Geology of the Waldheim 7.5-Minute Quadrangle, LA

Louisiana Geological Survey

Introduction, Location, and Geologic Setting

The Waldheim 7.5-minute quadrangle lies within the Plio–Pleistocene uplands north of Lake Pontchartrain, in the drainage basin of the Tchefuncte River in the southeastern Louisiana coastal plain (Figures 1, 2). The axis of the deep-subsurface lower Cretaceous shelf edge (Toledo Bend flexure), which trends west-northwest to east-southeast, lies approximately 10 km (6 mi) south of the southern edge of the study area. The surface of Waldheim quadrangle comprises strata of (1) the Pliocene Citronelle Formation, Upland allogroup, characterized by the highest elevations and deeply dissected ridge-and-ravine topography lacking any original constructional landforms, and (2) the Pleistocene Prairie Allogroup, at lower elevations, comprising an older and higher subunit (Irene alloformation) and the extensive, younger and lower Hammond alloformation, each characterized by a preserved depositional surface with indistinct constructional topography. These Plio–Pleistocene strata are covered by late Pleistocene Sicily Island Loess that is thinner than 1 m, and are incised by Holocene undifferentiated alluvium of Tchefuncte River tributaries belonging to the Bogue Falaya River system.

The units recognized and mapped in this investigation are summarized in Figures 3 and 4.

Previous Work

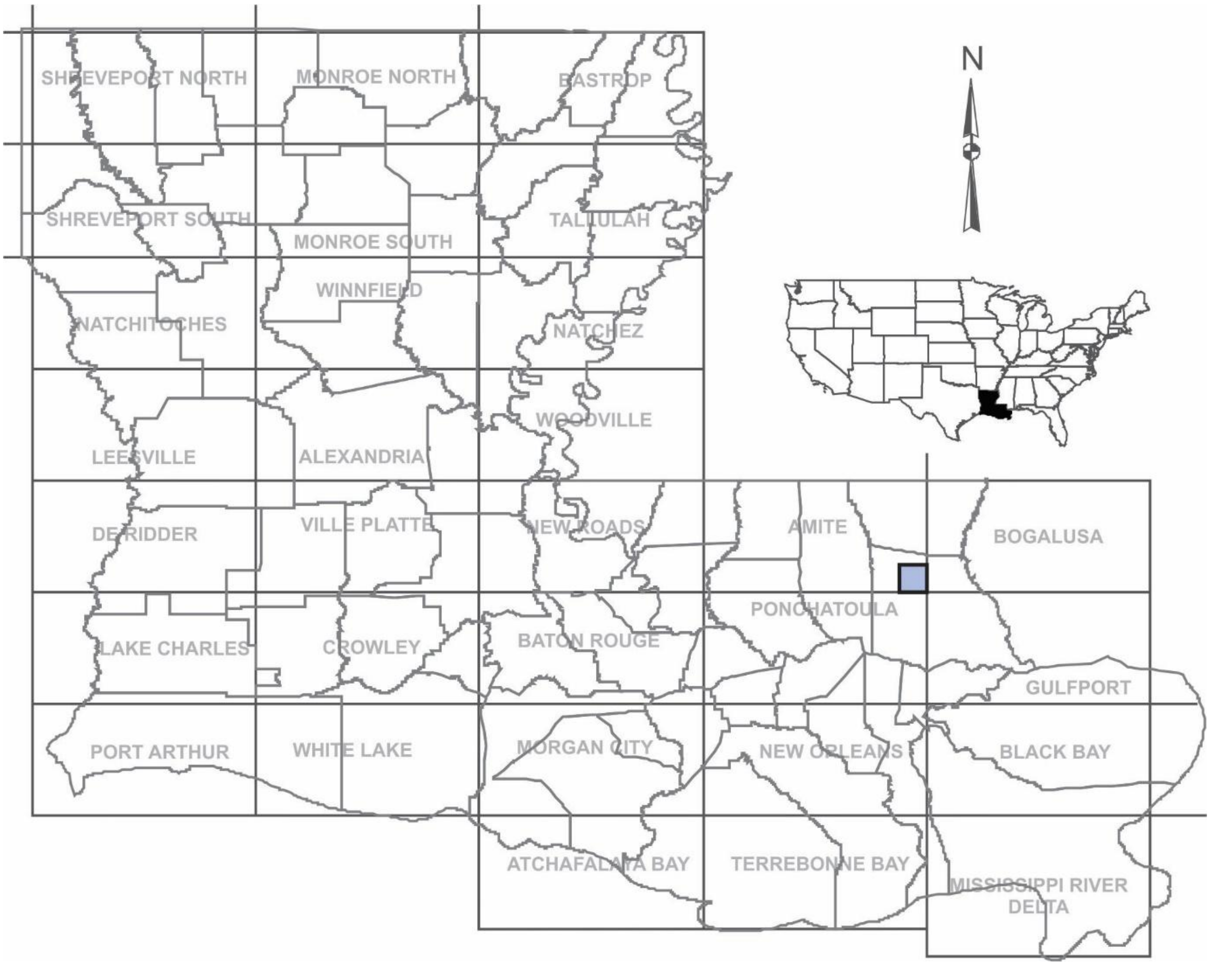
The Waldheim quadrangle occupies the southeastern corner of the Amite 30 × 60 minute quadrangle, the surface geology of which was compiled at 1:100,000 scale by McCulloh et al. (1997) and digitally recompiled by McCulloh and Heinrich (2008), both with STATEMAP support, and later prepared as a Louisiana Geological Survey (LGS) lithograph (McCulloh et al., 2009). The original 1996–1997 STATEMAP project involved compilations of the adjoining 30 × 60 minute quadrangles, also later prepared as lithographs: Ponchatoula (McCulloh et al., 2003a), Bogalusa (Heinrich and McCulloh, 2007a), and Gulfport (Heinrich et al., 2004). The project benefited from a drilling component by which the most problematic map-unit assignments were tested with a Giddings hydraulic probe.

The quadrangle is located in northern St. Tammany Parish. Self (1980, 1986) mapped the surface geology of the uplands of all of Louisiana's "Florida" parishes in southeastern Louisiana, though at 1:250,000 scale. Surface-geologic maps at 1:62,500 scale were prepared of Washington and St. Tammany Parishes by Cullinan (1969), and of St. Helena and Tangipahoa Parishes by Campbell (1972).

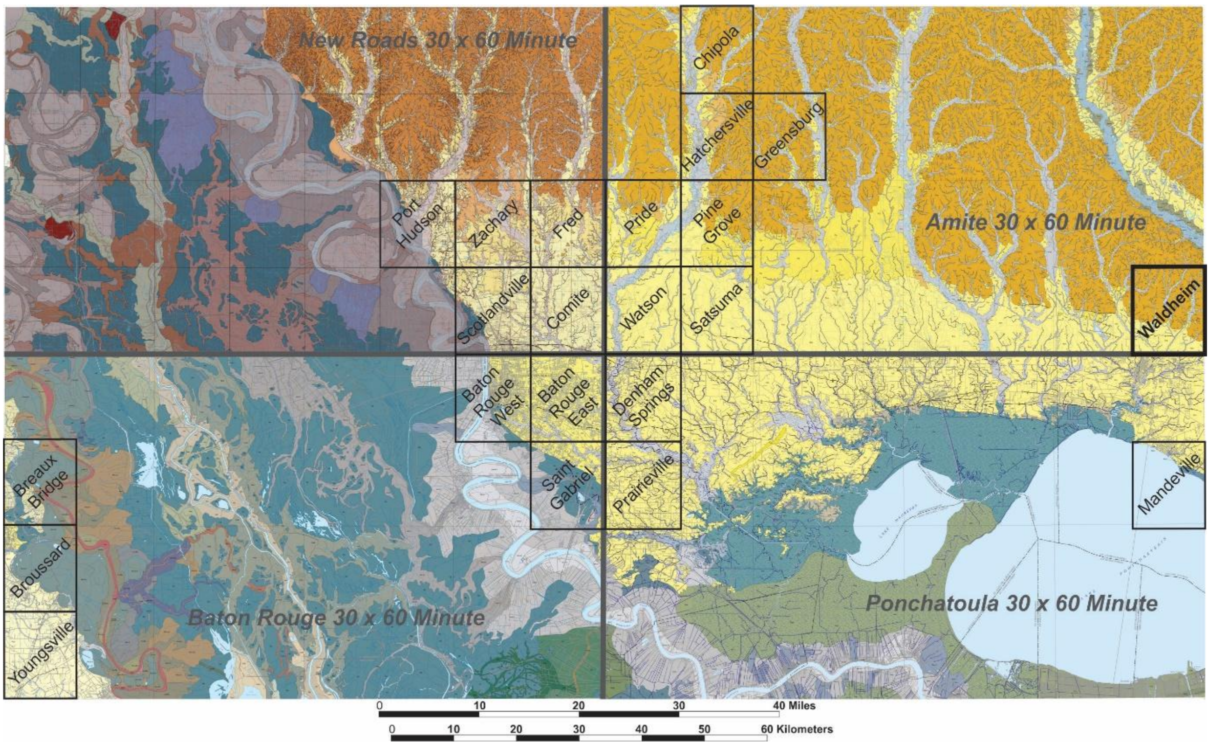
Tomaszewski et al. (2002) detailed groundwater conditions pertinent to the Southern Hills aquifer system, and Van Biersel and Milner (2010) summarized its distribution, recharge area, proportions of water-use categories, and pumpage rates.

Methods

The investigators reviewed legacy information and made new interpretations consulting remotely sensed imagery (comprising aerial photography, lidar DEMs, and other sources) and soils databases published by the Natural Resources Conservation Service (NRCS) to develop a draft surface geology layer for the study area. Field work was conducted to access the subsoil in road- and drainage-associated excavations, to examine and sample the texture and composition of the surface-geologic map units. Field observations were then synthesized with the draft surface geology to prepare an updated integrated surface geology layer for the 7.5-minute quadrangle.



1. Location of Waldheim 7.5-minute quadrangle, southeastern Louisiana.



2. Surface geology of the greater Baton Rouge area and environs (mosaic of Heinrich and Autin, 2000; Heinrich and McCulloh, 2007b; and McCulloh et al., 2003a, 2009). Waldheim 7.5-minute quadrangle is shown in relation to other mapped quadrangles. Port Hudson, Scotlandville, Baton Rouge West, and Saint Gabriel quadrangles span the boundary between the Holocene Mississippi alluvial plain and Pliocene (orange) and Pleistocene (yellow to pale orange) sediment of the flanking uplands.

QUATERNARY SYSTEM

HOLOCENE

Hua Holocene undifferentiated alluvium

PLEISTOCENE

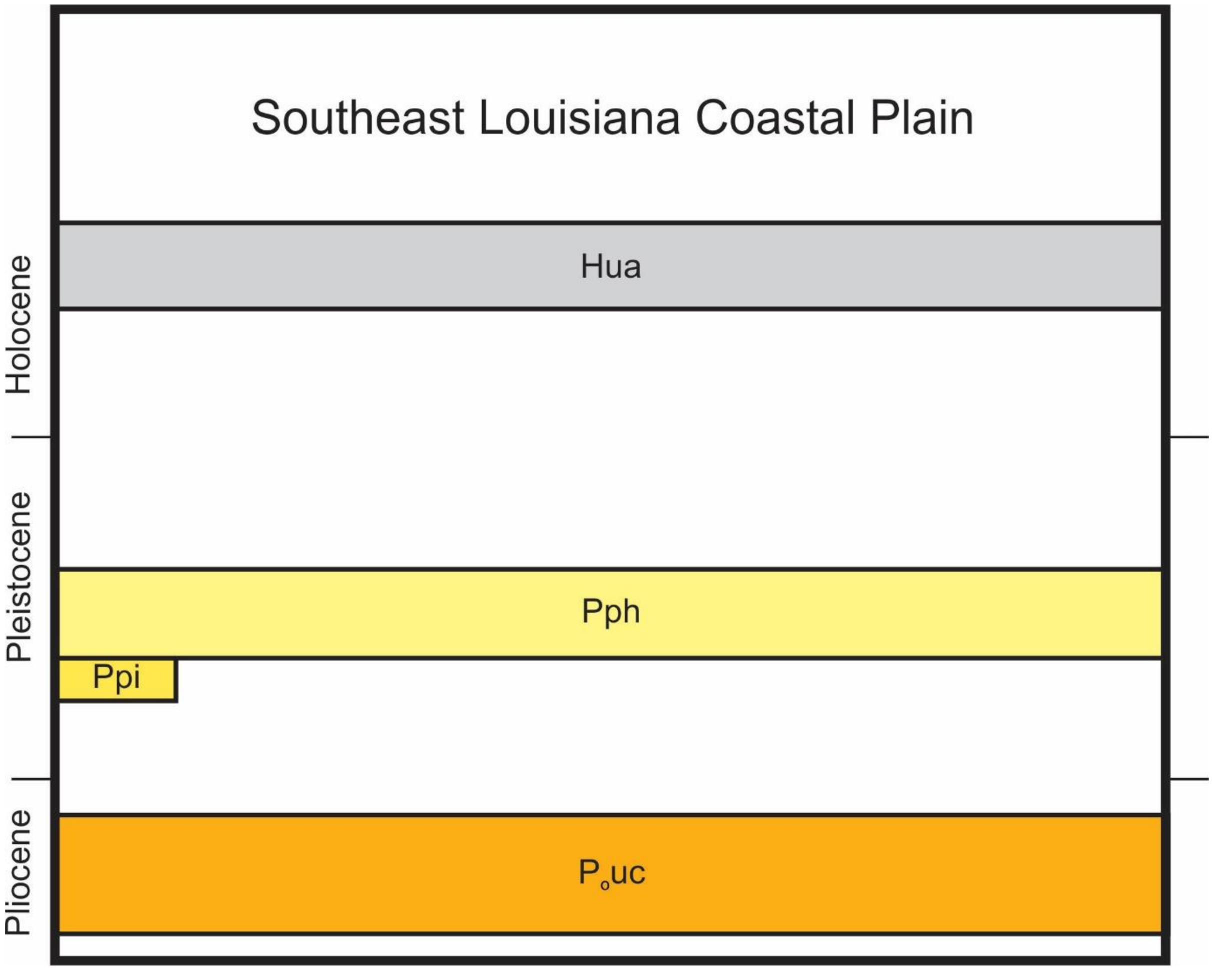
PRAIRIE ALLOGROUP
Pp Prairie Allogroup, undifferentiated
Pph Hammond alloformation
Ppi Irene alloformation

TERTIARY SYSTEM

PLIOCENE

UPLAND ALLOGROUP
Pouc Citronelle Formation

3. Units mapped in the Waldheim 7.5-minute quadrangle.



4. Correlation of strata mapped in the Waldheim 7.5-minute quadrangle.

Allostratigraphic Approach to Pleistocene Unit Definitions

In the late 1980s the LGS had begun exploring the application of allostratigraphic concepts and nomenclature to the mapping of surface Plio–Pleistocene units (e.g., Autin, 1988). In Louisiana these units show a series of geomorphic attributes and preservation states correlative with their relative ages, which eventually led LGS to conclude that allostratigraphy offers an effective if not essential approach to their delineation and classification (McCulloh et al., 2003b). The Plio–Pleistocene strata for which allostratigraphic nomenclature presently has value to LGS all are situated updip of the hinge zone of northern Gulf basin subsidence, and show a clear spectrum of preservation from pristine younger strata to trace relicts and remnants of older strata persisting in the coastal outcrop belt and on high ridgetops in places updip of it. Allounit nomenclature has figured heavily in the STATEMAP-funded geologic mapping projects of the past two decades because Quaternary strata occupy approximately three-fourths of the surface of Louisiana. The surface of the Waldheim quadrangle consists exclusively of Quaternary and Pliocene strata, which dictated a continuation of this practice for this investigation.

Citronelle Formation, Upland allogroup (Pliocene)

The Citronelle Formation was first recognized and mapped by Hilgard (1860) as the “Orange Sand Formation” that consisted of a widespread, surficial mantle of weathered sands and gravels that cover much of the state of Mississippi. As originally defined and mapped it consisted of a mixture of Pliocene sands and gravels and weathered “bedrock.” In order to conform to the policies of the U.S. Geological Survey, which forbade the use of descriptive names for formations, Hilgard (1891) renamed his "Orange Sand Formation" as the “Lafayette Formation” for railroad cuts at Oxford in Lafayette County, Mississippi. Also, it replaced another name, the Appomattox Formation, used for these sands and gravels. It was under the name Lafayette Formation that McGee (1891) published a treatise on this stratigraphic unit (Dockery and Thompson, 2016).

Later, Matson (1916) named the Citronelle Formation for highly weathered, nonmarine, Pliocene sediments that occupy the seaward margin of the Gulf Coastal Plain that extends from western Florida to Texas and consist of yellow and red sands and clays and include significant amounts of gravel near their landward margins. The type locality is a 3- to 4-mile stretch of the Mobile and Ohio Railroad north of the town of Citronelle in Mobile County, Alabama. South of its type locality, it contains a fossiliferous clay bed with a well-preserved flora that was regarded by Berry (1916) as Pliocene in age (Dockery and Thompson, 2016).

The regional distribution of the Citronelle Formation has been mapped and illustrated by numerous studies. They include Matson (1916); Doering (1935, 1956); and the “High Terraces” of Mossa and Autin (1989) and of Snead and McCulloh (1984). A georeferenced comparison using ArcGIS of Fisk’s (1938a) Williana, Bentley, and Montgomery Formations as illustrated by Bernard and Leblanc (1965, their figure 2) with published LGS 30 × 60 degree geologic quadrangle maps (Heinrich and Autin, 2000; Heinrich and McCulloh, 2007a, 2007b; and McCulloh et al., 2009) indicates they are all subdivisions of the Citronelle Formation. Only the southern edge of Fisk’s “Montgomery Formation” overlaps with the northern edges of the Montpelier and Irene alloformations.

The Citronelle Formation consists largely of reddish brown sands, interbedded sands and gravels, and gravels. The gravel content of these sediments decreases and their clay content increases gulfward. The coarse-grained nature of the Citronelle contrasts greatly with the finer-grained overlying and underlying units. The gravels of the Citronelle Formation consist largely of highly weathered, honey-colored chert pebbles. Very well-rounded quartz granules are also typically present within the Citronelle Formation along with typically deep red to purplish silt and claystone intraclasts (Self, 1986, Otvos, 2004).

The upper and lower contacts of the Citronelle Formation are unconformities. The Citronelle lies unconformably above the Miocene Pascagoula Formation (Bicker, 1969). Either loess or Pleistocene alloformations overlie the deeply eroded upper surface of the Citronelle Formation, which is characterized by a thick, reddish, well-developed paleosol (Autin, 1984). This deeply weathered surface is characterized by well-developed clay skins, plinthite, and ironstone nodules, and a vermicular fabric of highly oxidized and more reduced zones is present. The reduced zones appear to be associated with both root casts and burrows (Mossa and Autin, 1989).

Regionally, the Citronelle Formation is largely unfossiliferous. It does contain reworked, silicified Paleozoic fossils within its chert gravels. These cherts formed by the silicification of Paleozoic carbonate rocks in the source areas such as the Nashville Dome. Later, these chert nodules were eroded from their parent carbonate strata and transported gulfward as gravels by fluvial systems (Smith and Meylan, 1983). The Citronelle Formation also contains large ironstone “cylinders” that are interpreted as root casts (Mossa and Autin, 1989).

Prairie Allogroup, undifferentiated (Pleistocene)

The Prairie Allogroup is a collection of late Pleistocene depositional sequences of alloformation rank (Autin et al., 1991; Heinrich, 2006). The sediments of the Prairie Allogroup accumulated within a diverse suite of coastal-plain settings, i.e., fluvial (meander-belt and backswamp), colluvial, possibly eolian, estuarine, deltaic, and shallow-marine environments. These largely fine-grained sediments accumulated over a considerable part of the late Pleistocene (Sangamon to Wisconsin) (Autin et al., 1991; Otvos, 2005; McCulloh et al., 2003a; Heinrich, 2006).

The surface of the Prairie Allogroup forms a coastal terrace along the northwest coast of the Gulf of Mexico from a point about 110 km (~70 mi) south of the Rio Grande within Mexico over to at least Mobile Bay, Alabama. This surface is the lowest continuous terrace lying above Holocene coastal and flood plains. This relatively undissected terrace exhibits constructional topography that is more poorly preserved than exhibited by terraces of the Deweyville Allogroup and lacking on older Pleistocene surfaces. It comprises multiple stratigraphic units of alloformation rank (Saucier and Snead, 1989; Autin et al., 1991; Dubar et al., 1991; Winker 1990).

Irene alloformation, Prairie Allogroup (Pleistocene)

The Irene alloformation is an unconformity-bounded stratigraphic unit separated from the underlying Montpelier alloformation and older units by a regional unconformity. The first use of the name "Irene" was by Durham et al. (1967) for the surface identified by Fisk (1938b) as the "second terrace" (the second terrace surface above present alluvial bottoms) in the western Florida Parishes of southeastern Louisiana. Fisk viewed this surface as the next elevated relict floodplain surface up from the "Port Hickey" or Prairie (upper surface of the Hammond alloformation of this report). Snead et al. (1998) used the name again in the same context, but in an allostratigraphic sense, to refer to the depositional sequence underlying the surface identified by Fisk. These authors kept the name "Prairie" as a formation-rank unit (alloformation) and referred to its subdivisions as allomembers; subsequent usage by the Louisiana Geological Survey elevated the Prairie to group rank and its subdivisions to formation rank.

According to Fisk (1938b):

> The coastwise Port Hickey Terrace is separated from the next higher one by an irregular slope, representing the eroded edge of the second coastwise surface. The base of this slope may be traced as an irregular line from Port Hudson eastward beyond Zachary . . . Isolated remnants of the higher surface commonly protrude as islands above the lower surface close to the separating slope. These remnants point to a former greater extent of the slope, and to its frayed character previous to Port Hickey alluviation. (p. 8, 10)

This surface lacks any discernible relict constructional surface morphology except for some relatively flat, sloping interfluves (ridge crests) and accordant summits. Within this quadrangle, the surface of the Irene alloformation is too scarce and badly eroded for its slope to be determined. Little is known about the lithology of the Irene alloformation, except that it is distinctly finer-grained than the underlying Citronelle Formation. Close to the Mississippi Valley, the Peoria and Sicily Island loesses blanket the surface of the Irene alloformation (Miller et al., 1985).

Within the Waldheim 7.5-minute quadrangle, information concerning the age of the Irene alloformation is lacking. An optical luminescence date of 206 ± 14 ka (Baker I-1) from this alloformation near Baker, Louisiana indicates that it dates to Marine Isotope Stage 7; that it correlates with the Bastrop alloformation in northern Louisiana; and that the Hammond alloformation postdates Marine Isotope Stage 7 (Shen et al., 2012, 2016).

Hammond alloformation, Prairie Allogroup (Pleistocene)

Within the Florida Parishes, the youngest and most extensive surficial unit is the Hammond alloformation of the Prairie Allogroup (Heinrich, 2006; McCulloh et al., 2009). Its name is derived from Hammond, Louisiana and the Hammond terrace of Matson (1916). It is an allostratigraphic unit that forms part of the Prairie Allogroup. The surface of the Hammond alloformation is a coast-parallel terrace that is 16–40 km (10–25 mi) wide and extends from the eastern valley wall of the Mississippi River alluvial valley eastward across the Florida Parishes and the Pearl River into Mississippi. It is the lowest and best preserved of the Pleistocene terraces found between the Mississippi and Pearl rivers. In the Florida Parishes it exhibits moderately to poorly preserved relict constructional landforms. These landforms include relict river courses, meander loops, ridge-and-swale topography, coastal ridges, and beach ridges. In some areas, they include valley walls and flood plains of entrenched valleys. Overall, the surface of the Hammond alloformation consists of a series merged alluvial cones that abruptly flatten out into a broad coastal plain. Within the Waldheim 7.5-minute quadrangle, the surface of the Hammond alloformation is well preserved and exhibits relict constructional topography.

Information concerning the age of the Hammond alloformation in the Waldheim 7.5-minute quadrangle is lacking. However, optical luminescence dates from the Baton Rouge and Denham Springs areas indicate that the Hammond alloformation is a mixture of sediments that accumulated during Marine Isotope Stages 5 and 3 and postdates Marine Isotope Stage 7 (Shen et al., 2012, 2016).

Sicily Island Loess (Pleistocene)

Within the Waldheim 7.5-minute quadrangle, a blanket of relatively homogeneous, seemingly nonstratified, unconsolidated, well-sorted silt blankets the formations of Pleistocene and Tertiary age. This surficial layer of well-sorted silt, which is called “loess,” is distinctive because of its unusually massive nature, uniformly tan to brown color, and extraordinary ability to form and maintain vertical slopes or cliffs (Miller et al., 1985; Pye and Johnson, 1988; McCraw and Autin, 1989; and Saucier, 1994).

Loess is eolian sediment that accumulated during times of near-maximum to early-waning glaciation. During such periods, seasonally prevailing, strong, north and northwest winds deflated large amounts of silt from recently deposited and unvegetated glacial outwash that accumulated within glacial valley trains. These seasonal winds then transported the material for tens to hundreds of kilometers (tens to hundreds of miles) to the east and south. Eventually, this deflated silt fell out of suspension and incrementally accumulated within adjacent uplands as a drape over either preexisting terraces or dissected, hilly landscape. The greatest amount and relatively coarsest of the silt accumulated closest to the source areas (Miller et al., 1985; Pye and Johnson, 1988; McCraw and Autin, 1989; and Saucier, 1994).

Only one loess blanket, Sicily Island Loess, occurs within the Waldheim 7.5-minute quadrangle. It is not depicted on the geologic map because in this area it is less than 1 m (3 ft) thick (Miller, 1983), the threshold value for depiction adopted by LGS. The favored age of the Sicily Island Loess is an Early Wisconsin age, which is consistent with its presence overlying the surface of the Irene Alloformation and its absence beneath the Peoria Loess where it overlies the Hammond alloformation.

Holocene alluvium

The Holocene sediments mapped in the Waldheim 7.5-minute quadrangle consist of undifferentiated deposits of upland streams, comprising unconsolidated alluvial deposits filling valleys of streams and creeks of the Bogue Falaya River system in the Tchefuncte River basin. The deposits of upland streams and alluvial deposits of minor streams and creeks have not been studied in detail and are poorly known. The textures of these sediments vary greatly from gravelly sand to either sandy mud or silty mud. Typically, the amount of coarse-grained sediments present directly reflects the texture of the local "bedrock."

Linear Features Suggestive of Surface Faulting

In southern Waldheim quadrangle, lidar DEMs resolve linear surface features that are reminiscent of fault-line scarps elsewhere in south Louisiana, patterned in an apparent *en echelon* array (Figure 5). Relief on these escarpments ranges from approximately 1.5 to 3 m (5 to 10 ft). At present no independent evidence is available to corroborate faulting at this location, i.e., current subsurface structure maps do not map faults there (e.g., Geomap Company, 2002, 2007). The absence of faults on subsurface maps, however, can in places reflect ineffectiveness of traditional (especially electric-log-based) subsurface techniques at resolving faults with displacement less than 15 m (50 ft). For example, the Scotlandville fault north of Baton Rouge has surface displacement of 1.5 to 2 m (5 to 7 ft). It is interpreted as a reactivated growth fault (Hanor, 1982; McCulloh and Heinrich, 2012) as it shows consistent uniform displacement, in this case averaging approximately 15 m, over a large vertical interval in the deeper subsurface. With its subsurface displacement magnitude near the threshold value of resolution by ordinary subsurface techniques, the Scotlandville fault typically is not depicted on subsurface structure maps.

Waldheim quadrangle occupies the southeastern corner of the Amite 30 × 60 minute quadrangle, previous compilations of the surface geology of which depicted a fault in this general area (McCulloh et al., 1997, 2008, 2009) but positioned approximately 1 km (0.6 mi) to the north. Though lidar imagery was consulted for the latter two compilations, the depiction largely reflected the retention of a legacy geomorphic interpretation originally made using 7.5-minute topography. Detailed review of lidar DEMs for the present investigation contradicted this interpretation and produced no positive indications of surface faulting at that position.

The area in which the linear surface features occur lies approximately 21 km (13 mi) north of the nearest mapped subsurface faults in the northern Lake Pontchartrain area (Geomap Company, 2002, 2007; Zimmerman and Breland, 2000, their figure 3), and lies approximately 14 to 19 km (9 to 12 mi) north of the nearest mapped surface faults north of the lake (McCulloh et al., 2003a). While it is plausible that unmapped subsurface faults with displacement less than 15 m occur in this area, for the present no demonstration of such faults can be made. Accordingly, the investigators concluded at the time of writing not to map even questionable surface faults there.

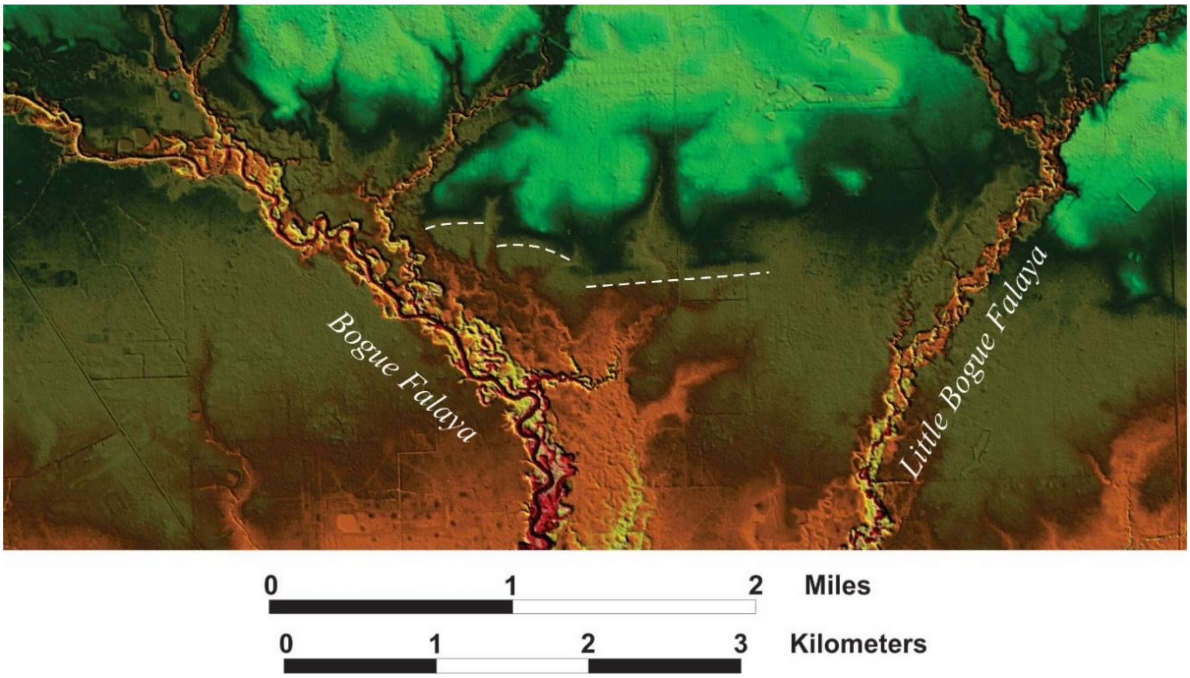


Figure 5. Lidar DEM mosaic showing surface linear features (dashed white lines) in southern Waldheim quadrangle.

Summary of Results

The surface of the Waldheim quadrangle comprises strata of the Pliocene Citronelle Formation, and Pleistocene stratigraphic units of the Prairie Allogroup consisting of sediment deposited by coastal rivers and streams. The Irene and Hammond alloformations of the Prairie Allogroup form part of a coast-parallel belt of terraced Pleistocene strata. These Plio–Pleistocene strata are covered by late Pleistocene Sicily Island Loess less than 1 m (3 ft) thick. Holocene strata comprise undifferentiated alluvium of the Bogue Falaya River and its tributaries in the drainage basin of the Tchefuncte River.

The geologic map of Waldheim quadrangle provides basic geologic data of potential value to the conduct of aggregate-mining activities. The area hosts sizable gravel resource potential in Pliocene sediment of the Citronelle Formation (Heinrich and McCulloh, 1999), which has produced significant sand and gravel in St. Tammany Parish directly to the north (U.S. Geological Survey, 2011). The 1:24,000-scale surface-geologic map of the study area also should serve efforts at protection of the Southern Hills aquifer system in the upper Amite River area.

Acknowledgments

The work described and summarized herein was supported by the National Cooperative Geologic Mapping Program, STATEMAP component, under cooperative agreement G19AC00223 with the U.S. Geological Survey.

References

Autin, W. J., 1988, Mapping alloformations in the Amite River, southeastern Louisiana: Geological Society of America Abstracts with Programs, v. 20, no. 4, p. 252.

Autin, W. J., 1984, Upland stratigraphy and geomorphology of southeastern Louisiana: Geological Society of America Abstracts with Programs, v. 16, no. 3, p. 123.

Autin, W. J., S. F. Burns, B. J. Miller, R. T. Saucier, and J. I. Snead, 1991, Quaternary geology of the Lower Mississippi Valley, *in* Morrison, R. B., ed., Quaternary non-glacial geology: conterminous United States: Boulder, Colorado, Geological Society of America, The Geology of North America, v. K–2, Chapter 18, p. 547–582.

Bernard, H. A., and R. J. LeBlanc, 1965, Resume of the Quaternary geology of the northwestern Gulf of Mexico, *in* Wright, H. E., Jr., and D. G. Frey, eds., The Quaternary of the United States: Princeton University Press, p. 137–186.

Berry, E. W., 1916, The flora of the Citronelle formation [Part 2], *in* Shorter contributions to general geology, 1916: U.S. Geological Survey Professional Paper, 98–L, p. 193–208.

Bicker, A. R. Jr. (compiler), 1969, Geologic map of Mississippi: Mississippi Geological Survey, Jackson, scale 1:500,000.

Campbell, C. L., 1972, Contributions to the geology of St. Helena and Tangipahoa parishes, Louisiana: U.S. Army Corps of Engineers, New Orleans District.

Cullinan, T. A., 1969, Contributions to the geology of Washington and St. Tammany parishes, Louisiana: U.S. Army Corps of Engineers, New Orleans District.

Dockery, D. T., III, and D. E. Thompson, 2016, Geology of Mississippi: University Press of Mississippi, Jackson, 692 p.

Doering, J., 1935, Post-Fleming surface formations of coastal southeast Texas and south Louisiana: American Association of Petroleum Geologists Bulletin, v. 19, no. 5, p. 651–688.

Doering, J. A., 1956, Review of Quaternary surface formations of the Gulf Coast region: American Association of Petroleum Geologists Bulletin, v. 40, p. 1816–1862.

DuBar, J. R., T. E. Ewing, E. L. Lundelius, Jr., E. G. Otvos, and C. D. Winker, 1991, Quaternary geology of the Gulf of Mexico Coastal Plain, *in* Morrison, R. B. ed., Quaternary non-glacial geology: conterminous United States: Boulder, Colorado, Geological Society of America, The Geology of North America, v. K–2, 672 p.

Durham, C. O., Jr., C. H. Moore, Jr., and B. Parsons, 1967, An agnostic view of the terraces: Natchez to New Orleans, *in* Kolb, C. R. and C. O. Durham, Jr., eds., Lower Mississippi alluvial valley and terraces: Field trip guidebook, Geological Society of America 1967 annual meeting, New Orleans, Louisiana, Part E, 22 p.

Fisk, H. N., 1938a, Geology of Grant and La Salle parishes: Louisiana Department of Conservation, Louisiana Geological Survey, Geological bulletin no. 10, 246 p. plus plates (includes two 1:62,500-scale geologic maps).

Fisk, H. N., 1938b, Pleistocene exposures in western Florida Parishes, Louisiana, *in* Fisk, H. N., H. G. Richards, C. A. Brown, and W. C. Steere, Contributions to the Pleistocene history of the Florida Parishes of Louisiana: Louisiana Department of Conservation, Louisiana Geological Survey, Geological bulletin no. 12, p. 3–25.

Geomap Company, 2002, Southeast Louisiana: Executive reference map 304, Geomap Company, Houston, Texas, scale 1:336,000.

Geomap Company, 2007, State of Louisiana: Geomap Company, Houston, Texas, scale ~1:360,000.

Hanor, J. S., 1982, Reactivation of fault movement, Tepetate fault zone, south central Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 32, p. 237–245.

Heinrich, P. V., 2006, Pleistocene and Holocene fluvial systems of the lower Pearl River, Mississippi and Louisiana, USA: Gulf Coast Association of Geological Societies Transactions, v. 56, p. 267–278.

Heinrich, P. V., and R. P. McCulloh (compilers), 2007a, Bogalusa 30 × 60 minute geologic quadrangle: Louisiana Geological Survey, Baton Rouge, scale 1:100,000.

Heinrich, P. V., and R. P. McCulloh (compilers), 2007b, New Roads, LA 30 × 60 minute geologic quadrangle: Unpublished map prepared in cooperation with U.S. Geological Survey, STATEMAP program, under cooperative agreement no. 06HQAG0043, Open-File Map 2007–04, Louisiana Geological Survey, Baton Rouge, scale 1:100,000.

Heinrich, P. V., and W. J. Autin (compilers), 2000, Baton Rouge 30 × 60 Minute Geologic Quadrangle: Louisiana Geological Survey, Baton Rouge, Scale 1:100,000.

Heinrich, P. V., and R. P. McCulloh, 1999, Mineral resources map of Louisiana: scale 1:500,000, Louisiana Geological Survey, Baton Rouge.

Heinrich, P. V., R. P. McCulloh, and J. Snead (compilers), 2004, Gulfport 30 × 60 Minute Geologic Quadrangle: Louisiana Geological Survey, Baton Rouge, scale 1:100,000.

Hilgard, E. W., 1891, Orange sand, Lagrange, and Appomattox: American Geologist, v. 8, p. 129–131.

Hilgard, E. W., 1860, Report on the geology and agriculture of the state of Mississippi: E. Barksdale, State Printer, Jackson, Mississippi, 391 p.

Matson, G. C., 1916, The Pliocene Citronelle formation of the Gulf Coastal Plain [Part 1], *in* Shorter contributions to general geology, 1916: U.S. Geological Survey Professional Paper no. 98–L, p. 167–192.

McCraw, D. J., and W. J. Autin, 1989, Lower Mississippi Valley Loess: Mississippi Valley Loess Tour Guidebook, INQUA Commission on Loess, North American Working Group, Baton Rouge, Louisiana, 35p.

McCulloh, R. P., and P. V. Heinrich, 2012, Surface faults of the south Louisiana growth-fault province, *in* Cox, R. T., M. P. Tuttle, O. S. Boyd, and J. Locat, eds., Recent Advances in North American Paleoseismology and Neotectonics East of the Rockies: Geological Society of America Special Paper 493, p. 37–50, doi:10.1130/2012.2493(03).

McCulloh, R. P., and P. V. Heinrich (compilers), 2008, Amite, LA 30 × 60 minute geologic quadrangle: Open-File Map 2008–03, Louisiana Geological Survey, Baton Rouge, scale 1:100,000.

McCulloh, R. P., P. V. Heinrich, and J. Snead (compilers), 2009, Amite 30 × 60 minute geologic quadrangle: Louisiana Geological Survey, Baton Rouge, scale 1:100,000.

McCulloh, R. P., P. V. Heinrich, and J. Snead (compilers), 2003a, Ponchatoula 30 × 60 Minute Geologic Quadrangle: Louisiana Geological Survey, Baton Rouge, scale 1:100,000.

McCulloh, R. P., Heinrich, P. V., and Snead, J. I., 2003b, Geology of the Ville Platte Quadrangle, Louisiana: Louisiana Geological Survey, Geological Pamphlet no. 14, 11 p. (to accompany the *Ville Platte 30 × 60 Minute Geologic Quadrangle*).

McCulloh, R. P., P. Heinrich, and J. Snead (compilers), 1997, Amite, Louisiana–Mississippi 30 × 60 minute geologic quadrangle: prepared in cooperation with U.S. Geological Survey, STATEMAP program, under cooperative agreement no. 1434-HQ-96-AG-01490, Louisiana Geological Survey, Baton Rouge, unpublished 1:100,000-scale map plus explanation and notes.

McGee, W. J., 1891, The Lafayette formation, *in* Powell, J. W., Twelfth annual report of the United States Geological Survey to the Secretary of the Interior, 1890–1891: Part I, U.S. Geological Survey Annual Report, v. 12, pt. 1, p. 347–521.

Miller, B. J. (compiler), [1983], [Distribution and thickness of loess in Jackson, Louisiana–Mississippi, Lake Charles, Louisiana–Texas, and Baton Rouge, Louisiana 1 × 2 degree quadrangles]: Louisiana State University Department of Agronomy, Louisiana Agricultural Center, Louisiana Agricultural Experiment Station, Baton Rouge, unpublished map, Louisiana Geological Survey, scale 1:250,000.

Miller, B. J., G. C. Lewis, J. J. Alford, and W. J. Day, 1985, Loesses in Louisiana and at Vicksburg, Mississippi: Field trip guidebook, Friends of the Pleistocene [South Central Cell], April 12–14, 1985, Louisiana State University Agricultural Center, 126 p.

Mossa, J., and W. J. Autin, eds., 1989, Quaternary geomorphology and stratigraphy of the Florida Parishes, southeastern Louisiana: a field trip: Guidebook Series No. 5, Louisiana Geological Survey, Baton Rouge, Louisiana, 98 p.

Otvos, E. G., 2004, Lithofacies and depositional environments of the Pliocene Citronelle Formation, Gulf of Mexico coastal plain: Southeastern Geology, v. 43, no. 1, p. 1–20.

Otvos, E. G., 2005, Numerical chronology of Pleistocene coastal plain and valley development: Extensive aggradation during glacial low sea-levels: Quaternary International, v. 135, p. 91–113.

Pye, K., and R. Johnson, 1988, Stratigraphy, geochemistry, and thermoluminescence ages of Lower Mississippi Valley loess: Earth Surface Processes and Landforms. v. 13, no. 2, p. 103–124.

Saucier, R. T., 1994, Geomorphology and Quaternary geologic history of the Lower Mississippi Valley: volume 1, Vicksburg, Mississippi, U. S. Army Corps of Engineers, Waterways Experiment Station, 364 p. plus appendices.

Saucier, R. T., and J. I. Snead (compilers), 1989, Quaternary geology of the Lower Mississippi Valley, *in* Morrison, R. B., ed., Quaternary non-glacial geology: conterminous United States: Boulder, Colorado, Geological Society of America, The Geology of North America, v. K–2, Plate 6, scale 1:1,100,000.

Self, R. P., 1986, Depositional environments and gravel distribution in the Plio–Pleistocene Citronelle formation of southeastern Louisiana: Gulf Coast Association of Geological Societies Transactions, v. 36, p. 561–573.

Self, R. P., 1980, Pliocene to Recent gravel deposits of the Florida parishes, southeast Louisiana: unpublished report prepared for Louisiana Geological Survey, Baton Rouge, under Department of Natural Resources contract no. 21530-80-03, 83 p. plus plates (includes one 1:250,000-scale geologic map).

Shen, Z., N. H. Dawers, T. E. Tornqvist, N. M. Gasparini, M. P. Hijma, and B. Mauz, 2016, Mechanisms of late Quaternary fault throw-rate variability along the north central Gulf of Mexico coast: implications for coastal subsidence: Basin Research, p. 1–14, doi:10.1111/bre.12184.

Shen, Z., T. E. Törnqvist, W. J. Autin, Z. R. P. Mateo, K. M. Straub, and B. Mauz, 2012, Rapid and widespread response of the Lower Mississippi River to eustatic forcing during the last glacial-interglacial cycle: Geological Society of America Bulletin, v. 124, no. 5–6, p. 690–704.

Smith, M. L., and M. Meylan, 1983, Red Bluff, Marion County, Mississippi: A Citronelle braided stream deposit: Gulf Coast Association of Geological Societies Transactions, v. 33, p. 419–433.

Snead, J. I., and R. P. McCulloh (compilers), 1984, Geologic map of Louisiana: Baton Rouge, Louisiana Department of Natural Resources, Louisiana Geological Survey, scale 1:500,000.

Snead, J. I., P. V. Heinrich, R. P. McCulloh, and W. J. Autin (compilers), 1998, Quaternary geologic map of Louisiana: unpublished map plus 12-p. expanded explanation and notes, prepared in cooperation with U.S. Geological Survey, STATEMAP program, under cooperative agreement no. 1434–HQ–97–AG–01812, scale 1:500,000.

Tomaszewski, D. J., J. K. Lovelace, and P. A. Ensminger, 2002, Water withdrawals and trends in ground-water levels and stream discharge in Louisiana: Water resources technical report no. 68, Louisiana Department of Transportation and Development, Public

Works and Water Resources Division, Water Resources Section, in cooperation with U.S. Geological Survey, Baton Rouge, 30 p.

U.S. Geological Survey, 2011, The mineral industry of Louisiana, *in* U.S. Geological Survey minerals yearbook—2008; 2008 Minerals Yearbook—Louisiana [advance release]: Reston, Virginia, U.S. Geological Survey, p. 20.1–20.2.

Van Biersel, T., and R. Milner (compilers), 2010, Louisiana's principal freshwater aquifers: Louisiana Geological Survey, Educational poster series no. 01–10, one oversized sheet.

Winker, C. D. (compiler), 1990, Quaternary geology, northwestern Gulf Coast, *in* Morrison, R. B., ed., Quaternary non-glacial geology: conterminous United States: Boulder, Colorado, Geological Society of America, The Geology of North America, v. K–2, Plate 8, scale 1:2,000,000.

Zimmerman, R. K., and F. C. Breland, Jr., 2000, Estimate of the potential petroleum resource of Lake Pontchartrain, *in* John, C. J., Project Manager, Environmental assessment and estimate of the potential petroleum resource of Lake Pontchartrain, Louisiana: Report prepared for Louisiana Department of Natural Resources, Office of Mineral Resources, Baton Rouge, under DNR Interagency Agreement #2400-00-01, Part II, 41 p.