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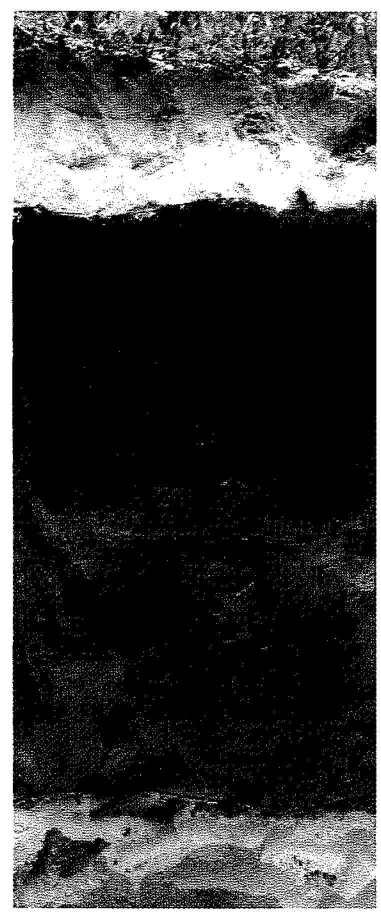

SPODOSOLS in Mississippi

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The photographs on the front cover show typical forest vegetation and an exposed Spodosol soil profile in the Coastal Flatwoods of Jackson County, Mississippi.

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Spodosols in Mississippi

Although soil surveys have been underway in Mississippi since the beginning of the 20th century, Spodosol soils have not been previously identified in the state. Spodosols are extensive in the eastern Gulf Coast Flatwoods of Florida (Major Land Resource Area 152A), but their occurrence in the western Gulf Coastal Plain has not been recognized. These soils were recognized in coastal Baldwin County, Alabama, but not in adjacent Mobile County, Alabama, which extends along the Gulf of Mexico and borders Mississippi.

Spodosols have been referred to as "white earths" and ground-water podzols in the past (Buol et al., 1989; Jenny, 1980). Spodosols are acid, sandy, mineral soils, which contain an illuvial subsurface horizon (spodic) with an accumulation of organic matter and sesquioxides (Soil Survey Staff, 1994; Brady, 1984; Jenny, 1980). The dark-colored spodic horizon usually occurs under a leached, light-colored horizon (albic), presenting a striking appearance. Buol et al. (1989) described Spodosols as the most eye-catching and photogenic soils in the world.

Spodosols occur in humid, temperate climates from near sea level to high elevation mountainous areas on several continents. Spodosols are estimated to comprise about 4.2% of the Earth's land area, but their extent may be declining under the impact of human disturbance by fire, logging, and agriculture (Buol et al., 1989). They comprise large areas in the northeastern and southern United States, Canada, Europe, Siberia, and also occur in South America and New Zealand (Buol et al., 1989). Spodosols are extensive in the southern Atlantic Coastal Plain and comprise about 6 million acres in Florida (Brassfield et al., 1983). They also occur in coastal regions of Georgia, South Carolina, North Carolina, and Virginia.

Forests are the dominant natural vegetation under which Spodosols have developed (Brady, 1984). The soils are associated with flora that are tolerant of high acidity and low nutrient levels (Jenny, 1980). Hemlock, pine, cypress, blueberry, rhodendron, and palmetto vegetation are commonly associated with Spodosols in the United States. In New Zealand, the Kauri pine (*Agathis australis*) is a well-known plant indicator of Spodosols (Jenny, 1980).

The subsurface spodic horizon is the critical feature necessary for a soil to be classed as a Spodosol. It is defined as an illuvial layer more than one inch thick, which contains 85% or more spodic materials (Soil Survey Staff, 1994). Spodic materials contain active amorphous organic matter and aluminum, with or without iron. The term "active" describes materials that have a high pH-dependent charge, a large surface area, and high water retention. Spodic horizons have been commonly referred to as "hardpans" in the past (Sellards and Gunter, 1910; Peech, 1939).

This report concerns the recognition and characterization of well-developed Spodosols in Jackson County, Mississippi.

The Setting

Jackson County is located in the southeastern part of the state (Figure 1). The county is bordered on the south by the Gulf of Mexico and on the east by Mobile County, Alabama. Elevations increase from sea level in the south to about 180 feet in the north. The Pamlico Scarp runs east-west in the county, dividing the coastal flatwoods in the south from the highland section in the north (Minshew et al., 1974). The coastal flatwoods range in elevation from about 10 to 40 feet above mean sea level and they are considered to be of Pleistocene age. The highlands are underlain by undifferentiated Tertiary and Citronelle (Pleistocene) fluvial-deltaic sands, silts, and clays (Minshew et al., 1974). The Pascagoula Formation is the oldest stratigraphic unit exposed in the county and is considered Miocene in age (Minshew et al., 1974). Younger coastal units overlie the Miocene units, which form the "basement" of the coastal area (Otvos, 1982). The flatwoods area is nearly level, with ill-defined surface drainage and scattered drainageways and swales. The highland region is dissected with well-defined dendritic drainage.

The Pascagoula and Escatawpa Rivers provide major drainage in the county, flowing from north to south (Figure 1). The Escatawpa River joins the Pascagoula River near Moss Point in the southern part of the county and they drain into the Gulf of Mexico.

Jackson County has a humid, subtropical climate with hot summers and mild winters (Cole and Dent, 1964). Average rainfall ranges from 58 inches on the coast to 73 inches in the interior. The average annual temperature is about 68 °F. The waters of the Mississippi Sound stabilize the temperature along the coast and inland about 10 miles. Soil temperatures are in the thermic range (59° to 72 °F).

Methods

Soils were described and sampled using standard methods (Soil Survey Staff, 1984). Particle-size distribution was determined by the hydrometer method and sieving (Day, 1965). Soil bulk density was determined on nondisturbed cores taken with a double cylinder sampler (Blake, 1965). Saturated hydraulic conductivity was determined on nondisturbed cores using the constant head method (Klute, 1965). Soil penetration resistance was measured with a recording penetrometer.

Soil organic matter was determined by wet combustion (Allison, 1965). Extractable acidity was determined by the

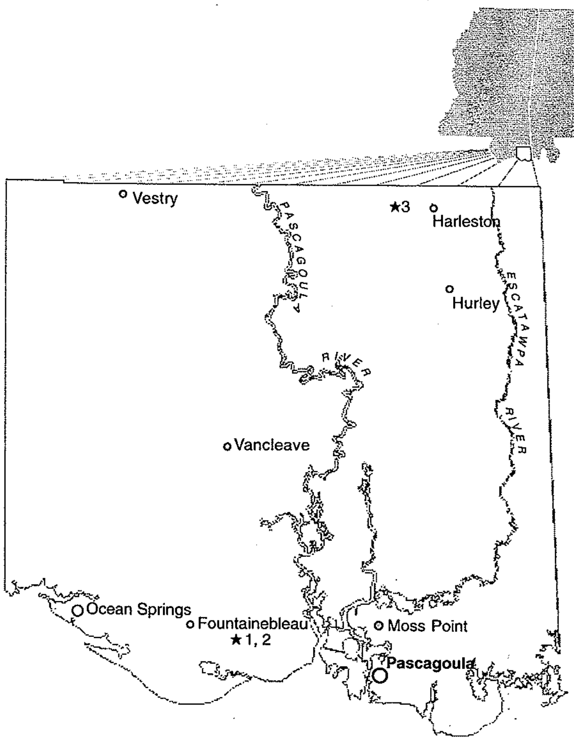

Figure 1. Location of study area.

$BaCl_2$-triethanolamine method (Peech, 1965). Cations were extracted with M NH_4OAC (pH 7.0) and determined by atomic absorption spectrophotometry. Exchangeable Al^{3+} was extracted with M KCl and determined by titration (Yuan, 1959). Soil pH was measured in a 1:1 soil/water suspension. Iron was fractionated using the method of Gamble and Daniels (1972). Total P contents were analyzed by HF and $HClO_4$ digestion in Platinum crucibles (Jackson, 1982).

Humic/fulvic acid compounds were determined by color ratio at 400 and 600 nm on 0.5 M NaOH extracts using a spectrophotometer (Tan and Giddens, 1972). Selected heavy metals (trace metals) were determined using the Environmental Protection Agency (EPA) method 3050 (EPA, 1989) and expressed on an oven-dry soil basis.

Surface detritus was measured in May 1992 in random 40-inch^2 (1 m^2) blocks and dried at 65 °C for 72 hours to determine dry weight. The dried plant material was ground to pass a 20-mesh screen and ashed at 500 °C for 4 hours, treated with 5 M HNO_3 and dried at 390 °C. The ash was taken up in 6 M HCl, diluted with distilled H_2O, and cations were determined by atomic absorption spectrophotometry. Nitrogen was determined by the Kjeldahl method (Bremner, 1960). Phosphorus was determined by the method of Olsen and Sommers (1982). Soil water was collected by pump in fresh auger holes (2.75-inch diameter). Cation concentrations in soil water samples were determined by atomic absorption spectrophotometry. Silicon in soil water was determined by the blue silicomolybdous acid procedure (Hallmark et al., 1982); and, electrical conductivity was measured with a conductivity meter.

Results and Discussion

Location

Spodosols were identified and studied in two diverse landscapes in Jackson County. One area was located near Fontainebleau, about 0.5 mile from the Gulf of Mexico at an elevation about 15 feet above sea level in the nearly level coastal flatwoods (Figure 1). The second area was located about 29 miles north of the Gulf near Harleston at an elevation about 100 feet above sea level in the dissected highland section of the county. Both areas are somewhat poorly drained with slope gradients of 0 to 2%.

Two pedons were studied in the southern site about 50 yards apart, with one adjacent to a drain (Pedon 2) and the other (Pedon 1) at a slightly higher position. The northern site (Pedon 3) was in a seep position at the base of two ridges.

Vegetation

The sites have dense mixed forest vegetation. The southern area contained live oak (*Quercus infectoria* Olivier), water oak (*Q. nigra* L.) loblolly pine (*pinus taeda* L.), palmetto [*Satal palmetto* (Walter) Schultes & Schultes f.], blueberry [*Vaccinium atrococcum* (A. Gravy) A.A. Heller], and bracken fern [*Pteridium aquilinum* (L.) Kuhn]. The northern site had water oak (*Q. nigra* L.), bay (*Laurus nobilis* L.), water tupelo (*Nyssa equatica* L.), wax myrtle (*Myrtus communis* L.), palmetto, and bracken fern. Acidophyllic brackenfern, wax myrtle, and palmetto comprised a very dense understory at both the northern and southern study areas.

The vegetation is tolerant to soil acidity and low nutrient status and is typical of the vegetative cover reported for Spodosols (Jenny, 1980; Buol et al., 1989). Previous studies indicate a strong relationship between acidophyllic vegetation and the occurrence of Spodosols (Buol, et al., 1989; Edelman, 1950; Jenny, 1980). Milfred et al. (1967) reported that removal of hemlock trees in northern Wisconsin resulted in fading of the spodic horizons in Spodosols. The estimated half-life for dissipation of spodic horizons was about 100 years following hemlock removal.

Jenny (1980) helped establish a preserve for Spodosols in a unique pigmy forest ecosystem in California to prevent the forest ecosystem from becoming extinct. The replenishment of organic compounds in the spodic horizon by surface vegetation appears to be a critical component of Spodosol genesis and persistence.

Morphology

Thick, matted organic detritus layers occurred at the soil surface at both study areas. A layer (Oi) of grayish brown leaves, twigs, and pine needles occurred from 2 inches to 1 inch above the mineral soil with an underlying reddish-brown layer (Oe) of partially decomposed detritus forming a dense fibrous mat from 1 inch to the mineral soil surface (Tables 1, 2, 3).

Table 1. Pedon description of Spodosol site 1, southern Jackson County. MS

(Moist Colors)

Oi — +2 to 1 inch; fresh leaves, twigs, acorns, and pine needles, loose at surface and matted at bottom of layer; abrupt smooth boundary.

Oe — +1 to 0 inch; reddish-brown (5YR 4/3) partially decomposed, fragmented detrirus with dense fibrous root mat of very fine to medium roots; abrupt smooth boundary.

A — 0 to 5 inches; very dark gray (10YR 3/1) sand; single grained; loose; few fine roots; abrupt smooth boundary.

E — 5 to 11 inches; gray (10YR 5/1) sand; single grained; loose; few fine roots; abrupt smooth boundary.

Bh_1 — 11 to 21 inches; dark brown (7.5YR 3/2) loamy sand; massive; firm; few fine roots; gradual smooth boundary.

Bh_2 — 21 to 27 inches; yellowish-brown (10YR 5/6) loamy sand; massive; firm; few fine roots; gradual smooth boundary.

Bh_3 — 27 to 36 inches; yellowish-brown (10YR 5/6) loamy sand; single grained; loose; common white (10YR 8/1) uncoated sand grains; gradual irregular boundary.

Bh_4 — 36 to 42 inches; yellowish-brown (10YR 5/8) sand; single grained; loose; many uncoated sand grains; gradual irregular boundary.

BC — 49 to 57 inches; light yellowish-brown (10YR 6/4) sand; single grained; loose; many uncoated quartz sand grains; gradual smooth boundary.

C — 57 to 72 inches; pale-brown (10YR 6/3) sand; single grained; loose; many uncoated sand grains; common very fine black (10YR 2/1) masses.

Table 2. Pedon description of Spodosol site 2, southern Jackson County, MS.

(Moist Colors)

Oi — +2 to 1 inch; fresh leaves, twigs, acorns, and pine needles; loose at surface and matted at bottom of layer; abrupt smooth boundary.

Oe — +1 to 0 inches; dark brown (10YR 4/3) and reddish brown (5YR 4/3) partially decomposed, dense fibrous root mat of very fine, medium, and coarse roots; abrupt boundary.

A — 0 to 4 inches; black (10YR 2/1) sand; weak fine granular structure; friable; common uncoated sand grains; many fine and medium roots; clear smooth boundary.

E — 4 to 11 inches; light gray (10YR 7/2) sand; single grained; loose; few fine roots; abrupt smooth boundary.

Bh — 11 to 36 inches; black (7.5 YR 2/0) loamy sand; massive; firm; gradual irregular boundary.

BC — 36 to 41 inches; strong brown (7.5YR 5/6) sand; massive; slightly firm; gradual wavy boundary.

C — 41 to 60 inches; white (10YR 8/2) sand; single grained; loose.

The partially decomposed Oe layer was bound by filamentous fungi and teeming with arthropods. The detritus layers were continuous over the Spodosols and tended to insulate the mineral surface horizons. Messenger et al. (1972) found high microbial populations in the mull humus of Spodosols in Michigan sands. Their research suggested surface organic horizons (0) are producers of water-soluble organic materials, which may be active agents in spodic horizon formation. Ugolini et al. (1977) found evidence of organic matter migration in Spodosols with particles as large as 0.5 to 1.5 mm diameter.

The soils exhibited similar morphology consisting of very dark gray to black surface horizons (A) overlying light gray to gray leached albic horizons (E) abruptly resting on dark brown to black spodic horizons (Bh) (Tables 1, 2, 3). The spodic horizons graded into lighter-colored BC or C horizons. The surface horizons (epipedons) ranged from 4 to 5 inches thick and were too thin to be classed as umbric epipedons. The leached, gray albic horizons (E) were 6 to 7 inches thick and were dominantly uncoated quartz grains. An abrupt, smooth boundary separated the gray albic horizon from the underlying dark-colored spodic horizon (Figure 2). In con-

Table 3. Pedon description of Spodosol site 3, northern Jackson County, MS.

(Moist Colors)

Oi — +2 to 1 inch; fresh leaves, twigs, and bark fragments; loose at surface and matted at bottom of layer; abrupt, smooth boundary.

Oe — +1 to 0 inches; reddish-brown (5YR 4/3), dark brown (10YR 4/3) and dark reddish-gray (5YR 4/2) partially decomposed detritus with dense root mat of very fine to medium roots; abrupt smooth boundary.

A — 0 to 5 inches; black (10YR 2/1) loamy sand; weak medium granular structure; very friable; common white (10YR 8/2) uncoated quartz grains; many fine and medium roots; clear smooth boundary.

E — 5 to 11 inches; light gray (10YR 7/2) sand; single grained; loose; common very fine black (10YR 2/1) coated quartz grains; few fine roots; abrupt smooth boundary.

Bh_1 — 11 to 15 inches; black (5YR 2.5/1) sand; massive; firm; few fine roots; gradual wavy boundary.

Bh_2 — 15 to 22 inches; dark reddish-brown (5YR 3/3) sand; massive; firm; common uncoated quartz grains; few fine roots; gradual irregular boundary.

Bh_3 — 22 to 31 inches; strong brown (7.5YR 4/6) sand with few medium distinct dark gray (10YR 4/1) streaks and many white (10YR 8/2) uncoated quartz grains; massive; slightly firm; gradual smooth boundary.

BC1 — 31 to 37 inches; dark brown (7.5YR 4/4) sand; single grained; loose; many uncoated quartz grains; gradual smooth boundary.

BC2 — 37 to 46 inches; brown (7.5YR 5/4) sand; single grained; loose; many uncoated quartz grains; abrupt smooth boundary.

C — 46 to 60 inches; light gray (10YR 7/2) sand; single grained; loose; few white (10YR 8/2) uncoated smooth concretions.

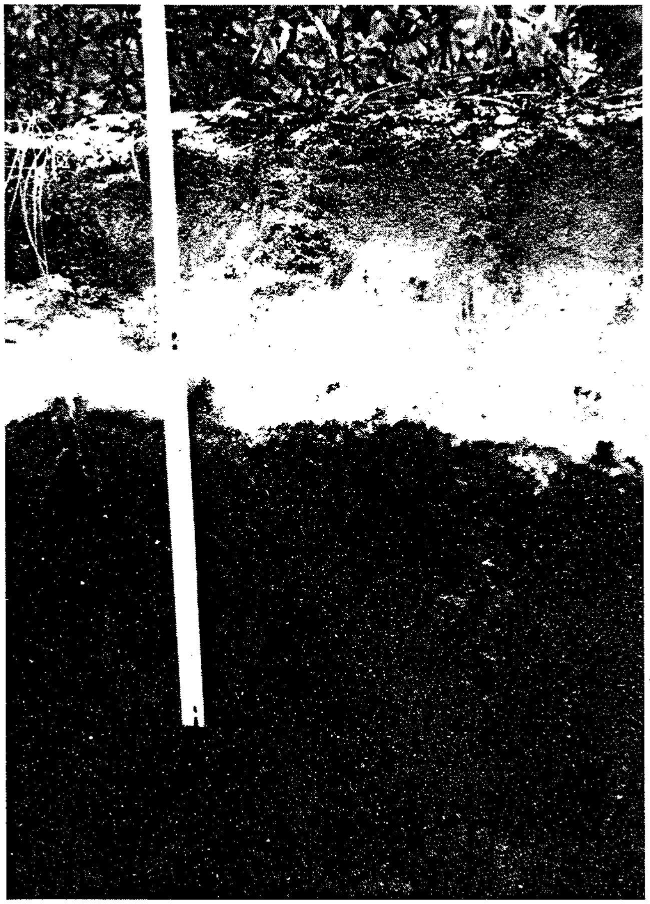

Figure 2. Photograph of Spodosol Site 3 showing the contrast of the spodic horizon.

trast, the lower boundary between the spodic and underlying BC or C horizons was generally irregular.

Spodic horizons occurred at 11 inches depth at all sites. Spodic horizons ranged in thickness from 20 inches in site 3 to 31 inches in site 1. Researchers reported some spodic horizons in North Carolina ranged as thick as 29 feet (Daniels et al., 1975). The spodic horizon at site 2 did not exhibit pronounced subhorizons similar to site 1, which was located about 50 yards distance at a slightly higher elevation. Multiple spodic horizons were encountered at site 3 at depths below 60 inches. The upper part of the spodic horizons was dark brown to black with Munsell hues of 7.5YR and 5YR and graded to lighter yellowish-brown and dark reddish-brown with increasing depth. Buol et al., (1989) reported upper spodic subhorizons were commonly black due to organic coatings of fulvic acids on quartz sand grains. Reporting on spodic horizons in the Netherlands, Edelman (1950) stated that spodic horizons were composed largely of quartz sand grains coated with humus if iron was not present in appreciable amounts.

Microscopic examination of the spodic horizons from the three sites revealed many of the coated sand grains had a cracked or wrinkled appearance in reflected light. Buol et al. (1989) reported the organic films around the sand grains become susceptible to cracking during droughts.

Soil structural development was weakly expressed in the Spodosol profiles (Tables 1, 2, 3). Surface horizons had weak fine to medium granular structure with friable consistency. Spodic horizons were massive and firm. The underlying C horizons were single grained and loose and lacked pedogenic development.

Physical Properties

Soil textures at the three sites were sand and loamy sand (Table 4). Medium sand (0.5-0.25 mm) dominated the sand fraction of all sites. Coarse sand (1.0 - 0.5 mm) content exceeded 20 percent in sites 2 and 3, but was less than 3 percent in site 1. Silt contents tended to decrease with increasing depths in all three profiles, with a maximum value of 11.5 percent in the spodic horizon (Bhl) of all sites. Maximum clay contents in the spodic horizons indicate clay accumulation (illuviation).

Soil bulk density increased in the spodic horizon with increasing depth (Table 5). Water movement was markedly reduced in the spodic horizon, with saturated hydraulic conductivity reduced from 13.3 inches per hour in the loose, sandy E (albic) horizon, to 0.05 inch per hour in the massive, firm Bhl (spodic) horizon of site 3 (Table 5). Although comprised of more than 90 percent sand, the spodic horizon

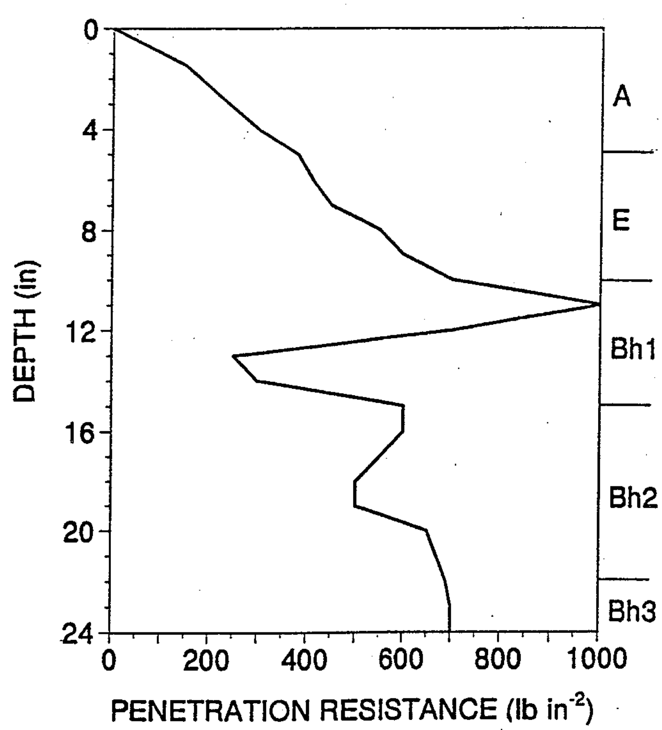

Figure 3. Soil penetration resistance of Spodosol at Site 3.

drastically reduced water movement. The continuous organic coating of sand grains tended to bind or cement the spodic horizon into a massive body with few interconnected, continuous pores.

Saturated hydraulic conductivity increased markedly in the underlying C horizon. Pettry et al., (1965) reported drastic reduction of nonsaturated hydraulic conductivity in spodic horizons of similar Spodosols in Florida. Early workers (Jones et al., 1948) reported the "hardpan" (spodic horizon) of Leon soils in Florida was relatively impervious to water. The restricted water movement in the Bh horizons could perch the water and induce horizontal flow.

Maximum soil penetration resistance occurred in the upper part of the spodic horizon as shown in Figure 3 for site 3. Values exceeded 1,000 lb/in^2 in the upper 3 inches of the spodic horizon when measured at field moisture conditions slightly below field capacity. Previous research on similar Florida Spodosols also showed high penetration resistance in the upper spodic horizon with values exceeding 1,000 lb/in^2 (Pettry et al., 1965).

Table 5. Soil bulk density and saturated hydraulic conductivity of Site 3.

Depth	Horizon	Bulk Density	Hydraulic Conductivity
(in)		(g/cc)	(in/hr)
0-5	A	1.15	6.80
5-11	E	1.56	13.30
11-15	Bh1	1.68	0.05
31-46	BC	1.74	0.36
46-60	C	1.76	10.40

Chemical Properties

Detritus contents (O horizons) indicated a large organic flux (Table 6) and nutrient biocycling. Carbon/nitrogen ratios decreased from the Oi horizons to the partially decomposed Oe horizons, which contained higher N levels. Calcium and magnesium contents in the undecomposed Oi horizons were

Table 4. Particle size distribution of Spodosol profiles at sites.

Pedon	Horizon	Depth (inches)	Particle-size distribution								
			Very coarse sand (2.0-1.0mm)	Coarse sand (1.0-0.5mm)	Medium sand (0.5-0.25mm)	Fine sand (0.25-0.10mm)	Very fine sand (0.10-0.05mm)	Total sand (2.0-0.05mm)	Silt (0.05-0.002mm)	Clay (<0.002mm)	Textural Class
1	A	0-5	0.54	2.91	80.53	5.71	0.50	90.19	7.78	2.03	SAND
	E	5-11	0.05	1.49	78.84	9.53	0.52	90.43	7.56	2.01	SAND
	Bh1	11-21	0.02	1.08	71.86	9.28	0.49	82.73	9.66	7.61	LOAMY SAND
	Bh2	21-27	0.00	1.13	73.15	8.75	0.47	83.50	8.40	8.10	LOAMY SAND
	Bh3	27-36	0.00	1.12	75.67	8.13	0.31	85.23	5.15	9.62	LOAMY SAND
	Bh4	36-42	0.18	1.94	74.92	12.68	0.36	90.08	2.34	7.58	SAND
	BC	42-49	0.02	1.92	79.33	14.63	0.26	96.16	0.06	3.78	SAND
	C1	49-57	0.04	2.26	79.26	15.57	0.15	97.28	0.21	2.51	SAND
	C2	57-72	0.03	1.39	66.81	29.69	0.16	98.00	0.00	2.00	SAND
2	A	0-4	4.81	42.28	37.34	4.76	0.41	89.60	7.84	2.56	SAND
	E	4-11	1.24	21.97	45.34	20.83	6.00	95.38	4.12	0.50	SAND
	Bh	11-36	1.58	24.99	37.95	16.83	4.08	85.43	11.55	3.02	LOAMY SAND
	BC	36-41	1.85	21.48	39.81	22.72	5.07	90.93	7.81	1.26	SAND
	C	41-60	1.99	30.52	56.13	7.63	1.00	97.27	2.23	0.50	SAND
3	A	0-5	3.37	35.26	37.38	9.61	1.00	86.62	10.82	2.56	LOAMY SAND
	E	5-11	1.75	26.36	42.37	20.89	4.46	95.83	2.92	1.25	SAND
	Bh1	11-15	1.52	25.17	41.97	18.08	3.67	90.41	6.55	3.04	SAND
	Bh2	15-22	1.40	24.67	43.66	18.83	3.40	91.96	5.52	2.52	SAND
	Bh3	22-31	1.42	24.23	41.68	20.88	4.09	92.30	4.69	3.01	SAND
	BC1	31-37	1.94	21.19	45.07	22.89	3.27	94.36	3.13	2.51	SAND
	BC2	37-46	0.91	26.94	57.76	10.90	0.56	97.07	0.93	2.00	SAND
	C	46-60	1.31	30.66	58.35	7.30	0.62	98.24	1.26	0.50	SAND

considerably higher than underlying Oe horizons. In contrast, phosphorus contents were greater in the partially decomposed Oe horizons where some concentration had occurred as coarse detritus was broken down to smaller fragments. Glen (1964) previously reported extensive plant nutrient recycling in Ultisols of the area.

The Spodols were extremely acidic, with pH values ranging from 3.5 to 3.7 in surface horizons and 3.9 to 5.0 in the subsoil (Table 7). Organic matter contents were highest in the surface horizons, which were rich in detritus, with a second maxima occurring in the spodic horizons (Table 7). Exchangeable cations (plant nutrients) were concentrated in the surface horizons and rapidly diminished with depth, reflecting the intense biocycling and retention by vegetation.

Exchangeable calcium was highest in the surface horizon at all three sites and none was detected below the A horizon

Table 6. Surface detritus contents and nutrient concentrations*.

Site	Horizon	Depth	Detritus	C	N	C/N	Ca	Mg	K	Na	P
		inches	lbs/acre	%	%		mg/kg (ppm)				
1	Oi	2-1	21,521	47	0.91	52	11,151	1,103	1,137	285	376
1	Oe	1-0	25,941	44	1.05	42	6,996	752	1,333	258	457
3	Oi	2-1	16,699	48	0.84	57	10,139	1,177	1,117	247	268
3	Oe	1-0	40,542	43	1.09	39	7,833	1,093	928	306	350

* Sampled May 1992.

Table 7. Selected chemical characteristics.

Site	Horizon	Depth	pH	Organic Matter	Exchangeable Cations Ca	Mg	K	Na	Acidity	Cation Exchange Capacity
		inches		%	$cmol_c kg^{-1}$					
1	A	0-5	3.7	4.8	0.21	0.34	0.07	0.01	14.08	14.71
	E	5-11	3.9	1.2	0.03	0.08	0.02	0.01	4.31	4.45
	Bh1	11-21	4.3	1.9	0.01	0.04	0.02	0.01	12.26	12.34
	Bh2	21-27	4.4	1.1	—	0.02	0.05	0.01	7.96	8.04
	Bh3	27-36	4.5	0.5	0.01	0.03	0.02	0.01	5.42	5.49
	Bh4	36-42	4.5	0.5	—	0.01	0.02	—	4.91	4.94
	BC	42-49	4.3	1.1	—	0.02	0.01	0.01	6.23	6.27
	C1	49-57	4.2	0.7	—	0.03	0.01	0.01	3.47	3.52
	C2	57-72	4.4	0.3	—	0.01	0.01	0.01	1.23	1.26
2	A	0-4	3.5	14.6	0.40	0.93	0.11	0.05	24.07	25.56
	E	4-11	4.4	0.3	0.01	0.02	—	—	0.63	0.66
	Bh	11-36	3.9	2.6	—	0.01	0.01	0.01	9.83	9.86
	BC	36-41	4.4	0.8	—	—	0.01	—	3.71	3.72
	C	41-60	4.5	0.0	—	—	—	0.01	0.11	0.12
3	A	0-5	3.7	13.3	0.42	1.03	0.11	0.03	30.61	32.20
	E	5-11	4.5	0.1	—	0.01	—	—	0.52	0.53
	Bh1	11-15	4.0	3.7	—	0.01	0.01	—	15.28	15.30
	Bh2	15-22	4.2	2.1	—	0.01	0.01	—	9.67	9.69
	Bh3	22-31	4.3	1.1	—	—	0.01	—	5.66	5.67
	BC1	31-37	4.5	0.6	—	—	—	—	3.55	3.55
	BC2	37-46	4.5	0.4	—	—	0.01	—	2.08	2.09
	C	46-60	5.0	0.0	—	—	—	—	0.19	0.19

— Not Detected

at site 3. All horizons had very low sodium levels indicating little influence from sea spray at sites located one-half mile from the Gulf of Mexico. Higher acidity levels in the surface and spodic horizons reflect the higher organic matter contents and leaching conditions.

Exchangeable aluminum levels were highest in surface and spodic horizons (Table 8). The soils had high aluminum saturation, which ranged to 83.3% in the C horizon of site 2. Iron contents were low at the three sites. Oxalate extractable (amorphous) and dithionite extractable (crystalline) iron were highest in the Bh horizon of pedon 1, which had the highest clay content. The optical densities at 410 nm of oxalate extracts had B/A horizon ratios exceeding 1 (Table 9), which New Zealand research (Daly, 1982) showed were diagnostic for spodic horizons. The free iron to clay ratios were not constant with depth (Table 8) but tended to increase and reach a maximum in the spodic horizon of site 1, which had higher clay contents than sites 2 and 3.

Total P was low in all the pedons studied (Table 8). Higher P levels in the A horizons of sites 2 and 3, which contained higher organic matter contents, indicated surface concentration and biocycling. Phosphorus fractionation of the site 3 pedon indicated organic-P comprised greater than 50% of the total-P in the A and Bh horizons with the proportion decreasing with increasing depth (Table 10).

Table 9. Acid ammonium oxalate extract optical density ratio of B/A horizons of Sites 1 and 3.

Site	Horizon	Depth	Optical Density Oxalate Extract B/A Horizons
		inches	
1	Bh1	11-21	1.42
	Bh2	21-27	1.04
	Bh3	27-36	1.07
	Bh4	36-42	1.53
3	Bh1	11-15	1.17
	Bh2	15-22	1.63
	Bh3	22-31	1.47

Table 8. Exchangable Al and percent saturation of cation capacity, and iron fractions of Spodosols.

Site	Horizon	Depth	Total P	Exchangeable Al	Al Saturation	Oxalate Fe	Dithionite Fe	Free Fe/ Clay
		inches	ppm	cmol kg^{-1}	%	---------- PPM ----------		
1	A	0-5	43	2.89	19.6	0.24	0.11	0.05
	E	5-11	26	1.34	30.1	0.09	0.10	0.05
	Bh1	11-21	59	3.02	24.5	1.77	1.30	0.17
	Bh2	21-27	62	1.52	18.9	0.33	1.30	0.16
	Bh3	27-36	70	1.55	28.2	0.23	1.87	0.19
	Bh4	36-42	94	1.19	24.1	0.65	4.07	0.53
	BC	42-49	40	1.67	26.6	0.04	0.23	0.06
	C1	49-57	34	1.15	32.7	0.05	0.10	0.04
	C2	57-72	21	0.43	34.1	0.02	0.04	0.02
2	A	0-4	66	3.78	14.8	0.18	0.04	0.01
	E	4-11	10	0.22	33.3	0.01	0.04	0.08
	Bh	11-36	18	2.77	28.1	0.01	0.04	0.01
	BC	36-41	21	0.92	24.7	0.02	0.04	0.03
	C	41-60	13	0.10	83.3	0.01	0.04	0.08
3	A	0-5	71	3.86	11.9	0.14	0.03	0.01
	E	5-11	7	0.14	26.4	0.01	0.04	0.03
	Bh1	11-15	19	3.35	21.9	0.01	0.05	0.02
	Bh2	15-22	18	2.42	24.9	0.01	0.03	0.01
	Bh3	22-31	21	1.40	24.7	0.01	0.03	0.01
	BC1	31-37	18	0.85	23.9	0.01	0.02	0.01
	BC2	37-46	13	0.60	28.7	0.00	0.02	0.01
	C	46-60	10	0.07	36.8	0.01	0.03	0.06

Table 10. Organic P and proportion of total P for Site 3.

Horizon	Depth	Organic P	Organic P Percent of Total P
	inches	ppm	%
A	0-5	57.6	80
E	5-11	1.2	17
Bh1	11-15	12.9	69
Bh2	15-22	12.1	65
Bh3	22-31	9.3	44
BC1	31-37	7.3	39
BC2	37-46	4.0	31
C	46-60	2.6	25

Heavy metal contents were extremely low in pedon 1 near sea level and pedon 3 at 100 feet elevation (Table 11). Iron was the most abundant metal, with maximum contents occurring in the spodic horizon of site 1. The higher Fe levels of site 1 coincide with higher clay contents. No Cd was detected at either location. The extremely acid conditions and high leaching environment are conducive for removal of heavy metals.

The color ratio value [E_4/E_6 = (extinction 400 nm/extinction 600 nm)] of the NaOH extract was determined to characterize the organic materials coating quartz sand grains. According to research by Tan (1972), a color ratio <7 corresponds to humic acids and related compounds with high molecular weights, while greater values correspond to fulvic acid groups. Color ratio values of NaOH extracts increased in the spodic horizons (Bh) of sites 1 and 3, suggesting an increase in fulvic acid content (Table 12) when compared to the A horizon.

Table 12. Color ratio values [E_4/E_6 = Extinction 400 nm/extinction 600 nm] of NaOH extracts of pedons at Sites 1 and 3.

Site	Depth	Horizon	Color ratio value
	inches		
1	0-5	A	4.2
	5-11	E	3.6
	11-21	Bh1	4.3
	21-27	Bh2	5.1
	27-36	Bh3	6.3
	36-42	Bh4	5.3
	42-49	BC	5.0
	49-57	C1	3.5
	57-72	C2	3.7
3	0-5	A	3.9
	5-11	E	3.3
	11-15	Bh1	5.0
	15-22	Bh2	6.1
	22-31	Bh3	7.0
	31-37	BC1	7.7
	37-46	BC2	6.7
	46-60	C	4.5

Soil Water Characteristics

The chemical composition of free-flowing soil water encountered at depths of 50 to 65 inches reflects the extremely acid, highly leached Spodosols (Table 13). Sodium was the dominant cation, with higher values at site 1 near the Gulf of Mexico. Silicon and K contents were also higher in site 1 located near sea level. Extremely low levels of Fe and Mn occurred at both sites. Electrical conductivity levels were very low.

Table 11. Heavy metal contents of pedons at Sites 1 and 3.

Site	Horizon	Depth	Fe	Mn	Zn	Cu	Pb	Cd	Ni
		inches	mg kg^{-1} (ppm)						
1	A	0-5	419	4.0	3.7	1.5	6.5	nd*	4.0
	E	5-11	238	1.4	1.7	0.7	0.8	nd	1.4
	Bh1	11-21	3,652	3.0	2.2	5.4	3.7	nd	3.0
	Bh2	21-27	3,147	4.1	3.9	5.4	3.1	nd	4.1
	Bh3	27-36	5,310	5.7	5.4	4.1	3.8	nd	5.7
	Bh4	36-42	7,104	12.9	4.4	3.5	4.7	nd	12.9
	BC	42-49	511	0.9	1.2	1.1	2.1	nd	0.9
	C1	49-57	221	0.5	2.4	0.8	1.7	nd	0.5
	C2	57-72	70	0.5	1.1	0.6	0.8	nd	0.5
3	A	0-5	268	3.7	2.1	0.8	6.5	nd	3.7
	E	5-11	11	0.5	0.9	0.2	0.5	nd	0.5
	Bh1	11-15	20	0.5	1.5	0.3	3.4	nd	0.5
	Bh2	15-22	44	0.8	0.2	0.6	1.8	nd	0.8
	Bh3	22-31	60	0.9	0.5	0.7	0.6	nd	0.9
	BC1	31-37	59	0.8	1.6	0.5	1.7	nd	0.8
	BC2	37-46	31	0.3	1.0	0.6	1.6	nd	0.3
	C	46-60	6	0.2	0.8	0.4	0.6	nd	0.2

* nd - not detected

Table 13. Chemical composition of free water in spodosols at sites 1 and 3.

Site	Ca	Mg	Na	K	Fe	Mn	Si	pH	EC
	----------	----------	----------	mgL	----------	----------	----------		mmhos cm^{-1}
1	0.2	1.4	6.1	1.4	0.04	0.04	2.50	4.20	0.061
3	0.7	0.9	3.6	0.6	0.06	0.06	1.24	4.07	0.043

Age of Spodic Horizons

Radiocarbon dating of spodic horizons indicated considerable difference in ages (Beta Laboratories, Coral Gables, FL). The Spodosol located at 100 feet elevation had an age of 3,650 years BP $\pm$ 50, while pedon 1 at 15 feet elevation had an age of 390 years BP $\pm$ 50. Both Spodosols are considered young pedogenically and represent a Holocene age. Radiocarbon dates of spodic horizons from a similar Leon soil in Brantley County, Georgia were reported as approximately 1,150 years BP (Lamont Lab, 1965).

Summary

Spodosols with well-developed spodic horizons were recognized in Mississippi for the first time. The soils are highly leached, coarse-textured, and extremely acid with very low levels of bases (plant nutrients). The soils are dominately covered by a forest of acidiphyllic vegetation and have pronounced organic litter layers overlying the mineral soil. Plant nutrients are concentrated in the surface horizons reflecting the intense biocycling by vegetation. Calcium was extremely low or not detectable in the subsoils. Aluminum saturation was high and comprised 15 to 83 percent of the cation exchange sites. Spodic horizons were dark colored, because of organic coatings of quartz grains, and had low iron contents. Radiocarbon dating indicated the spodic horizons are Holocene age ranging from 390 near sea level to 3,650 years BP at 100 feet elevation.

Total Spodosol acreage in Mississippi is limited; however, it is important to recognize the complex pedogensis these soils represent, and their western occurrence along the Gulf of Mexico. The striking relationship with vegetation and nutrient recycling reflect the unique character of these soils. The Spodosols we examined were dominantly sandy, siliceous, thermic Aeric Alaquods. With the recognition of Spodosols, eight soil orders are known to exist in Mississippi, reflecting diverse parent materials and soil-forming factors.

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