Summary Report for the 2007–2008 STATEMAP Project:
Geologic Mapping to Support Improved Database Development and Understanding of Urban Corridors, Critical Aquifers, and Special Areas of Environmental Concern in Texas

Final Report

by

Edward W. Collins and Thomas A. Tremblay

Prepared for
U.S. Geological Survey
Under Cooperative Agreement No. 07HQAG0072

Bureau of Economic Geology
Scott W. Tinker, Director
John A. and Katherine G. Jackson School of Geosciences
The University of Texas at Austin

April 2008

CONTENTS

Figures

ABSTRACT

The *Geologic Map of the Southeast Part of the Austin, Texas, 30 x 60 Minute Quadrangle: Central Texas Population Corridor Encompassing Bastrop and Smithville*, scale 1:100,000, was constructed through digital compilation of eight 1:24,000-scale open-file geologic maps. The map is intended to be used by professionals and laypersons as a source of general geologic information that relates to land and resource use and management. Geology of the area consists mostly of Paleocene through Eocene mud- and sand-rich units. Minor Upper Cretaceous marine marl and calcareous mud deposits are in the western study area. Quaternary high-gravel deposits and well-defined terrace deposits of the Colorado River also occur. Bedrock units typically exhibit eastward regional dips of less than 2°. In the west and east parts of the study area, northeast-striking normal faults cut strata. Aquifer units include the Carrizo-Wilcox, Queen City, and Sparta. Resources include sand, gravel, clay, lignite, and oil.

PROJECT: DIGITAL COMPILATION MAPPING OF SOUTHEAST AUSTIN CORRIDOR, TEXAS (1:100,000): SOUTHEAST PART OF AUSTIN, TEXAS, 30 × 60 MINUTE QUADRANGLE

Introduction

This Texas STATEMAP project, similar to previous projects for STATEMAP, involved the geologic mapping of an area where improved geologic information can impact development, land and resource use, environmental protection, and public education (fig.1). The map produced for this project, *Geologic Map of the Southeast Part of the Austin, Texas, 30 x 60 Minute Quadrangle: Central Texas Population Corridor Encompassing Bastrop and Smithville* (scale 1:100,000), provides basic geologic

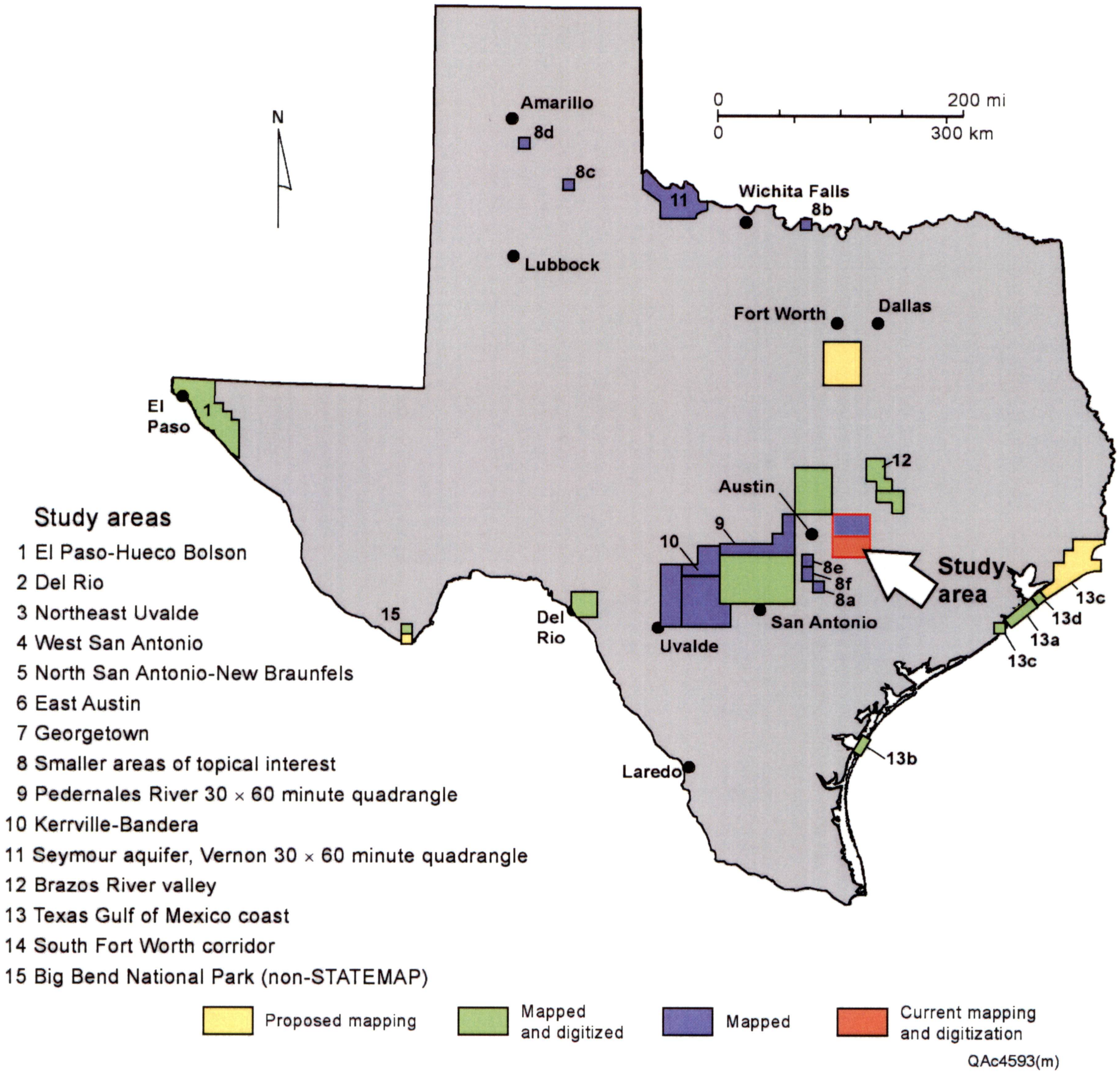

Figure 1. Location of Texas project study area.

information that can be used by laypersons, as well as professionals, who are involved in managing Earth and water resources, planning land use, and designing construction projects within this population/transportation corridor southeast of Austin, Texas (map plate, in pocket). The map plate (in pocket) includes an inset location map, cross sections, stratigraphic column, inset photographs and diagrams, and explanation and summary text. These illustrations that accompany the map are described in the text that follows. Also, much of this text is included on the map plate for geologic summary. The study area, about

15 mi southeast of downtown Austin, Texas, is crossed by two major highways, U.S. 71 and U.S. 290. The area is also within part of the Carrizo-Wilcox aquifer and recharge zone, a significant sandstone aquifer of Texas. Sandstones of the Queen City and Sparta aquifers overlie Carrizo-Wilcox deposits in the east part of the map area. Earth resources of the area include sand, gravel, clay, lignite, and oil. Bastrop and Buescher State Parks and a relatively large Lower Colorado River Authority (LCRA) park, McKinney Roughs Nature Park, lie in the map area. The Lower Colorado River Trail, coinciding with the Colorado River, also crosses the study area.

Geology illustrated on this map is based on field and aerial-photograph interpretations by the author after review and compilation of previous works. Previous mapping studies include regional geologic, environmental-geologic, and land resource maps by Proctor and others (1974), Kier and others (1977), and Henry and Basciano (1979). Master's theses maps by Plummer (1949), Ridley (1954), and Ferguson (1958) illustrate the geology in varying levels of detail for small parts of the study area. Useful soil maps were done by Werchan and others (1974) and Baker (1979). Webber (1968) and Blum (1992) mapped and described Quaternary deposits associated with the Colorado River for investigations that focused on the river's geomorphology, Quaternary stratigraphy, and evolution, although following the stratigraphic subdivisions that they interpreted was beyond the scope of our mapping for this STATEMAP project.

Eight 1:24,000-scale open-file geologic maps that cover the study area and that were mapped by the author between 1999 and 2001 include geologic maps of the Bastrop, Bastrop SW, Lake Bastrop, Paige, Utley, Smithville, Smithville NW, and Winchester quadrangles (Collins, 2000a, b, c, d; 2001a, b, c, d). Mapping, reviewing map interpretations, studying subsurface stratigraphic and groundwater data, developing cross sections, and digitizing open-file maps continued during 2007 and 2008 for the construction of this 1:100,000-scale geologic map of the southeast part of the Austin, Texas, 30 × 60 minute quadrangle. The region is vegetated enough to make viewing geologic outcrops difficult. Outcrops best for viewing geologic units are mostly along roadcuts, along the banks of the Colorado River, and in pits. Recognizing differences in vegetation, soil, and landscape development between some units aided in mapping of geologic units. Study of geophysical logs of wells drilled throughout the area also helped in interpreting the area's geology.

Geology

The map area consists of hilly to flat terrain that is typical of the west-central margin of the Gulf Coastal Plain of Texas. The Colorado River and its well-defined 2- to 4-mi-wide valley is the dominant physiographic feature (Photo 1, map plate). In general, higher ground elevations range between 500 and 650 ft, whereas ground elevation near the Colorado River southeast of Smithville is below 300 ft. The area's geology is composed of Upper Cretaceous, Paleocene, and Eocene strata having regional dips generally less than 2° southeastward. Normal faults of the Milano Fault Zone locally cut strata in the central to eastern map area. Quaternary terrace and alluvial deposits of the Colorado River and its tributaries overlie bedrock deposits throughout the area.

Upper Cretaceous marl and calcareous clay of the upper part of the Navarro Group lie in the northwest part of the study area. Marl and clay of the Navarro and underlying Taylor Groups are often undivided on geologic maps of the region because of sparse outcrops. In the study area Navarro deposits are covered mostly by vegetation and clay-rich soil. Contact with overlying Paleocene Midway deposits is inferred.

Paleocene through Eocene units represent marine, deltaic, and fluvial deposition during repetitive cycles of transgression and regression (Fisher, 1964; Galloway and others, 1991; Galloway and others, 2000). Midway Group deposits are dominated by marine slope and possibly shelf mudstone, with minor limestone lenses and glauconitic sand intervals. Midway outcrops are rare because these deposits erode relatively easily and they are covered by vegetation and clay-rich soil. Overlying Midway strata are Wilcox Group mudstones and sandstones of the Hooper, Simsboro, and Calvert Bluff Formations. The Hooper consists of mudstone, along with some sandstone and minor lignite. Ayers and Lewis (1985) reported that, in general, Hooper sediments record prodelta through distributary-channel fill, delta-plain mudstone, and lignite deposition. Some Hooper marine deposits containing thin beds of the oyster *Ostrea duvali* (Plummer, 1949) suggest that at least part of the study area was a marine embayment during some Hooper deposition. Simsboro sandstone with lesser mudstone and mudstone conglomerate and local thin lignite overlie Hooper deposits (Photo 2, map plate). Ayers and Lewis (1985) reported that Simsboro sediments were deposited by a bed- to mixed-load fluvial system (McGowen and Garner, 1970) that fed Wilcox deltas farther basinward (Fisher and McGowen, 1967). Calvert Bluff deposits are mudstone, along with some siltstone and sandstone and various amounts of lignite. Kaiser (1978) and Ayers and Lewis (1985) interpreted that Calvert Bluff sediments had been deposited in lower alluvial and upper to lower deltaic-plain settings. They concluded that Simsboro and Calvert Bluff deposition indicates a change from the dominantly alluvial-plain Simsboro to the more deltaic Calvert

Bluff. Overlying Wilcox Group deposits are Carrizo Formation sandstone and lesser siltstone and mudstone (Photo 3, map plate). Ayers and Lewis (1985) reported that the Carrizo at outcrop is fluvial, although downdip and east of the map study area it is deltaic (Photo 4, map plate).

Eocene strata above the Carrizo Formation represent repetitive packages of transgressive to regressive deposits (Fisher, 1964). Fisher (1964) reported that the transgressive deposits generally include open-marine, glauconitic sands and marls overlain by restricted marine clays. He noted that in some areas, open-marine clays that are interbedded with or overlie basal glauconitic strata represent inundative deposits. Regressive deposits generally consist of fluvial to marginal marine, sand-rich deposits overlain by lagoonal and floodplain, mud-rich, carbonaceous deposits. Units composing these transgressive-regressive strata packages include the Reklaw-Queen City, Weches-Sparta, and Cook Mountain-Yegua Formations (Stenzel, 1938; Fisher, 1964; Guevara and Garcia, 1972; Ricoy and Brown, 1977; Hobday, 1980). The Reklaw Formation is sand-rich and glauconitic in its lower part, and mostly mudstone and siltstone with lesser thin sandstone in its upper part. Queen City deposits are principally quartz sandstone, along with lesser siltstone and mudstone. The Weches Formation is composed of quartz-rich, glauconitic greensand, mudstone, and claystone. This fossiliferous unit is overlain by Sparta Formation quartz sandstone. The Cook Mountain Formation is mostly mudstone and claystone, along with some glauconitic sandstone. It is fossiliferous and overlain by Yegua Formation sandstone, mudstone, claystone, and lignite.

Quaternary terrace deposits that overlie Cretaceous to Eocene units consist of remnant gravel-rich deposits that are at higher elevations than the broad, well-developed terraces at varied elevations adjacent to the Colorado River. At some places high-gravel deposits are well cemented by hematite and limonite. At other places the high gravel appears to be remnant lag deposits.

Structure

Normal faults in the eastern study area are part of the northeast-striking Milano Fault Zone, a zone of multiple grabens (Ewing and others, 1990). In the western study area, normal faults may be a northern extension of the Luling Fault Zone, a zone of predominately west-dipping normal faults. These fault zones bound the west margin of the Gulf Basin. In the map area, precise fault identification and measurements in outcrop are difficult because of thick vegetation, soil cover, and rapid weathering of outcrops. Broad discontinuities in the stratigraphy along the outcrop belt, local outcrops, and subsurface data, however, enabled previous workers, and this author, to identify and approximate some faults (Ridley, 1954; Sharp, 1966; Follett, 1970; Proctor and others, 1974; Morrison-Knudson Company, 1982; Gaylord and others, 1985; Collins, 2000a, b, c, d; 2001a, b, c, d). Gaylord and others (1985) reviewed the structure of the Camp Swift area within the west part of the study area and reported that a northeast-striking fault west of Camp Swift has a throw of 250 ft, whereas a smaller fault at the southeast part of Camp Swift displays a throw of 15 to 25 ft. Some 1940's oil-prospect data of Elliot (1947a, b) indicate that he thought faults of the Camp Swift area extended southwestward, south of the Colorado River, but these could not be verified to map at the ground surface because of the sparseness of data. North of the Camp Swift area, Sharp (1966) reported another northeast-striking fault near Elgin that dips westward about 50°. The Milano Fault Zone in the east part of the map area was mapped partly by Ridley (1954), who noted that sandstone adjacent to the fault surface was commonly indurated and cemented by limonite. Proctor and others (1974) also mapped numerous faults composing the Milano Fault Zone, and their work was relied on greatly for the current study.

Aspects of fault timing are uncertain. Youngest deposits known to be offset are Eocene, although Oligocene through Pliocene deposits are absent in the fault-zone area. Because obvious fault scarps in Pleistocene and younger alluvial deposits are absent, detailed studies involving techniques such as trenching of Quaternary alluvial deposits overlying faults have not been done. Weeks (1945) reported that fault movement on faults bounding the west and north margin of the Texas Gulf Coastal Plain occurred during the late Oligocene or early Miocene because transported Cretaceous fossils and limestone and chert pebbles that occur in some lower Tertiary deposits of the Gulf coastal plain imply relative uplift and related fault movement to expose Cretaceous rocks as a source (Weeks, 1945). Historical seismicity has been sparse, with one earthquake being reported in the map area—the 1887 Paige earthquake having an assigned magnitude of 4.1 (Carlson, 1984; Davis and others, 1989)—and two other earthquakes near the map area—the 1873 Manor earthquake and the 1902 Creedmoor earthquake, both having assigned magnitudes of 3.6.

Clues to the origin of these faults lie in their regional geographic position. They are part of a regional zone that marks the edge of the Texas Gulf Coastal Plain. Gulfward extension, flexure, and tilting are likely to have occurred along the perimeter of the Gulf of Mexico Basin. Also, downdip slippage on subsurface Jurassic salt is a likely extensional process that has occurred. The Milano faults of the study area and related Mexia faults may be breakaways that formed above the edge of Jurassic salt, marking updip termination of thin-skinned extension (Jackson, 1982).

Resources and Land Use

Geological considerations are key to managing and planning use of land and natural resources, as well as to designing construction projects within the map region. In his regional study, Woodruff (1979) related surface geology to process units and material-landform units, partly on the basis of physical and landscape characteristics of geologic units. For example, in the Bastrop-Smithville area, he determined that much of the Colorado River valley consists of flood-prone areas and valley bottoms, where slopes are low and processes consist of erosion, slope failure, sediment deposition, and surface-water infiltration. He classified the Simsboro, Carrizo, Queen City, and Sparta sandstone outcrop belts as hilly, sandy, aquifer-recharge areas. Hooper and Calvert Bluff outcrops contain sandstone recharge areas, as well as mud- and clay-rich areas having shrinking and swelling soils. Midway, Reklaw, Weches, and Cook Mountain deposits make up clay and sandy-clay areas, which may have poor drainage, local erosion, shrinking and swelling soils, and slumping of oversteepened slopes.

The map area has had a long history of providing Earth resources, including sand, gravel, clay, lignite, and oil. Groundwater resources are possibly one of the most important natural resources. Three sandstone aquifers are: Carrizo-Wilcox, Queen City, and Sparta. Colorado River terrace deposits may also provide lesser amounts of shallow groundwater.

Mining of gravel and sand from Colorado River terrace deposits, high-gravel deposits, and some of the Tertiary units has met some past demands of development. Sand and gravel continue to be important future resources. Some well-cemented Eocene sandstones and Quaternary conglomerate have been used for aggregate and building stone, but these rocks probably have limited future resource potential because of relatively minor availability. Clay was used as early as 1841 for brick construction in the Smithville area (Nickell, 1939). The Elgin-Butler Brick Company, which has been operating since 1901 a few miles north of the study area, uses Wilcox clay to make brick and tile (Hunt, 2004).

Inactive pits from local mining of sand and gravel, and possibly clay, are relatively common. These abandoned pits are of environmental concern because they have the potential to be used for illegal dumping, which could impair surface-water and groundwater quality.

Commercial lignite lies mostly in the lower part of the Wilcox Calvert Bluff Formation, although the Hooper and Simsboro Formations contain lesser amounts of lignite (Kaiser, 1974, 1976, 1978; Kaiser and others, 1978, 1980; Morrison-Knudson Company, 1982; Ayers and Lewis, 1985). In general, thickest lignite seams are usually relatively thin (1 to 5 ft thick). Lignite was first mined in Bastrop County in the late 1860's (Williams, 2004). Early lignite mining was underground and apparently reached a peak in the mid-1920's, when between 9 and 11 companies were operating; only 2 companies were still mining in 1939 (Nickell, 1939; Williams, 2004). Lignite mining in the region ceased in the mid-1940's, but regional interest in mining lignite renewed in the 1950's with mining in Milam County, north of the map area (Dietrich and Lonsdale, 1958). In the map area, the Powell Bend lignite strip mine was permitted and opened in the 1980's (Morrison-Knudson Company, 1982). It closed in 1993.

Oil exploration and production also have had a long history in the map area. Exploring for oil in subsurface Cretaceous strata has occurred periodically throughout the map area since the 1940's. It is out of this map's scope to provide information on subsurface geologic framework related to hydrocarbon targets and traps. However, it is worth noting that infrastructure related to hydrocarbon exploration and production is linked to land use. Oil-field practices, including drilling of wells and construction of pits, pipelines, and roads, have been most abundant in the east and southwest parts of the study area (fig. 1 inset on map plate).

The principal aquifer of the area is the Carrizo-Wilcox (Follett, 1970; Thorkildsen and Price, 1991; Fisher and others, 1996). Thickest sandstone intervals of this aquifer are generally within the Simsboro and Carrizo Formations, although the Calvert Bluff may also contain some relatively thick sandstone intervals. The map lists the depth to water, and corresponding altitude, for several representative water wells (map plate). A complete water-well database is maintained by the Texas Water Development Board. The base of fresh water in this aquifer across the map area ranges from altitudes near +150 ft in the west study area to near –1,000 ft in the southwest (Fig. 2 inset on map plate). Dutton (1999) reported that during the past 45 yr, groundwater pumpage from the aquifer has increased substantially, primarily because of mining needs. Results of regional groundwater modeling studies by Dutton (1999) and Dutton and Nicot (2004) suggest that groundwater will remain available to meet withdrawal scenarios through the year 2050.

Queen City and Sparta aquifers lie above the Carrizo-Wilcox in the east part of the study area. These sandstone aquifers are thinner than the Carrizo-Wilcox but provide shallower fresh water. Some shallow wells also produce from Colorado River alluvial deposits. These wells are probably used mostly for irrigation and livestock.

ACKNOWLEDGMENTS

Work for this map was supported partly by the STATEMAP Program, administered by the U.S. Geological Survey. This study also benefited from subsurface data assembled for the Texas Commission on Environmental Quality Surface Casing Data Information Site. Online data collected from the Texas Water Development Board and the Texas Natural Resources Information Services also aided this study. Editing was by Lana Dieterich. Photo preparation was by David Stephens. GIS database and map digitization was coordinated by Thomas A. Tremblay. Map graphics was by John T. Ames under supervision of Joel L. Lardon, Graphics Manager. Views and conclusions contained in this map are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government. The author disclaims any responsibility or liability for interpretations from this map or digital data or decisions based thereon.

REFERENCES

Ayers, W. B., Jr., and Lewis, A. H., 1985, The Wilcox Group and Carrizo Sand (Paleogene) in East-Central Texas: depositional systems and deep-basin lignite: The University of Texas at Austin, Bureau of Economic Geology, 19 p., 30 pls.

Baker, F. E., 1979, Soil survey of Bastrop County, Texas: U.S. Department of Agriculture, Soil Conservation Service, variously paginated.

Blum, M. D., 1992, Modern depositional environments and recent alluvial history of the lower Colorado River, Gulf Coastal Plain of Texas: The University of Texas at Austin, Ph.D. Dissertation, 286 p.

Collins, E. W., 2000a, Geologic map of the Bastrop quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, open-file map prepared for the U.S.

Geological Survey under cooperative agreement no. 99HQAG0070, 1 sheet, scale 1:24,000.

________ 2000b, Geologic map of the Bastrop SW quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, open-file map prepared for the U.S. Geological Survey under cooperative agreement no. 99HQAG0070, 1 sheet, scale 1:24,000.

________ 2000c, Geologic map of the Lake Bastrop quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, open-file map prepared for the U.S. Geological Survey under cooperative agreement no. 99HQAG0070, 1 sheet, scale 1:24,000.

________ 2000d, Geologic map of the Utley quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, open-file map prepared for the U.S. Geological Survey under cooperative agreement no. 99HQAG0070, 1 sheet, scale 1:24,000.

________ 2001a, Geologic map of the Paige quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, open-file map prepared for the U.S. Geological Survey under cooperative agreement no. 00HQAG0015, 1 sheet, scale 1:24,000.

________ 2001b, Geologic map of the Smithville quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, open-file map prepared for the U.S. Geological Survey under cooperative agreement no. 00HQAG0015, 1 sheet, scale 1:24,000.

________ 2001c, Geologic map of the Smithville SW quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, open-file map prepared for the U.S. Geological Survey under cooperative agreement no. 00HQAG0015, 1 sheet, scale 1:24,000.

________ 2001d, Geologic map of the Winchester quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, open-file map prepared for the U.S. Geological Survey under cooperative agreement no. 00HQAG0015, 1 sheet, scale 1:24,000.

Carlson, S. M., 1984, Investigations of recent and historical seismicity in East Texas: The University of Texas at Austin, Master's thesis, 197 p.

Davis, S. D., Pennington, W. D., and Carlson, S. M., 1989, A compendium of earthquake activity in Texas: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 89-3, 27 p., 4 microfiche.

Dietrich, J. W., and Lonsdale, J. T., 1958, Mineral resources of the Colorado River industrial development association area: University of Texas, Austin, Bureau of Economic Geology Report of Investigations No. 37, 84 p.

Dutton, A. R., 1999, Groundwater availability in the Carrizo-Wilcox aquifer in Central Texas—numerical simulations of 2000 through 2050 withdrawal projections: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 256, 53 p.

Dutton, A. R., and Nicot, J. -P., 2004, Groundwater-availability modeling: an example from the central part of the Carrizo-Wilcox aquifer, Texas, *in* Mace, R. E., and

Williams, Berney, trip coordinators, Lignite, clay, and water: the Wilcox Group in Central Texas: Austin Geological Society, Field Trip Guidebook 23, p. 47–71.

Elliot, J. E., 1947a, Geological report of the oil possibilities of the Powell Bend fault lying contiguous to the L. Leverenz-T. Highsmith-C.S. Smith Surveys, Bastrop County, Texas: Unpublished report donated to University of Texas, Austin, Bureau of Economic Geology, 10 p.

_______ 1947b, Geological report on the oil possibilities of the Hooper Bend-Cedar Creek area lying southwest of Hooper Bend in the Colorado River, Bastrop County, Texas: Unpublished report donated to University of Texas, Austin, Bureau of Economic Geology, 16 p.

Ewing, T. E., 1990, Tectonic map of Texas: The University of Texas at Austin, Bureau of Economic Geology, scale 1:750,000.

Ferguson, W. K., 1958, Geology of parts of Bastrop and Fayette Counties, Texas: University of Texas, Austin, Master's thesis, 195 p.

Fisher, R. S., Mace, R. E., and Boghici, Erika, 1996, Ground-water and surface-water hydrology of Camp Swift, Bastrop County, Texas: The University of Texas at Austin, Bureau of Economic Geology, final contract report prepared for the Adjutant General's Department of Texas, Texas Army National Guard, and the Nature Conservancy of Texas, under contract no. Texas THCB-95-1-05-01, 72 p. + 4 apps.

Fisher, W. L., 1964, Sedimentary patterns in Eocene cyclic deposits, northern Gulf Coast region: Kansas Geological Survey Bulletin 169, p. 151–170.

Fisher, W. L., and McGowen, J. H., 1967, Depositional systems in the Wilcox Group of Texas and their relationship to occurrence of oil and gas: The University of Texas at Austin, Bureau of Economic Geology, Geological Circular 67-4, 21 p.

Follett, C. R., 1970, Ground-water resources of Bastrop County, Texas: Texas Water Development Board Report 109, 138 p.

Galloway, W. E., Bebout, D. G., Fisher, W. L., Dunlap, J. B., Jr., Cabrera-Castro, R., Lugo-Rivera, J. E., and Scott, T. M., 1991, Cenozoic, *in* Salvador, Amos, ed., The Gulf of Mexico Basin: Geological Society of America, vol. J, p. 245–324.

Galloway, W. E., Ganey-Curry, P. E., Li, Xiang, and Buffler, R. T., 2000, Cenozoic depositional history of the Gulf of Mexico basin: AAPG Bulletin v. 84, no. 11, p. 1743–1774.

Gaylord, J. L., Slade, R. M., Ruiz, L. M., Welborn, C. T., and Baker, E. T., Jr., 1985, Water-resources appraisal of the Camp Swift lignite area, Central Texas: U.S. Geological Survey, Water-Resources Investigations Report 84-4333, 164 p.

Guevara, E. H., and Garcia, R., 1972, Depositional systems and oil-gas reservoirs in the Queen City Formation (Eocene), Texas: Gulf Coast Association of Geological Societies Transactions, v. 22, p. 1–22.

Henry, C. D., and Basciano, J. M., 1979, Environmental geology of the Wilcox Group lignite belt, East Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 98, 28 p. + 7 maps.

Hobday, D. K., 1980, Geology of the Queen City Formation and associated units, *in* Perkins, B. F., and Hobday, D. K., eds., 1980, Middle Eocene coastal plain and nearshore deposits of East Texas—a field guide to the Queen City Formation and related papers: Society of Economic Paleontologists and Mineralogists, p. 1–48.

Hunt, B. B., 2004, Geology and manufacturing of clay resources in the Wilcox Group, Butler, Texas, *in* Mace, R. E., and Williams, Berney, trip coordinators, Lignite, clay, and water: the Wilcox Group in Central Texas: Austin Geological Society, Field Trip Guidebook 23, p. 73–84.

Jackson, M. P. A., 1982, Fault tectonics of the East Texas Basin: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 82-4, 31 p.

Kaiser, W. R., 1974, Texas lignite: near-surface and deep-basin resources: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 79, 70 p. + 1 app.

Kaiser, W. R., 1976, Calvert Bluff (Wilcox Group) sedimentation and the occurrence of lignite at Alcoa and Butler, Texas: The University of Texas at Austin, Bureau of Economic Geology, Research Note 2, 10 p.

Kaiser, W. R., 1978, Depositional systems in the Wilcox Group (Eocene) of east-central Texas and the occurrence of lignite, *in* Kaiser, W. R., ed., Proceedings, 1976 Gulf Coast Lignite Conference: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 90, p. 33–53.

Kaiser, W. R., Ayers, W. B., Jr., and LaBrie, L. W., 1980, Lignite resources in Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 104, 52 p.

Kaiser, W. R., Johnston, J. E., and Bach, W. N., 1978, Sand-body geometry and the occurrence of lignite in the Eocene of Texas: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 78-4, 19 p.

Kier, R. S., Garner, L. E., and Brown, L. F., Jr., 1977, Land resources of Texas: The University of Texas at Austin, Bureau of Economic Geology, scale 1:500,000, 4 sheets.

McGowen, J. H., and Garner, L. E., 1970, Physiographic features and stratification types of coarse-grained point bars, modern and ancient examples: Sedimentology, v. 24, p. 77–111.

Morrison-Knudsen Company, Inc., 1982, Application for surface mining operation permit: report prepared for Lower Colorado River Authority, v. 1, 2, and 3, variously paginated.

Nickell, C. O., 1939, Report on the mineral resources of Bastrop County, Texas: University of Texas, Austin, Bureau of Economic Geology, Mineral Resource Survey Circular No. 20, 3 p.

Plummer, R. S., Jr., 1949, The geology of west-central Bastrop County, Texas: University of Texas, Austin, Master's thesis, 41 p.

Proctor, C. V., Jr., Brown, T. E., McGowen, J. H., and Waechter, N. B., 1974, Austin sheet: The University of Texas at Austin, Bureau of Economic Geology, Geologic Atlas of Texas, V. E. Barnes, project director, scale 1:250,000; reprinted 1988.

Ricoy, J. U., and Brown, L. F., Jr., 1977, Depositional systems in the Sparta Formation (Eocene), Gulf Coast Basin of Texas: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 77-7, 16 p.

Ridley, W. C., 1954, Geology of the northwest corner of the Smithville quadrangle, Bastrop County, Texas: University of Texas, Austin, Master's thesis, 73 p.

Sharp, W. W., Jr., 1966, Example of stratigraphic confusion: type locality of Butler Clay member of Rockdale Formation (Wilcox Group), Bastrop County, Texas: American Association of Petroleum Geologists Bulletin, v. 50, no. 7, p, 1444–1454.

Stenzel, H. B., 1938, The geology of Leon County, Texas: University of Texas, Austin, Publication No. 3818, 295 p.

Thorkildsen, David, and Price, R. D., 1991, Ground-water resources of the Carrizo-Wilcox aquifer in the Central Texas region: Texas Water Development Board, Report 332, 46 p.

Webber, G. E., 1968, Geology of the fluvial deposits of the Colorado River valley, Central Texas: The University of Texas at Austin, Master's thesis, 119 p.

Weeks, A. W., 1945, Balcones, Luling, and Mexia fault zones in Texas: American Association of Petroleum Geologists Bulletin, v. 29, no. 12, p. 1733–1737.

Werchan, L. E., Lowther, A. C., and Ramsey, R. N., 1974, Soil survey Travis County, Texas: U.S. Department of Agriculture, Soil Conservation Service, variously paginated.

Williams, Berney, 2004, Historic mining sites of interest in Bastrop, Lee, and Milam Counties, *in* Mace, R. E., and Williams, Berney, trip coordinators, Lignite, clay, and water: the Wilcox Group in Central Texas: Austin Geological Society, Field Trip Guidebook 23, p. 3–14.

Woodruff, C. M., Jr., 1979, Land resource overview of the Capital Area Planning Council Region, Texas—a nontechnical guide: The University of Texas at Austin, Bureau of Economic Geology, 29 p. + 1 map, 3 pls.