STUDIES RELATED TO WILDERNESS
WILDERNESS AREAS

MINERAL RESOURCES OF THE BRADWELL BAY WILDERNESS *and* THE SOPCHOPPY RIVER STUDY AREA, WAKULLA COUNTY, FLORIDA

GEOLOGICAL SURVEY BULLETIN 1431

Mineral Resources of the Bradwell Bay Wilderness and the Sopchoppy River Study Area, Wakulla County, Florida

By CORNELIA C CAMERON, U S Geological Survey,
and PETER C MORY, U S Bureau of Mines

With sections on

PHOSPHATE

By JAMES B. CATHCART, U.S. Geological Survey

SAND

By PHILIP J. GERACI, U.S Geological Survey

STUDIES RELATED TO WILDERNESS – WILDERNESS AREAS

GEOLOGICAL SURVEY BULLETIN 1431

An evaluation of the mineral potential of the area

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON 1977

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress Cataloging in Publication Data

Cameron, Cornelia Clermont, 1911–

Mineral resources of the Bradwell Bay Wilderness and the Sopchoppy River Study Area, Wakulla County, Florida.

(Studies related to wilderness—wilderness areas) (Geological Survey bulletin ; 1431)

Bibliography· p.

1. Mines and mineral resources—Florida—Wakulla Co. I. Mory, Peter C., joint author II. Title Mineral resources of the Bradwell Bay Wilderness and the Sopchoppy River Study Area . . III Series IV Series: United States Geological Survey.

Bulletin ; 1431

QE75 B9 no 1431 [TN24.F6] 557.3'08s [553'.09759'89] 76-27691

For sale by the Superintendent of Documents, U S Government Printing Office
Washington D C 20402
Stock Number 024-001-02983-9

STUDIES RELATED TO WILDERNESS

WILDERNESS AREAS
and
WILDERNESS STUDY AREAS

Under the Wilderness Act (Public Law 88–577, Sept 3, 1964) certain areas within the National forests previously classified as "wilderness," "wild," or "canoe" were incorporated into the National Wilderness Preservation System as wilderness areas The act provides that the U S Geological Survey and the U S Bureau of Mines survey these wilderness areas to determine the mineral values, if any, that may be present The act also directs that results of such surveys are to be made available to the public and submitted to the President and Congress This bulletin reports the results of a mineral survey of the Bradwell Bay Wilderness, Florida; which was established as a wilderness by Public Law 93–622 (Jan 3, 1975).

The act also provided that areas under consideration for wilderness designation should be studied for suitability for incorporation into the Wilderness System The mineral surveys constitute one aspect of the suitability studies. This report also discusses the results of a mineral survey of some National Forest lands in the Sopchoppy River Study Area, Florida, that is being considered for Wilderness designation. The area studied is in the Apalachicola National Forest, Wakulla County, in northwestern Florida, and is adjacent to Bradwell Bay Wilderness

CONTENTS

ILLUSTRATIONS

TABLES

STUDIES RELATED TO WILDERNESS—WILDERNESS AREAS

MINERAL RESOURCES OF THE BRADWELL BAY WILDERNESS AND THE SOPCHOPPY RIVER STUDY AREA, WAKULLA COUNTY, FLORIDA

By CORNELIA C. CAMERON, U.S. Geological Survey,
and PETER C. MORY, U.S. Bureau of Mines

SUMMARY

The Bradwell Bay Wilderness and Sopchoppy River Study Area comprise 23,000 acres (93 km²) in the Apalachicola National Forest in the Florida panhandle. The area is a swamp covered, almost flat surface of a terrace in which the Sopchoppy River is entrenched. Deposits directly underlying the terrace surface generally consist of as much as 30 feet (9 m) of sand, clay, muck, and peat of Pliocene to Holocene age overlying limestone and marl of Miocene age. The limestone and marl are on the east flank of the gulf trough, and are underlain by a thick sequence of older Tertiary and Cretaceous sedimentary rocks. Older formations of probable Jurassic, Triassic, Paleozoic, and Precambrian ages are known from scattered holes drilled for oil in surrounding areas.

The Hawthorn Formation of middle Miocene age, from which phosphate and fuller's earth are chiefly produced in Florida, is not found in the Study Area; therefore, the potential for resources of phosphate is low. Phosphate pellets, however, were found in auger holes in sand above the St. Marks and Jackson Bluff Formations of early and late Miocene age, respectively. The pellets are mostly in sands deposited in an estuary during Pliocene or early Pleistocene time; they were derived from older rocks, presumably the Hawthorn Formation.

Approximately 136,000 tons (123,000 metric tons) of air-dried peat are available from bay swamps in the Study Area, but the deposits are too shallow and widespread to make mining economically feasible. Large quantities of quartz sand are available in abandoned beach ridges and in deposits that were originally laid down in a shallow nearshore marine environment, but sieve tests show that the sand is generally too fine for mortar and masonry use; it is not suitable as moulding or glass sand because it lacks the required size grades and purity.

The northern Florida, southern Alabama, and Georgia region produces oil, phosphate, fuller's earth, sand, and peat. The Study Area is about 175 miles (280 km) east-southeast of the Jay oilfield in the western panhandle of Florida. Part of the production is from the Smackover Formation of Jurassic age, which

is also the target formation for drilling in the vicinity of the Study Area Four oil test wells have been drilled in the vicinity of the Study Area but all proved to be unsuccessful Phillips Petroleum Company completed a well in Leon County at a depth of 10,466 feet (3,190 m) Placid Oil Company drilled a well in Wakulla County to 12,116 feet (3,693 m) and two in Liberty County, one to 12,131 feet (3,698 m) and the second to 12,400 feet (3,780 m) These three test wells are alined along a northeast trend immediately northwest of the Bradwell Bay area The oil and gas potential of the Bradwell Bay-Sopchoppy area is low

INTRODUCTION

The Bradwell Bay Wilderness and the Sopchoppy River Study Area are within the Apalachicola National Forest, Wakulla County, Fla., approximately 20 miles (32 km) southwest of Tallahassee (fig 1) Bradwell Bay comprises 22,000 acres (89 km^2) of swamp and pine woods bordered on the northeast by the Sopchoppy River Study Area, a narrow strip of 1,100 acres (4.5 km^2) along the river. The Wilderness is one of many swamps in the Florida panhandle called "bays" because of the bay trees growing in them.

At first glance, Bradwell Bay appears to be a tangle of vegetation extending monotonously in all directions However, an alert observer soon discovers patterns of contrasting trees and shrubs that reflect environmental factors such as changes in elevation, microrelief, drainage, soil porosity, and acidity. These vegetation patterns are valuable to the study and mapping of the surficial geology and peat deposits.

The Study Area is in the East Gulf Coastal Plain which in this region is divided into two subprovinces, the Tallahassee Hills on the north and the Apalachicola Coastal Lowlands on the south (Puri and Vernon, 1964, p. 7–15) The Cody scarp is the east-west dividing line between the subprovinces (fig 2) The surface from the toe of this scarp drops about 25 feet (7 6 m) to the northern edge of Wakulla County where it is 100 feet (30.5 m) above sea level The surface continues to drop southward across Bradwell Bay to the modern shoreline. Slight differences in surface altitudes in the swamps on this surface mark abandoned beach ridges and spits, and a few low scarps

The rolling surface covered by sand and peat has an average relief of less than 20 feet (6.1 m), although total relief in the area is more than 50 feet (15.3 m). Surface elevations range from 89 feet (27 1 m) above sea level on the west and north to less than 30 feet (9 1 m) along the Sopchoppy River and other streams at the southeast edge of the area. The Sopchoppy River flows southward

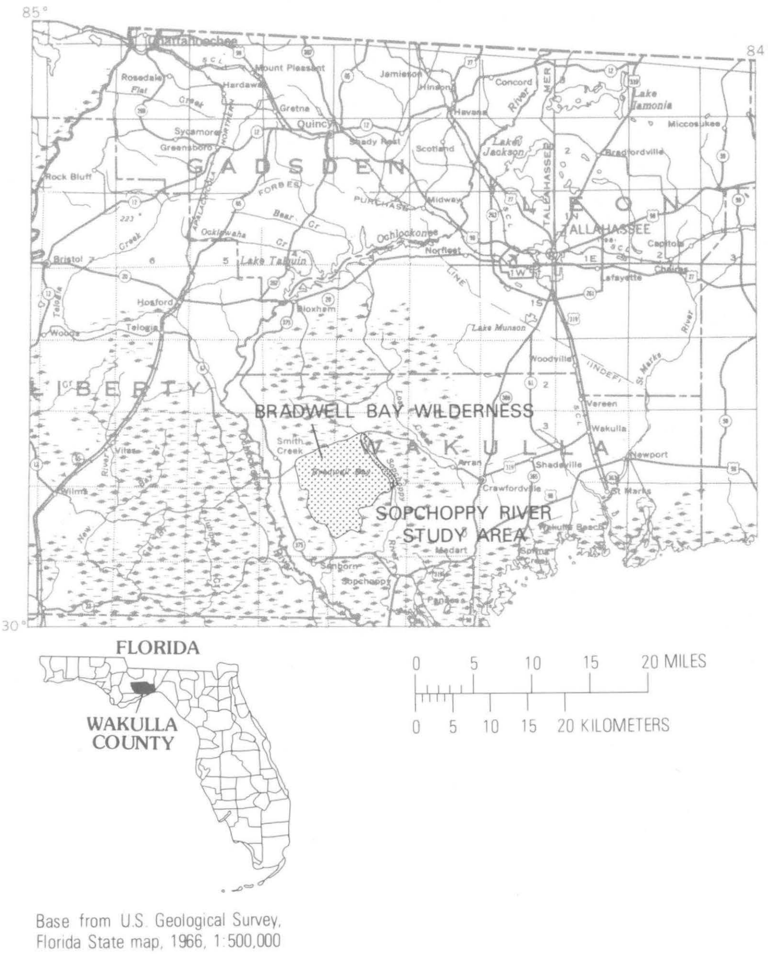
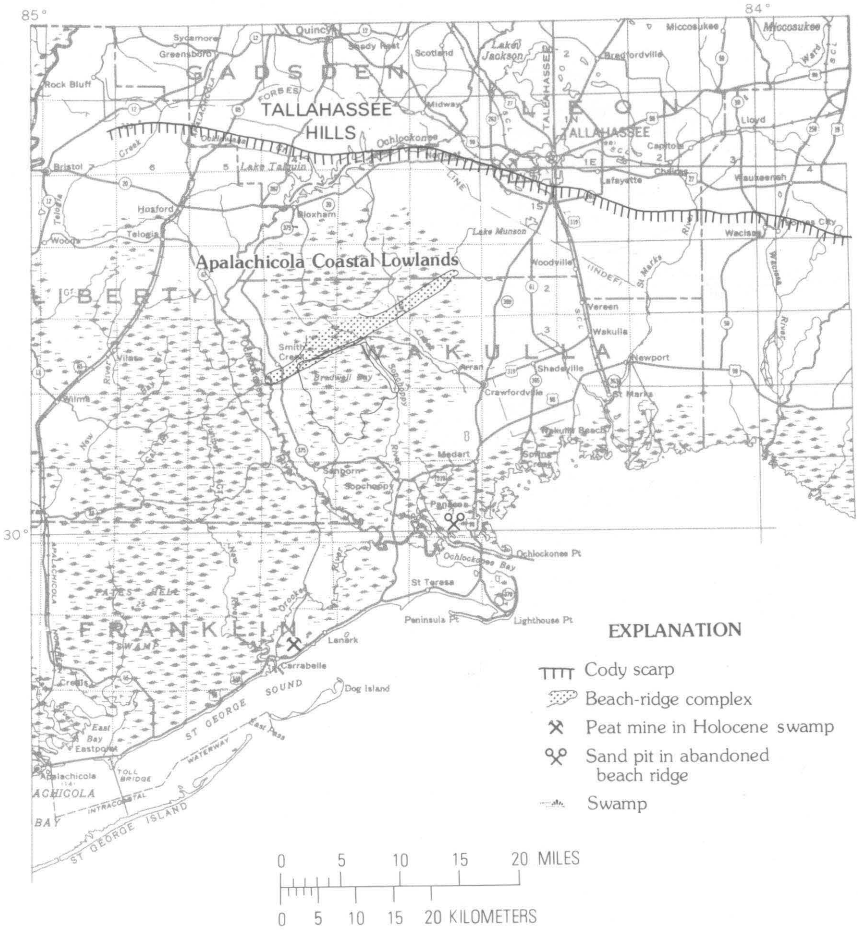


FIGURE 1.—Location of Bradwell Bay Wilderness and the Sopchoppy River Study Area, Wakulla County, Fla.

from a flat-floored valley in the north through a narrow V-shaped valley cut into a sand-covered, deeply weathered limestone terrane (fig. 3) along the eastern edge of Bradwell Bay. The stream gradient is about 5 feet per mile (0.9 m per km.)

PRESENT INVESTIGATION

The U.S. Geological Survey and the U.S. Bureau of Mines conducted a study of the mineral resources of the Bradwell Bay Wilderness and the Sopchoppy River Study Area in 1974. The study consisted of mapping the surficial deposits using power drill and



Base from U.S. Geological Survey, Florida State map, 1966, 1:500,000

FIGURE 2.—Physiography of Bradwell Bay and vicinity indicating location of major scarp, beach-ridge complex, and swamps.

hand auger to determine thickness and stratigraphy. Eight holes were drilled using a light truck-mounted Simco rotary auger which had a 30-foot (9.1 m) depth capability (pl. 1). Cuttings were logged in the field with the aid of a binocular microscope. Thirty-seven samples were collected from the drill stem at 1–5 foot (0.3–1.5 m) intervals for laboratory study. Access to the area was by foot from U.S. Forest Service roads on the perimeter of the Study Area. The few bedrock exposures along the Sopchoppy River were studied from a canoe. Nearby sand pits and oil and gas drilling sites were visited. In addition, industry, State, and Federal agencies were contacted for information about prospecting and mining

FIGURE 3.—Sopchoppy River, a view north from U.S. Forest Service Route 329.

activities within and adjacent to the Study Area. Records of leasing and prospecting activities were obtained from the U.S. Bureau of Land Management in Washington, D.C., and from the U.S. Forest Service in Atlanta, Ga.

ACKNOWLEDGMENTS

Appreciation is extended to the staff of the U.S. Department of Agriculture Soil Conservation Service and the U.S. Forest Service, Apalachicola National Forest, stationed at Crawfordville, Wakulla County, for assistance in mapping Bradwell Bay. Appreciation is also extended to Placid Oil Co. of Dallas, Tex., for information on their oil and gas exploration in the general area. C. W. Hendry, Woodson R. Oglesby, and David Curry, Florida Department of Natural Resources, Bureau of Geology, provided helpful background material on the geology of the area. Personnel from the U.S. Forest Service (Atlanta, Ga., and Tallahassee, Fla.) and the U.S. Bureau of Land Management (Washington, D.C.) aided in gathering information for this report. We are grateful for the assistance of Katherine L. Varnes, U.S. Geological Survey, in the preparation of the oil and gas section, and the assistance of Leonard Shapiro, U.S. Geological Survey, in the identification of phosphate pellets in subsurface samples.

PREVIOUS STUDIES

No detailed geologic mapping has been done in the Bradwell Bay Wilderness or the Sopchoppy River Study Area. The earliest geologic map of Florida (Cooke, 1945) shows a patch of Hawthorn Formation (middle Miocene) along the Sopchoppy River, Tampa Limestone (lower Miocene) in the east half of Wakulla County, and upper Pleistocene deposits in the west half of the county. Suwannee Limestone of Oligocene age is shown in the extreme southeast corner of the county. The geologic map compiled by Puri and Vernon (1964) is also very generalized. The Hawthorn Formation is not recognized in Wakulla County, and the Tampa Limestone, called the St. Marks Formation by Puri and Vernon (1964), extends from the Sopchoppy River eastward into Jefferson County. Bedrock under the unconsolidated mantle west of the Sopchoppy River is mapped as Jackson Bluff Formation of late Miocene age Later county reports, namely, those on Leon County (Hendry and Sproul, 1966) and Jefferson County (Yon, 1966), give detailed descriptions of the geology north and east of Wakulla County.

Ages of the unconsolidated mantle materials in the Florida panhandle have long been under discussion Throughout Pleistocene time there was a cyclic eustatic adjustment of sea level to the several buildups and meltings of the polar ice caps. Cooke (1939, 1945) thought that during each glacial stage the ocean levels dropped, and the seas receded from the land; during the interglacial stages, the seas advanced upon the land. Each advance of the sea was believed to produce a plain, called a terrace, and each terrace was separated from the adjoining higher and older one by a seaward-facing erosion escarpment The highest level of the seas was during the earliest part of the Pleistocene, and each succeeding high stand of sea level was lower than the previous one

Cooke (1939, 1945) proposed at least seven interglacial marine terraces along the gulf coast of Florida Vernon (1942) recognized four interglacial marine terraces and a high-level deltaic plain, and MacNeil (1950) recognized three interglacial marine terraces and one post-Wisconsin interglacial marine terrace. The terrace features in the Bradwell Bay area between 70 and 100 feet (21.3 and 30 5 m) altitude were called Wicomico; these include part of the beach-ridge complex shown in figure 2. The rest of the Study Area was called Penholoway shoreline and terrace Accordingly, the sequence of sands, silts, clays, and organic sediments over rocks of Miocene age were divided into the Wicomico Formation at the bottom and the Penholoway Formation at the top. MacNeil (1950) assigned both formations to Sangamon age; the Wicomico

Formation was believed to have been deposited during a marine transgression, and the Penholoway Formation, lying conformably on the Wicomico, during the recessional stage. Puri and Vernon (1964) also recognized the Wicomico terrace as Sangamon in age. However, Alt and Brooks (1967) believe that the confusion in the interpretation of the emerged shorelines in Florida seems to have been caused by failure to associate correctly the physiographic or shoreline features and terrace stratigraphy. Alt and Brooks describe the upper Miocene sediments as related to the 215–250 foot (66–76 m) shoreline, and assign a late Miocene age to this stand of sea level. The Wicomico shoreline at an altitude of 90 to 100 feet (27.4 to 30.5 m) is, therefore, younger than the late Miocene. Several soils associated with this shoreline are absent on the corresponding terrace This means that while the soils were forming as products of weathering on the uplands, sand was being deposited on the seaward side of the shoreline As fossil faunas in these beds have been referred to the Pliocene, the terraces associated with the Wicomico and Penholoway shorelines could be either late Pliocene or early Pleistocene in age according to Alt and Brooks. More recently, Tanner (1967) assigned the Wicomico shoreline and terrace to the earlier half of the Pliocene.

Studies have been made of mineral resources nearby but not in the Bradwell Bay area. Hendry and Sproul (1966) mentioned five unsuccessful wells drilled in search of oil and gas in the area where Jefferson, Leon, and Wakulla Counties join, and one well, also unsuccessful, 12 miles (19 km) away in Taylor County. Cathcart (1968) discussed the phosphate deposits in Florida, and Rainwater (1971) and Hottman (1973) discussed petroleum potential in north Florida Patterson (1974) has given the most up-to-date information on deposits of fuller's earth in the area immediately north of Wakulla County. Peat deposits were studied by Davis (1946) in neighboring Franklin, Leon, and Jefferson Counties

GEOLOGY

The exposed geology of Bradwell Bay Wilderness consists of surficial deposits of sand, silt, clay, peat, and muck of probable Pliocene to Holocene age (pl. 1) Bedrock exposures of older rock are limited to the banks and bed of the Sopchoppy River; in periods of low water, bedrock is exposed from the bridge over the river on U.S. Forest Service Route 329 for about 3 miles (5 km) upstream. Here, limestone of St Marks Formation of early Miocene age forms a karst, featuring honeycomb weathering and sinks. Older Oligocene and younger Miocene rocks are exposed in southeastern

Wakulla County and in adjacent counties to the north and east (fig. 4). The pre-Oligocene rocks are known only from drill holes in the surrounding areas.

PRE-OLIGOCENE ROCKS

The pre-Oligocene geology of the Bradwell Bay Wilderness is not well known but can be inferred from published sections of deep

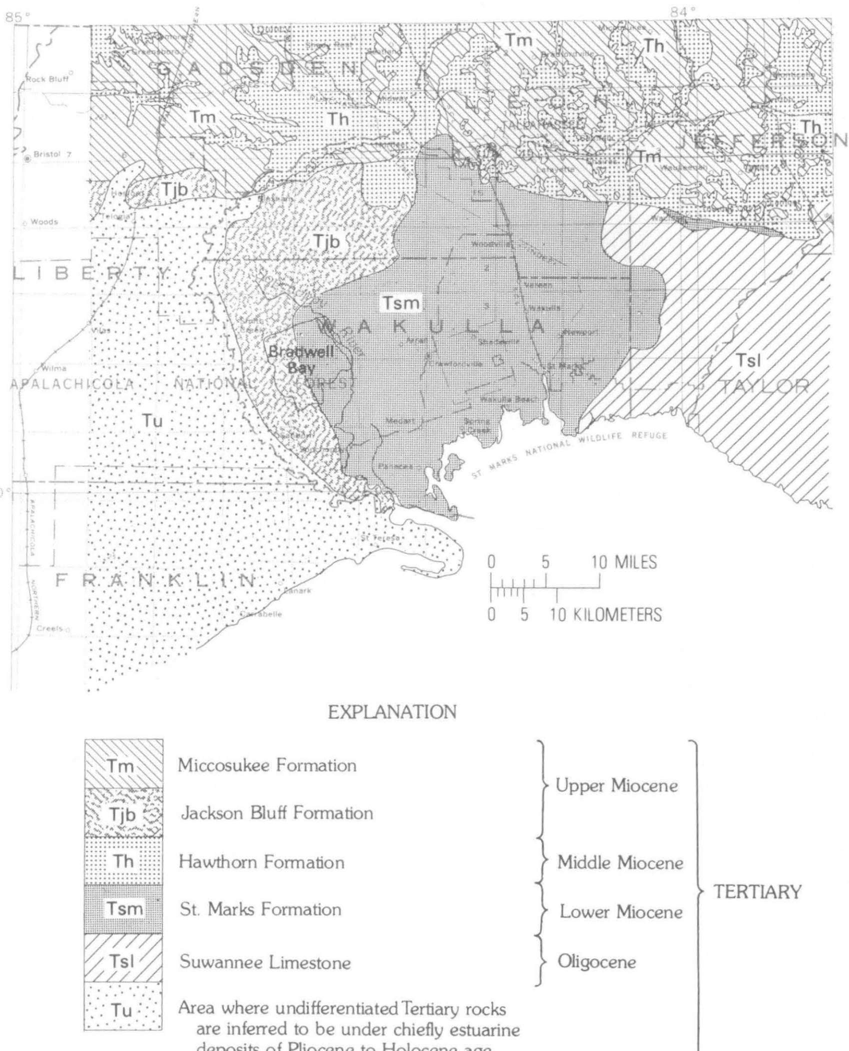


FIGURE 4.—Bedrock geologic map of Bradwell Bay and vicinity. Compiled from Patterson, 1974; Hendry and Sproul, 1966; Yon, 1966; Puri and Vernon, 1964.

wells in adjacent areas and peninsular Florida. The oldest rocks penetrated in these wells are crystalline rocks such as granite and diorite of Precambrian age (Puri and Vernon, 1964, p. 16). These rocks are part of the basement complex that is exposed at the surface in the Piedmont province of Georgia. The eroded surface of these rocks dips southward from Georgia to more than 8,000 feet (2,440 m) below sea level in the Bradwell Bay area (Rainwater, 1971, p. 1317). Overlying this basement complex in some areas of Florida are rhyolitic lavas and pyroclastic rocks of Precambrian or early Paleozoic age. In Wakulla County, one well (table 1, well 6) bottomed in red shale and sandstone of probable Triassic age, which overlie Paleozoic sedimentary rocks (Puri and Vernon, 1964, p. 22). One reconstruction of the pre-Cretaceous geology of Florida suggests that the Bradwell Bay area is underlain by lower Paleozoic sedimentary rocks and a narrow northeast-trending fault depression or graben filled with Triassic rocks (Rainwater, 1971, p. 1321–1323)

After Triassic time, a thick sequence of sedimentary rocks of Jurassic age was deposited in continental and marine environments west and southwest of the Bradwell Bay area. Newkirk (1971) suggested in his maps of the updip limits of Jurassic formations that Jurassic sedimentary rocks may pinch out a little northwest of the Bradwell Bay area. Lack of detailed logs of available drilling prevents confirmation of this suggestion

After deposition of Jurassic sediments, the Apalachicola embayment began to form; its axis is just west of the Bradwell Bay area. This shallow depression was filled with Lower Cretaceous marine and nonmarine sediments which reached a thickness of 3,000 to 5,000 feet (915 to 1525 m), and Upper Cretaceous marine carbonate deposits which accumulated to a thickness of about 1,500 feet (460 m) (Rainwater, 1971, p 1324–1331)

The Cretaceous sedimentary rocks are overlain by about 2,000 feet (610 m) of Paleocene and Eocene marine carbonate rocks which are poorly exposed in Jefferson and Taylor Counties east of Bradwell Bay and in Jackson County to the northwest (Rainwater, 1971, p 1331–1341; Puri and Vernon, 1964, fig 14) The older Tertiary sediments and overlying Oligocene and Miocene rocks were deposited in a narrow seaway called the Gulf Trough (Herrick and Vorhis, 1963; Patterson, 1974, p. 6)

OLIGOCENE ROCKS

The Suwannee Limestone, named by Cooke (1936), is a yellowish limestone that is exposed along the Suwannee River from Ella-

TABLE 1—*Exploratory oil and gas well data*

[Source Florida Geological Survey, Oil and Gas Reports and Records]

Well No (fig 7)	Company or owner's name	Well or farm name	County	Sec	T	R	Year of completion	Elevation of derrick floor (ft)	Total depth of well (ft)
1	Pure Oil Company	Neal Lumber and Manufacturing Co, No 1	Liberty	33	2S	8W	1946	69	4,506
2	R T Adams Drilling Company	St Joe Paper Co, No 1	Liberty	6	1S	6W	1948	188	4,267
3	Placid Oil Company	Placid Oil Co, No 1, U S A 27–2	Wakulla	27	2S	3W	1974	99	12,116
4	Central Florida Oil and Gas Company	Rhodes No 1	Leon	11	2S	1E	1924	50	3,755
5	Phillips Petroleum Company	St Joe Paper Co, No 1	Leon	14	2S	1E	1974	33	10,466
6	Ravlin-Brown	V G Phillips No 1	Wakulla	14	3S	1E	1943	28	5,766
7	Bonheur Development Company	Cates No 1	Wakulla	16	3S	1E	1919	17	2,169
8	Bonheur Development Company	Cates No 2	Wakulla	16	3S	1E	1921	17	1,980
9	Pure Oil Company	Gex and Lewin, No 2	Franklin	15	6S	4W	Location abandoned in 1946 because of high water	--	--
10	Pure Oil Company	St Joe Paper Co, No 2	Franklin	34	6S	4W	1946	22	4,787
11	A R Temple et a	A S Mitchell et al, No 1	Franklin	14	7S	5W	1953	18	4,819
12	Humble Oil and Refining Company	A S Mitchell et al, No 1	Franklin	21	6S	5W	1953	20	4,736
13	Pure Oil Company	H C Lester, No 1	Franklin	17	7S	7W	1946	28	4,976
14	Pure Oil Company	Gex and Lewin, No 1	Liberty	24	5S	6W	1946	27	4,744
15	Gulf Coast Drilling and Exploration Company	Gulf Coast and Exploration Co, No 1, U S A 4–1	Liberty	4	5S	7W	1959	49	10,010
16	Placid Oil Company	Placid Oil Co, No 1, U S A 16–2	Liberty	16	4S	6W	1974	--	12,400
17	Placid Oil Company	Placid Oil Co, No 1, U S A 26–4	Liberty	26	3S	5W	1974	--	12,131

ville nearly to White Springs, Fla. It is the oldest bedrock below the Pliocene and Pleistocene mantle in the vicinity of Bradwell Bay (fig. 4). Because outcrops are scarce in Wakulla and Leon Counties, it is known chiefly from studies of water-well cuttings; in Jefferson County where it forms a subsurface karst topography, it is also known from river-bed exposures.

The Suwannee is a light-yellow or cream-colored dolomitic limestone, which contains secondary silica in the form of opal and chert and which is as much as 204 feet (62 m) thick in Leon County and 336 feet (102 m) thick in Jefferson County. Locally, thickness varies greatly; subsurface maps of the top of the Suwannee Limestone in Leon and Jefferson Counties reveal buried karst topography (Yon, 1966; Hendry and Sproul, 1966)

Hendry and Sproul (1966, p. 59) noted that the Suwannee overlies upper Eocene beds unconformably in Leon County and is unconformably overlain by the St. Marks, Hawthorn, or Miccosukee Formations of Miocene Age. The Suwannee Limestone typically has much less sand and is either much lighter colored and more crystalline or more dolomitic than the younger St. Marks Formation It also contains abundant Oligocene microfossils, the following Foraminifera are common: *Rotalia, Lepidocyclina, Operculinoides,* and *Quinqueloculina.*

MIOCENE ROCKS

ST MARKS FORMATION[1]

The name St Marks was used by Puri (1953, p 17–21, Puri and Vernon, 1964, p 125) for the calcareous downdip lithofacies of the previously named Tampa Limestone of early Miocene age. The type locality of the St Marks is about 2 miles (3 km) south of Crawfordville where the limestone is noted for the large oysters and pectens in its molluscan fauna. Sediments are predominantly fine- to medium-grained, partly recrystallized, silty to sandy limestones (calcilutites to calcarenites) that have been dolomitized in differing amounts The color ranges from very pale orange for the slightly dolomitized rocks to grayish orange for the highly dolomitized rocks. The limestone has an overall slightly chalky to earthy appearance The silt and sand are composed of rounded to subrounded quartz Contact with the overlying Hawthorn Formation is unconformable, the Hawthorn being principally a clastic sequence containing stringers and lenses of limestone

[1] St Marks facies of Puri (1953) herein adopted as St Marks Formation as used by Puri and Vernon (1964) for usage by the U S Geological Survey

The thickness of the St. Marks Formation ranges from 0 to more than 200 feet (61 m). Because it rests on karst formed on the Suwannee Limestone, and because of a later karst formed by erosion and solution on the surface of the St. Marks, thickness cannot be accurately determined. Beds dip southwest toward the axis of the Gulf trough. Not only is the top of the St. Marks deeper in the western part of the Bradwell Bay vicinity, but wells penetrate a greater thickness of the formation (Hendry and Sproul, 1966, p. 63).

The St. Marks Formation is exposed in the bed of the Sopchoppy River throughout the southern half of its course across the Sopchoppy Study Area, and is found intermittently along the banks to a height of 1–10 feet (0.3–3 m) where not covered by younger sands This limestone is correlated with that at the type locality of the St. Marks about 7 miles (11 km) to the east. The rock in the river bed is most easily studied at the edges of deep pools, presumed to be in limestone sinks It is cream-colored, finely granular, partly recrystallized limestone, in places slightly dolomitic and stained with limonite The limy material forms a matrix for rounded-to-subrounded coarse frosted quartz grains, small pebbles, and silt Locally, the stone consists of fragments of oyster and pecten molds. The rock along the river bank, where it has been protected from erosion by running water, is similar, but creamy greasy clay containing the rounded-to-subrounded quartz grains is found in molds of oyster and pecten shells; chemical weathering has dissolved away the shells and produced a saprolite. Cuttings at the bottoms of auger holes 1, 3, 4, and 9 (pl 1) contained pieces of the same type of rock as exposed in the Sopchoppy River bed and fragments of oyster and pecten. For this reason, the contact between the St. Marks and the Jackson Bluff was moved westward from the position shown on the Geologic Map of Florida (Puri and Vernon, 1964)

HAWTHORN FORMATION

The Hawthorn Formation in the general area of study is restricted to a belt across Gadsden, Leon, and Jefferson Counties generally north of the Cody scarp. Thus, the formation pinches out well to the north of Bradwell Bay (fig. 4). However, it is of interest to this report because in post-Miocene time, this northern area was the source of sediments brought into the Bradwell Bay Wilderness and the Sopchoppy River Study Area

The term Hawthorn beds was originally applied to beds of phosphatic sandstone, sand, ferruginous gravels, and greenish clays exposed in Alachua County, Fla., by Dall (Dall and Harris, 1892, p. 107). "The name Hawthorn Formation has since been used throughout northern Florida and most of the Coastal Plain region of Georgia and Alabama for problematical beds in several different ways. Most of the problems related to this formation result from its variable characteristics, its gradational relationships with formations above and below it, and poor and weathered exposures, which make it impossible to observe all the formations at one place" (Patterson, 1974, p. 10). Patterson concluded that it is probably best to recognize that the Hawthorn is neither the youngest nor the oldest of the Miocene formations in the Coastal Plain and that the middle Miocene is a realistic age assignment for this formation Patterson applied the name Hawthorn Formation in Gadsden and Leon Counties to rocks primarily of marine origin between the Tampa Limestone (St Marks Formation) and the Jackson Bluff Formation.

In the area north of Bradwell Bay, Patterson describes the Hawthorn Formation as consisting of fine- to medium-grained quartz sand containing much silt and clay The sand is mostly rounded and subrounded quartz, and most of it is intermixed with clay and silt The Hawthorn here also contains commercial deposits of fuller's earth and other clays and a few very sandy limestone beds Phosphate, opal concretions, and secondary opal are found locally. Fossils are rare except in some of the carbonate beds, which contain Foraminifera and ostracode faunas, and in fuller's earth, which contains microfossils. The Hawthorn rests unconformably on the St. Marks Formation. Hendry and Sproul (1966, p 67) stated that the limestones in the Hawthorn and the St Marks are similar, but that the Hawthorn is more calcitic and the included quartz grains are more clear and angular; moreover, the St. Marks is not phosphatic The unconformable relationship determined from well borings between the Hawthorn and underlying St. Marks becomes less distinct westward in the Gulf trough where clastic materials were being deposited very rapidly in a shallow marine environment.

JACKSON BLUFF FORMATION [2]

Puri and Vernon (1964, p 202) applied the name Jackson Bluff to the *Ecophora* and *Cancellaria* biofacies of Choctawhatchee age because they are typically exposed at Jackson Bluff, 13 miles (21 km) north of Bradwell Bay on the Ochlockonee River in Leon

[2] Jackson Bluff Formation of Puri and Vernon (1964) herein adopted for usage by the U S Geological Survey

County. The term Choctawhatchee was introduced by Matson and Clapp (1909, p. 114) for upper Miocene sediments in west Florida that they called marl. The Jackson Bluff Formation includes all sediments of the *Ecphora* and *Cancellaria* biofaces above the Hawthorn Formation and below the Miccosukee Formation and younger deposits. The Geologic Map of Florida compiled by Puri and Vernon (1964) limits the distribution of the Jackson Bluff to the western half of Wakulla County. Hendry and Sproul (1966, p. 76) recorded a maximum depth of 26 feet (8 m) for the Jackson Bluff in Liberty County 2 miles (3 km) west of Jackson Bluff, where it is a little more than 10 feet (3 m) thick. They also noted that it thins to a featheredge at the eastern border of Leon County, and that closely spaced outcrop and core-hole data indicate a southerly dip of about 7 feet per mile (1.3 m per km) for the formation, an amount that cannot be applied regionally. At the type section in Leon County, the Jackson Bluff Formation is composed of a shell marl that is pale orange, light gray, grayish orange, and blue gray; the marl is very sandy and contains abundant shells of *Cancellaria* and *Pecten* (Hendry and Sproul, 1966, p. 77–78).

The Jackson Bluff Formation was found in Bradwell Bay at the bottom of auger holes 8, 7, and 5 (pl. 1), where it is covered by about 20 feet (6.1 m) of younger sands, silts, clay, peat, and muck. Cuttings revealed light-orange, cream, and very light gray or off-white marl containing fragments of *Pecten* and *Cancellaria,* a marine pelecypod and a marine gastropod, respectively. The marl contained much fine to coarse angular to subangular quartz sand grains and was found under noncalcareous dark-gray clayey quartz sand, interpreted to be post-Miocene in age. Therefore, as mapped in this report, the eastern boundary of the Jackson Bluff almost bisects Bradwell Bay and is 5 or 6 miles (8–10 km) west of the boundary shown by Puri and Vernon (1964)

MICCOSUKEE FORMATION [3]

The Miccosukee Formation is restricted to the area north of the Cody scarp, where it is unconformable on older formations. As used by Hendry and Yon (1967), the formation consists of a reddish-brown, brown, and yellowish-brown clay, medium-to-coarse sand, and thin kaolinitic crossbedded clay beds. It also contains channel-fill deposits and lenticular units of coarse gravel. Marine fossils are scarce, but *Callianassa* borings are found locally. The original thickness has been given as 80–100 feet (24.4–30.5 m)

[3] The Miccosukee Formation of Puri and Vernon (1964) is herein adopted for usage by the U S Geological Survey

(Hendry and Sproul, 1966, p. 84–85) ; however, the formation has been eroded, so that the thickness varies from 0 to 100 feet (30.5 m).

POST-MIOCENE DEPOSITS AND ENVIRONMENTAL INTERPRETATION

Sand, silt, clay, muck, and peat blanket the Miocene rocks in the area of study to a depth of generally 20–30 feet (6.1–9.1 m) ; however, in drill hole 10 to the northeast, in the area where the Sopchoppy River crosses an old beach-ridge complex, this depth is greater than 30 feet (9.1 m). This unconsolidated sequence is described in tables 2 and 3, plate 1, and figure 5, as it appears in drill cuttings and a riverbank exposure For convenience of discussion, these deposits, categorized roughly on mode of origin, are assigned to Units a, b, c, d, and e.

Unit a appears in drill holes 1, 3, 4, and 5 over limestone and marl of St. Marks and Jackson Bluff age; it is correlated with the base of the section exposed in the bank of the Sopchoppy River where it is interpreted as material belonging to a weathered land

TABLE 2.—*Section of post-Miocene deposits of east bank of Sopchoppy River (SE ¼ SW ¼ Sec. 26, T 3S., R 3W.)*

[Cross sections in pl 1 are partly based on this table]

Depth in feet (meters)	Description	Environmental interpretation
0–5 (0–1.5)	Quartz sand, medium to fine, angular to subangular, few frosted quartz grains, tan silt	Beach and nearshore shelf sea have transgressed tidal marsh, the predominantly fine angular sand and tan silt resembles water deposition rather than wind deposition
5–6 (1.5–1.8)	Clean white quartz sand, medium, subangular	Windblown sand over marsh
6–10 (1.8–3)	Quartz sand, medium to fine, angular, black clay and humate containing marsh-plant fragments	Tidal marsh Material resembles that in nearby modern tidal marsh
10–14 (3–4.3)	Crossbedded, coarse to fine, angular to subangular, tan iron-stained sand containing layers of muck	Crossbedding typical of estuary deposit near river mouth
14–15 (4.3–4.6)	Coarse subrounded to angular sand and pebbles cemented with iron and containing a block 14 inches (36 cm) long and 4 inches (10 cm) wide of gymnosperm wood with annual rings	Lagoon deposit, wood washed in from an adjacent forest Annual rings indicate a climate having seasons
15–20 (4.6–6.1)	Gray to greenish-gray, very greasy noncalcareous clay containing marsh-grass roots and quartz sand, angular to subangular, coarse to medium Large dull quartz grains	Weathered land surface indicated by weathered residual material
20 + (6.1 +)	Limestone, cream-colored, finely granular, partly recrystallized limonite stains, contains rounded to subrounded quartz grains, small pebbles and silt, oyster and pecten molds (St. Marks Formation)	Marine

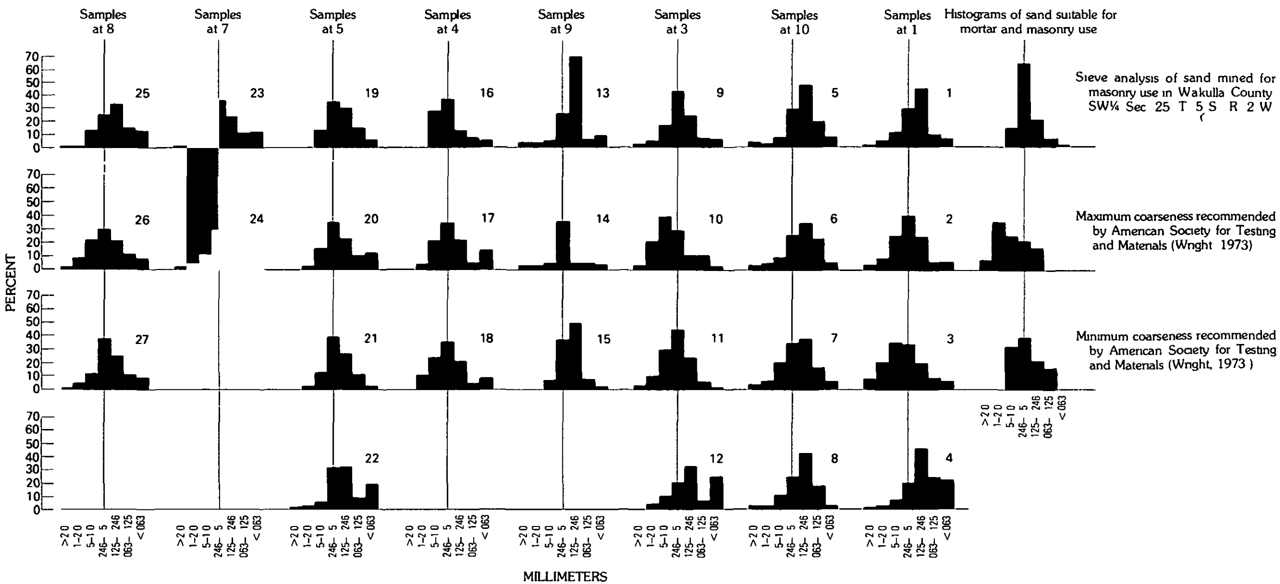


FIGURE 5 —Histograms of sieved samples from drill holes See plate 1 for sample location in each hole Log descriptions are given in table 3

TABLE 3.—*Drill logs*

[Cross sections in pl 1 are partly based on this table]

Depth in feet (meters)	Description	Environmental interpretation
	Drill hole 1 [SW¼ SE¼ Sec 27, T 3 S R 3 W]	
0–5 (0–1 5)	Quartz sand, medium to fine, angular to subangular, large grains dull Reddish-brown clay and silt	Beach and nearshore shelf sand that washed over tidal marsh behind barrier bar
5–10 (1 5–3)	Quartz sand, coarse to fine, rounded to angular, very dark reddish-brown clay and silt, black humate *Spartina* fragments (tidal-marsh muck)	Tidal marsh behind barrier bar *Spartina* is tidal marsh grass
10–15 (3–4 6)	Quartz sand, angular to subangular, medium to fine Reddish-brown clay and silt	Deposition in lagoon behind barrier bar
15–20 (4 6–6 1)	Quartz sand, tan to brown, coarse to medium, some very angular dull quartz pebbles Humate	Deposition in lagoon near mouth of river
20–25 (6 1–7 6)	Quartz sand fine angular tan clay, shell fragments Greenish clay, not calcareous	Estuary over weathered land surface Shell fragments are from thin-shelled mollusks typical of swamps and places with quiet water Clay is probably product of weathering
25–26 (7 6–7 9)	Quartz sand, fine, angular, some large dull grains, cream-colored clay, very calcareous (lime enriched)	Reworked ancient soil mixed with river and marine sand Lime, in part, may have concentrated in old soil horizon
26 + (7 9 +)	Limestone (St Marks Formation)	Marine
	Drill hole 3 [SW corner NW¼ SW¼ Sec 2, T 4 S, R 3 W]	
0–3 (0–0 9)	Quartz sand, coarse to fine, angular to subangular	Beach and nearshore shelf sand washed over tidal marsh behind barrier bar
3–5 (0 9–1 5)	Quartz sand, coarse to fine, angular to subangular, large grains clear to dull, brown clay and silt Marsh-plant roots in black clay (tidal muck)	Tidal marsh behind barrier bar
5–10 (1 5–3)	Quartz sand, fine angular Marsh-plant roots Much humate (tidal-marsh muck)	Tidal marsh behind barrier bar
10–15 (3–4 6)	Quartz sand, coarse to fine, mostly angular Dark-gray clay Much humate	Lagoon near mouth of river which brought in coarse sand and humate
15–19 (4 6–5 8)	As above, containing pelecypod fragments, white calcareous clay, phosphate pellets, molds of marine mollusks composed of calcareous matrix	Estuary into which washed phosphate pellets and pelecypod fragments, deposition was on weathered soil developed on St Marks Formation Original shells of marine mollusks dissolved before secondary lime enrichment
19 + (5 8 +)	Limestone fragments, sand grains fine, medium, and coarse, coarse grains dull (St Marks Formation)	Marine
	Drill hole 4 [NW¼ SW¼ Sec 9, T 4 S, R 3 W]	
0–5 (0–1 5)	Quartz sand, medium, angular to subangular Reddish-brown clay Tidal-marsh-plant rhizomes and marsh-grass fragments	Beach over tidal marsh Sand washed over marsh during storms
5–10 (1 5–3)	Quartz sand, very coarse to very fine, subangular to angular Reddish-brown, carbonized wood fragments	Lagoon near river mouth Wood was transported

TABLE 3 —*Drill logs*—Continued

Depth in feet (meters)	Description	Environmental interpretation
Drill hole 4—Continued [NW¼ SW¼ Sec 9, T 4 S, R 3 W]		
10–15 (3–4 6)	Quartz sand, medium to very fine, angular to subangular Some coarse dull quartz grains Pebbles of quartz containing black opal Phosphate pellets Reddish-brown clay	Large quartz grains pebbles, and pellets were probably deposited in lagoon near river mouth
15–20 (4 6–6 1)	Quartz sand, fine angular, some pebbles and coarse grains rounded and dull Dark-brown clay Carbonized wood	As immediately above Wood washed in lagoon from nearby forest, or from eroded peat deposits
20–25 (6 1–7 6)	Quartz sand, very fine, angular, light-gray clay Partly carbonized wood Phosphate pellets Oyster shells	Oysters typical of lagoon environment
25–27 (7 6–8 2)	Quartz sand, medium to fine, angular Gray to tan clay, root tubules	Soil on weathered bedrock
27 + (8 2 +)	Cream-colored limestone Pecten Coarse rounded dull quartz grains (St Marks Formation)	Marine
Drill hole 5 [Center Sec 20, T 4 S R 3 W]		
0–2 (0–0 6)	Sandy muck (black silty, sandy clay with humate) in modern titi swamp (Titi is a small tree common in swamps of southeastern United States)	Freshwater swamp
2–5 (0 6–1 5)	Quartz sand, medium to fine, angular Some sand similar to that in beach ridge of drill hole 8	Beach
5–15 (1 5–4 6)	Quartz sand, medium to coarse, angular to subangular Quartz pebbles Reddish-brown clay	Lagoon, coarse quartz brought in by streams Fines indicate quiet water
15–20 (4 6–6 1)	Quartz sand, medium, angular Subrounded quartz pebbles Light- to dark-gray clay Limonite streaks	Lagoon
20–25 (6 1–7 6)	Quartz sand, medium to fine, angular to subangular Gray to orange clay Phosphate pellets Fragments of marine mollusk shells Carbonized wood	Lagoon Marine mollusks indicate that these animals lived in lagoon, phosphate pellets and wood fragments were transported
25–26 (7 6–7 9)	Greenish-gray to cream-colored calcareous clay containing limonite streaks Much medium angular quartz sand similar to that in bedrock below	Weathered land surface Calcareous clay does not contain fossils and may be lime-enriched soil horizon
26 + (7 9 +)	Marl containing marine shells, and sand as above (Jackson Bluff Formation)	Marine
Drill hole 7 [NW¼ SE¼ Sec 14, T 4 S, R 4 W]		
0–5 (0–1 5)	Sandy muck (black silty, sandy clay with humate) in modern titi swamp	Freshwater swamp
5–9 (1 5–2 7)	Quartz sand, medium to fine, angular, containing large frosted quartz grains	Nearshore shelf Sea has transgressed the lagoon and estuary
9–15 (2 7–4 6)	As above, containing carbonized wood and root tubules of marsh plants	Lagoon and estuary
15–19 (4 6–5 8)	Quartz sand, coarse to very fine, rounded to angular, carbonized wood, limonite streaks	Lagoon and estuary

TABLE 3 —*Drill logs*—Continued

Depth in feet (meters)	Description	Environmental interpretation
	Drill hole 7—Continued [NW¼ SE¼ Sec 14, T 4 S, R 4 W]	
19–22 (5 8–6 7)	Quartz sand, fine, angular Frosted coarse quartz grains Tidal-marsh-plants roots	Tidal marsh buried under sand of transgressing sea
22–23 (6 7–7)	White shell marl (Jackson Bluff Formation)	Marine
	Drill hole 8 [NE¼ NE¼ Sec 3, T 4 S, R 4 W]	
0–3 (0–0 9)	Quartz sand, medium to fine, angular	Beach and nearshore shelf sand Forms a topographic ridge
3–5 (0 9–1 5)	Muck (black clay, humate, silt, fine angular sand) Peat containing roots of tidal marsh plants	Tidal marsh buried by sand during storms and (or) transgressing sea Plant roots similar to those in nearby modern tidal marsh
5–15 (1 5–4 6)	Quartz sand, coarse to very fine, subangular to angular Tan silt and clay	Nearshore shelf seaward of barrier bar or a lagoon that filled and supported tidal marsh
15–20 (4 6–6 1)	Quartz sand, coarse to medium, angular to subangular Light-gray clay	Clay similar to that in bottoms of nearby lagoon along modern shore
20–22 (6 1–6 7)	Quartz sand, coarse to fine, angular Dark-gray to black clay, phosphate pellets, and phosphatic shell fragments	Estuary into which stream emptied pellets and shell fragments obtained from older sediments north of Study Area
22–25 (6 7–7 6)	White marl containing medium angular quartz sand and *Cancellaria* (Jackson Bluff Formation)	Fossils are marine
	Drill hole 9 [NE¼ NW¼ Sec 24, T 3 S, R 4 W]	
0–2 (0–0 6)	Quartz sand, medium to fine, angular	Beach ridge
2–3 (0 6–0 9)	Muck (black clay, humate, silt, fine angular sand) Peat containing roots of tidal-marsh plants	Tidal marsh, material similar to that in nearby modern tidal marsh
3–5 (0 9–1 5)	Quartz sand, medium to fine, angular Tan clay	Beach composed of sand similar to that at surface (0–2 ft) (0–0 6 m) above
5–10 (1 5–3)	Black silty muck containing root tubules *Spartina*	Tidal marsh *Spartina* is a typical tidal-marsh grass
10–15 (3–4 6)	Quartz sand, medium to fine, angular, chocolate-brown clay much humate	Material similar to that in nearby modern tidal marsh
15–20 (4 6–6 1)	Quartz sand, medium to fine, angular to subangular some frosted coarse grains Some brown humate	Nearshore shelf or lagoon containing coarse quartz grains and humate from stream escaping into sea
20 + (6 1 +)	Limestone fragments (St Marks Formation)	Marine
	Drill hole 10 [NE¼ NW¼ Sec 16, T 3 S, R 3 W]	
0–5 (0–1 5)	Quartz sand, medium to fine angular, some coarse frosted quartz grains	Beach or nearshore shelf Sea has transgressed underlying marsh
5–10 (1 5–3)	Quartz sand, medium- to fine-grained, subrounded to angular Dark red-brown clay and silt containing *Spartina*, much humate	Tidal marsh
10–30 (3–9 1)	Quartz sand, medium- to fine-grained, subangular to angular Some coarse, frosted quartz grains Some tan clay Bedrock not penetrated	Lagoon filled and created marsh above

surface. The buried residuum at the exposure site consists of noncalcareous greenish greasy clay containing marsh grass roots similar to those in modern marshes along the coast in Wakulla County. This clay may represent an old marsh bottom in which the black organic matter and humates were oxidized or water transported before the initial marine advance.

A similar greenish clay appears in the 20–25-foot (6 1–7.6 m) interval in drill hole 1 over 1 foot (0 3 m) of cream-colored calcareous clay on limestone at a depth of 26 feet (7.9 m). The lime in the clay here and in other holes where Unit a lies over bedrock, is believed to be secondary, the result of calcium carbonate enrichment of the paleosol C horizon. One indication of this is the presence in drill hole 3 of molds of marine mollusks consisting of a calcareous sandy matrix; the original lime shells had been dissolved away before the lime in the matrix was precipitated. Another indication that the material in Unit a is residuum belonging to a land surface now buried, is the presence of quartz grains of the same sizes and degrees of rounding in both bedrock and overlying unconsolidated material. The residuum was eventually reworked and incorporated into the base of overlying sediments believed to have been deposited in estuary and lagoon environments.

Unit b consists of sand, silt, and clay deposited in lagoons or estuaries. This material is on residuum in all drill holes except 7, 8, 9 in the west and north, where it is on bedrock, and in 10, where it presumably is on bedrock. It is correlated with the crossbedded sand and iron-stained conglomerate that are found in the riverbank exposure in the 10–15 feet (3–4 6 m) interval, at this place the unit contains gymnosperm wood. This material at this exposure is believed to have been dumped by a river into a lagoon where waters were relatively quiet so that quartz-grain angularity could be preserved The muck (black organic sand and silt) is similar to that in nearby modern lagoons. Variety in size of quartz grains and degree of angularity is common throughout drill-hole cuttings assigned to Unit b. Other indications of near river-mouth deposition are humates (drill holes 1 and 3), phosphate pellets (drill holes 3, 4, 5, and 8), and wood fragments (drill holes 4 and 7). Marine shell fragments in Unit b were observed in cuttings of holes 1, 3, 4 and 5.

Unit c is tidal-marsh peat and muck, and is easily identified by the black or very dark red color of the clay, humate, silt, fine angular sand, and partly decayed organic material, and by the presence of roots, rhizomes, stems, and leaves of the kind of plants living today in the tidal marshes that fringe the shore of Wakulla County. *Spartina* is an example of such a plant. The tidal-marsh deposits of Unit c lie on the deposits of Unit b and are overlain by sand of marine origin. Also, in drill holes 4, 8, and 9, the tidal-marsh deposits of Unit c are interfingered or interbedded with the marine sand, indicating that the buried tidal marshes were disconnected areally as are the modern tidal marshes. Tidal-marsh environments inferred from the drill cuttings alternated with marine environments from time to time at the same locations.

Unit d is characterized by mostly medium- to fine-grained angular to subangular quartz and underlies the present undulating ground surface and basins containing freshwater swamps. It also rests on and interfingers or interbeds with tidal-marsh sediments. This sand is believed to have been deposited in an environment that changed from lagoonal to nearshore on the seaward side of barrier bars and beach-ridge complexes. It also is a component of the beach-ridge complexes, having been formed by seaward erosion of the beach and landward deposition to cover tidal marshes behind the barriers. Part of this burial was accomplished by the wind, as indicated by the foot (0.3 m) of white, clean sand composed of medium-sized subangular quartz grains in the 5–6-foot (1.5–1.8-m) interval of the riverbank section. This sand suggests wind action on a barrier bar after it emerged above sea level. The tidal marsh in the riverbank section came into being when blowing sand and wave-borne sand filled the lagoon behind a barrier bar to a depth shallow enough to support marsh plants. Continued contribution of sand from the seaward direction accounts for the sand in the tidal-marsh peat and muck. Interpretation of the rock sequence in Units c and d in drill holes 8, 9, and 10 could be based on the principle that an oscillation of the sea brings about a cycle of marine, lagoon, tidal marsh, and finally a return to marine conditions at the time of the subsequent deposits. Of course, tidal marshes may be buried locally during periods of intense wave actions, but the series of barrier bars required for the formation of the beach-ridge complexes on the east, west, and north margins of Bradwell Bay tend to indicate eustatic sea-level changes.

Unit e consists of peat composed of moss and other plants growing in modern freshwater swamps. The peat is associated with muck derived from the oxidation of the peat and with sand washed in from adjacent rises in the surface of Unit d. Areal extent of Unit e is shown in the two peat map units and the muck and sand unit of plate 1*A*. The muck and sand unit is 2 feet (0.6 m) deep in drill hole 5 and 5 feet (1.5 m) deep in drill hole 7. This material is black silty, sandy clay containing humate. Both sites are in freshwater swamps which have predominantly titi-type vegetation (named for the characteristic tree, black titi). Hand-auger holes provided additional information. Examples are at locations 12 and 13 along traverse *B–B′*. The log at hand-auger hole 12 in a titi swamps is as follows:

0 to 6 in. (0 to 0.15 m)	sphagnum peat
6 in. to 3 ft (0 15 to 0.9 m)	light-gray sand
3 ft to 4 ft (0.9 to 1.2 m)	light-gray sandy clay
4 ft + (1.2 m+)	white clayey sand; probably top of Unit d

The log at hand-auger hole 13 in a titi swamp is as follows:

1 to 6 in. (0.25 cm to 0.15 m)	sphagnum peat
6 in to 1 ft (0.15 m to 0.3 m)	black muck
1 ft to 3 ft (0.3 to 0.9 m)	sandy muck
3 ft to 6 ft (0.9 m to 1 8 m)	tidal-marsh muck belonging to Unit c

The log at hand-auger hole 14 just northeast of drill hole 8 is also in a titi swamp. Here the log is as follows:

0 to 6 in. (0 to 0.15 m)	black muck
6 in. to 1 ft (0.15 m to 0 3 m)	very sandy black muck
1 ft to 3 ft (0 3 m to 0.9 m)	mucky sand
3 ft to 4 ft (0.9 m to 1.2 m)	fine white sand, probably belonging to Unit d

Unit e, representing a freshwater swamp type of environment, was deposited well after the sea regressed south of Bradwell Bay

Units a, b, c, and d are materials underlying the Penholoway terrace, interpreted by Cooke (1945), MacNeil (1950), and Puri and Vernon (1964) to have formed in the Sangamon, a Pleistocene interglacial stage. Deposition, according to these authors, took place during the marine Wicomico transgression and also during the Penholoway regression when sea-level stand is believed to have produced the Penholoway shoreline at the seaward edge of the barrier-beach complex at the north boundary of Bradwell Bay

This reconnaissance study is an attempt to illustrate the general nature of events that produced the existing terrane, namely weathering of the bedrock, advance of the sea at an estuary, formation of lagoons behind barrier bars where tidal marshes formed, retreat of the sea and formation of freshwater swamps. Evidence is not available in the area of study to support more than one transgression and regression during deposition of Units a, b, and possibly the lower part of d; the lowermost tidal marshes of Unit c may represent both trangression and regression. However, the uppermost tidal-marsh deposits (Unit c) formed during a second marine transgression as the result of filling of the back barrier lagoons. These marshes were subsequently overridden by the landward-advancing beach ridge.

The Penholoway shoreline is interpreted in this report as a beach-ridge complex made by an advancing sea rather than by a retreating sea as Cooke and others believed. The age of the unconsolidated sequence of the beach-ridge complex ranges from Pliocene (Tanner, 1967) through Holocene Peat and muck have continued to form in the freshwater swamps from the date of initiation of swamp environment following final withdrawal of the sea. However, fire eliminated much peat from time to time so that the present peat and muck at the surface are unquestionably modern

RESOURCE POTENTIAL AND ECONOMIC APPRAISAL

OIL AND GAS

Oil and gas are produced in Florida in four fields, all far from Bradwell Bay (fig. 6). The nearest production of oil and gas is from the Jay field, approximately 175 miles (282 km) northwest of the Study Area, in Santa Rosa County, Fla. Three small fields in the south Florida basin are more than 300 miles (482 km) away. Figure 7 shows the past, present, and proposed drilling locations adjacent to the Study Area; table 1 presents data on these wells. The first wildcat drilling for oil and gas was in 1919, when the Bonheur Development Company drilled the Cates No. 1 in sec 16, T. 3 S, R. 1 E (Gunter, 1949, p 101) All wells drilled before 1959 were less than 6,000 feet (1,830 m) deep; Lower Cretaceous petroliferous sediments were the objective. Production in the Jay field is from the Smackover Formation (Upper Jurassic) at a depth of about 16,000 feet (4,900 m). As a result of this production, there is a current interest in the potential for oil and gas in the updip extension of the Smackover Formation at drilling depths greater than 10,000 feet (3,000 m) in Wakulla and Liberty Counties.

Placid Oil Company (written and oral commun., 1974) has conducted seismic exploration around the periphery of the Study Area, which company personnel believe has potential for oil and gas on a seismic high in the Jurassic rocks. However, the company has completed a dry hole in Wakulla County to a depth of 12,116

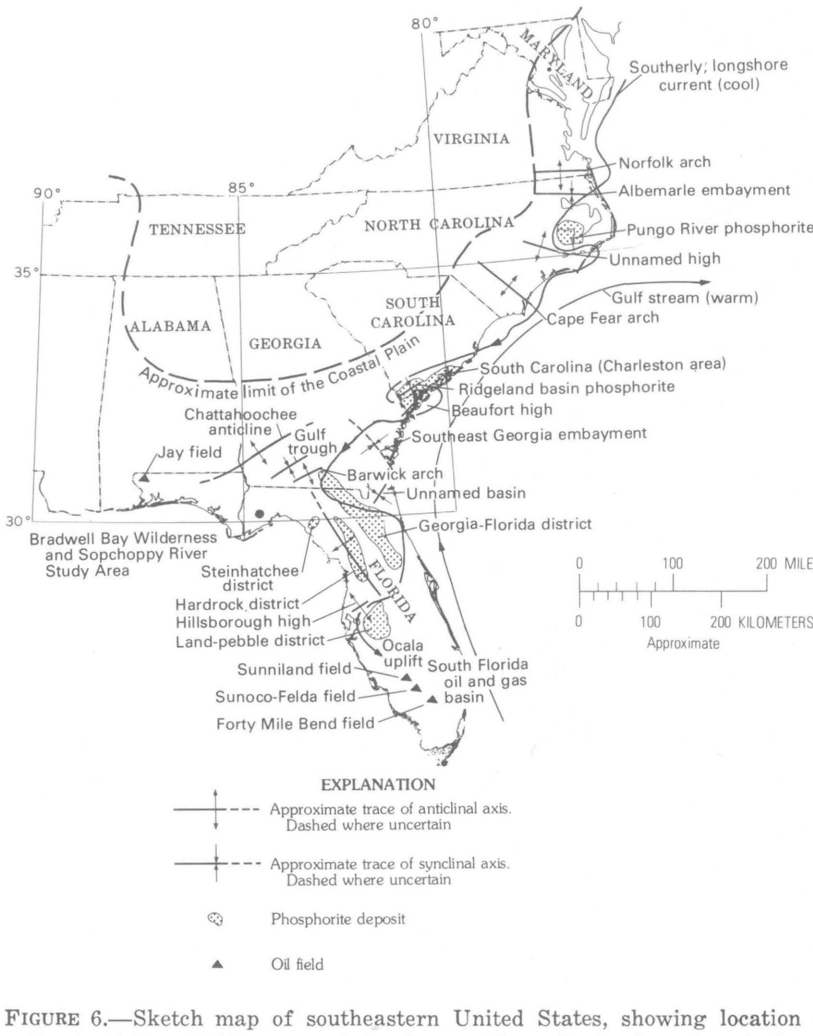


FIGURE 6.—Sketch map of southeastern United States, showing location of Bradwell Bay Wilderness and Sopchoppy River Study Area in relation to the structure of the Coastal Plain, paleocurrents, phosphorite deposits, and oil fields. Map adapted from Cathcart (1968).

feet (3,700 m) in sec. 27, T. 2 S., R. 3 W., (fig. 7, no. 3) and is presently (1975) drilling a well in Liberty County, sec. 26, T. 3 S., R. 5 W., (fig. 7, no. 17), approximately 4½ miles (7 km) west of the Study Area. The company has also been issued a drilling permit from the State of Florida to drill in sec. 16, T. 4 S., R. 6 W., (fig. 7, no. 16). The three holes in this program are along a northeast-trending line immediately northwest of the Study Area. Recent information indicates that Placid Oil Company has finished drilling in Liberty County. The well in sec. 26, T. 3 S., R. 5 W., (fig. 7, no. 17) was drilled to a total depth of 12,131 feet (3,698 m), and the well in sec. 16, T. 4 S., R 6 W., was bottomed at a depth of 12,400 feet (3,780 m); both proved to be dry (David Curry, Florida Dept. of Nat. Resources, written commun., 1976).

Phillips Petroleum Company recently completed a dry hole in Leon County, sec. 14, T. 2 S., R. 1 E. (fig. 7, no. 5), to a depth of 10,466 feet (3,190 m).

OIL AND GAS LEASE STATUS WITHIN THE STUDY AREA

Oil and gas lease applications have been filed with the U.S. Bureau of Land Management on all tracts within the area of study. Oil and gas leases were issued on 82 percent of the area between November 1970 and April 1971. Lease applications covering 15 percent of the Study Area have been rejected but are under appeal; 3 percent of the area covered by lease applications has had no Bureau of Land Management action as of July 15, 1974 (fig. 7). No drilling for oil and gas has taken place in the Study Area.

All the issued leases are assigned to Placid Oil Company or its corporate affiliates, Hunt Petroleum Corporation and Hassie Hunt Trust, of Dallas, Tex

OIL AND GAS POTENTIAL

The Bradwell Bay area has a low oil and gas potential. The Smackover Formation (Upper Jurassic), which is the primary drilling target in the Mississippi-Alabama-Florida panhandle region, appears to pinch out west of the Bradwell Bay area (Newkirk, 1971, p 939) The Lower Cretaceous limestones, which yield oil in southern Florida, are not present in the Wakulla County area. Here, the Lower Cretaceous section is composed of terrigenous clastic rocks in which no accumulations of oil or gas have been found, and, according to Rainwater (1971, p. 1324), none are expected. Rainwater (1971, p. 1331) also stated that the tectonic and sedimentational history of peninsular Florida and adjacent continental shelves during Late Cretaceous time was not favorable for oil and gas generation. Reel and Griffin (1971) believe that the minimum temperature for petroleum maturation is 221° F (105° C) Hottman (1973, p 62) found a good correlation between areas of petroleum production and the geothermal gradient. Thus, if a given sedimentary section is to be considered a potential petroleum producer, it must reach this temperature above the basement rocks Reel and Griffin (1971) contoured the geothermal gradient of Florida from bottom well-hole temperature data. Their potential

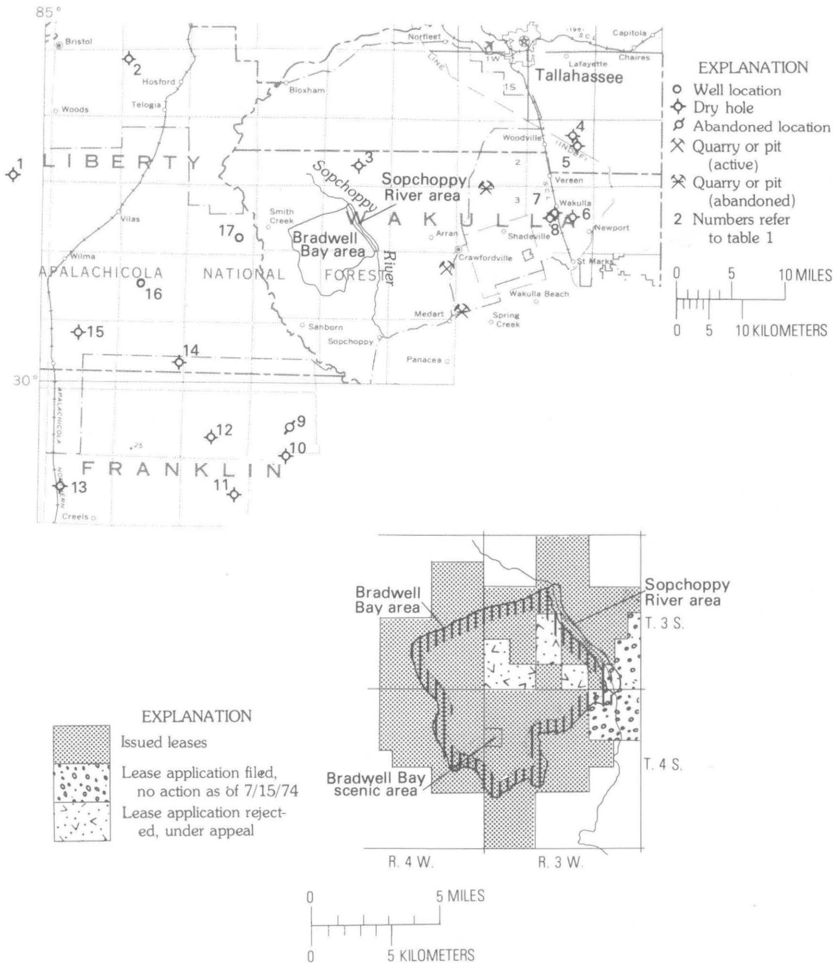


FIGURE 7.—Locations of quarries and oil and gas drill holes. Inset shows oil and gas lease status within area of this report.

petroleum areas coincide with the present producing oil fields in the southern peninsular and western Florida panhandle, both far from the Bradwell Bay area. It may be that hydrocarbons had been generated in the study area, but no evidence of an oil trap was found in the abandoned test wells in the vicinity.

PHOSPHATE

By JAMES B. CATHCART

Phosphate pellets are widespread in marine sedimentary rocks of Cretaceous to Holocene age on the Coastal Plains of the eastern and southern United States. Economic deposits of phosphorite are confined to the Atlantic Coastal Plain and are known only in rocks of middle Miocene age or in younger rocks that derived much or all of their phosphate from middle Miocene rocks.

In the Atlantic Coastal Plain, phosphate pellets are particularly widespread from North Carolina to the southern tip of Florida in rocks of middle Miocene age, although some pellets are found in rocks of Cretaceous to Holocene age In the Gulf Coastal Plain, phosphate is widespread only in rocks of Cretaceous and Paleocene age. Younger rocks contain phosphate pellets at only a few localities where they were probably reworked from older rocks.

Economic phosphorite deposits are in part structurally controlled. All are in basins on the flanks of positive areas that were rising at the time of phosphate deposition, all are on the north or east sides of the positive areas, except for those of the land-pebble district of south Florida; all are in positions that suggest that phosphorus could have been supplied by cool, southward-moving nearshore ocean currents. Phosphate was precipitated in the basins when cool water, diverted by the positive areas, was turbulently mixed with warm waters of the Florida Current and the Gulf Stream (fig 6). The scarcity of phosphate in Tertiary rocks of the Gulf Coast is probably due to the position of the Floridan Plateau, which diverted currents away from the Caribbean and Gulf Coast.

The phosphate deposits of the north Florida–south Georgia areas are mostly in the Hawthorn Formation of middle Miocene age, but some may be in rocks of Pliocene age that contain material reworked from older rocks The Hawthorn Formation crops out in Leon and Gadsden Counties north of Bradwell Bay, but appears to be absent in Wakulla County where the younger Jackson Bluff Formation of late Miocene age lies unconformably on the St Marks Formation (Vernon and Puri, 1965). Where it crops out in Leon and Gadsden Counties, the Hawthorn Formation consists of sand, clay, clayey sand, and marl or rarely limestone and contains only traces of phosphatic material (Patterson, 1974, p. 11) In Bradwell Bay, phosphate pellets and phosphatic shells were found only in post-Miocene deposits as part of estuary sediments derived from older rocks (table 3, drill holes 3, 4, 5, and 8) ; therefore, the potential for phosphate resources is low.

PEAT

Buried layers of peat, muck, lignite, and sapropelite, and streaks of these and other carbonaceous materials have been found in many wells, core holes, and a few quarries, and also along eroded beaches and in road excavations in many parts of Florida (Davis, 1946). Peat consists of partly decayed vegetable matter, inorganic materials, and water in varying proportions, the usual proportions for industrial use being 10 percent solid matter to 90 percent water. Outside the industry, the term "peat" also applies to partly decayed vegetable matter having a much higher percent solid content and a much lower percent water content. In fact, the distinction between peat and lignite may sometimes be obscure. Lignite is generally considered to be a brownish-black coal in which alteration of vegetable matter has proceeded farther than in peat, but not as far as in subbituminous coal. In common vernacular, peat can be confused with muck, which is any dark-colored clay, silt, and sand found in wet places and having a high percentage of decomposed or finely comminuted organic material. Sapropelite is coal derived from algal material.

The need for specific classification has been recognized by the peat industry, and the American Society for Testing and Materials (ASTM) Committee on Peat consequently proposed a standard classification. According to the ASTM Committee D–29 (ASTM D2607–69), the term "peat" may be used commercially only with respect to organic matter of geological origin, and not for lignite or other coal. According to the ASTM (1969) definition, peat forms mainly from dead-plant remains through the agency of water in the absence of air; it is found in a bog, swampland, or marsh and has an ash content not exceeding 25 percent on a dry-weight basis. The classification below is based on five major peat types determined by kind of plant material and fiber content Fiber is defined as plant material retained on a No 100 (ASTM) sieve (that is, 0.005 in (0 15 mm) or larger) and includes stems, leaves, or fragments of bog plants but no wood particles larger than 0.5 inch (12 7 mm) in greatest dimensions; it excludes shells and inorganic fragments such as stones, sand, and gravel. Percentages of fiber are based on oven-dry weight at 221° F (105° C), not on volume.

Sphagnum-moss peat (peat moss) —The ovendried peat contains a minimum of $66\frac{2}{3}$ percent sphagnum moss fiber of the total content by weight. These fibers are stems and leaves of sphagnum in which the fibrous and cellular structure is recognizable.

Hypnum-moss peat —The oven-dried peat contains a minimum of $33\frac{1}{3}$ percent fiber content by weight, of which hypnum moss fibers compose more than 50 percent These fibers are stems and leaves of various hypnum mosses in which the fibrous and cellular structure is recognizable.

Reed-sedge peat.—The oven-dried peat contains a minimum of 33⅓ percent fiber by weight, of which reed-sedge and other non-moss fibers compose more than 50 percent

Peat humus —The oven-dried peat contains less than 33⅓ percent fiber by weight.

Other peat —This covers all forms of peat not herein classified.

According to this ASTM classification, none of the buried tidal-marsh peat in the area of study can qualify as commercial peat because its ash content far exceeds 25 percent.

However, Davis, in 1946, reported peat suitable for industrial use in a few marshes, and in titi, bay, gum, and cypress swamps in Jefferson, Leon, Liberty, and Franklin Counties. This peat was being used by local nurseries and individuals for their gardens. Today, the nearest peat-mining operation is just south of the Study Area near Carrabelle in Franklin County, where peat humus is mined from the swamp and sold in bulk and packaged form Location of this mine is shown in figure 2.

Peat forms in wetlands where material accumulates faster than it is destroyed by aerobic bacteria or fire Different types of plant material produce different types or amounts of peat Fourteen communities of plants of natural vegetation types in the Apalachicola National Forest were described by Andre F. Clewell (1974).[4] These vegetation types grade into one another, they range from the type living where it is relatively high and dry to the type living where it is low and wet on a surface of almost imperceptible relief. Three dominant vegetation types, namely, pine-palmetto flatwood, bay swamp, and titi swamp appear in the Bradwell Bay Wilderness and Sopchoppy River Study Area. These were mapped by traverses on the ground and over the area in a plane with the air photographs (pl 1) Common and scientific names used in the descriptions of the vegetation types follow Kurz and Godfrey (1962) for trees, and Radford, Ahles, and Bell (1968) for other plants The authorships of scientific names can be obtained from these references

The most favorable environment for peat accumulation in the Study Area is the bay swamp (fig 8), which is characterized by the presence of sweetbay *(Magnolia virginiana)*. Less dominant trees and shrubs are black titi *(Cliftonia monophylla)*, blackgum *(Nyssa biflora)*, cypress *(Taxodium ascendens)*, pond pine *(Pinus serotina)*, swamp bay *(Persea palustris)*, bamboo *(Smilax laurifolia)*, bayberry *(Myrica heterophylla)*, and swamp Cyrilla *(Cyrilla racemiflora)*

[4] Clewell, A F, 1971, The vegetation of the Apalachicola National Forest an ecological perspective prepared under Contract No 38-2249, U S Dept of Agriculture Forest Service, Atlanta, Ga, and submitted to the Office of the Forest Supervisor, Tallahassee, Fla, p 1-159

FIGURE 8.—Bay swamp near Monkey Creek at east border of Study Area. View looking toward swamp from pine-palmetto flatwoods in the foreground.

Sphagnum spp , a common peat-forming moss, generally covers the ground. Ferns, sedges (for example, *Carex glaucescens)*, and grasses (for example, *Panicum tenerum)* are less abundant. The bay swamp plant community appears as large shrubs and trees, many of which have broad leathery evergreen leaves They appear in swampy depressions and minor drainages that are scattered among the pine flatwoods. However, large areas of bay swamps in the west and southwest of the area are bordered by titi swamps The wood in the large tree trunks makes good peat when preserved. Bay swamps are not as susceptible to fires as the pine-palmetto flatwoods, as the water table is probably within 4 inches (10.2 cm) of the soil surface at all times, and sometimes the surface is inundated to a depth of several inches (cm). Moss, peat, and humus peat in bay swamps in the Study Area is as much as 4 feet (1 2 m) thick but is eroded into hummocks and hollows. The peat overlies highly organic sand where probed

The titi swamps are tangles of shrubs and small trees higher than a man's head, but contain only thin deposits of peat. The most common plants are black titi *(Cliftonia monophylla)*, fetterbush *(Lyonia lucida)*, and swamp and little leaf Cyrillas *(Cyrilla racemiflora* and *parviflora)*. Pines, except for the widely scattered pond pine *(Pinus serotina)*, are notably absent. Wire grass and other herbaceous plants also are absent from the ground cover except near bordering flatwoods that have not been burned over recently Where titi swamps border bay swamps, the borders are brushy between the two Titi-vegetation type is dominant in Bradwell Bay, where more than 15 square miles (38 85 km^2) is covered by titi swamps; the largest continuous swamp is near the center The water table is near the surface except during droughts Temporary inundations are frequent during rainy periods, and waist-deep pools are present throughout the year. The ground consists of silica sand stained with organic matter, in many places overlain with humus peat which may accumulate to a depth of 1 foot (0.3 m). Roots bind the peat, but surface water cuts erosional channels more than 1 foot (0 3 m) deep, making the surface of the swamp very uneven Titi swamps are least prone to fire, but they do not provide thick masses of pulpy material that has good peat-forming potential.

The least likely environment for peat accumulation in the Study Area is on the sandy plains that slope as much as 4 percent, and where the ground is saturated to the surface only during periods of rain The pine-palmetto flatwoods (figs 9 and 10) represent such plains The dominant tree in these flatwoods in the Study

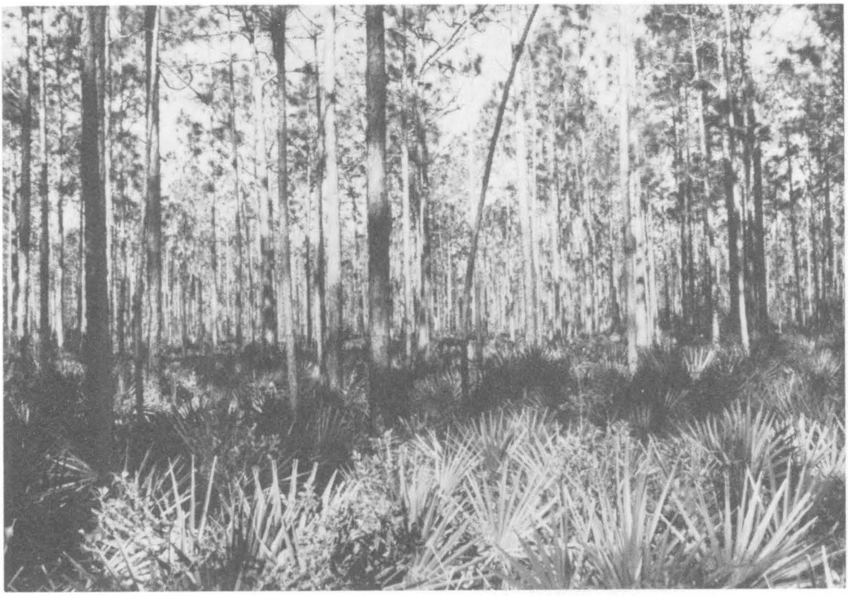


FIGURE 9.—Pine-palmetto flatwoods in Study Area near the Sopchoppy River.

Area is slash pine *(Pinus elliotti)*, although long-leaf pine *(Pinus palustris)* is also present. The ground is covered by wire grass *(Aristida stricta)*, and saw palmetto *(Serenoa repens)*. The pine-palmetto flatwoods are most extensive along the north, east, and southeast margins of the Study Area, but are found as islands in the swamps of the interior. Frequent fires and severe fluctuation of the ground-water table preclude peat formation.

The most favorable area for formation of peat is delineated on figure 8. Fibrous moss and humus peat 1 to 4 feet (0.3–1.2 m) thick is in bay swamps protected from fire encroachment by surrounding titi swamps that act as buffers. Elsewhere, bay swamps are adjacent to fire-prone pine-palmetto flatwoods and are subject to burning before much peat can accumulate. Within this most favorable type of area are an estimated 136,000 tons (123,000 metric tons) of air-dried peat having an ash content of not more than 25 percent (maximum ash content recommended by ASTM standard for commercial-quality peat). However, the cost of mining such a shallow discontinuous layer where drainage, clearing, and access problems are severe would discourage peat producers at this time when thicker peat in more accessible areas is available elsewhere in Florida.

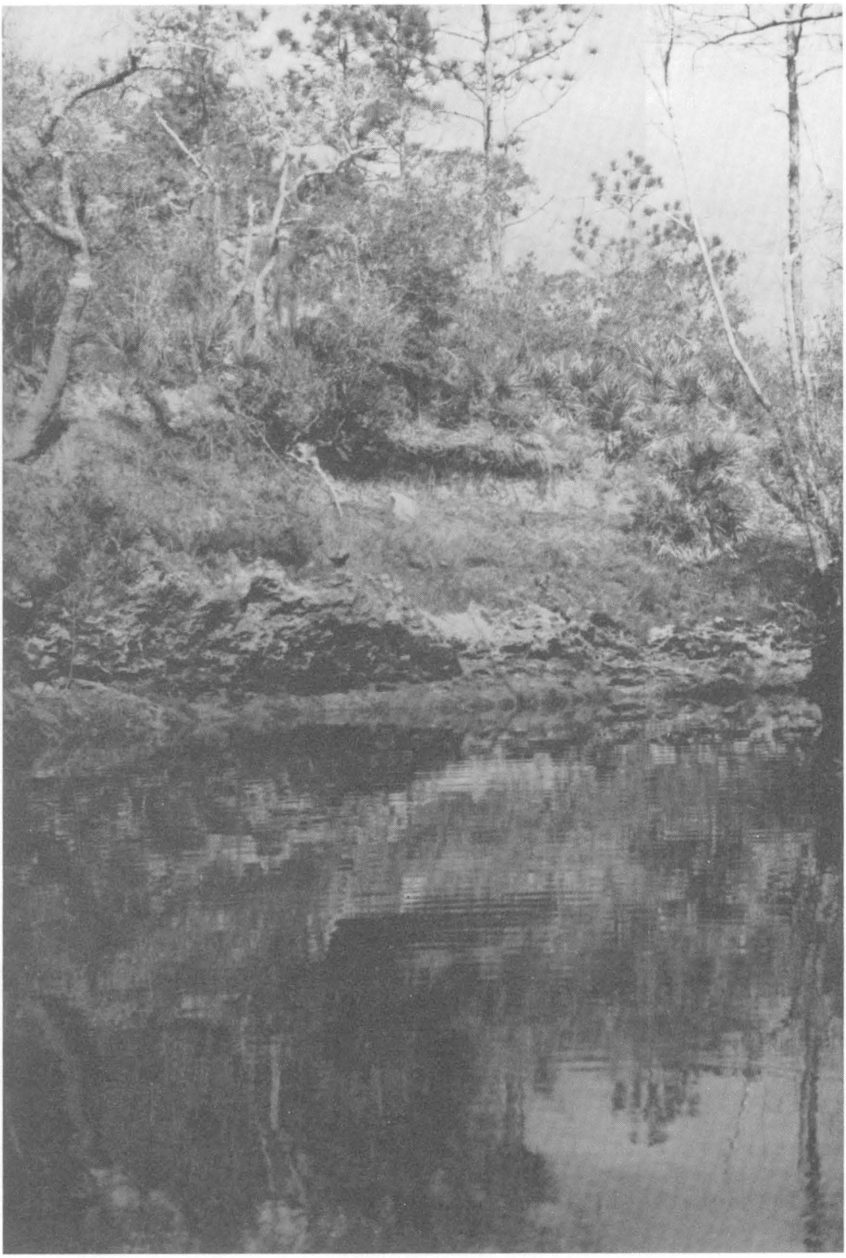


FIGURE 10.—Limestone of the St. Marks Formation cropping out at edge of Sopchoppy River in Study Area. Pine-palmetto flatwoods on sand overlying the limestone.

SAND

By PHILIP J GERACI

Quartz sand from abandoned beaches on terraces south of Panacea (fig 1) in Wakulla County is used for masonry and mortar. Such sand is also abundant in the Study Area and is easily accessible in the beach-ridge complex along the northern border Twenty-seven samples obtained from eight drill holes (pl. 1) were sieved. Approximately half of each bulk sample was washed in No. 230 sieve to remove humate, silt, and clay. The weight loss was added to the pan fraction after sieving U S standard sieves numbered 10, 18, 36, 60, 120, and 230 were used which have openings of 2.0, 1.0, 0.5, 0 246, 0 125, and 0 063 mm, respectively Percents by weight for each size fraction were calculated, and the data were plotted as histograms (fig 5) for easy comparison with histograms of sand from the currently operating pit in an abandoned-beach ridge south of Panacea (fig 2) and with size fractions recommended by the American Society for Testing and Materials for cement and masonry use

According to the analysis, the sand used locally for mortar and masonry contains 14 percent coarse grade, 62 percent medium grade, and 19 percent fine grade The American Society for Testing and Materials (Wright, 1973) recommends that sand for mortar and masonry contain 30 to 31 percent very coarse grade, 25 to 31 percent coarse grade, and 20 percent medium grade. The samples from drill sites 9 and 10 (pl 1, fig 5) peak in the fine grade, suggesting that the sand in this relict beach, which is even finer than the sand at the local commercial pit, is too fine for mortar and masonry use. Thirteen of the samples peak in the medium grade within a range of 20 to 40 percent Twelve of these are from drill sites 3, 4, 5, 7, and 8 (pl 1; fig 5). Sands from these drill sites come somewhat closer to complying with the ASTM recommendations, but, taken as a whole, the sand of the Study Area is unacceptable to poorly acceptable for use in mortar and masonry.

The beach and nearshore shelf sand at the surface of the Study Area (pl. 1) is not recommended as a source of moulding and glass sands as defined by the American Foundrymen's Society (1952, p. 29, 30, 212) Beds of tidal-marsh deposits near the surface (pl. 1) are contaminants Nor are the sands here of economic importance as a source of heavy minerals. Panned concentrates taken from sand bars in the bed of the Sopchoppy River contained small quantities of ilmenite, kyanite, sphene, and rutile and lesser amounts of zircon, tourmaline, and garnet. These minerals are also scattered throughout the sand cuttings from the test holes in which composition of the sands is about 99 percent quartz.

Natural sand produced from an abandoned sand pit in sec. 31, T. 4 S, R. 1 W. was used for local road construction (fig. 7). Roads surrounding the Study Area utilize sand locally obtained.

STONE FOR CONCRETE AGGREGATE AND LIME

Limestone from the St. Marks Formation is at or near the surface in eastern Wakulla County. The nearest active limestone quarry to the Study Area is in sec. 12, T. 4 S., R. 2 W., about 2.3 miles (3.7 km) south of Crawfordville (fig. 7); it supplies crushed limestone, calcareous sandstone, and sand for use as road metal and fill for local roads. In the past, limestone quarries were operated in sec. 4, T. 2 S., R. 1 W. (fig. 7) and in sec. 16, T. 3 S., R. 1 E. (Sellards, 1917, p. 111). Material from these quarries was sold in bulk, crushed for concrete aggregate, or ground for agricultural purposes.

Bedrock outcrops in the Study Area are rare. A few feet of St. Marks limestone crops out in the banks of the Sopchoppy River in several places (fig. 10). Elsewhere, the limestone is buried under at least 25–30 feet (7.6–9.1 m) of overburden. Its commercial possibilities are limited because limestone deposits are available closer to present demand centers.

FULLER'S EARTH AND OTHER CLAYS

The Florida-Georgia fuller's earth district, the major area for producing fuller's earth in the United States, includes parts of Gadsden County, Fla., and Decatur and Grady Counties, Ga. Active mines within this district are 24 miles (39 km) north of the Study Area (Stowasser, 1972, p. 199). The fuller's earth deposits are found in the Hawthorn Formation and have been mined continually since 1891 (Patterson, 1974, p. 16). Limited deposits of fuller's earth extend into the southwestern part of Leon County and the western part of Wakulla County (Sellards, 1917, p. 112), but no production has been reported from these areas. Because the Hawthorn Formation has not been found in the Study Area, the potential for fuller's earth here is low.

Clay interpreted to be residuum at depth intervals of 5–20 feet (1.5–6.1 m) in the bank of the Sopchoppy River (tables 2, 3), 20–26 feet (6.1–7.9 m) in drill hole 1 and 15–19 feet (4.6–5.8 m) in drill hole 3, is sandy and without adsorbent property. This material has low potential for use in making brick because of its limited extent and remoteness from market.

REFERENCES CITED

Alt, David, and Brooks, H K, 1965, Age of the Florida marine terraces Jour. Geology, v 73, p 406–411.

American Foundrymen's Society, 1952, Foundry Sand Handbook· Chicago, Ill, Am Foundrymen's Soc, 265 p

American Society for Testing and Materials, 1969, D2607–69, Standard classification of peats, mosses, humus, and related products. Philadelphia, Pa., 1 p

Cathcart, J. B., 1968, Phosphate in the Atlantic and Gulf Coastal Plains, *in* Forum on geology of industrial minerals, 4th Austin, Tex, Proc Texas Univ Bur Econ Geology, p 23–34

Cooke, C W., 1936, Suwannee Limestone of Florida [abs] Geol Soc America Proc. 1935, p. 71–72

——— 1939, Scenery of Florida interpreted by a geologist. Florida Dept Conserv Geol Bull 17, 118 p

——— 1945, Geology of Florida Florida Geol. Survey Bull 29, 339 p

Dall, W H, and Harris, G D, 1892, Correlation papers, Neocene U S Geol Survey Bull 84, 349 p

Davis, J H, 1946, The peat deposits of Florida, their occurrence, development, and uses Florida Geol Survey Bull 30, 247 p

Gunter, Herman, 1949, Exploration for oil and gas in Florida Florida Geol Survey Inf Circ 1, rev ed, 106 p

Hendry, C W, Jr, and Sproul, C R, 1966, Geology and ground-water resources of Leon County, Florida Florida Geol Survey Bull 47, 178 p

Hendry, C. W, Jr, and Yon, J. W, Jr, 1967, Stratigraphy of upper Miocene Miccosukee Formation, Leon and Jefferson Counties, Fla Am Assoc Petroleum Geologists Bull v 51, no 2, p 250–256

Herrick, S. M, and Vorhis, R C, 1963, Subsurface geology of the Georgia Coastal Plain Georgia Geol Survey Inf Circ 25, 78 p.

Hottman, W E, 1973, Geology of the northeastern Gulf of Mexico, *in* Structure of the Gulf Basin, Part 1 New Orleans Geol Soc, p 43–68

Kurz, H, and Godfrey, R K, 1962, Trees of northern Florida Gainesville, Fla, Univ Florida Press, 311 p

MacNeil, F S, 1950, Pleistocene shore lines in Florida and Georgia U.S Geol Survey Prof Paper 221–F, p 95–107.

Matson, G C, and Clapp, F G, 1909, A preliminary report on the geology of Florida with special reference to the stratigraphy· Florida Geol Survey 2d Ann. Rept, p. 25–173.

Newkirk, T F, 1971, Possible future petroleum potential of Jurassic, Western Gulf Basin, *in* Cram, I. H, ed, Future petroleum provinces of the United States—their geology and potential Am Assoc Petroleum Geologists Mem 15, v 2, p 927–953

Patterson, S H, 1974, Fuller's earth and other industrial mineral resources of the Meigs-Attapulgus-Quincy district, Georgia and Florida U S Geol Survey Prof Paper 828, 45 p

Puri, H S, 1953, Contributions to the study of the Miocene of the Florida panhandle Florida Geol Survey Bull 36, 345 p

Puri, H S, and Vernon, R O, 1964, Summary of the geology of Florida and a guidebook to the classic exposures Florida Geol Survey Spec Pub 5, rev. ed., 312 p.

Radford, A E, Ahles, H E, and Bell, C R, 1968, Manual of the vascular flora of the Carolinas. Chapel Hill, N C, Univ North Carolina Press, 1183 p

Rainwater, E H, 1971, Possible future petroleum potential of peninsular Florida and adjacent continental shelves, *in* Cram, I H, ed, Future petroleum provinces of the United States—their geology and potential. Am Assoc Petroleum Geologists Mem 15, v 2, p 1311–1341.

Reel, D A, and Griffin, G M, 1971, Potentially petroliferous trends in Florida as defined by geothermal gradients Gulf Coast Assoc. Geol Socs. Trans, v 21, p 31–36

Sellards, E H, 1917, Geology between the Ocklocknee and Aucilla Rivers in Florida Florida Geol Survey 9th Ann Rept, p 85–139

Stowasser, W F, 1972, The mineral industry of Florida U.S Bur. Mines, Minerals Yearbook 1970, v 2, p 195–206

Tanner, W F, 1667, Table 1, *in* Sedimentation and coastal features of the Alligator Point area and the area between the Penholloway and Steinhatchee Rivers Geol Soc America, Southeastern Sec, Annual Meeting 1967, Tallahassee, Fla, Field Trip 1 Guidebook, p 6

Vernon, R. O, 1942, Geology of Holmes and Washington Counties, Florida Florida Geol. Survey Bull 21, 161 p.

Vernon, R O, and Puri, H S, 1965, Geologic map of Florida: Florida Div Geology Map Ser 18, 1 2,000,000

Wright, A P, 1973, Environmental geology and hydrology, Tampa area Florida Bur Geology Spec Pub 19, 94 p

Yon, J W, Jr, 1966, Geology of Jefferson County, Florida· Florida Geol Survey Bull 48, 119 p

☆ U S Government Printing Office 1977—240 961/86