MINERAL RESOURCE POTENTIAL OF HELL HOLE BAY, WAMBAW SWAMP, LITTLE WAMBAW SWAMP, AND WAMBAW CREEK WILDERNESSES, BERKELEY AND CHARLESTON COUNTIES, SOUTH CAROLINA

By

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STUDIES RELATED TO WILDERNESS

Under the provisions of the Wilderness Act (Public Law 88-577, September 3, 1964) and related acts the U.S. Geological Survey and the U.S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Areas officially designated as "wilderness," "wild," or "canoe" when the act was passed were incorporated into the National Wilderness Preservation System, and some of them are presently being studied. The act 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. The act directs that the results of such surveys are to be made available to the public and be submitted to the President and the Congress. This report discusses the results of a mineral survey of the Hell Hole Bay, Wambaw Swamp, Little Wambaw Swamp, and Wambaw Creek Wildernesses, Francis Marion National Forest, Berkeley and Charleston Counties, South Carolina. These areas were established as wildernesses by Public Law 96-560, December 22, 1980.

MINERAL RESOURCE POTENTIAL SUMMARY STATEMENT

Hell Hole Bay, Little Wambaw Swamp, Wambaw Creek, and Wambaw Swamp Wildernesses are coastal plain swamplands located in the Francis Marion National Forest, Berkeley and Charleston Counties, South Carolina. Unconsolidated Quaternary sediments, ranging from 10 to more than 60 ft thick, overlie the Tertiary-age Santee Limestone in the Hell Hole Bay and Wambaw Creek Wildernesses and the Cooper Formation in the Wambaw Swamp and Little Wambaw Swamp Wildernesses.

All surface and mineral rights in the wildernesses are owned by the Federal Government. There are no active or pending mineral leases in the Francis Marion National Forest.

Peat is a potential resource only in Wambaw Swamp, where approximately 810,000 tons on the dry basis occurs. A small amount of clay, suitable for structural-clay products and expanded lightweight aggregate, is of potential importance in the Hell Hole Bay and Wambaw Creek Wildernesses. Although phosphate concentrations occur in Little Wambaw Swamp and Wambaw Swamp, they are low grade. Uranium and heavy minerals occurring in the wildernesses are in amounts too small to be a resource potential. Sand suitable for the ceramics industry and limestone suitable for agricultural lime, crushed stone, and cement are more easily obtainable in greater amounts elsewhere on the coastal plain. Oil and gas are not known to occur in the South Carolina Coastal Plain. Recent speculation suggests the possibility of hydrocarbon accumulation at great depth in the region. This possibility has not been tested.

INTRODUCTION

Four wildernesses, including Hell Hole Bay (1,980 acres), Wambaw Swamp (5,100 acres), Little Wambaw Swamp (5,000 acres) and Wambaw Creek (1,640 acres), are all swamplands in the Francis Marion National Forest on the lower Atlantic Coastal Plain of South Carolina about 30 mi northeast of Charleston (fig. 1). They are located between the Cooper and Santee Rivers near the boundary of Berkeley and Charleston Counties. Hell Hole Bay, Wambaw Swamp, and Little Wambaw Swamp serve as collecting basins for the surrounding sandy uplands. Drainage of Hell Hole Bay is essentially subsurface. Wambaw Swamp lies at the head of Wambaw Creek flowing northeast to the Santee River, and Wambaw Creek Wilderness extends along the creek's floodplain. Little Wambaw Swamp is drained by Steed Creek, a branch of Awandaw Creek that empties into the Atlantic Ocean.

Vegetation of these wildernesses is generally similiar. Tupelo and water gum, along with stands of bald cypress, are the prominent tall trees; red maple, sweet bay, southern bayberry, and lencothoe are common in the understory. Herbaceous vegetation is neither rank nor rich in species due to flooding and heavy shade. Pine and oak forests are located on the

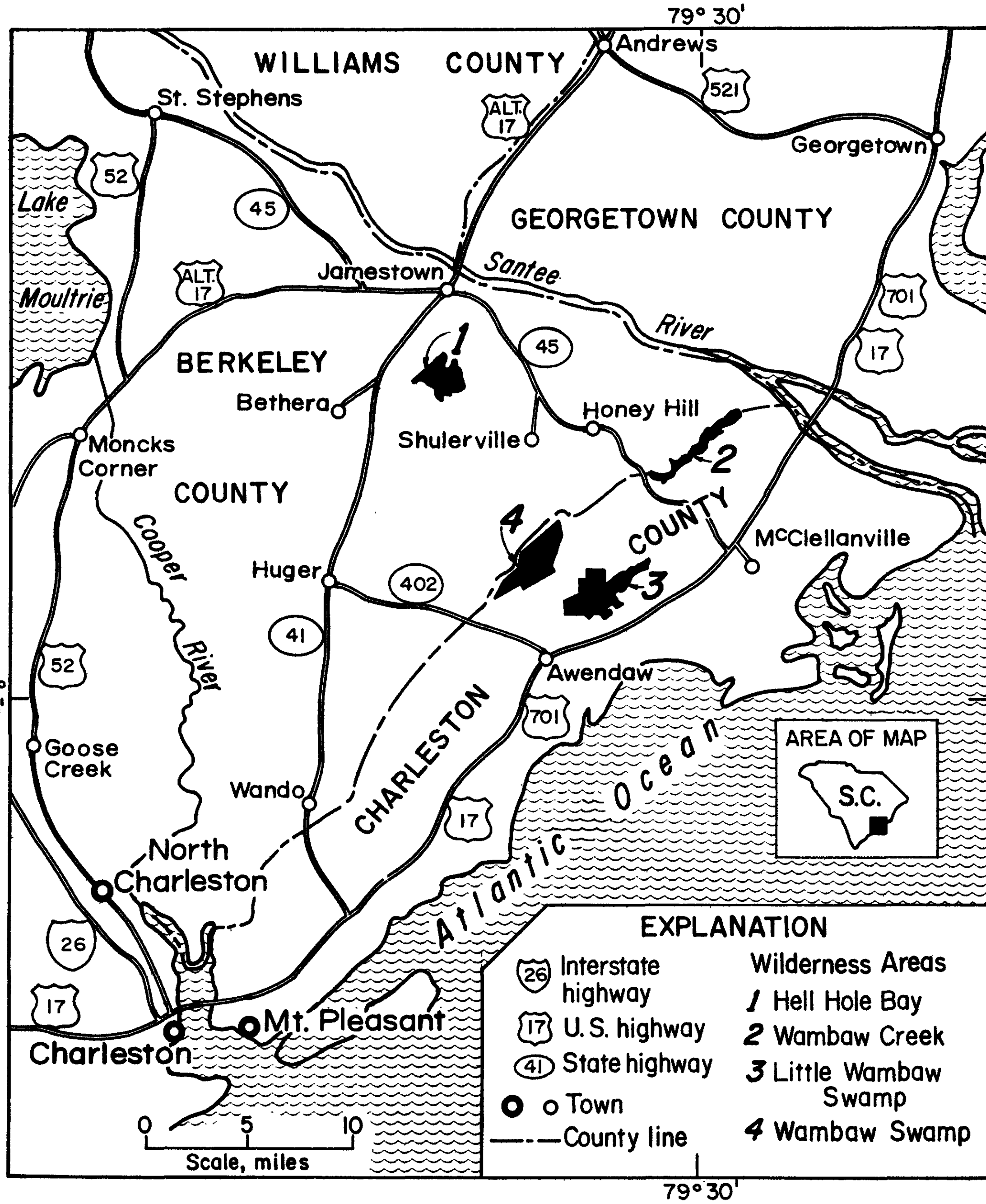

Figure 1.--Index map of the Hell Hole Bay, Wambaw Swamp, Little Wambaw Swamp and Wambaw Creek Wildernesses

bordering dry areas. Relief in each wilderness is so slight that at first glance the swamps appear to be masses of vegetation extending monotonously in all directions. However, a second look reveals patterns of contrasting trees and shrubs that reflect environmental factors, such as changes in microrelief, drainage, soil porosity, and acidity. These vegetation patterns are valuable in the study and mapping of the surficial geology, including peat deposits.

Previous Studies

The stratigraphic framework of the South Carolina Coastal Plain is summarized by Cooke (1936) and Cooke and MacNeil (1952). Cooke's geologic map is outdated, but at present no small-scale map, other than a generalized map of the Charleston area by McCartan and others (1982), and few large-scale geologic maps are available to replace it. Malde (1959) published a 1:24,000 geologic map of the Ladson Quadrangle, located northwest of Charleston.

D. J. Colquhoun (1965, 1969, 1974) has done extensive work on the geomorphology of the area and has presented valuable information on the stratigraphy of surficial units. DuBar and others (1972) have studied the area across the Santee River from the study areas.

Phosphate resources of the Charleston phosphate district have been discussed by Sloan (1908), Rogers (1914), Altschuler and others (1958), Malde (1959), and Force and others (1978). A nearby clay deposit is described by Heron and others (1965).

The study of the Wambaw Swamp Wilderness by Cameron and others (1979) serves as background for the present study of the larger area.

Present Investigations

Clay M. Martin and Gertrude C. Gazdik conducted a field reconnaissance of the wildernesses in the spring of 1982. Information concerning subsurface deposits was obtained from the South Carolina Geological Survey and from Donald J. Colquhoun, University of South Carolina. Cornelia C. Cameron and Andrew E. Grosz conducted a field investigation in January 1982, including power augering with the assistance of Earl M. Lemon, Jr. and hand augering with the Macaulay peat auger and the Davis peat sampler.[1] Geologic mapping is based on both power- and hand-auger data interpreted in the field, as well as correlations of vegetation patterns on the ground with those on aerial photographs and soil maps (Miller, 1971). Cuttings from 17 power-auger holes (PAH) and one hand-auger hole were submitted to the laboratories of the U.S. Geological Survey (USGS) at Reston, Va. for peat and heavy mineral analyses. Nine of the clay samples from several power-auger holes were analyzed for ceramic properties and lightweight aggregate potential by U.S. Bureau of Mines (USBM), Tuscaloosa Metallurgy Research Center, Tuscaloosa, Ala. (sample localities are on accompanying map).

Acknowledgments

Appreciation is extended to Donald J. Colquhoun of the University of South Carolina and Alan-Jon Zupan and Arthur H. Maybin of the South Carolina Geological Survey for the time spent discussing mineral commodities in the wildernesses, and to the Giant Portland Cement Company for permitting access to their quarry at Harleyville, S.C. Special acknowledgment is given Richard Worsley and Jim Knight of that company.The assistance of John Pryor, District Ranger, U.S. Forest Service,Wambaw Ranger District, and his staff is greatly appreciated.

GEOLOGY

Unconsolidated deposits of Quaternary age conceal the somewhat more indurated sediments of the Santee Limestone and Cooper Formation of Tertiary age in and near the four wildernesses. These sedimentary rocks probably overlie 2,000 to 2,400 ft of Upper Cretaceous and Paleocene sediments. No deep drilling has been done in the wildernesses, but reasonable projections can be made from test holes located to the northeast and southwest (Bureau of Land Management, 1978; Siple, 1958; Gohn and others, 1977, 1978a, 1978b).

The oldest formation penetrated by the power-auger drill is the Santee Limestone of middle or middle and late Eocene age (Ward and others, 1979; Baum and others, 1980). It lies closest to the surface in Hell Hole Bay and Wambaw Creek Wildernesses and is deepest in southern parts of Wambaw and Little Wambaw Swamps.

The Cooper Formation (Eocene-Oligocene) described by Stephenson (1914), Cooke and MacNeil (1952), Malde (1959), and Ward and others (1979), consists of carbonate sand, clay, and phosphate. It lies unconformably on the Santee Limestone. Phosphate nodules, representing an old erosional surface at the base of the Cooper, extends across Wambaw and Little Wambaw Swamps (fig. 2).

Deposits of clay, silt, sand, and gravel of Quaternary age unconformably overlie the Santee Limestone and Cooper Formation in and near the four wildernesses. These deposits reach a thickness greater than 60 ft at the southern borders of Wambaw Swamp and Little Wambaw Swamp. The oldest deposits are beds of granular to shelly, coarse- to medium-grained feldspathic sand locally grading upward into silty clay. These sand-clay couplets reflect fluvial (at the base) to upper estuary (at the top) depositional environments. Therefore, beds of sand and clay may be of commercial quality at one site and not at another because the beds lack horizontal uniformity. The estuary deposits are in turn overlain by calcareous sandy muds and muddy fine-grained sands, typical of nearshore shelf, lagoon, and inlet environments. Over these deposits are well-sorted sands that form the gentle rises of former barrier islands and sand-spit deposits. Fine-grained sand, silt, and organic clay fills the channels that were cut into the older sediments by the regressing sea. Peat and muck of Holocene age represent the current stage of sedimentation in the fresh-water swamps that are presently found in the wildernesses.

MINERAL RESOURCE POTENTIAL

Peat, used by the agriculture, horticulture, and fuel industries, is the only potential mineral resource in the study area. Clay, suitable for structural-clay products and expanded lightweight aggregate, is present in very small amounts and is a possible potential resource only in the Wambaw Creek and Hell

[1]Use of trade names is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

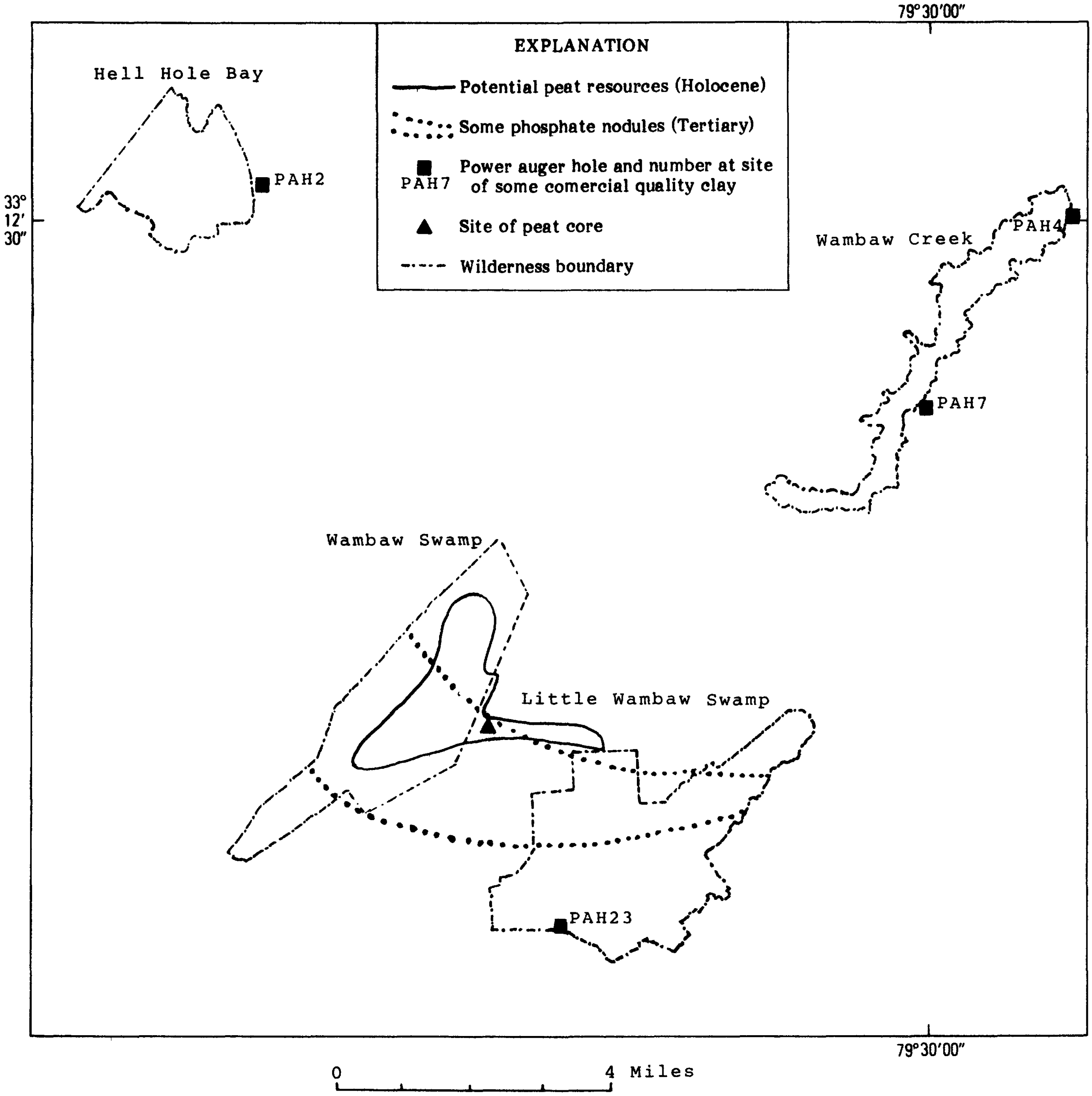

Figure 2.--Map of Hell Hole Bay, Wambaw Creek, Wambaw Swamp and Little Wambaw Swamp Wildernesses showing area of potential peat resources, site of peat core, area of some phosphate nodules and sites of power-auger holes penetrating small amounts of clay.

Hole Bay Wildernesses. Uranium and heavy minerals occurring in the wildernesses also are in amounts too small to be potentially important. Although phosphate concentrations occur in Little Wambaw Swamp and Wambaw Swamp, they are low grade. Sand, suitable for the ceramics industry, and limestone, used for agricultural lime, crushed stone, and cement, are more easily obtainable in greater amounts elsewhere on the coastal plain. Oil and gas are not known to occur in the South Carolina Coastal Plain. Recent speculation suggests the possibility of hydrocarbon accumulation at great depth in the region but as yet, this theory has not been tested.

Peat

810,000 tons of humus peat on the dry basis (computed as 200 tons per acre-foot at an average thickness of 5 ft) is available in Wambaw Swamp (fig. 2). Analyses of samples (table 1) from this deposit show that it is acceptable for agricultural and fuel use. These samples are comparable with those of the deposit near Creswell, NC, where a $250 million peat-to-methanol conversion plant is under consturction at a lower coastal plain peat deposit (Davis, 1982).

Peat has been mined commercially for agricultural and horticultural use from only one locality in South Carolina—near Green Pond, Colleton County, about 50 mi southwest of the wildernesses. According to USBM statistical records, mining has been continuous since 1958.

Phosphate

More than 13 million long tons of phosphate rock were mined in the Charleston area from 1867 until 1938, when richer deposits in Florida and Tennessee were developed (Malde, 1959). Little information is available regarding the grade of phosphate mined, but drill-hole samples by Malde (1959) give values of 5.6 to 9.6 percent phosphate P_2O_5 as the higher range of values for analyses of Cooper "marl" samples from the Charleston phosphate area.

The higher phosphate values are in zones of secondary enrichment which occur locally in the weathered upper part of the Cooper Formation and in the overlying sediments. Enrichment has occurred where erosion has removed phosphatic Cooper Formation from some areas, then leached, reworked, and redeposited it in others. The resulting 2- to 3-foot-thick, unconsolidated conglomerate that unconformably overlies the weathered surface of the Cooper contains a concentration of phosphate nodules that commonly range from sand to pebble size. Recent studies of the Cooper Formation by Force and others (1978) give an average P_2O_5 value of 5.4 percent in the secondary enrichment zones. Some readings, however, were as high as 13.9 percent.

Based on power-auger information, it is estimated that approximately 200 acres of Little Wambaw Swamp and 600 acres of Wambaw Swamp are underlain by the Cooper. Figure 2 shows the area where the phosphate nodule layer averages 3 ft thick, the P_2O_5 content is about 8 percent, and the overburden is 40 to 60 ft thick. These deposits do not compare favorably with similar deposits currently being mined in Florida, which are generally 20 or more ft thick, more than 25 percent P_2O_5, and have overburden thicknesses which vary, but are frequently in the 15 to 40 ft range.

Clay

Clay beds of varying quality and size occur in unconsolidated Quaternary-age sediments above the Santee Limestone and the Cooper Formation. These beds are normally associated with lagoonal environments, behind barrier dune-scarp structures, or with river estuaries. The only clay deposit near the wildernesses that has been commercially recovered is a river-terrace deposit along the Santee River near St. Stephens, S.C., about 20 mi northwest of Hell Hole Bay (Heron and others, 1965). The clay, used in the manufacture of bricks, is not currently being mined.

In the Little Wambaw Swamp Wilderness, PAH-23 showed a possible source of commercial clay at a depth of 34 to 60 ft. It is a noncalcareous, homogenous, sticky, blue-gray clay with detrital wood and a few foraminifera tests. X-ray diffraction indicated the primary clay mineral to be kaolinite.

Clay beds in the other 22 auger holes are thin; only one exceeds 9 ft in thickness. This clay, from PAH-2 near Hell Hole Bay, is within 2 ft of the surface and is 18 ft thick. In slow-firing tests, the upper 14 ft of clay (Sample 13-14 from PAH-2) showed good firing qualities with a firing range of 1,100-1,250° C, indicating suitability for structural clay products (table 2). Samples 2 (PAH-4), 10 (PAH-7), and 16 (PAH-2) (table 2) also fired successfully, but none of these clay beds exceeded 6 ft in thickness at the sample site. In testing the clays for use in expanded lightweight aggregate, only sample 16 (PAH-2) showed good bloating qualities (table 2).

These clay beds, laid down in fluvial, estuarine, and tidal environments, tend to form irregular deposits varying in thickness over short distances and are often limited in extent. Additional augering would be necessary to define the size and determine thickness variations of the clay deposits.

Uranium

Uranium is present in the phosphatic material of the Charleston-area deposits. Its percentage is directly related to the phosphate content of the sediments. Force and others (1978) calculated that zones of secondary phosphate enrichment associated with the Cooper Formation average 60 parts per million (ppm) uranium.

Five auger-hole samples from two sites adjacent to Little Wambaw Swamp (PAH-20 and PAH-21) yielded from 33 to 123 ppm uranium, well below the 200 ppm currently considered the lowest grade economically feasible to mine from easily leached deposits (Cameron and others, 1979). Deposits in Little Wambaw Swamp, besides being low grade, average only 3 ft thick and are overlain by 40 to 60 ft of overburden.

Limestone

Both the Santee Limestone and Cooper Formation have been quarried in South Carolina for various uses. At present, the Santee is being quarried for agricultural lime and crushed stone near Jamestown, S.C., and for cement near Harleyville,

Table 1.—*Analyses of peat samples from hand-augered core.*

Sample No.	Ash (Percent dry weight basis)	pH	Moisture (Percent as received)	Peat type
CC82-1	8.28	4.25	86.09	Humus
CC82-2	9.24	3.95	88.64	Humus

[1]Analyst - R. Moore, USGS Laboratories, Reston, Va.

Table 2.--*Evaluation of clay samples, Hell Hole Bay and Wambaw Creek Wildernesses.*

[Testing performed by the U.S. Bureau of Mines, Tuscaloosa Research Center, Tuscaloosa, Ala.]

Sample number	Power-auger hole number	Sample depth (feet)	Raw properties	Slow-fire tests: Temp. °C	Munsell color	Moh's hardness	Linear shrinkage (percent)	Absorption (percent)	Apparent porosity (percent)	Bulk density gm/cc	Potential use
13-14	PAH-2	2-16	Water of plasticity: 26.7% Working properties: plastic Drying shrinkage: 5.0% Dry strength: good pH: 4.9 HCl effervescence: none	1000	5 YR 7/8	3	5.0	22.5	37.3	1.66	Structural clay products (e.g., building brick at 1100-1250°C). Good firing range.
				1050	5 YR 7/6	3	7.5	19.5	3.9	1.73	
				1100	5 YR 6/8	4	7.5	17.0	30.9	1.81	
				1150	5 YR 6/8	4	7.5	16.1	29.6	1.84	
				1200	2.5 YR 4/8	5	10.0	14.3	26.9	1.88	
				1250	2.5 YR 4/4	5	10.0	11.1	22.1	1.99	
16	PAH-2	29-33	Water of plasticity: 31.1% Working properties: plastic Drying shrinkage: 5.0% Dry strength: good pH: 4.8 HCl effervescence: none	1000	5 YR 6/8	3	5.0	27.8	42.1	1.52	Structural clay products (e.g., building brick at 1200-1250°C).
				1050	5 YR 6/8	3	7.5	23.9	38.4	1.61	
				1100	5 YR 5/8	3	7.5	22.3	6.8	1.65	
				1150	2.5 YR 5/8	3	7.5	21.7	36.3	1.67	
				1200	2.5 YR 4/6	4	10.0	17.7	31.4	1.78	
				1250	2.5 YR 4/4	5	12.5	12.6	24.8	1.97	
2	PAH-4	9-13	Water of plasticity: 31.2% Working properties: plastic Drying shrinkage: 5.0% Dry strength: good pH: 6.6 HCl effervescence: none	1000	7.5 YR 7/8	3	5.0	28.6	42.9	1.50	Structural clay products (e.g., building brick at 1200-1250°C).
				1050	7.5 YR 7/8	3	7.5	25.1	39.6	1.58	
				1100	7.5 YR 7/8	3	10.0	22.7	37.4	1.65	
				1150	7.5 YR 6/10	3	10.0	22.1	36.6	1.66	
				1200	7.5 YR 6/8	4	10.0	18.2	31.9	1.76	
				1250	7.5 YR 6/6	4	10.0	14.6	27.0	1.85	
10	PAH-7	5-11	Water of plasticity: 18.9% Working properties: short Drying shrinkage: 5.0% Dry strength: fair pH: 6.9 HCl effervescence: none	1000	7.5 YR 8/6	3	5.0	18.5	33.2	1.79	Structural clay products (e.g., building brick at 1250°C).
				1050	7.5 YR 8/6	3	5.0	18.2	32.6	1.79	
				1100	5 YR 7/6	3	5.0	17.1	31.4	1.83	
				1150	5 YR 6/10	3	5.0	17.1	31.3	1,83	
				1200	2.5 YR 5/8	3	5.0	14.5	27.3	1.89	
				1250	2.5 YR 4/4	4	7.5	12.7	24.6	1.94	

Sample number	Power-auger hole number	Sample depth (feet)	Preliminary bloating test: Temp. °C	Absorption (percent)	Bulk density (gm/cc)	Bulk density (lb/ft)	Remarks	Potential use
16	PAH-2	29-33	1050	15.5	1.48	92.4	No expansion	Lightweight aggregate at 1150°C.
			1100	14.0	1.32	82.4	Slight expansion	
			1150	14.2	.91	56.8	Good pore structure	

S.C., about 50 mi west of the wildernesses. In the past, the Cooper has been used in the manufacture of cement and, in places, its magnesium content may make it valuable as a source of agricultural lime. Neither the Santee nor the Cooper is exposed in or near the wilderness areas. The Santee is within 10 to 25 ft below the surface in Hell Hole Bay and Wambaw Creek Wildernesses. Overburden in Wambaw Swamp and Little Wambaw Swamp is at least 50 ft thick. Both the Santee and the Cooper are more accessible elsewhere in the region.

Sand

Large deposits of well-sorted sand of marine origin occur at the surface in the barrier bars adjacent to the wildernesses, but within the wilderness boundaries the sands are interbedded with lagoonal and swamp-deposited clays and organic material. Some of the sand beds underlying the swamps are of fluvial origin (Colquhoun and others, 1972), and contain from 10 to 50 percent potassium feldspar (Cameron and others, 1979) which is of possible interest to the ceramics industry. However, since well-sorted, high-quality, easily assessible sand occurs throughout the coastal plain in both beach and fluvial deposits, the sands under the wildernesses are of little economic importance at this time.

Heavy Minerals

Heavy-mineral concentrations in beach sands are a major source of titanium and zircon, while a variety of other industrial minerals are recovered as byproducts. Both the USBM and private companies have drilled the South Carolina Coastal Plain in search of heavy-mineral concentrations, but mining ventures have not been successful.

Available drilling information from the vicinity of the wildernesses indicates that heavy minerals are concentrated to less than 3 percent of the total sand and many of the concentrated heavy minerals are not of economic value. Florida deposits presently being mined have heavy-mineral concentrations of 3.5 to 4.5 percent with about 45 percent of the concentrate being titanium minerals (ilmenite and rutile), plus large percentages of zircon and varying amounts of other economically valuable minerals (Calver, 1957).

Drilling of eight holes by the USBM near Wambaw Creek Wilderness in the 1950's indicated that the average heavy-mineral content was 2.9 percent (Williams, 1967). The amount of ilmenite in the heavy-mineral concentrate from one hole was reported as 41 percent. This high value for ilmenite has not been substantiated by more recent drilling in the area (Arthur H. Maybin, South Carolina Division of Geology, oral commun., 1982), and exact locations of the eight holes are not available.

Results of mineral determinations for three auger holes near the Little Wambaw Swamp Wilderness show the concentration of heavy minerals as less than 3 percent (table 3). Titanium minerals make up 14 percent of the heavy-mineral concentrate (12 percent ilmenite and 2 percent rutile); the major minerals, hornblende and epidote, are not of economic value. Analysis of samples from power-auger sites at Wambaw Swamp, Wambaw Creek, and Hell Hole Bay confirmed the absence of economical heavy-mineral concentrations (table 4).

Oil and Gas

Oil and gas have never been produced in South Carolina. Rodehamel (1979) assessed the probability of discovering commercial quantities of hydrocarbons as low. He stated, in part, that sedimentary layers on the coastal plain are thin, that the area lacks adequate source beds, and that suitable traps are unknown.

Seismic studies suggest that sedimentary rocks may underlie crystalline rock in the core of the southern Appalachians west of the wilderness areas (Harris and Bayer, 1979; Cook and others, 1979). The crystalline rock, formerly considered to be in-place basement rock, has recently been theorized to have been overthrust from the east. It has also been suggested that the concealed sedimentary strata are likely hydrocarbon traps and that they exist as far east as the present coastal plain (Cooke and others, 1979, 1980; Behrendt and others, (1981). This possibility has not yet been tested by deep drilling in the area.

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Table 3.--*Heavy minerals in Pliestocene sands of the Little Wambaw Swamp Wilderness.*

APPROXIMATE WEIGHT PERCENT OF HEAVY MINERALS (P .5%)

Drill site	Depth (feet)	Heavy minerals (p 2.85) in weight percent	"Ilmenite"*	Magnetite	Amphibole +Pyroxene	Epidote	Garnet	Staurolite	Sulfides	Phosphate	Zircon	Sillimanite	Rutile
PAH-14	25.0-27.5	0.7	8	1	20	30	3	8	4	P	-	3	P
PAH-14	38.0-40.0	0.9	6	1	20	30	5	9	7	P	P	4	2
PAH-20	0-17	0.8	5	1	20	30	P	12	-	1	2	4	2
PAH-23	5.0-9.0	2.7	10	P	30	15	2	4	-	P	P	5	1
PAH-23	25.5-26.0	1.7	12	P	25	20	2	7	1	1	2	2	2
PAH-23	55.0-60.0	1.1	9	P	30	25	5	7	3	3	P	P	P
PAH-23	64.0-69.0	2.0	5	P	30	25	2	5	2	4	2	2	2

*"Ilmenite" is defined by magnetism, density, color, and opacity, but consists mostly of alteration products.

Table 4.--*Heavy minerals in Pliestocene sands of the Wambaw Swamp, Wambaw Creek, and Hell Hole Bay Wildernesses.*

Drill site*	Depth (feet)	Heavy minerals (S.G. 2.85) in weight percent	Mineralogy[1] (shown in order of decreasing abundance)
PAH-1	12-19	0.14	Amphibole, epidote, sillimanite, ilmenite, staurolite, garnet, rutile, zircon
PAH-3	0-3	2.54	Amphibole[2], epidote, ilmenite[3], staurolite, sillimanite[4], zircon, rutile
PAH-3	19-22	0.10	Limonite, amphibole, ilmenite, sillimanite, epidote, zircon, rutile
PAH-5	2-5	0.03	Sillimanite, ilmenite, epidote, amphibole, staurolite, rutile, zircon
PAH-7	11-20	0.92	Amphibole, epidote, sillimanite, ilmenite, staurolite, rutile, zircon, sulfides
PAH-9	0-5	1.27	Ilmenite, epidote, sillimanite, staurolite, amphibole, tourmaline, zircon, rutile
PAH-9	11-21	0.30	Amphibole, epidote, ilmenite, sillimanite, staurolite, rutile, zircon, mica
PAH-9	28-41	0.05	Amphibole, epidote, sillimanite, staurolite, ilmenite, zircon, rutile
PAH-18	0-15.5	0.23	Amphibole, sillimanite, epidote, ilmenite, staurolite, tourmaline, zircon, rutile, mica
PAH-19	0-10	0.13	Amphibole, ilmenite, sillimanite, staurolite, epidote, rutile, zircon
PAH-19	10-14	0.38	Amphibole, sillimanite, ilmenite, epidote, staurolite, rutile, zircon
PAH-19	27-35	0.61	Amphibole, epidote, sillimanite, ilmenite, tourmaline, rutile, zircon, phosphate
PAH-19	35-40	1.04	Amphibole, epidote, sillimanite, tourmaline, ilmenite, staurolite, garnet, zircon, rutile
PAH-19	48-55	0.39	Amphibole, epidote, sillimanite, ilmenite, staurolite, garnet, zircon, rutile
PAH-22	0-7	1.20	Amphibole, epidote, sillimanite, staurolite, ilmenite, tourmaline, garnet, zircon, rutile
PAH-22	9-14	0.47	Epidote, amphibole, sillimanite, ilmenite, staurolite, tourmaline, zircon, mica, rutile
PAH-22	14.5-19	0.90	Amphibole, epidote, ilmenite, sillimanite, tourmaline, staurolite, mica, sulfides, zircon, rutile
PAH-24	0-13	0.60	Amphibole, epidote, sillimanite, ilmenite, staurolite, tourmaline, rutile, zircon
PAH-24	13-18	0.19	Amphibole, epidote, sillimanite, staurolite, ilmenite, mica, tourmaline, rutile, zircon
PAH-24	22-25	0.30	Amphibole, epidote, sillimanite, staurolite, mica, ilmenite, phosphate, tourmaline, zircon, rutile

*Power-auger holes drilled by Earl M. Lemon, Jr., USGS
Mineral separations by Cynthia M. Sears, USGS

1 All samples contain trace magnetite
2 Includes pyroxene
3 Ilmenite is defined by magnetism, density, color, and opacity, but consists mostly of alteration products.
4 Includes kyanite

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