, Report on selected north Louisiana and south Arkansas oil and gas fields and regional geology: Shreveport Geological Society Reference Volume V, 202 p.

Shreveport Geological Society, 1980, Report on selected oil and gas fields, north Louisiana and south Arkansas: Shreveport Geological Society Reference Volume VI, 160 p.

Shreveport Geological Society, 1987, Report on selected oil and gas fields, Arkansas, Louisiana, Texas and Mississippi: Shreveport Geological Society Reference Volume VII, 153 p.

Sloane, B.J., Jr., 1958, The subsurface Jurassic Bodcaw sand in Louisiana: Louisiana Geological Survey Geological Bulletin 33, 33 p.

Sonnenberg, S.A., 1976, Interpretation of Cotton Valley depositional environment from core study, Frierson field, Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 26, p. 320–325.

Spencer, C.W., 1987, Hydrocarbon generation as a mechanism for overpressuring in Rocky Mountain region: American Association of Petroleum Geologists Bulletin, v. 71, no. 4, p. 368–388.

Swain, F.M., 1944, Stratigraphy of Cotton Valley beds of northern Gulf Coastal Plain: American Association of Petroleum Geologists Bulletin, v. 28, no. 5, p. 577–614.

Thomas, W.A., and Mann, C.J., 1963, Correlation chart of the upper Cotton Valley sands, *in* Herrmann, L.A., ed., Shreveport Geological Society Reference Report, v. V, p. 9–17.

Thomas, W.A., and Mann, C.J., 1966, Late Jurassic depositional environments, Louisiana and Arkansas: American Association of Petroleum Geologists Bulletin, v. 50, no. 1, p. 178–182.

Tissot, B.P., and Welte, D.H., 1978, Petroleum formation and occurrence: New York, Springer-Verlag, 538 p.

Trojan, M., 1985, Effects of diagenesis on reservoir properties and log response, Upper Jurassic Taylor Sandstone, Cotton Valley Group, Lincoln Parish, Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 35, p. 515–523.

U.S. Geological Survey World Energy Assessment Team, 2000, U.S. Geological Survey World Petroleum Assessment 2000—Description and results: U.S. Geological Survey Digital Data Series DDS-60, Multidisk set version 1.0, 4 CD-ROMs.

Waples, D.W., 1980, Time and temperature in petroleum formation—Application of Lopatin's method to petroleum exploration: American Association of Petroleum Geologists Bulletin, v. 64, no. 6, p. 916–926.

Wescott, W.A., 1983, Diagenesis of Cotton Valley sandstone (Upper Jurassic), east Texas—Implications for tight gas formation pay recognition: American Association of Petroleum Geologists Bulletin, v. 67, no. 6, p. 1002–1013.

Wescott, W.A., 1985, Diagenesis of Cotton Valley sandstone (Upper Jurassic), east Texas—Implications for tight gas formation pay recognition—Reply: American Association of Petroleum Geologists Bulletin, v. 69, no. 5, p. 816–818.

Wescott, W.A., and Hood, W.C., 1991, Hydrocarbon generation and migration routes in the East Texas Basin: Gulf Coast Association of Geological Societies Transactions, v. 41, p. 675.

White, W.A., and Garrett, C.M., Jr., 1992, KJ-1. Hosston Formation and Cotton Valley Group sandstones—Sabine Uplift, *in* Bebout, D.G., White, W.A., Garrett, C.M., Jr., and Hentz, T.F., eds., Atlas of major central and eastern Gulf Coast gas reservoirs: Austin, Tex., University of Texas, Bureau of Economic Geology, p. 63–64.

White, W.A., Garrett, C.M., Jr., and Woodward, M., 1992, JS-1. Cotton Valley shallow-marine sandstone—ARKLA region, *in* Bebout, D.G., White, W.A., Garrett, C.M., Jr., and Hentz, T.F., eds., Atlas of major central and eastern Gulf Coast gas reservoirs: Austin, Tex., University of Texas, Bureau of Economic Geology, p. 72–74.

Worrall, D.M., and Snelson, S., 1989, Evolution of the northern Gulf of Mexico, with emphasis on Cenozoic growth faulting and the role of salt, *in* Bally, A.W., and Palmer, A.R., eds., The geology of North America—An overview: Boulder, Colo., Geological Society of America, Geology of North America, v. A, p. 97–138.

Appendix 1. Basic input data for the Cotton Valley Blanket Sandstone Gas Assessment Unit (50490201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [A.U., assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmbo, million barrels of oil; ngl, natural gas liquids]

SEVENTH APPROXIMATION
DATA FORM FOR CONVENTIONAL ASSESSMENT UNITS (NOGA, Version 5, 6-30-01)

Assessment Geologist:……..	T.S. Dyman and S.M. Condon	Date:	11/19/2001
Region:………………………..	North America	Number:	5
Province:………………………	Louisiana-Mississippi Salt Basins	Number:	5049
Total Petroleum System:……	Jurassic-Cretaceous Interior Salt Basins	Number:	504902
Assessment Unit:……………	Cotton Valley Blanket Sandstone Gas	Number	50490201
Based on Data as of:……….	PI/Dwights 04/01/2001 and NRG Assoc. 1998		
Notes from Assessor……….	Includes East Texas Basin (5048). Assessed in 1995 as continuous gas play (4923).		

CHARACTERISTICS OF ASSESSMENT UNIT

Oil (<20,000 cfg/bo overall) **or** Gas (≥20,000 cfg/bo overall):… Gas

What is the minimum accumulation size?………. 0.5 mmboe grown
(the smallest accumulation that has potential to be added to reserves in the next 30 years)

No. of discovered accumulations exceeding minimum size:…….. Oil: 1 Gas: 8
Established (>13 accums.) ____ Frontier (1-13 accums.) X Hypothetical (no accums.) ____

Median size (grown) of discovered oil accumulation (mmbo):
1st 3rd ____ 2nd 3rd ____ 3rd 3rd ____
Median size (grown) of discovered gas accumulations (bcfg):
1st 3rd 176 2nd 3rd 10.4 3rd 3rd ____

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an undiscovered accum. ≥ minimum size……………	1.0
2. **ROCKS:** Adequate reservoirs, traps, and seals for an undiscovered accum. ≥ minimum size……	1.0
3. **TIMING OF GEOLOGIC EVENTS:** Favorable timing for an undiscovered accum. ≥ minimum size	1.0

Assessment-Unit GEOLOGIC Probability ____

4. **ACCESSIBILITY:** Adequate location to allow exploration for an undiscovered accumulation ≥ minimum size……………………………………………………………………………… 1.0

UNDISCOVERED ACCUMULATIONS

No. of Undiscovered Accumulations: How many undiscovered accums. exist that are ≥ min. size?:
(uncertainty of fixed but unknown values)

	min. no. (>0)	median no.	max no.
Oil Accumulations:…………………	0	0	0
Gas Accumulations:……………….	1	2	4

Sizes of Undiscovered Accumulations: What are the sizes (**grown**) of the above accums?:
(variations in the sizes of undiscovered accumulations)

	min. size	median size	max. size
Oil in Oil Accumulations (mmbo):…..….			
Gas in Gas Accumulations (bcfg):….….	3	6	50

Appendix 1. Basic input data for the Cotton Valley Blanket Sandstone Gas Assessment Unit (50490201). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01) [A.U., assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmbo, million barrels of oil; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Cotton Valley Blanket Sandstone Gas, 50490201

AVERAGE RATIOS FOR UNDISCOVERED ACCUMS., TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

Oil Accumulations:	minimum	median	maximum
Gas/oil ratio (cfg/bo)………………………..………			
NGL/gas ratio (bngl/mmcfg)……………………...….			

Gas Accumulations:	minimum	median	maximum
Liquids/gas ratio (bliq/mmcfg)….…………..……..	25	50	75
Oil/gas ratio (bo/mmcfg)…………………………….…			

SELECTED ANCILLARY DATA FOR UNDISCOVERED ACCUMULATIONS

Oil Accumulations:	minimum	median	maximum
API gravity (degrees)…………………….…………			
Sulfur content of oil (%)………………………...…..			
Drilling Depth (m) ……………...……………..……..			
Depth (m) of water (if applicable)……………...…..			

Gas Accumulations:	minimum	median	maximum
Inert gas content (%)…………………………....……	0.1	1	15
CO_2 content (%)……………………………….....….	1	2.5	9
Hydrogen-sulfide content (%)………………...…….	0	0	0
Drilling Depth (m)……………………………………	2100	2600	3000
Depth (m) of water (if applicable)………………….			

Appendix 1. Basic input data for the Cotton Valley Massive Sandstone Gas Assessment Unit (50490202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [A.U., assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmbo, million barrels of oil; ngl, natural gas liquids]—Continued

SEVENTH APPROXIMATION
DATA FORM FOR CONVENTIONAL ASSESSMENT UNITS (NOGA, Version 5, 6-30-01)

Assessment Geologist:……..	T.S. Dyman and S.M. Condon	Date:	11/19/2001
Region:………………………..	North America	Number:	5
Province:………………………	Louisiana-Mississippi Salt Basins	Number:	5049
Total Petroleum System:……	Jurassic-Cretaceous Interior Salt Basins	Number:	504902
Assessment Unit:……………	Cotton Valley Massive Sandstone Gas	Number:	50490202
Based on Data as of:……….	PI/Dwights 04/01/2001 and NRG Assoc. 1998		
Notes from Assessor……….	Includes East Texas Basin (5048). Assessed in 1995 as parts of plays 4922 and 4924.		

CHARACTERISTICS OF ASSESSMENT UNIT

Oil (<20,000 cfg/bo overall) **or** Gas (≥20,000 cfg/bo overall):… Gas

What is the minimum accumulation size?………. 0.5 mmboe grown
(the smallest accumulation that has potential to be added to reserves in the next 30 years)

No. of discovered accumulations exceeding minimum size:…….. Oil: 0 Gas: 44
Established (>13 accums.) X Frontier (1-13 accums.) ____ Hypothetical (no accums.) ____

Median size (grown) of discovered oil accumulation (mmbo):
1st 3rd ____ 2nd 3rd ____ 3rd 3rd ____
Median size (grown) of discovered gas accumulations (bcfg):
1st 3rd 47 2nd 3rd 10 3rd 3rd 23

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an undiscovered accum. ≥ minimum size……………	1.0
2. **ROCKS:** Adequate reservoirs, traps, and seals for an undiscovered accum. ≥ minimum size……	1.0
3. **TIMING OF GEOLOGIC EVENTS:** Favorable timing for an undiscovered accum. ≥ minimum size	1.0

Assessment-Unit GEOLOGIC Probability ____

4. **ACCESSIBILITY:** Adequate location to allow exploration for an undiscovered accumulation ≥ minimum size………………………………………………………..………………..……..………… 1.0

UNDISCOVERED ACCUMULATIONS

No. of Undiscovered Accumulations: How many undiscovered accums. exist that are ≥ min. size?:
(uncertainty of fixed but unknown values)

	min. no. (>0)	median no.	max no.
Oil Accumulations:…………………	0	0	0
Gas Accumulations:………………	3	18	50

Sizes of Undiscovered Accumulations: What are the sizes (**grown**) of the above accums?:
(variations in the sizes of undiscovered accumulations)

	min. size	median size	max. size
Oil in Oil Accumulations (mmbo):…...….			
Gas in Gas Accumulations (bcfg):….….	3	18	350

Appendix 1. Basic input data for the Cotton Valley Massive Sandstone Gas Assessment Unit (50490202). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [A.U., assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmbo, million barrels of oil; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Cotton Valley Massive Sandstone Gas, 50490202

AVERAGE RATIOS FOR UNDISCOVERED ACCUMS., TO ASSESS COPRODUCTS

Oil Accumulations:	minimum	median	maximum
Gas/oil ratio (cfg/bo)			
NGL/gas ratio (bngl/mmcfg)			

Gas Accumulations:	minimum	median	maximum
Liquids/gas ratio (bliq/mmcfg)	15	30	45
Oil/gas ratio (bo/mmcfg)			

SELECTED ANCILLARY DATA FOR UNDISCOVERED ACCUMULATIONS

Oil Accumulations:	minimum	median	maximum
API gravity (degrees)			
Sulfur content of oil (%)			
Drilling Depth (m)			
Depth (m) of water (if applicable)			

Gas Accumulations:	minimum	median	maximum
Inert gas content (%)	0	0.9	7
CO_2 content (%)	1	3	10
Hydrogen-sulfide content (%)	0	0	0
Drilling Depth (m)	2400	3000	6100
Depth (m) of water (if applicable)	0	10	20

Appendix 1. Basic input data for the Cotton Valley Updip Oil and Gas Assessment Unit (50490203). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [A.U., assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmbo, million barrels of oil; ngl, natural gas liquids]—Continued

SEVENTH APPROXIMATION
DATA FORM FOR CONVENTIONAL ASSESSMENT UNITS (NOGA, Version 5, 6-30-01)

Assessment Geologist:……..	T.S. Dyman and S.M. Condon	Date:	11/20/2001
Region:………………………..	North America	Number:	5
Province:………………………	Louisiana-Mississippi Salt Basins	Number:	5049
Total Petroleum System:……	Jurassic-Cretaceous Interior Salt Basins	Number:	504902
Assessment Unit:……………	Cotton Valley Updip Oil and Gas	Number:	50490203
Based on Data as of:……….	PI/Dwights 04/01/2001 and NRG Assoc. 1998		
Notes from Assessor……….	Includes East Texas Basin (5048). Approximately equivalent to 1995 assessed play 4921.		

CHARACTERISTICS OF ASSESSMENT UNIT

Oil (<20,000 cfg/bo overall) **or** Gas (≥20,000 cfg/bo overall):… Gas

What is the minimum accumulation size?………. 0.5 mmboe grown
(the smallest accumulation that has potential to be added to reserves in the next 30 years)

No. of discovered accumulations exceeding minimum size:…….. Oil: 28 Gas: 4
Established (>13 accums.) X Frontier (1-13 accums.) ____ Hypothetical (no accums.) ____

Median size (grown) of discovered oil accumulation (mmbo):
1st 3rd 3 2nd 3rd 3.5 3rd 3rd 1.9
Median size (grown) of discovered gas accumulations (bcfg):
1st 3rd 4.1 2nd 3rd 8.7 3rd 3rd ____

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an undiscovered accum. ≥ minimum size……………	1.0
2. **ROCKS:** Adequate reservoirs, traps, and seals for an undiscovered accum. ≥ minimum size……	1.0
3. **TIMING OF GEOLOGIC EVENTS:** Favorable timing for an undiscovered accum. ≥ minimum size	1.0

Assessment-Unit GEOLOGIC Probability ____

4. **ACCESSIBILITY:** Adequate location to allow exploration for an undiscovered accumulation ≥ minimum size……………………………………………………..………………..……..………… 1.0

UNDISCOVERED ACCUMULATIONS

No. of Undiscovered Accumulations: How many undiscovered accums. exist that are ≥ min. size?:
(uncertainty of fixed but unknown values)

	min. no. (>0)	median no.	max no.
Oil Accumulations:…………………	3	12	30
Gas Accumulations:………………	1	2	4

Sizes of Undiscovered Accumulations: What are the sizes (**grown**) of the above accums?:
(variations in the sizes of undiscovered accumulations)

	min. size	median size	max. size
Oil in Oil Accumulations (mmbo):…...…	0.5	1.7	12
Gas in Gas Accumulations (bcfg):….….	3	6	50

Appendix 1. Basic input data for the Cotton Valley Updip Oil and Gas Assessment Unit (50490203). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [A.U., assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmbo, million barrels of oil; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Cotton Valley Updip Oil and Gas, 50490203

AVERAGE RATIOS FOR UNDISCOVERED ACCUMS., TO ASSESS COPRODUCTS

Oil Accumulations:	minimum	median	maximum
Gas/oil ratio (cfg/bo)………………………...………	450	900	1350
NGL/gas ratio (bngl/mmcfg)……………………...….	25	50	75

Gas Accumulations:	minimum	median	maximum
Liquids/gas ratio (bliq/mmcfg)….………….……..	15	30	45
Oil/gas ratio (bo/mmcfg)…………………………….			

SELECTED ANCILLARY DATA FOR UNDISCOVERED ACCUMULATIONS

Oil Accumulations:	minimum	median	maximum
API gravity (degrees)…………………….………….	15	40	55
Sulfur content of oil (%)…………………………...…..	0	0.4	1.5
Drilling Depth (m) ……………...…………….……..	900	3600	5800
Depth (m) of water (if applicable)……………...…..	0	10	20

Gas Accumulations:	minimum	median	maximum
Inert gas content (%)……………………….....…….	0.1	0.7	1.5
CO_2 content (%)……………………………….....….	1	4.5	7
Hydrogen-sulfide content (%)……………….....…….	0	0	0
Drilling Depth (m)……………………………………	900	3600	5800
Depth (m) of water (if applicable)………………….	0	10	20

Appendix 1. Basic input data for the Cotton Valley Hypothetical Updip Oil Assessment Unit (50490204). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [A.U., assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmbo, million barrels of oil; ngl, natural gas liquids]—Continued

SEVENTH APPROXIMATION
DATA FORM FOR CONVENTIONAL ASSESSMENT UNITS (NOGA, Version 5, 6-30-01)

Assessment Geologist:……..	T.S. Dyman and S.M. Condon	Date:	11/20/2001
Region:………………………..	North America	Number:	5
Province:………………………	Louisiana-Mississippi Salt Basins	Number:	5049
Total Petroleum System:……	Jurassic-Cretaceous Interior Salt Basins	Number:	504902
Assessment Unit:……………	Cotton Valley Hypothetical Updip Oil	Number:	50490204
Based on Data as of:……….	PI/Dwights 04/01/2001		
Notes from Assessor……….	Includes East Texas Basin (5048).		

CHARACTERISTICS OF ASSESSMENT UNIT

Oil (<20,000 cfg/bo overall) **or** Gas (≥20,000 cfg/bo overall):… Gas

What is the minimum accumulation size?………. 0.5 mmboe grown
(the smallest accumulation that has potential to be added to reserves in the next 30 years)

No. of discovered accumulations exceeding minimum size:……… Oil: 0 Gas: 0
Established (>13 accums.) ____ Frontier (1-13 accums.) ____ Hypothetical (no accums X

Median size (grown) of discovered oil accumulation (mmbo):
1st 3rd ____ 2nd 3rd ____ 3rd 3rd ____
Median size (grown) of discovered gas accumulations (bcfg):
1st 3rd ____ 2nd 3rd ____ 3rd 3rd ____

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an undiscovered accum. ≥ minimum size……………	0.8
2. **ROCKS:** Adequate reservoirs, traps, and seals for an undiscovered accum. ≥ minimum size……	0.7
3. **TIMING OF GEOLOGIC EVENTS:** Favorable timing for an undiscovered accum. ≥ minimum size	1.0

Assessment-Unit GEOLOGIC Probability ____

4. **ACCESSIBILITY:** Adequate location to allow exploration for an undiscovered accumulation ≥ minimum size……………………………………………………………………………… 1.0

UNDISCOVERED ACCUMULATIONS

No. of Undiscovered Accumulations: How many undiscovered accums. exist that are ≥ min. size?:
(uncertainty of fixed but unknown values)

	min. no. (>0)	median no.	max no.
Oil Accumulations:…………………	1	3	7
Gas Accumulations:………………	0	0	0

Sizes of Undiscovered Accumulations: What are the sizes (**grown**) of the above accums?:
(variations in the sizes of undiscovered accumulations)

	min. size	median size	max. size
Oil in Oil Accumulations (mmbo):…..….	0.5	1.5	8
Gas in Gas Accumulations (bcfg):….….			

Appendix 1. Basic input data for the Cotton Valley Hypothetical Updip Oil Assessment Unit (50490204). SEVENTH APPROXIMATION DATA FORM (NOGA, Version 5, 6–30–01). [A.U., assessment unit; bcfg, billion cubic feet of gas; bliq/mmcfg, barrels of liquid per million cubic feet of gas; bngl/mmcfg, barrels of natural gas liquids per million cubic feet of gas; cfg/bo, cubic feet of gas per barrel of oil; m, meters; min., minimum; mmbo, million barrels of oil; ngl, natural gas liquids]—Continued

Assessment Unit (name, no.)
Cotton Valley Hypothetical Updip Oil, 50490204

AVERAGE RATIOS FOR UNDISCOVERED ACCUMS., TO ASSESS COPRODUCTS

Oil Accumulations:	minimum	median	maximum
Gas/oil ratio (cfg/bo)……………………	450	900	1350
NGL/gas ratio (bngl/mmcfg)……………………	25	50	75

Gas Accumulations:	minimum	median	maximum
Liquids/gas ratio (bliq/mmcfg)……………………			
Oil/gas ratio (bo/mmcfg)……………………			

SELECTED ANCILLARY DATA FOR UNDISCOVERED ACCUMULATIONS

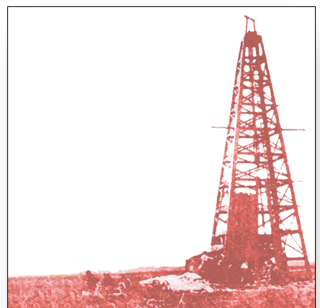
Oil Accumulations:	minimum	median	maximum
API gravity (degrees)……………………	15	40	50
Sulfur content of oil (%)……………………	0	0.4	1.5
Drilling Depth (m) ……………………	600	2100	3600
Depth (m) of water (if applicable)……………………	0	10	20

Gas Accumulations:	minimum	median	maximum
Inert gas content (%)……………………			
CO_2 content (%)……………………			
Hydrogen-sulfide content (%)……………………			
Drilling Depth (m)……………………			
Depth (m) of water (if applicable)……………………			

Appendix 2. List of wells used on cross section shown in plate 6.

[D & A, drilled and abandoned]

Map No.	Location	State	County	Field	Operator	Lease	Well No.	API	Final Status	Total Depth (ft)	Completion Date
3	Sec. 30, T. 12 N., R. 4 W.	Louisiana	Winn	Calvin	Getty Oil	USA-ES 9447	1	17127205520000	Gas	15,020	1/1/1078
5	Sec. 20, T. 12 N., R. 2 W.	Louisiana	Winn	Wildcat	Continental Oil Co.	Tremont Lbr. Co.	1	17127202810000	D & A	16,155	5/8/1973
8	Sec. 6, T. 15 N., R. 6 W.	Louisiana	Bienville	Lucky	Placid Oil Co.	Wood E N	2	17013200350000	Gas	13,576	3/21/1978
9	Sec. 1, T. 16 N., R. 6 W.	Louisiana	Bienville	Bear Creek	Southern Nat. Gas Co.	T J Cummings	2	17013001830000	Gas	13,000	6/8/1966
12a	Sec. 34, T. 19 N., R. 4 W.	Louisiana	Lincoln	Terryville	IMC Exploration Co.	McGehee P M	1	17061202500000	Gas	13,995	10/11/1980
12	Sec. 11, T. 19 N., R. 4 W.	Louisiana	Lincoln	Hico-Knowles	The California Co.	F H Calloway	1	17061002700002	Oil	12,441	4/2/1967
12.5	Sec. 3, T. 20 N., R. 4 W.	Louisiana	Lincoln	Lisbon	Cities Service O&G Corp.	Carter ‘B’	1	17061204730000	Oil	11,430	12/15/1986
13	Sec. 27, T. 21 N., R. 4 W.	Louisiana	Claiborne	Lisbon	Amoco Prod. Co.	Enloe Estate	1	17027204200000	D & A	11,000	1/31/1978
14	Sec. 5, T. 22 N., R. 4 W.	Louisiana	Claiborne	Wildcat	Roy M Huffington, Inc.	Moss	1	17027204490000	D & A	11,100	11/29/1977



Click here to return to
Volume Title Page