

# Geology of the Satsuma 7.5-Minute Quadrangle, LA

*Louisiana Geological Survey*

## Introduction, Location, and Geologic Setting

The Satsuma 7.5-minute quadrangle lies within the Plio–Pleistocene uplands east of the lower Mississippi River valley, in the drainage basin of the Amite River in the southeastern Louisiana coastal plain (Figures 1, 2). The axis of the subsurface lower Cretaceous shelf edge (Toledo Bend flexure), which trends west-northwest to east-southeast, lies beneath the northern edge of the study area. The surface comprises strata of the Pleistocene Prairie Allogroup, consisting of 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 Pleistocene strata are covered by late Pleistocene Peoria Loess that is thinner than 1 m, with the 1-m thickness contour lying up to 10 km (6 mi) to the west, and are incised by Holocene undifferentiated alluvium of the Amite River and its tributaries. The loess-covered Hammond surface in the southern portion of the quadrangle is transected by a down-to-basin fault, striking generally west-northwest to east-southeast (Figure 2).

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

## Previous Work

The Satsuma quadrangle lies in the southwestern portion 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 investigation benefited from a drilling component by which the most problematic map-unit assignments were tested with a total of 15 holes drilled with a Giddings hydraulic probe.

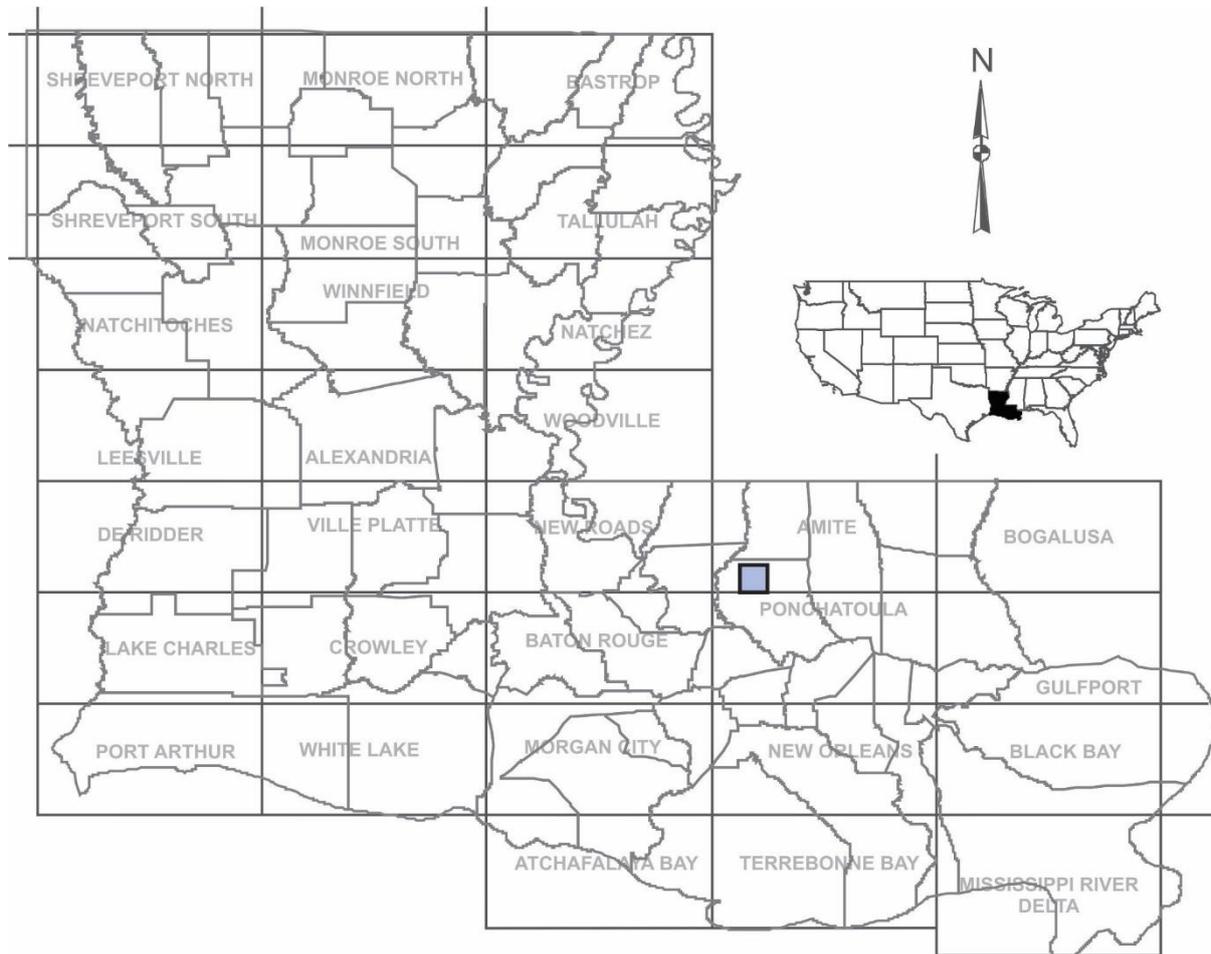
The quadrangle lies entirely within north-central Livingston Parish (Figures 1, 2). Self (1980, 1986) mapped the surface geology of the uplands of all of Louisiana’s “Florida” parishes in southeastern Louisiana, though at 1:250,000 scale. Delcourt (1974) mapped the surface geology of East Feliciana Parish at 1:62,000 scale, and Campbell (1972) mapped that of St. Helena Parish at 1:62,500 scale. Autin and McCulloh (1991) mapped the surface geology of East Baton Rouge Parish at 1:24,000 scale. South Louisiana surface faults were summarized by McCulloh and Heinrich (2012), and interpreted as the surface expression of reactivated deep-subsurface growth faults originally known through oil and gas exploration work.

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.

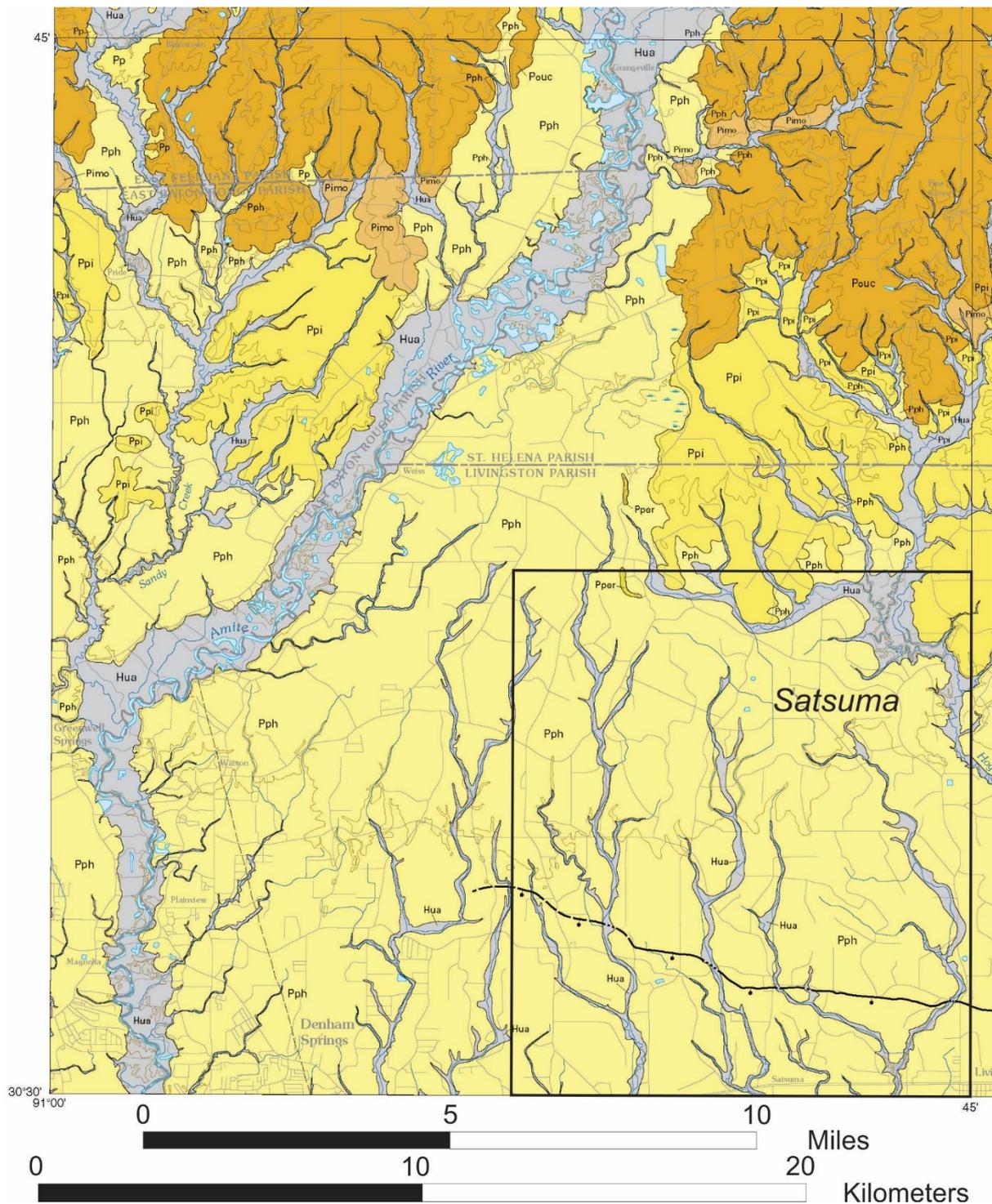
## Methods

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 Satsuma 7.5-minute quadrangle, southeastern Louisiana.



2. Surface geology of Satsuma 7.5-minute quadrangle and vicinity (adapted from McCulloh et al., 2009). (**Pouc**, Citronelle Formation, Upland allogroup (Pliocene); **Pimo**, Montpelier alloformation, Intermediate allogroup (Pleistocene); **Ppi**, Irene alloformation, Prairie Allogroup (Pleistocene); **Pph**, Hammond alloformation, Prairie Allogroup (Pleistocene); **Pp**, Prairie Allogroup, undifferentiated (Pleistocene); **Hua**, Holocene undifferentiated alluvium.)

QUATERNARY SYSTEM

HOLOCENE

Hua Holocene undifferentiated alluvium

PLEISTOCENE

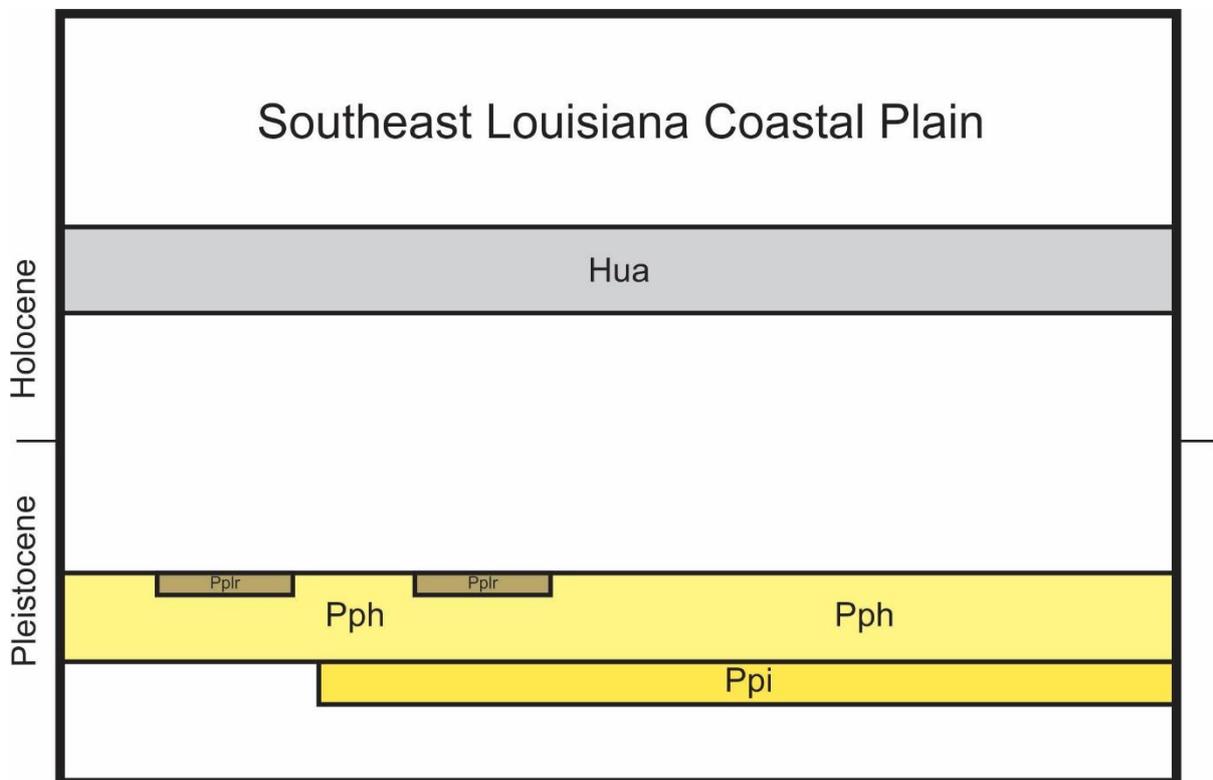
PRAIRIE ALLOGROUP

Pplr Relict Pleistocene ridges

Pph Hammond alloformation

Ppi Irene alloformation

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



4. Correlation of strata mapped in the Satsuma 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., 2003). 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. Allunit 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 Satsuma quadrangle consists exclusively of Quaternary strata, which dictated a continuation of this practice for this investigation.

### **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., 2003; 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 embayed and irregular character is exemplified by the dissected surface of the Irene alloformation in the Satsuma 7.5-minute quadrangle, especially in the quadrangle's northeastern portion. This surface lacks any discernible relict constructional surface morphology except for rare relatively flat, sloping interfluves (ridge crests) and accordant summits. The slope of its terrace is too poorly preserved to accurately measure its dip. At this time, 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 Satsuma 7.5-minute quadrangle, information concerning the age of the Irene alloformation is lacking. An optical luminescence date of  $206 \pm 14$  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. In areas to the south of the Satsuma quadrangle, faulting has displaced the surface of the Hammond alloformation, creating numerous fault-line scarps.

Within the Satsuma 7.5-minute quadrangle, the surface of the Hammond alloformation is well preserved and exhibits relict constructional topography although it is entrenched by the modern Amite River and disturbed by gravel mining. In this area, the surface of the Hammond alloformation exhibits the radiating paleochannels of a distributive fluvial system that forms a relict alluvial cone of the Amite River. Also, along the northwest border, the Salem Cemetery occupies a prominent, north-south-trending sand ridge that is about 200 m (660 ft) wide. This sand ridge rises about 4 m (13 ft) above the adjacent surface of the Hammond alloformation. The slope of the alluvial cone within the study area is about 1 m/km (5.28 ft/mi). Very little is known about the lithology of the Hammond alloformation within this quadrangle. Geotechnical borings from the Laser Interferometer Gravitational-Wave Observatory (LIGO) show that the upper 10 m (~30 ft) of the Hammond alloformation locally consist of light gray and greenish silty clay and clay with discontinuous beds of light gray and tan silty sand and sand that all lack any discernible organic material.

Information concerning the age of the Hammond alloformation in the Satsuma 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).

### **Peoria Loess (Pleistocene)**

Within the Satsuma 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).

The two loess sheets that occur within the Satsuma 7.5-minute quadrangle are, from youngest to oldest, the Peoria and Sicily Island loesses. Numerous radiocarbon, thermoluminescence, and optical luminescence dates and other lines of evidence have been used to determine the age of the Peoria Loess. It has been found to be unquestionably of Late Wisconsin age, between 22,000 and 12,500 years BP, and consistent with the age of known meltwater valley trains (Miller et al., 1985; Pye and Johnson, 1988; McCraw and Autin, 1989; and Saucier, 1994). 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 Satsuma 7.5-minute quadrangle consist of undifferentiated deposits of small upland streams; unconsolidated alluvial deposits of minor streams and creeks filling valleys; and the meander belt of the Amite River. The deposits of small 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.”

In the case of the Amite River valley, the sediments within it reflect its formation by a coarse-grained meandering river. Within it, lateral accretion associated with the secondary development of chutes and cutoffs are the processes that govern sediment deposition. As a result, the floodplain exhibits point bar and scroll bar ridges and active and abandoned thalweg channels and chute channels. The sediments underlying the floodplain consist of two facies, a lower sandy facies and an upper silty facies, associated with these processes and landforms. The lower sandy facies consists of point bar, scroll bar, and channel lag deposits that typically

are stratified. The upper silty facies consist of gray and brown silt. The gray silt occurs as lenticular to V-shaped fills of abandoned chute and thalweg channels. The brown silt comprises natural levees and the upper portion of abandoned chute and thalweg channel fills (Autin, 1985, 1989; Mossa and Autin, 1989). These sediments were differentiated by Autin (1989) into three alloformations, known as the Magnolia Bridge, Denham Springs, and Watson alloformations on the basis of unconformable boundaries, landscape morphology, and relative pedogenic development. These units were not mapped in this investigation because of lack of the detailed information needed to differentiate them.

### **Fault**

The Hammond surface in the southern portion of the quadrangle is transected by a west-northwest- to east-southeast-striking down-to-basin fault (Figure 2). The fault is interpreted as the surface expression of a deep-subsurface growth fault reactivated since the late Pliocene by depositional loading induced by voluminous sedimentation accompanying continental deglaciation (Heinrich, 2005; McCulloh and Heinrich, 2012). The maximum surface displacement across this fault within the quadrangle extent, inferred from the maximum relief on the fault-line scarp, is 4 m (13 ft) and occurs along a short reach lying directly south of the approximate midpoint of the LIGO Livingston installation.

### **Summary of Results**

The surface of the Satsuma quadrangle comprises strata of the Pleistocene Prairie Allogroup consisting of sediment deposited by the Amite River and by coastal processes. The Irene and Hammond alloformations of the Prairie Allogroup, form part of a coast-parallel belt of terraced Pleistocene strata. These Pleistocene strata are covered by late Pleistocene Peoria Loess up to slightly greater than 1 m thick. The Hammond surface is transected by a single mapped down-to-basin fault in the southern portion of the quadrangle. Holocene strata comprise undifferentiated alluvium of the Amite River and its tributaries.

The geologic map of Satsuma quadrangle provides basic geologic data of potential value to the conduct of aggregate-mining activities in the Amite River flood plain. The area hosts sizable sand and gravel resource potential in Holocene floodplain sediment and Pleistocene strata of the Prairie Allogroup (Heinrich and McCulloh, 1999). The area has produced significant sand and gravel in the past decade (U.S. Geological Survey, 2011), and production activities have moved progressively northward in recent years. 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 G18AC00179 with the U.S. Geological Survey.

### **References**

Autin, W. J., 1989, Geomorphic and stratigraphic evolution of the middle Amite River valley, southeastern Louisiana: Ph.D. dissertation, Louisiana State University, Baton Rouge, 177 p.

- 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., 1985, Alluvial morphology and stratigraphy of a meandering segment of the Amite River, southeastern Louisiana: Southeastern Geology, v. 26, no. 2, p. 95–110.
- 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., and R. P. McCulloh (compilers), 1991, Geologic and derivative engineering geology hazard maps of East Baton Rouge Parish, Louisiana: Louisiana Geological Survey Open-File Series No. 91–01, prepared for East Baton Rouge Parish Department of Public Works under project no. 90-MS-CP-0024, 31 plates [1:24,000-scale] plus index and explanation.
- 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.
- 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.
- Delcourt, P. A., 1974, Quaternary geology and paleoecology of West and East Feliciana parishes, Louisiana, and Wilkinson County, Mississippi: M.S. thesis, Louisiana State University, Baton Rouge, 175 p. plus plates (includes one 1:62,000-scale geologic map).
- 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.
- Dockery, D. T., III, and D. E. Thompson, 2016, Geology of Mississippi: Jackson, Mississippi, University Press of Mississippi, 692 p.
- 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.

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., 2005, Distribution and origin of fault-line scarps of southwest Louisiana, USA: *Gulf Coast Association of Geological Societies Transactions*, v. 55, p. 284–293.

Heinrich, P. V., and R. P. McCulloh (compilers), 2007, Bogalusa 30 × 60 minute geologic quadrangle: 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.

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.

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., Heinrich, P. V., and Snead, J. I., 2003, 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., 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.

- 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.
- 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.