U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Results of drilling in the English Hill area, Benton Hills, Scott County, Missouri

by

Richard W. Harrison[1], Ronald J. Litwin[1], John E. Repetski[1], David Mason[1], and Art Schultz[1]

Open-File Report 96-44

1. USGS Reston, Virginia

Results of drilling in the English Hill area, Benton Hills, Scott County, Missouri

by
Richard W. Harrison, Ronald J. Litwin, John E. Repetski, David Mason, and Art Schultz

U.S. Geological Survey Open-File Report 96-44

Introduction

This report presents analysis of three cores recovered during drilling in the English Hill area of the Benton Hills, Scott County, Missouri in September and November, 1993. This work is an integral part of geologic investigations in the area by the U.S. Geological Survey to understand the stratigraphy, structure, and geologic history of the northern Mississippi embayment and the New Madrid seismic zone. The drilling program was coordinated with a seismic-reflection survey (Mini-Sosie) conducted by the U.S. Geological Survey's Branch of Geological Risk Assessment and the Missouri Department of Natural Resources, Division of Geology and Land Survey, whose initial results were reported by Palmer and Hoffman (1994). Research was supported by the National Earthquake Hazards Reduction Program.

The Benton Hills is an upland area, generally regarded as an extension of Crowleys Ridge, at the head of the Mississippi embayment in southeastern Missouri (fig. 1). Topographically, the

Figure 1. Map showing location of the Benton Hills in southeast Missouri; upland areas are shaded, northernmost portion of Mississippi Embayment is unshaded, diagonally ruled lines represent the New Madrid seismic zone; Loc. A- approximate site of Location 1 sample of Herrick and Tschudy (1967); Loc. B- approximate site of Location 5 sample of Herrick and Tschudy (1967); Loc. C- approximate site of New Madrid test wells 1 and 1-x described by Frederickson and others (1982).

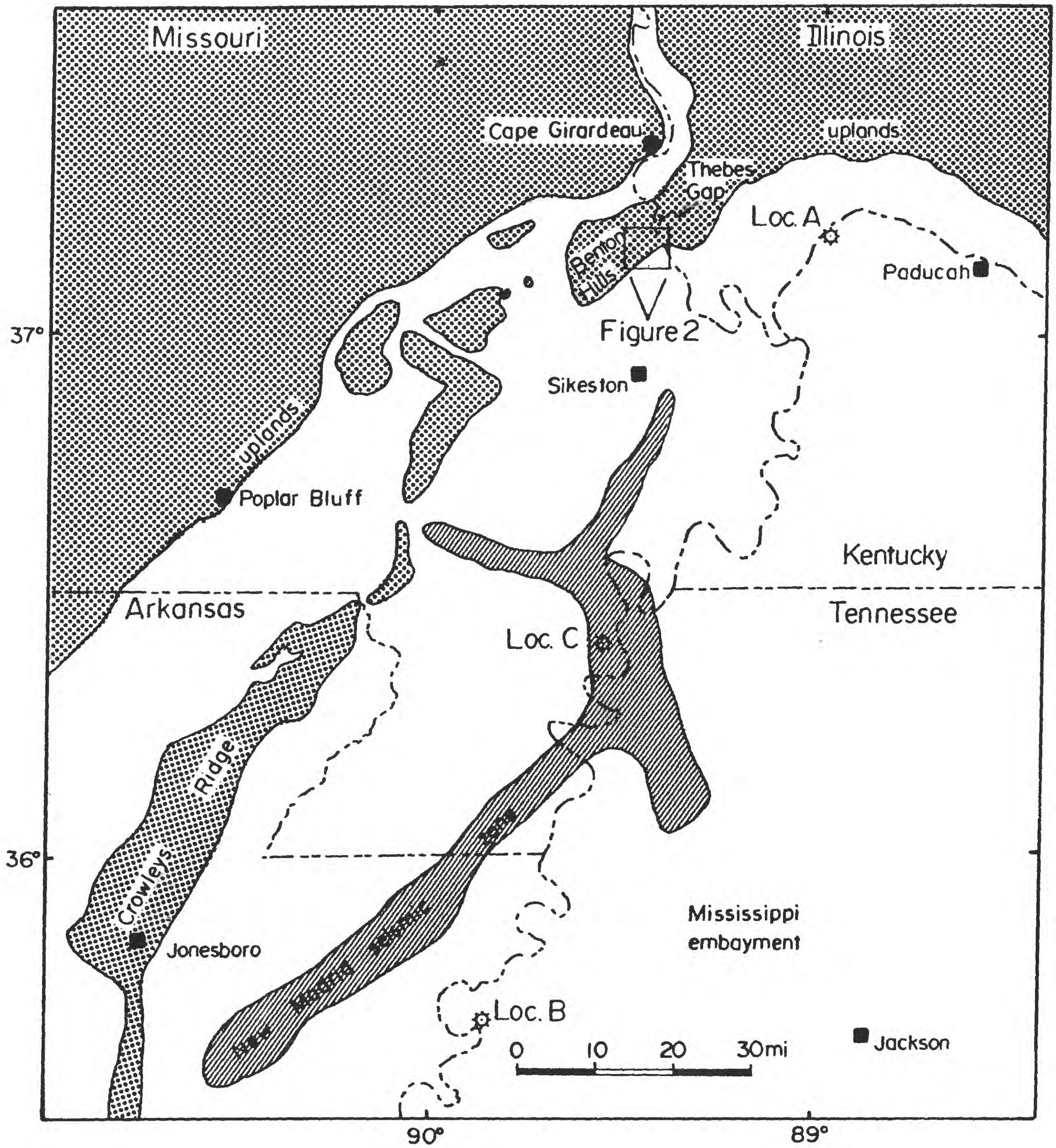

Missouri
Illinois
Cape Girardeau
uplands
Thebes Gap
Loc. A
Benton Hills
Paducah
Figure 2
37°
Sikeston
uplands
Poplar Bluff
Kentucky
Arkansas
Tennessee
Loc. C
Crowleys Ridge
36°
Mississippi embayment
Jonesboro
Loc. B
0 10 20 30mi
Jackson
90°
89°

Figure I.

Benton Hills resemble an inclined block, gently tilted down to the northwest. They are highest along their southeastern margin, where a prominent scarp rises approximately 150 ft above alluvial lowlands of the ancestral Ohio and Mississippi Rivers, and are separated from upland areas in southern Illinois to the east by Thebes Gap, a narrow gorge cut by the Mississippi River. The Benton Hills region is the area closest to the New Madrid seismic zone where Paleozoic through Quaternary formations either crop out or are present in the shallow subsurface.

Several broad problems directed this research in the Benton Hills: 1) a need to supplement the Mesozoic and Cenozoic stratigraphy of the northernmost part of the Mississippi embayment; 2) the need to establish continuity of structural features from well-exposed areas to covered areas; 3) the need to interpret the geologic history of the area, particularly structural aspects; and 4) the necessity to evaluate the seismic potential for the area. Related, but more specific goals were to investigate reports of possible Quaternary faulting in the area (Stewart, 1942; Stewart and McManamy, 1944; Palmer and Hoffman, 1993), and to determine whether the prominent scarp on the southeastern margin of the Benton Hills is fault related or formed through other geologic processes.

This report summarizes a small, but important, portion of the the overall efforts towards resolving the above problems. Previous contributions include an analysis of the tectonic history of the area (Harrison and Schultz, 1994) and a detailed geologic map of the Thebes 7.5-minute quadrangle, Missouri and Illinois (Harrison, in press). More complete descriptions and interpretations of research investigations in the Benton Hills will be presented when ongoing work is completed.

Discussion

Figure 2a is a generalized geologic map of part of the Benton Hills that shows the locations of the three core holes; figure 2b is an explanation for this geologic map. Core hole BH-1 was collared in an abandoned gravel quarry near the crest of the Benton Hills. This hole, coupled with exposures in the wall of the quarry, provide the most complete Mesozoic and Cenozoic stratigraphic section in the area (see fig. 3 and appendix A). Core hole BH-2, collared at the foot of the Benton Hills escarpment, penetrated a nearly complete Cretaceous section (fig. 4, appendix B) and core hole BH-3 penetrated a Quaternary section and probably the lowermost Cretaceous section (fig. 5, appendix C). Conodont analyses indicate that, in all three drill holes, Cretaceous strata

Figure 2. a) Generalized geologic map of part of the Benton Hills that shows locations of drill holes, geologic cross section A-A', and Mini-Sosie seismic reflection line.

b) Explanation of symbols and abbreviations used in Figure 2a.

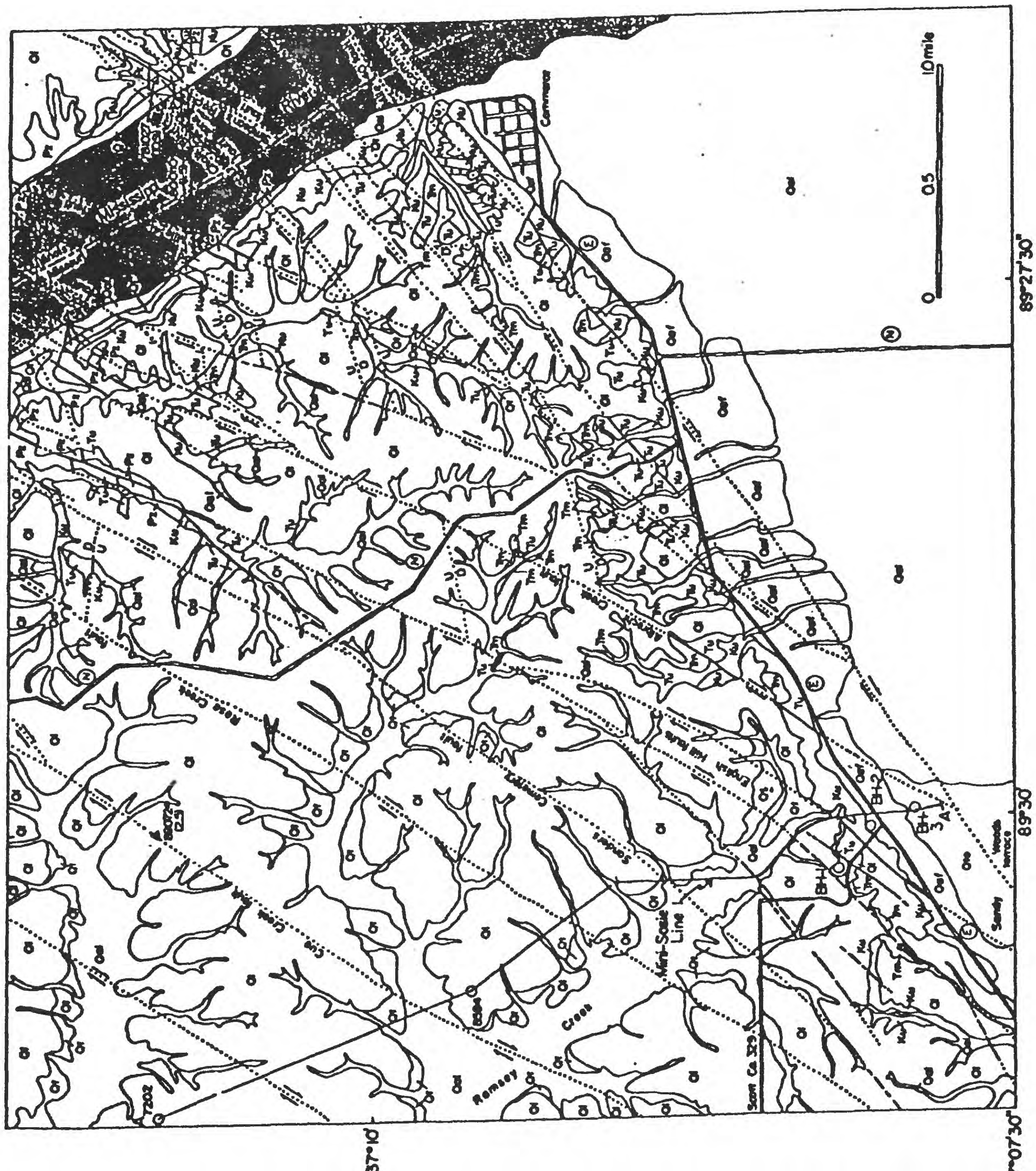

Commerce
0
0.5
1.0 mile
89°27'30"
89°30'
37°10'
37°07'30"
Rose Creek
Ramsey Creek
Mini-Sosie Line
Scott Co. 329
BH-1
BH-2
BH-3A
Woods terrace
Sandy

Figure 2a

EXPLANATION

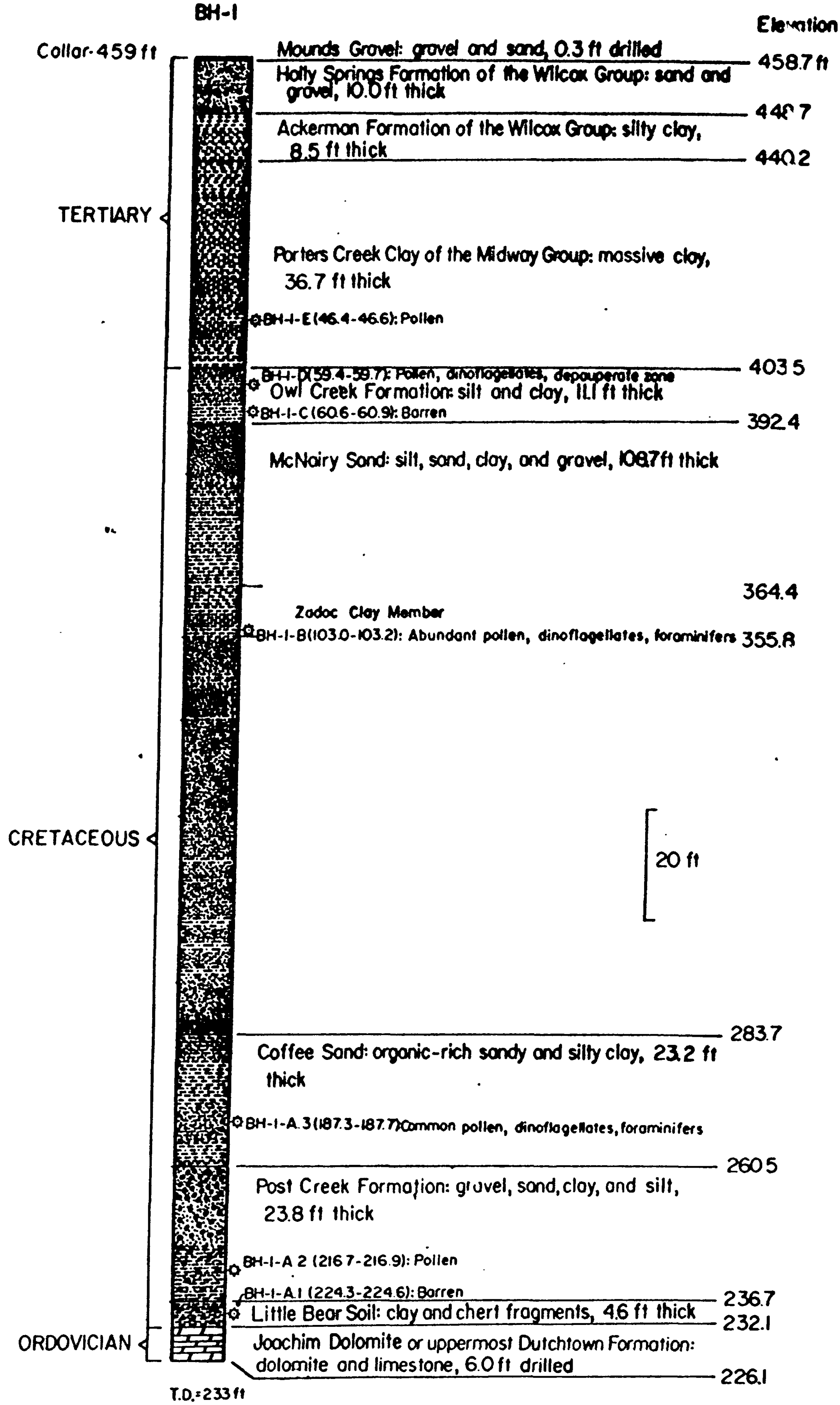
Qal	Quaternary alluvium
Qaf	Quaternary alluvial fans shed from Benton Hills escarpment
Qt Qto	Quaternary terraces Quaternary terrace of ancestral Ohio River
Ql	Quaternary loess
Tm	Tertiary Mounds Gravel
Tu	Tertiary (Paleogene) undivided
Ku	Cretaceous undivided
Pz	Paleozoic undivided
Osp	St. Peter Sandstone
	Strike-slip fault - dotted where covered, arrows indicate sense of last movement
D U	Normal fault - dotted where covered, bar and ball or D on downthrown block
	Air-photo lineament
▲	Earthquake epicenter - showing identification number and magnitude in parenthesis
⊙	Core hole location

Figure 2b

Figure 3. Stratigraphic column for core hole BH-1, see appendix A for descriptive log.

Figure 4. Stratigraphic column for core hole BH-2, see appendix B for descriptive log.

Figure 5. Stratigraphic column for core hole BH-3, see appendic C for descriptive log.



BH-1
Elevation
Collar-459 ft
Mounds Gravel: gravel and sand, 0.3 ft drilled
458.7 ft
Holly Springs Formation of the Wilcox Group: sand and gravel, 10.0 ft thick
448.7
Ackerman Formation of the Wilcox Group: silty clay, 8.5 ft thick
440.2
TERTIARY
Porters Creek Clay of the Midway Group: massive clay, 36.7 ft thick
BH-1-E (46.4-46.6): Pollen
403.5
BH-1-D (59.4-59.7): Pollen, dinoflagellates, depauperate zone
Owl Creek Formation: silt and clay, 11.1 ft thick
BH-1-C (60.6-60.9): Barren
392.4
McNairy Sand: silt, sand, clay, and gravel, 108.7 ft thick
364.4
Zadoc Clay Member
BH-1-B (103.0-103.2): Abundant pollen, dinoflagellates, foraminifers
355.8
CRETACEOUS
20 ft
283.7
Coffee Sand: organic-rich sandy and silty clay, 23.2 ft thick
BH-1-A.3 (187.3-187.7) Common pollen, dinoflagellates, foraminifers
260.5
Post Creek Formation: gravel, sand, clay, and silt, 23.8 ft thick
BH-1-A 2 (216.7-216.9): Pollen
BH-1-A.1 (224.3-224.6): Barren
236.7
Little Bear Soil: clay and chert fragments, 4.6 ft thick
232.1
ORDOVICIAN
Joachim Dolomite or uppermost Dutchtown Formation: dolomite and limestone, 6.0 ft drilled
226.1
T.D.=233 ft

Figure 3.

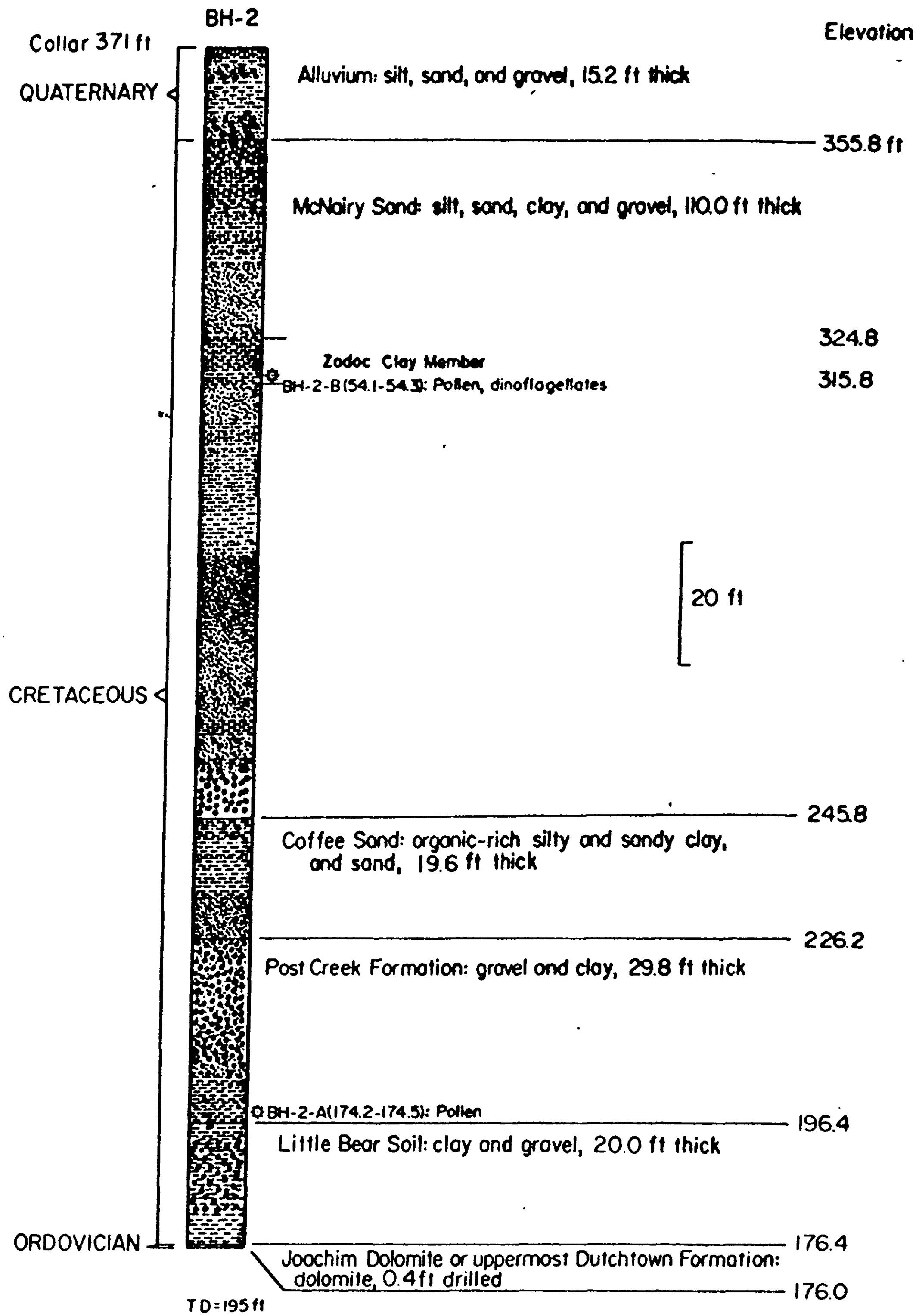
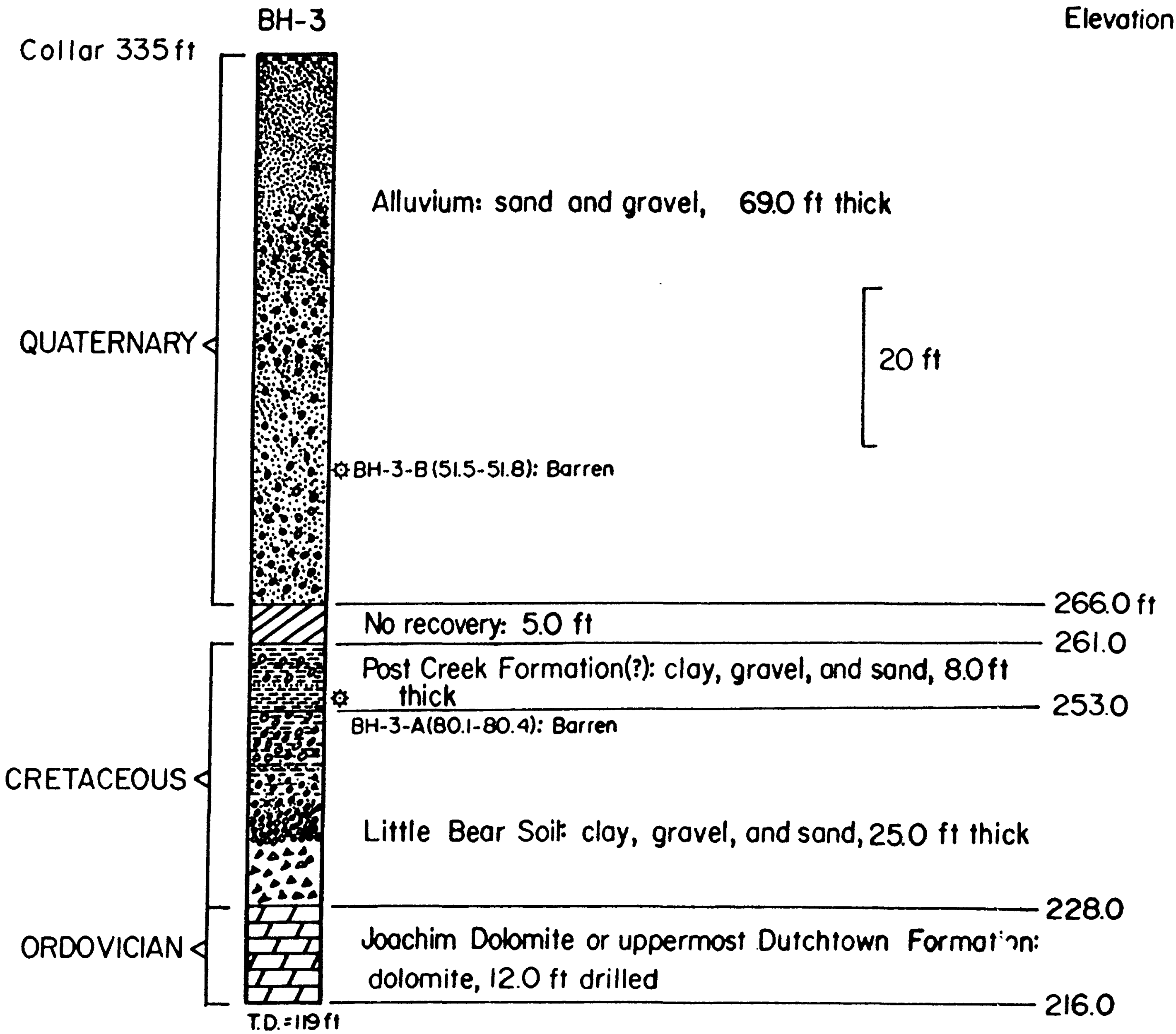

BH-2
Collar 371 ft
Elevation
QUATERNARY
Alluvium: silt, sand, and gravel, 15.2 ft thick
355.8 ft
McNairy Sand: silt, sand, clay, and gravel, 110.0 ft thick
324.8
Zodoc Clay Member
BH-2-B(54.1-54.3): Pollen, dinoflagellates
315.8
20 ft
CRETACEOUS
245.8
Coffee Sand: organic-rich silty and sandy clay, and sand, 19.6 ft thick
226.2
Post Creek Formation: gravel and clay, 29.8 ft thick
BH-2-A(174.2-174.5): Pollen
196.4
Little Bear Soil: clay and gravel, 20.0 ft thick
ORDOVICIAN
176.4
Joachim Dolomite or uppermost Dutchtown Formation: dolomite, 0.4 ft drilled
176.0
TD=195 ft

Figure 4.



BH-3
Elevation
Collar 335 ft
QUATERNARY
Alluvium: sand and gravel, 69.0 ft thick
20 ft
BH-3-B (51.5-51.8): Barren
266.0 ft
No recovery: 5.0 ft
261.0
Post Creek Formation(?): clay, gravel, and sand, 8.0 ft thick
253.0
BH-3-A(80.1-80.4): Barren
CRETACEOUS
Little Bear Soil: clay, gravel, and sand, 25.0 ft thick
228.0
ORDOVICIAN
Joachim Dolomite or uppermost Dutchtown Format'on: dolomite, 12.0 ft drilled
216.0
T.D.=119 ft

Figure 5.

overlie Middle Ordovician strata of the Joachim Dolomite or uppermost Dutchtown Formation (table 1).

Little Bear Formation (or Soil)

The oldest post-Paleozoic unit encountered in core hole BH-1 is correlative with the Little Bear Formation of Mellen (1937), also known as Little Bear Soil (Willman and Frye, 1975). This unit is a regolith that formed on the regional unconformity that truncates Paleozoic rocks. It consists of strongly weathered and convoluted clays mixed with angular to subangular gravel and sand. Iron oxides and root casts are abundant. Thickness of Little Bear Formation ranged from 4.6 to 20.0 ft in the drill holes.

A large percentage of illite in the clay fraction appears to be characteristic of the Little Bear Formation and probably reflects an extensive weathering history (fig. 6, table 2). This characteristic is not found in any other Cretaceous or Tertiary unit in the upper Mississippi embayment (Pryor and Glass, 1961).

Little Bear Formation occurs as isolated erosional remnants around the eastern and northern margins of the Mississippi embayment. Although several exposures have been described in southern Illinois (Pryor and Ross, 1962; Ross, 1963; Kolata and others, 1981), this is the first reported occurrence in Missouri.

Drill hole; Depth in feet	USGS collection number	Strati-graphic unit	Conodonts	Age and paleoenvironment	CAI	Sample Mass (g)	>20 Mesh insoluble residue (g)	20-200 Mesh insoluble residue (g)
BH1; 228-229.5	11108-CO	Most likely Joachim Dolomite	5 *Erismodus* cf. *E. asymmetricus* (Branson and Mehl); 1-Sa or Pa; 2-Sc; 1-Sb; 1-M or Pb elements 1 unassigned genus and species; = "*Neocoleodus*" of some authors 1 unassigned neurodont element fragment 1 indeterminate bar fragment	Middle Ordovician; most likely Blackriveran. Paleoenvironment: Shallow, warm, marine, probably restricted circulation at least periodically.	1-1/2	500	10	0
BH1; 230	11109-CO		1 *Erismodus* cf. *E. asymmetricus* (Branson & Mehl); Pb element 1 indeterminate bar element fragment	Middle Ordovician; most likely Blackriveran. Paleoenvironment: same as for above sample.	1-1/2	700	60	32
BH1; 231-232	11110-CO		1 *Erismodus* cf. *E. asymmetricus* (Branson & Mehl); Pb element 1 indeterminate bar element fragment	Middle Ordovician; most likely Blackriveran. Paleoenvironment: same as for above.	1-1/2	600	20	15
BH1; 231.9-233	11111-CO		5 *Curtognathus* sp.; 4 cardiodellid elements; 1 curtognathid el. 5 *Erismodus* cf. *E. asymmetricus* (Branson & Mehl); 4-Sc; 1-Pa els. 1 *Phragmodus* sp.; Sc el.	Middle Ordovician; most likely Blackriveran. Paleoenvironment: same as for above.	1-1/2	1400	50	19
BH2; 195	11112-CO		2 *Erismodus* cf. *E. asymmetricus* (Branson & Mehl): 1 Sc; 1 M or Pa element	Middle Ordovician; most likely Blackriveran. Paleoenvironment: same as for samples from BH1 drillhole.	1+	400	20	21
BH3; 109-111	11113-CO		3 *Curtognathus* sp.: 2 trucherognathid; 1 cardiodellid elements 1 *Erismodus* cf. *E. asymmetricus* (Branson & Mehl): Sb element 2 indeterminate bar fragments	Middle Ordovician; most likely Blackriveran. Paleoenvironment: same as for samples from BH1 drillhole.	1-1/2 to 2	1600	30	15
BH3; 115-117	11114-CO		1 *Curtognathus* sp.; cardiodellid element 1 Undetermined genus and species	Middle Ordovician; most likely Blackriveran. Paleoenvironment: same as for samples from BH1 drillhole.	1-1/2 to 2	1200	30	38
BH3; 118	NA		No microfossils found.	Age not determined.	NA	1600	40	39

Table 1

Conodont analyses of Paleozoic rocks encountered in drilling.

Figure 6. Ternary diagram showing relative percentages of clays for Cretaceous and Tertiary sediments encountered in drilling; data presented in table 2.

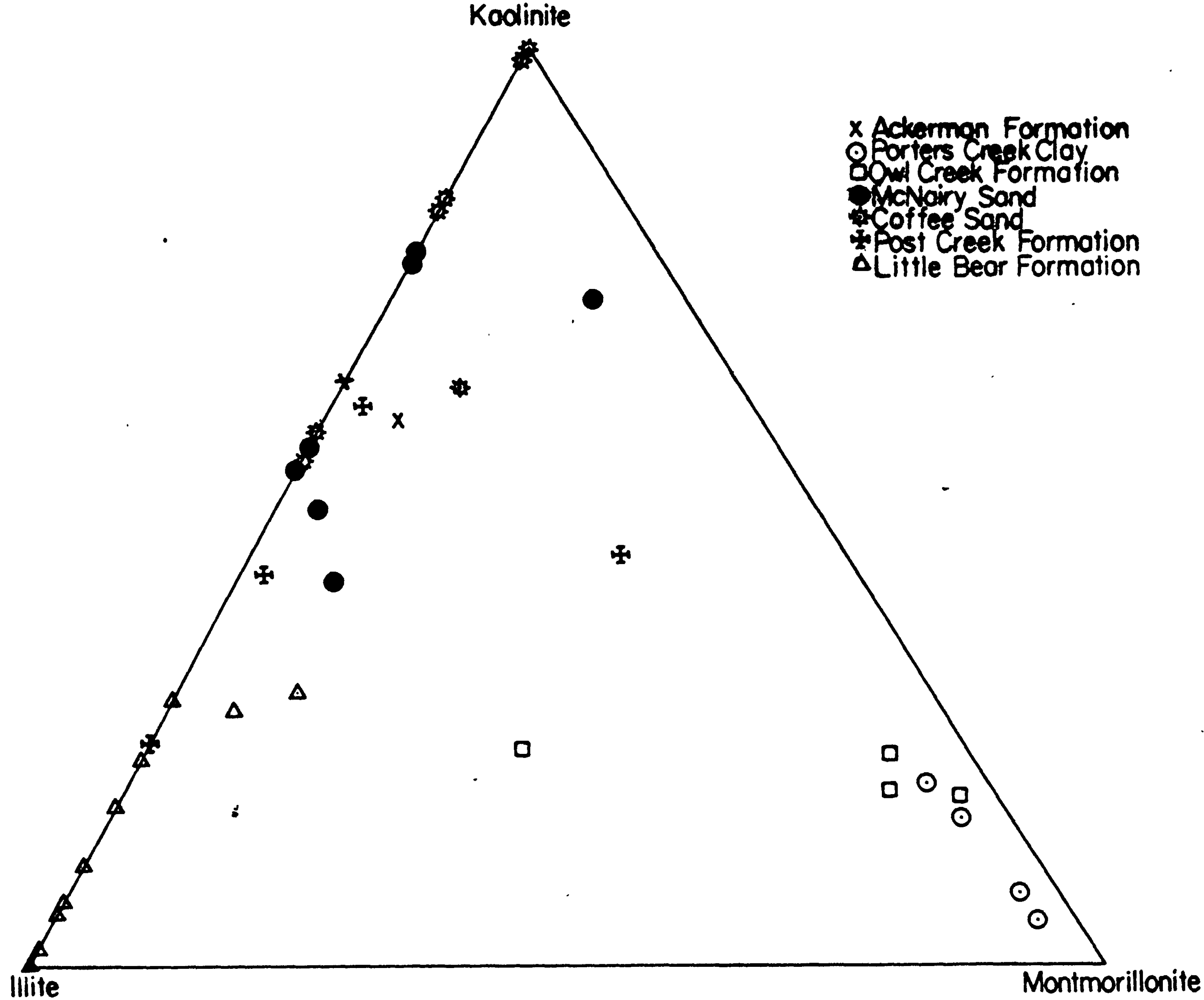

Kaolinite
Illite
Montmorillonite
x Ackerman Formation
Porters Creek Clay
Owl Creek Formation
McNairy Sand
Coffee Sand
Post Creek Formation
Little Bear Formation

Figure 6.

Table 2.--Semi-quantified x-ray data of clay fraction from Benton Hills drill holes; relative % of M-montmorillonite, I-illite, and K-kaolinite. Depths in feet

Drill hole	depth	Formation	M	I	K
BH-1	10.2	Ackerman Fm.		34	59
BH-1	15.0	Ackerman Fm.		36	64
BH-1	19.0	Porters Creek Clay	74	6	20
BH-1	25.0	Porters Creek Clay	79	5	16
BH-1	31.0	Porters Creek Clay	91	4	5
BH-1	45.0	Porters Creek Clay	85	3	12
BH-1	50.0	Porters Creek Clay	88	4	8
BH-1	55.5	Owl Creek Fm.	71	10	19
BH-1	58.9	Owl Creek Fm.	23	42	35
BH-1	59.5	Owl Creek Fm.	78	4	18
BH-1	60.3	Owl Creek Fm.	69	8	23
BH-1	84.0	McNairy Sand, Zadoc		46	54
BH-1	95.0	McNairy Sand, Zadoc	4	46	50
BH-1	114.0	McNairy Sand		44	56
BH-1	145.0	McNairy Sand	9	49	42
BH-1	180.0	Coffee Sand		16	84
BH-1	184.0	Coffee Sand		<1	>99
BH-1	196.0	Coffee Sand	11*	26	63
BH-1	207.0	Post Creek Fm.	34	21	45
BH-1	215.5	Post Creek Fm.	2	55	43
BH-1	222.5	Little Bear Soil		89	11
BH-1	226.5	Little Bear Soil		93	7
BH-2	47.0	McNairy Sand, Zadoc		22	78
BH-2	54.0	McNairy Sand, Zadoc		23	77
BH-2	114.0	McNairy Sand	8	19	73
BH-2	126.0	Coffee Sand		42	58
BH-2	131.0	Coffee Sand		17	83
BH-2	144.0	Coffee Sand			100
BH-2	165.0	Post Creek Fm.		76	24
BH-2	165.5	Post Creek Fm.	3	36	61
BH-2	167.0	Little Bear Fm.		98	2
BH-2	173.7	Little Bear Fm.		77	23
BH-2	174.0	Little Bear Fm.		83	17
BH-2	194.0	Little Bear Fm.		100	
BH-3	80.0	Post Creek Fm.		45	55
BH-3	83.0	Little Bear Fm.		83	17
BH-3	89.0	Little Bear Fm.		71	29

BH-3	97.0	Little Bear Fm.		94	6
BH-3	98.0	Little Bear Fm.	11	59	30
BH-3	119.0	Little Bear Fm.	5	67	28

* includes 7% vermiculite

Little Bear Formation is generally regarded as a pre-Cenomanian soil-stratigraphic unit (Willman and Frye, 1975) and possibly is equivalent to similar paleosols in the same stratigraphic position elsewhere in the eastern and southern Gulf Coast Plain (Siglec and Reinhardt, 1985). Samples of this unit analyzed for fossil pcllen were barren.

"Post Creek Formation"

Overlying the Little Bear Formation are deposits of heterolithic gravels and sand, clay, and silt. Gravels consist of variously colored, subangular to subrounded cherts and range in size up to cobbles. Sand consists of fine to very fine grains of white, clear, and frosted quartz, and variously colored cherts. Some intervals in this unit are poorly sorted, massive, and lack bedding features.

Traditionally, gravel deposits at this stratigraphic interval in the Midcontinent of the United States have been correlated with Smith and Johnson's (1887) Tuscaloosa Formation, named for exposures near Tuscaloosa, Alabama (Pryor, 1960; Pryor and Ross, 1962; Marcher and Stearns, 1962; Stearns and Marcher, 1962; Ross, 1964; Willman and Frye, 1975; Kolata and others, 1981). Christopher (1980, 1982) dated the Tuscaloosa Formation near its type section as late Cenomanian on the basis of fossil palynomorphs. However, pollen from "Tuscaloosa-type" sediments recovered in cores BH-1 and BH-2 suggest a middle to late Campanian age (table 3, plate 1), or approximately 12 to 14 m.y. younger than Tuscaloosa Formation at its type section. Our age assessment is based on the presence of several pollen taxa whose first occurrence is in sediments of middle to late Campanian age in the Atlantic Coastal Plain and the Mississippi embayment. These include forms C3B-1, C3B-2, and CP3D-3 of Wolfe (1976), as well as *Extremipollis* cf. *E. caminus* and *?Pseudoculopolollis admirabilis* (=NJ-2 and NR-1, respectively, of Wolfe, 1976). The presence of *Osculapollis perspectus* suggests an age probably no younger than late Campanian, as established by Tschudy (1975) for its occurrence in sediments elsewhere in the Mississippi embayment.

Arguments for transgressive deposition are encumbered by the occurrence of a depositional hiatus in the Mississippi embayment from the late Cenomanian to the late Coniacian (Pryor, 1960; Tschudy, 1975). Therefore, a new name, "Post Creek Formation", is being proposed for this unit for exposures in the banks of Post Creek Cutoff, immediately south of the Joppa to Grand Chains Highway, in the center of section 2, T. 15 S., R. 2 E., Bandana 7.5-minute quadrangle, Pulaski County, Illinois.

Table 3. Stratigraphic occurrence of selected palynomorph taxa in cores BH-1 and BH-2, also see plate 1. Dinoflagellate identifications are considered tentative. Key is as follows: "x" denotes verified occurrence, "?" denotes questionable occurrence, and "o" denotes range-through or occurrence in age-equavalent strata elsewhere in the Mississippi embayment or Atlantic Coastal Plain.

STRATIGRAPHIC UNIT	Not sampled(x), Barren(B), and Conodonts(C)	Sample core depth (feet)	C3B-1 (Wolfe, 1976)	C3B-2 (Wolfe, 1976)	Nk-1 (Wolfe, 1976)	*Pseudatlantopollis simulatus*	*Semioculopollis sp. A**	*Trudopollis variabilis*	*Osculapollis perspectus*	*Extremipollis caminus*	*Proteacidites spp.*	*Choanopollenites consanguineus*	*Choanopollenites transitus*	*Extremipollis vivus*	*Vacuopollis munitus*	*Holkopollenites***	*Extremipollis versatilis*	*Trudopollis sp. A**	*Thompsonipollis aff. T. magnificoides*	NM-1 (Wolfe, 1976)	*Osculapollis aequalis*	*Pseudoculopollis admirabilis*	*Pseudoplicapollis serena*	C3B-3 (Frederiksen et al., 1982; Wolfe, 1976)	*Plicapollis usitatus*	*Interpollis cf. I. supplingensis*	*Plicapollis vacuus*	*Plicapollis retusus*	*Nudopollis aff. N. thiergartii*	*Tricolporites****	*Thompsonipollis expolitus*	*Minorpollis cf. M. minima*	*Pseudoplicapollis endocuspis*	*Megatriopollis sp.*	*Caryapollenites veripites*	*Alnus trina*	*Alnus vera*	Juglandaceae indet.	*Pistillipollenites mcgregorii*	*Nyssapollenites sp.*	*Ulmipollenites krempii*	*Corsinipollenites sp.*	*Thompsonipollis magnifica*	*Exochosphaeridium bifidum******	*Spiniferites ramosus ramosus*	*Paleohystrichophora infusorioides******	*Ceratopsis cf C. diebelii*	*Ceratopsis striata*	*Isabelladinium*	*Dinogymnium*	PROBABLE AGE RANGE
· Mounds Gravel	x																															NOT EXAMINED												NOT EXAMINED							?Miocene to Pliocene
?Holly Springs Formation	x																															NOT EXAMINED												NOT EXAMINED							Tertiary (pre-Miocene)
?Ackerman Formation	x																															NOT EXAMINED												NOT EXAMINED							Tertiary (pre-Miocene)
Porters Creek Clay		-46																														x	?	?	x	x	x	x	x	x	x	x	x						x	x	upper Paleocene (Thanetian/Sabinian)
Owl Creek Formation		-60									x	x	x	x	x	x							o	x	x	x	x	x	x	x	x	x																			middle to late Maastrichtian
McNairy Sand (Zadoc Clay)		-103						x	x	x	o	x	x	x	x	x					x	x	o	o	x																			x	x	x	x	x	x	x	early to middle Maastrichtian
Coffee Sand		-187				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x																											late Campanian****
Post Creek Formation		-216	x	x	x	x	x	x	x	x	x	x	x	x	x	x																																			middle to late Campanian
Little Bear Soil	B																																																		barren (age unknown)
Joachim Dolomite	C	>228	Conodont evidence presented elsewhere this paper																																																middle Ordovician (Blackriveran)

x denotes occurrence in sample

o denotes apparent absence in sample, although the taxon occurs in this interval elsewhere

* (Tschudy, 1975)

**(=CP3D-3 of Wolfe, 1976)

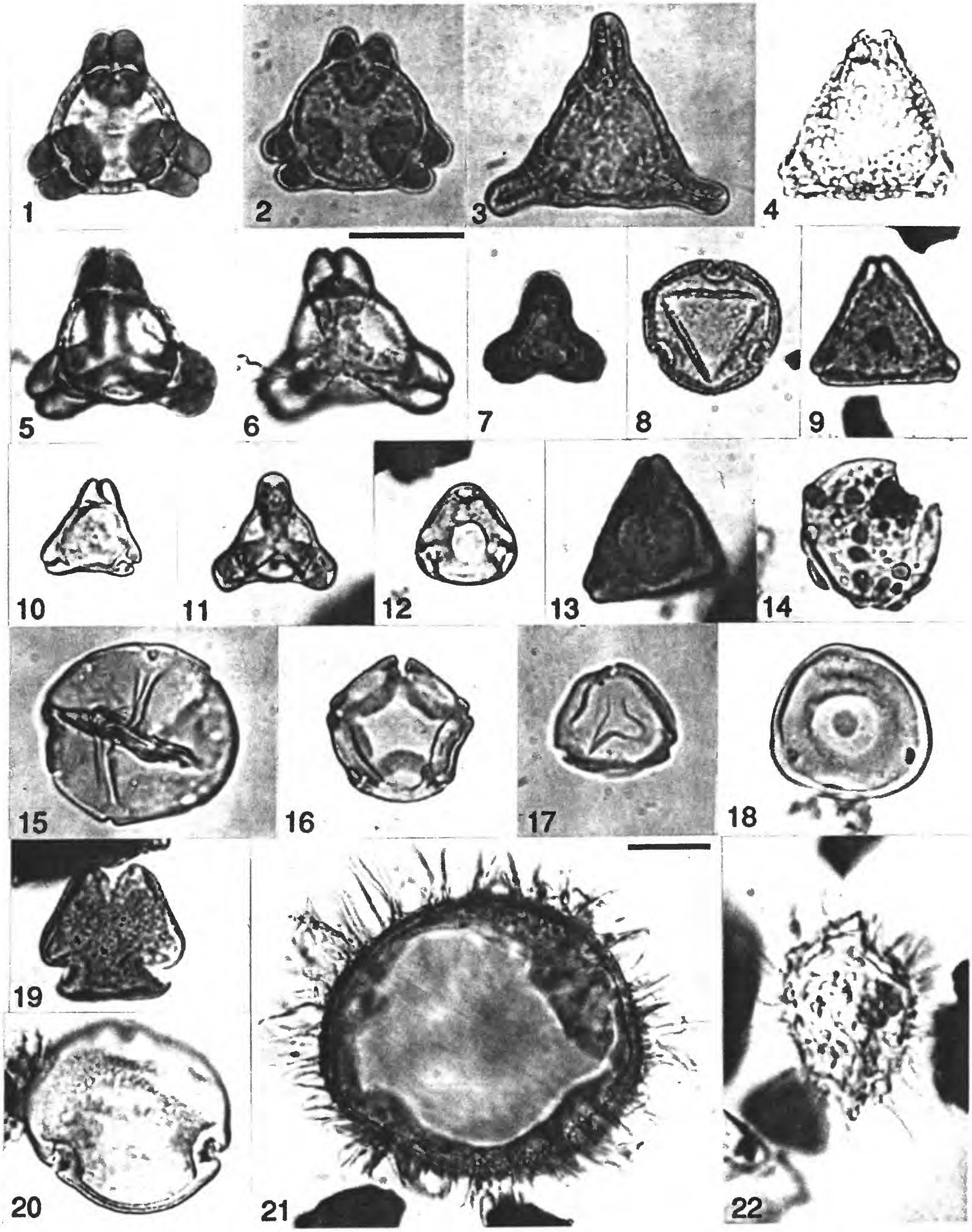
***(=CP3A-3 of Wolfe, 1976)

**** Age determined partly on the basis of its stratigraphic position below the Coon Creek Tongue of the Ripley Fm., which has been dated as nannofossil Subzone CC22C (see discussion in Burnett et al., 1992). Burnett et al. (1992) proposed that the first occurrence of the belemnite Belemnella lanceolata be accepted as the base of the Maastrichtian, and noted that it lies above the last occurrence of Globotruncana calcarata.

*****These taxa have apparent last occurrences in Campanian strata in east-central New Jersey (Aurisano, 1989). However, a hiatus exists above their last occurrences there (at the Mt.Laurel-Navesink boundary, per Self-Trail and Bybell, 1995, and Sugarman et al., 1995) that precludes absolute determination of the true age of these species' last occurrence in the Tom's River Well. We therefore do not propose to restrict this sample's age to the late Campanian solely on the basis of these two taxa. Their reported occurrence here also may represent reworked specimens, relict specimens, or misidentified specimens.

Plate 1. Selected palynomorph taxa from core BH-1 and BH-2. Scale for all specimens is 20um; scale bar is located in top right corner of fig. 6; scale bar for fig. 21 (also 20um) is located in top right of figure.

1,2. *Semioculopollis* sp. A (Tschudy, 1976).
3. *Extremipollis caminus*.
4. *Proteacidites* sp.
5. *Pseudoculopollis admirabilis* (low focus).
6. *Pseudoculopollis admirabilis* (high focus).
7. *Choanopollenites transitus*.
8. *Thompsonipollis* aff. T. *magnificoides* (per Tschudy, 1975).
9. *Vacuopollis munitus*.
10. *Pseudoplicapollis serena*.
11. *Plicapollis usitatus*.
12. *Interpollis* cf. *I. supplingensis* (per Tschudy, 1975).
13. *Nudopollis* aff. *N. thiergartii* (per Tschudy, 1975).
14. *Pistillipollenites mcgregorii*.
15. *Juglandaceae*, indet.
16. *Alnus vera*.
17. *Alnus trina*.
18. *Caryapollenites veripites*.
19. *Holkopollenites* sp. ("CP3D-3" of Wolfe, 1976).
20. *Thompsonipollis magnifica*.
21. *Exochosphaeridium bifidum*. (Note separate bar scale)
22. *Palaeohystrichophora infusorioides*.


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22

The "Post Creek Formation" consists largely of residual material transported by mass-wasting and fluvial processes. The majority of clasts in this unit appear to be locally derived.

Coffee Sand

Overlying the "Post Creek Formation" is a sequence of lignite-rich marine clays (figs. 3, 4, and 5). They typically are sandy or silty (mainly quartz and lesser amounts of chert), slightly micaceous, and contain pyrite nodules and rare pebbles of chert. Dinoflagellates and foraminifers are present, but not abundant. Palynologic analyses of these sediments suggest a late Campanian to possibly early Maastrichtian age (table 3, plate 1). This age assessment is based on the presence of *Trudopollis variabilis*, Trudopollis sp. A of Tschudy (1975), *Osculapollis aequalis*, *Osculapollis perspectus*, *Pseudatlantopolis simulatus*, Semioculopollis sp. A of Tschudy (1975), *Choanopollenites consanguineus*, *Choanopollenites transitus*, *Extremipollis versatilis*, *Extremipollis vivus*, *Extremipollis caminus (=NR-1 of Wolfe, 1976)*, and *Vacuopollis munitus*. These taxa generally have their first occurrence in late Campanian sediments of the Mississippi embayment and/or the Atlantic Coastal Plain (Tschudy, 1975; Wolfe, 1976). The presence of *Proteacidites* (type PR-4 of

Wolfe, 1976), the tricolpate taxon C3C-3 of Wolfe (1976), and *Osculapollis aequalis* suggest that this unit is probably no younger than late Campanian.

Based on this age determination, stratigraphic position, and lithologic similarities, this unit is correlated with the Ccffee Sand of Safford (1864). From its type locality along the bluffs of the Tennessee River below Coffee Landing, Hardin County, Tennessee, Safford (1864) gives the following description:

> "The Coffee Sand consists mostly of stratified sands usually containing scales of mica. Thin leaves of dark clay are often interstratified with the sand, the clay leaves occasionally predominating. It very generally contains woody fragments and leaves, converted more or less into lignite."

Coffee Sand at its type locality was identified as Campanian in age by Tschudy (1975) from pollen analysis. Clay fractions of the Coffee Sand in the Benton Hills (fig. 6, table 2) are consistent with those determined for the unit elsewhere by Pryor and Glass (1961). Coffee Sand was 23.2 ft and 19.6 ft thick in core holes BH-1 and BH-2, respectively; it was not encountered in BH-3.

We interpret the Coffee Sand as lagoonal and nearshore-marine sediments deposited by a transgressive Campanian sea. The identification of this unit in the Benton Hills marks its northernmost occurrence known to date. The absence of Coffee Sand and other Campanian deposits in the Jackson Purchase region of western Kentucky (Davis and others, 1973; Olive, 1980) and the New Madrid area of southeast Missouri (Frederiksen and others, 1982) indicates that a geographic gap exists between deposits in the Benton Hills and those in Tennessee (fig 7). This gap, plus gravel deposits at the base of the McNairy Sand (see below), strongly suggest a period of post-Coffee and pre-McNairy erosion in parts of the northern Mississippi embayment. It is further suggested that a Campanian seaway occupied the entire Mississippi embayment and that its marine deposits were subsequently removed via uplift and erosion along the central and southwestern portions of the embayment. This argument is supported by the fact that the boundary of Coffee Sand occurrence in Tennessee and Arkansas virtually coincides with the southeast margin of the buried Reelfoot rift, a margin characterized by high-angle reverse faults active during the Late Cretaceous (Luzietti and others, 1995). These faults are compatible with structures that would be required to produce uplift and erosion of the Coffee Sand in the above described areas.

McNairy Sand

Overlying the Coffee Sand is the McNairy Sand. In core holes

Figure 7. Map of northern Mississippi embayment showing the geographic gap that exists between the main occurrence belt of the Coffee Sand and location of Coffee Sand in the Benton Hills drill core.

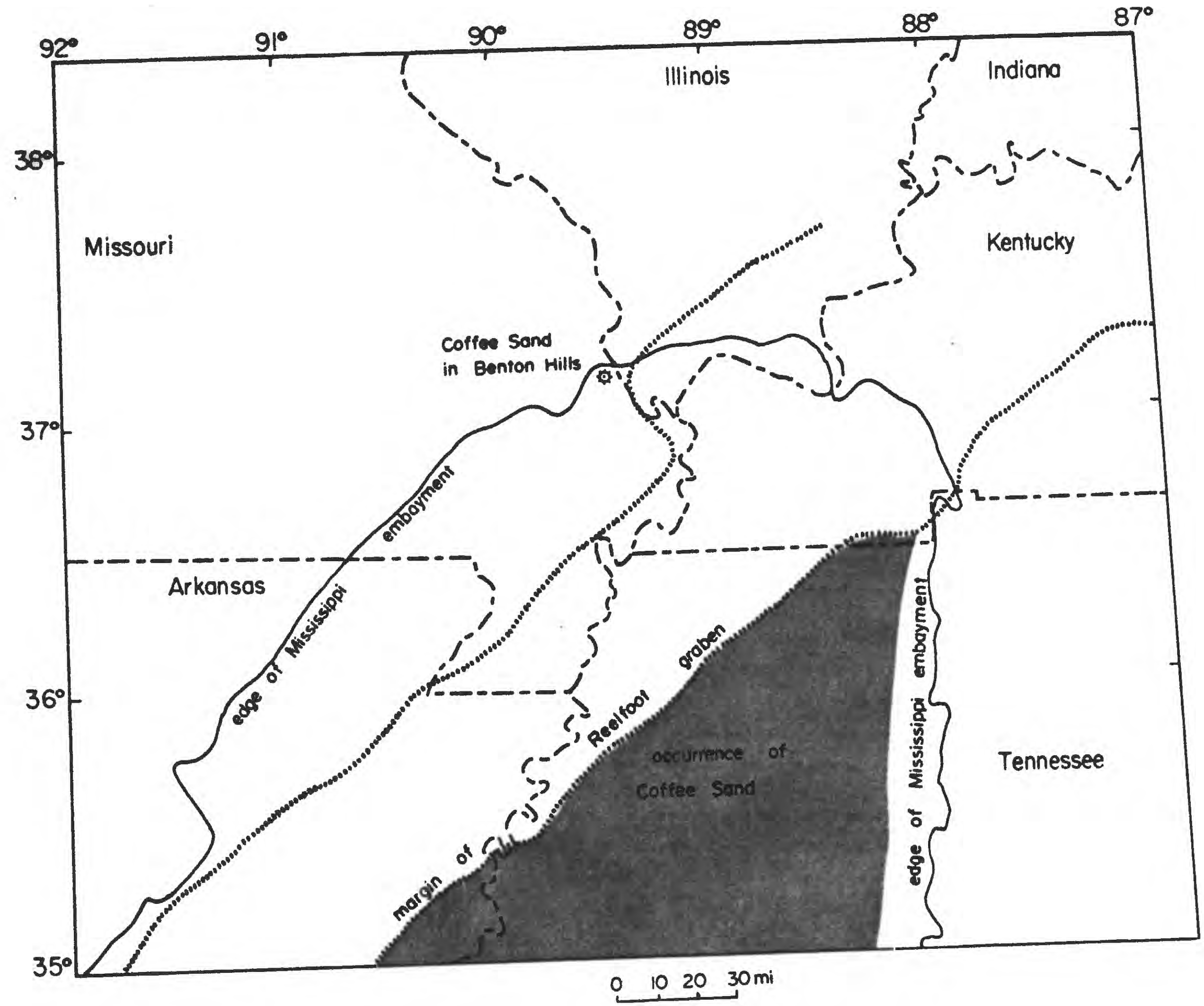

92°
91°
90°
89°
88°
87°
38°
37°
36°
35°
Illinois
Indiana
Missouri
Kentucky
Coffee Sand
in Benton Hills
Arkansas
Tennessee
edge of Mississippi embayment
edge of Mississippi embayment
margin of Reelfoot graben
occurrence of
Coffee Sand
0 10 20 30 mi

Figure 7.

BH-1 and BH-2, an 3.1 to 7.2 ft interval of sand, gravel, and clay occurs at the contact between these units; it is assigned here to the McNairy Sand. In this interval, gravels consist of heterolithic clasts of dominantly chert and lesser orthoquartzite that range in size from granules to cobbles; sand is clayey, fine-grained, well-sorted, rounded to subrounded quartz.

Overlying the coarse basal interval, McNairy Sand consists of silt, very fine- to fine-grained sand, dark clay, and interbedded lignitic silt and clay. Silt- and sand-sized material consists of clear quartz, muscovite, and dark opaque minerals. Clay intervals generally are dark gray, silty, and commonly contain thin seams of muscovite. The maximum thickness of the McNairy Sand observed in this study was 108.7 ft in core BH-1.

A massive clay interval, informally known as the "Zadoc clay" (McQueen, 1939; Stewart, 1942), or "Zodoc clay" (Grohskopf and Howe, 1961), is a prominent stratigraphic marker in the upper one-third of the McNairy Sand (figs. 3 and 4). The clay is approximately 9 ft thick in cores BH-1 and BH-2, consists of brown to black, lignitic, pyritic plastic clay, and contains the most diverse microfossil assemblage encountered during this study. Dinoflagellates and foraminifers are abundant. Fossil pollen suggest an early to middle Maastrichtian age (table 3). This age assessment is based in part on the common occurrence of *Plicapollis usitatus* and the presence of the tricolporate taxon CP3D-3 (Wolfe, 1976), *Vacuopollis munitus*, *Choanopollenites consanguineus*, *Extremipollis caminus*, and *Extremipollis vivus* in the dispersed pollen component. The presence of the dinoflagellate taxa *Paleohystrichophora infusorioides* and *Exochosphaeridium bifidum* however are problematic and may suggest a youngest age of Campanian for this uni. These taxa have apparent youngest occurrences in the northern Atlantic Coastal Plain (Aurisano, 1989). However, a hiatus exists above their last occurrences there, at the Mt. Laurel-Navesink boundary (Self-Trail and Bybell, 1995; Sugarman and others, 1995), that precludes absolute determination of the true age of the last occurrence of these species in the Toms River Well. We therefore do not propose to restrict this samples age to the late Campanian solely on the basis of these two taxa. Their reported occurrence here also may represent reworked specimens, relict specimens, or misidentified specimens. As such, this unit probably correlates with the top of the *Disconodinium wilsonii* Zone or the basal *Chatangiella robusta* Zone of Aurisano (1989). Clay analyses of the McNairy Sand show dominant kaolinite and illite mineral compositions (table 2, fig. 6).

A discontinuous bed of case-hardened sandstone to orthoquartzite near the base of the McNairy Sand crops out in various places in the Benton Hills. It is as much as 15 ft thick and is informally known as the Commerce quartzite (Stewart, 1942; Johnson, 1985). It was not encountered in any of our drilling.

Sediments of the McNairy Sand are interpreted as representing environments of deposition that alternated from fluvial and upper deltaic conditions (silt and sand) to shallow-marine conditions (clays). Pryor (1960) concluded that the McNairy Sand was derived chiefly from metamorphic rocks of the Appalachian Mountains and transported southwestward by a single, large fluvial system. Davis and others (1973) conversely argued that multiple distributaries delivered clastic sediments into the northern Mississippi embayment during this time.

In our investigations, we have found no evidence to support Pryors' (1960) suggestion that the Coffee and McNairy Sands are laterally gradational with each other. Our conclusions are similar to those reached by Moore and Brown (1969), and Russell and Parks (1975) from work in western Tennessee.

Owl Creek Formation

The Owl Creek Formation conformably overlies the McNairy Sand in the Benton Hills. It consists of silt, clay, and sand. This unit is very slightly calcareous and is typically glauconitic, but in core hole BH-1, glauconite in the Owl Creek was altered to iron oxides. Farrar and others (1935) reported fossil marine invertebrates and plant remains in outcrops approximately 1.5 mi northeast of our drill holes; none were observed in our drill core, however possible silt-filled molds were noted in the upper portion of the Owl Creek Formation in BH-1 (appendix A).

Pollen analysis indicates a late Maastrichtian age for this unit (table 3). This age assessment is based on the presence of *Plicapollis usitatus*, *Interpollis* cf. *I. supplingensis*, *Choanopollenites consanguineus*, *Plicapollis vacuus*, *Extremipollis vivus*, *Vacuopollis munitus*, and *Nudopollis* aff. *N. thiergartii*. A youngest age of late Maastrichtian is supported by the presence of *Proteacidites* spp., *Interpollis* cf. I. *supplingensis*, and *Vacuopollis munitus*.

The clay mineral composition of the Owl Creek Formation in the Benton Hills drill holes is montmorillonite rich and distinct from clays in the McNairy Sand (fig. 6, table 2). This is in good agreement with the data of Pryor and Glass (1961). Pryor (1960) interpreted the environment of deposition of the Owl Creek Formation as a prodelta marine shelf. This unit was 11.1 ft thick in core hole BH-1 and was not encountered in the other cores.

Porters Creek Clay

In core hole BH-1, Porters Creek Clay of the Midway Group unconformably overlies the Owl Creek Formation (fig. 4, appendix A). The fossiliferous and glauconitic Clayton Formation, which occurs stratigraphically between these two units elsewhere, was not present. In BH-1, Porters Creek Clay is 36.7 ft thick and consists of massive, light- to medium-gray, silty clay. Lignite and muscovite are common. The clay fraction is dominantly montmorillonite (fig. 6, table 2). Identification of relict glass shards and pumice fragments in the Porters Creek Clay in the northern Mississippi embayment (Grim, 1933; Allen, 1934; and Simms, 1972) indicates that this unit is in part volcaniclastic.

Porters Creek Clay was deposited in a shallow epeiric sea (Herrick and Tschudy, 1967) during the maximum marine transgression in the Mississippi embayment (Stearns, 1957). This unit is ubiquitous in the embayment.

Pollen analysis of the Porters Creek Clay in the Benton Hills indicates a late Paleocene (Thanetian or~Sabinian) age (table 3). A Paleocene age is suggested by the combined occurrence of *Pseudoplicapollis endocuspis*, *Choanopollenites transitus*, *Nudopollis* aff. *N. thiergartii*, and *Thomsonipollis magnifica*. Additionally, the presence of *Alnus trina*, *Pistillipollenites* *mcgregorii*, *Corsinipollenites* sp., *Ulmipollenites krempii*, and *Caryapollenites veripites* support a late Paleocene age for the lower part of Porters Creek Clay in core hole BH-1 on the basis of geologic age ranges established for these taxa in the Mississippi embayment (Frederiksen, 1980; Frederiksen and others, 1982), the Atlantic Coastal Plain (Frederiksen and Christopher, 1978), and the Western Interior of the United States (Nichols and Ott, 1978). Our age determination corroborates the age suggested for this unit previously by Herrick and Tschudy (1967) from analysis of surface samples collected nearby in Ballard County, Kentucky and a sidewall-core sample taken in Lauderdale County, Tennessee (fig. 1, loc. A & B). However, this age is younger than the early Paleocene (Midwayan) age previously suggested for Porters Creek Clay by Frederiksen and others (1982) from sample cuttings collected from the New Madrid test wells (fig. 1, loc. C). Their age assignment was based largely on the presence of the dinoflagellate *Spinidinium densispinatum* in this stratigraphic interval. Additional work on this interval is in progress.

Wilcox Group

Strict designation of strata that directly overlie Porters Creek Clay in the Benton Hills as Wilcox Group is somewhat problematic. The Missouri Division of Geology and Land Survey has consistently referred to Tertiary strata above the Midway Group and below Mounds Gravel as the Wilcox since this stratigraphic interval was first recognized in southeast Missouri by Lamar and Sutton (1930) and identified by E.W. Berry of the U.S. Geological Survey as containing plant species typical of the Wilcox Group (reported in Farrar and others, 1935). The Wilcox Group in southeast Missouri subsequently was divided into a basal Ackerman Formation (silty clay), an overlying Holly Springs Formation (sand and lesser gravel), and the uppermost Idalia clay member (informal) of the Holly Springs Formation (Koenig, 1961; Grohskopf, 1955; Stewart, 1942; Farrar and McManamy, 1937; Farrar and others, 1935). More recently, subsurface investigators of the Mississippi embayment have divided the Wilcox Group into a basal Old Breastworks Formation (mainly silt), a middle Fort Pillow Sand, and an upper Flour Island Formation (mainly silt and clay) (Moore and Brown, 1969; Frederiksen and others, 1982). Frederiksen and others (1982) determined that the Paleocene-Eocene boundary occurs in the Flour Island Formation.

At first appearance, there seems to be close correlation between the two sets of nomenclature. However, from work in the Jackson Purchase region of western Kentucky, Olive (1980) describes the occurrence of black chert pebbles as characteristic of the Eocene Jackson and Claiborne Formations, but not the Wilcox Group. Black chert pebbles are common in the Holly Springs Formation in Missouri. Thus based on lithologic similarities, the Holly Springs Formation could be correlative to either the Jackson and/or Claiborne Formations. A perusal of flora species (Berry, 1916) used to name the Wilcox Group in Missouri does not preclude possible correlation with the Jackson and/or Claiborne Formations. This matter remains unresolved, and in this report the nomenclature of the Missouri Division of Geology and Land Survey is used.

Ackerman Formation of the Wilcox Group

Overlying Porters Creek Clay in core hole BH-1 is approximately 8.5 ft of brightly colored, silty clay termed the Ackerman Formation in Missouri stratigraphic nomenclature (Koenig, 1961). The lower contact of this unit with Porters Creek Clay was not observed due to core loss. Elsewhere, the contact is described as sharp and marked by either glauconitic sandstone, boulders of bauxitic clay, or enigmatic boulders of quartzite as much as 3 to 4 ft in diameter (Stewart, 1942; Koenig, 1961). The clay mineral suite of the Ackerman Formation is montmorillonite poor, in sharp contrast with the Porters Creek Clay (fig. 6, table 2).

Holly Springs Formation of the Wilcox Group

Overlying the Ackerman formation in core hole BH-1 is approximately 10 ft of coarse sand and gravel called the Holly Springs Formation in Missouri stratigraphic nomenclature. These sediments are poorly sorted and consist of rounded to subrounded grains of variously colored quartz and gray, white, and black chert. Minor amounts of orthoquartzite grains also occur. Abundant iron oxides give the unit a characteristic red color. This unit is interpreted to be of fluvial origin, and marks the final regression of seas from the northern Mississippi embayment.

Mounds Gravel

Core hole BH-1 was collared on the floor of an abandoned gravel quarry, virtually on the contact between the Holly Springs Formation and the overlying Mounds Gravel. The walls of this quarry and several others in the vicinity provide excellent exposures of the Mounds Gravel. This unit consists of very poorly sorted, matrix-supported, well-rounded to subrounded, heterolithic gravel and intercalated sand lenses. Detailed studies of lithology and mineral composition are given by Lamar and Reynolds (1951) and Potter (1955a). Gravel lithologies are dominantly various-colored cherts and lesser amounts of white and light-pink quartz. Chert clasts are coated with a characteristic yellowish-brown patina. Clasts are generally 3 in. or less in diameter, but cobbles 6 in. or greater are relatively common. Rare clasts of silica-replaced petrified wood also occur, some of which are as much as 1 ft in diameter. Pristine edges on the petrified wood suggest pre-silicification weathering and disintegration, as well as in situ petrifaction. Notably absent in the Mounds Gravel in the Benton Hills are clasts of feldspathic igneous rocks or carbonate material. Sand occurs as matrix in gravel beds and as lenses as much as 15 ft thick. Sand grains are typically stained reddish brown by iron oxides and consist of quartz and lesser amounts of lithic fragments.

Much confusion of nomenclature and long-standing controversy of age and origin surround this unit. The name, Mounds Gravel, was applied by Willman and Frye (1970) to deposits previously called Lafayette (or Lafayette-type) Gravel, Tertiary gravel, "Plio-Pleistocene" gravel, or continental deposits by many other workers. Mounds Gravel was placed in the Upland Complex of Autin and others (1991) and correlated with the Willis Formation of Louisiana and Texas, and the Citronelle Formation which extends along the Coastal Plain from Texas to Virginia. Similar upland deposits are also found in western Missouri, eastern Kansas, and Oklahoma (Madole and others, 1991).

Based on analysis of terrace levels, Fisk (1944) considered these gravels to be Pleistocene in age and of glacial-outwash origin. Potter (1955b) contradicted Fisk's interpretation and from petrologic and physiographic evidence argued for a preglacial Pliocene age. A Pliocene age is also suggested by Lamar and Sutton (1930), Weller (1940), and Leighton and Willman (1949). Olive (1980) concluded that gravel of two ages occurred in western Kentucky: an upper-level gravel containing pollen of Miocene(?) and Pliocene age, and a lower-level, reworked gravel containing Pleistocene pollen. He suggested that erosion and redistribution of the older gravel to lower elevations began in late Pliocene and probably continued into the early Pleistocene.

Mounds Gravel in the Benton Hills occurs at relatively high elevations, from 450 to 580 ft above mean sea level, and shows no indication of reworking. Thus, this unit is believed to be Pliocene or Miocene(?) in age. It is as much as 80 ft thick in the Benton Hills and both upper and lower contacts are pronounced unconformities.

Structure

Stratigraphic intercepts penetrated by the Benton Hills core holes provide control for structural interpretations of the area, especially for evaluating the seismic reflection survey (Mini-Sosie Line 1). Offsets of all stratigraphic contacts between cores BH-1 and BH-2 indicate that the extensive faulting observed in the Thebes Gap area continues into the English Hill area (see fig. 2a). Figure 8 is a cross section that depicts faulting in the area and shows the more detailed interval covered by the Mini-Sosie survey. All indications are that Tertiary through Paleozoic units have been strongly affected by faulting and folding (for analysis see Harrison and Schultz, 1994, and Harrison, in press). Trenches recently excavated in the area in a cooperative effort with the Missouri Department of Natural Resources, Division of Geology and Land Survey have revealed several fault strands related to the English Hill fault that cut late Pleistocene Peoria Loess, a unit consisting of wind-blown glacial silt that blankets much of the Benton Hills. Initial results and interpretations of this trenching activity are presented by Harrison and others (1995).

The presence of a prominent lineament in the magnetic basement (Arkansas to Illinois lineament of Hildenbrand and Hendricks, 1995) that lies directly beneath the Benton Hills scarp is of considerable importance to our ongoing structural studies. Some of the faulting shown on Figure 8 possibly is related to this deep and

Figure 8. Cross section A-A' through the southern Benton Hills; location shown on figure 2a; QKu- Quaternary through Cretaceous units, undivided; Ojd- Ordovician Joachim Dolomite and Dutchtown Formation; Ospe- Ordovician St. Peter Sandstone and Everton Formation; Oe- Everton Formation; data for drill holes #8594 and 7202 are from Water Well Files of the Missouri Department of Natural Resources, Division of Geology and Land Survey, Rolla, Missouri.

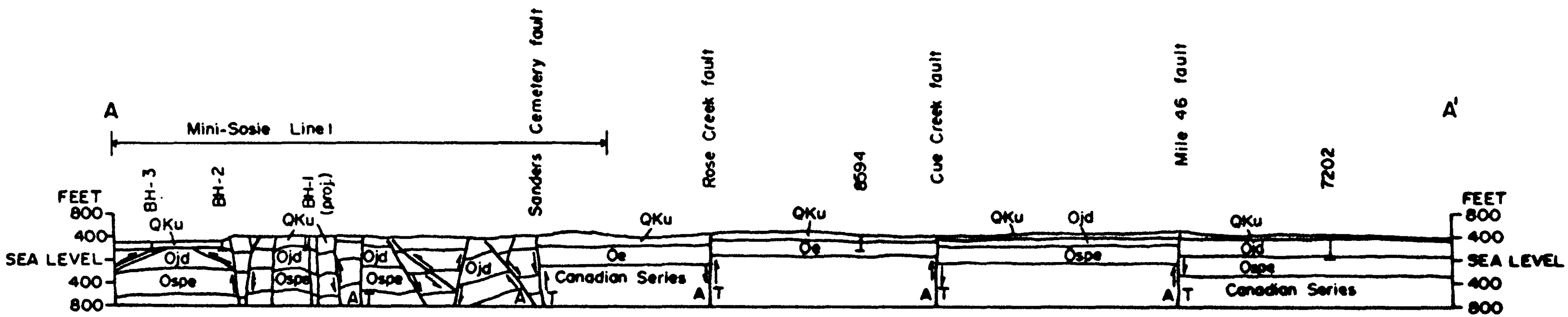

A
A'
Mini-Sosie Line 1
BH-3
BH-2
BH-1 (proj.)
Sanders
Cemetery fault
Rose Creek fault
8594
Cue Creek fault
Mile 46 fault
7202
FEET
800
400
SEA LEVEL
400
800
QKu
Ojd
Ospe
Oe
Canadian Series
A
T

Figure 8.

probably ancient structure.

References

Allen, V.T., 1934, Petrography and origin of the Fuller's earth of southeastern Missouri: Economic Geology, v. 29, p. 590-598.

Aurisano, R.W., 1989, Upper Cretaceous dinoflagellate biostratigraphy of the subsurface Atlantic Coastal Plain of New Jersey and Delaware, U.S.A.: Palynology, v. 13, p. 143-179.

Autin, W.J., Burns, S.F., Miller, B.J., Saucier, R.T., and Snead, J.I., 1991, Quaternary geology of the Lower Mississippi Valley; *in* Morrison, R.B., ed., Quaternary Nonglacial Geology; Conterminous U.S.: Geological Society of America, The Geology of North America, v. K-2, p. 547-582.

Berry, E.W., 1916, The lower Eocene floras of southeastern North America: U.S. Geological Survey Professional Paper 91, 481 p.

Burnett, J.A., Hancock, J.M., Kennedy, W.J., and Lord, A.R., 1992, Macrofossil, planktonic foraminiferal and nannofossil zonation at the Campanian/Maastrichtian boundary: Newsletter on stratigraphy, v. 27, no. 3, p. 157-172.

Christopher, R.A., 1980, Palynological evidence for assigning an Eaglefordian age (Late Cretaceous) to the Tuscaloosa Group of Alabama (abs.): Gulf Coast Section SEPM Research Conference Program and abstracts, Houston, Texas, p. 12-13

Christopher, R.A., 1982, Palynostratigraphy of the basal Cretaceous units of the eastern Gulf and southern Atlantic Coastal Plains; *in* Arden, D.D., Beck, B.F., and Morrow, E., eds., Proceedings from the Second Symposium on the Geology of the Southern Coastal Plain: Georgia Geological Survey Circular 53, p. 10-23.

Davis, R.W., Lambert, T.W., and Hansen, A.J., Jr., 1973, Subsurface geology and ground-water resources of the Jackson Purchase region, Kentucky: U.S. Geological Survey Water-Supply Paper 1987, 66 p.

Farrar, W., Grenfell, D.S., and Allen, V.T., 1935, The geology and bleaching clays of southeast Missouri: Missouri Geological Survey and Water Resources, 58th Biennial Report 1933-34,

Appendix I, 78 p.

Farrar, W., and McManamy, L., 1937, The geology of Stoddard County, Missouri: Missouri Geological Survey and Water Resources, 59th Biennial Report 1935-36, Appendix 6, 92 p.

Fisk, H.N., 1944, Geological investigation of the alluvial valley of the lower Mississippi River: U.S. Army Corps of Engineers, Mississippi River Commission, Vicksburg, Mississippi, 78 p.

Frederiksen, N.O., 1980, Paleogene sporomorphs from South Carolina and quantitative correlations with the Gulf Coast: Palynology, v. 4, p. 125-179.

Frederiksen, N.O., and Christopher, R.A., 1978, Taxonomy and biostratigraphy of Late Cretaceous and Paleogene triatriate pollen from South Carolina: Palynology, v. 2, p. 113-145.

Frederiksen, N.O., Bybell, L.M., Christopher, R.A., Crone, A.J., Edwards, L.E., Gibson, T.G., Hazel, J.E., Repetski, J.E., Russ, D.P., Smith, C.C., and Ward, L.W., 1982, Biostratigraphy and paleoecology of Lower Paleozoic, Upper Cretaceous, and lower Tertiary rocks in U.S. Geological Survey New Madrid test wells, southeastern Missouri: Tulane Studies in Geology and Paleontology, v. 17, no. 2, p. 23-45.

Grim, R.E., 1933, Petrography of the Fuller's earth deposits, Olmstead, Illinois, with a brief study of some non-Illinois earths: Economic Geology, v. 28, p. 344-363.

Grohskopf, J.G., 1955, Subsurface geology of the Mississippi Embayment of southeast Missouri: Missouri Geological Survey and Water Resources, 2nd Series, v. 37, 133 p.

Grohskopf, J.G., and Howe, W.B., 1961, Cretaceous System; *in* Koenig, J.W., ed., The Stratigraphic Succession in Missouri: Missouri Division of Geological Survey and Water Resources, 2nd Series, v. 40, p. 123-124.

Harrison, R.W., in press, Geologic map of the Thebes 7.5-minute quadrangle, Illinois and Missouri: U.S. Geological Survey, 1:24,000.

Harrison, R.W., and Schultz, Art, 1994, Strike-slip faulting at Thebes Gap, Missouri and Illinois: Implications for New Madrid tectonism: Tectonics, v. 12, no. 2, p. 246-257.

Harrison, R.W., Hoffman, Daviod, Palmer, J.R., Vaughn, J.D., and Schultz, 1995, Late Quaternary defromation on the English Hill fault, southeast Missouri: Geological Society of America Abstracts with Programs, v. 27, no. 6, p. 389.

Herrick, S.M., and Tschudy, R.H., 1967, Microfossil evidence for correlation of Paleocene strata in Ballard County, Kentucky, with the lower part of the Porters Creek Clay: U.S. Geological Survey Professional Paper 575-B, p. B40-B44.

Hildenbrand, T.G., and Hendricks, J.D., 1995, Geophysical setting of the Reelfoot rift and relations between rift structures and the New Madrid seismic zone, *in* Shedlock, K.M., and Johnston, A.C., eds., Investigations of the New Madrid seismic zone: U. S. Geological Survey Professional Paper 1538-E, 30 p.

Johnson, W.D., 1985, Geologic map of the Scott City quadrangle and part of the Thebes quadrangle, Scott and Cape Girardeau

Counties, Missouri: U. S. Geological Survey, Miscellaneous Field Studies Map MF-1803, scale 1:24,000, 2 sheets.

Koenig, J.W., 1961, Tertiary System, in Koenig, J.W., ed., The Stratigraphic Succession in Missouri: Missouri Geological Survey and Water Resources, 2nd Series, v. 40, p. 125-130.

Kolata, D.R., Treworgy, J.D., and Masters, J.M., 1981, Structural framework of the Mississippi Embayment of southern Illinois: Illinois State Geological Survey Circular 516, 38 p.

Lamar, J.E., and Reynolds, R.R., 1951, Notes on the Illinois "Lafayette" Gravel: Illinois State Geological Survey Circular 179, p. 95-108.

Lamar, J.E., and Sutton, A.H., 1930, Cretaceous and Tertiary sediments of Kentucky, Illinois, and Missouri: American Association of Petroleum Geologists Bulletin, v. 14, p. 845-866.

Leighton, M.M., and Willman, H.B., 1949, Late Cenozoic geology of Mississippi Valley, in Itinerary, 2nd Bienn. State Geologists

Field Conference: Illinois State Geological Survey, 86 p.

Luzietti, E.A., Kanter, L.R., Schweig, E.S. III, Shedlock, K.M., and VanArsdale, R.B., 1995, Shallow deformation along the Crittenden County fault zone near the southeastern margin of the Reelfoot rift, northeastern Arkansas; in Shedlock, K.M., and Johnston, A.C., eds., Investigations of the New Madrid seismic zone: U.S. Geological Survey Professional Paper 1538-J, 23 p.

Madole, R.F., Ferring, C.R., Guccione, M.J., Hall, S.A., Johnson, W.C., and Sorenson, C.J., 1991, Quaternary geology of the Osage Plains and Interior Highlands, in Morrison, R.B., ed., Quaternary Nonglacial Geology; Conterminous U.S.: Geological Society of America, The Geology of North America, v. K-2, p. 503-545.

Marcher, M.V., and Stearns, R.G., 1962, Tuscaloosa Formation in Tennessee: Geological Society of America Bulletin, v. 73, p. 1365-1386.

McQueen, H.S., 1939, Road log for third day of field conference, Cape Girardeau and "Embayment Missouri" areas: Kansas Geological Society, 13th Guidebook, p. 59-76.

Mellen, F.F., 1937, Little Bear residuum: Mississippi Geological Survey Bulletin 34, 36 p.

Moore, G.K., and Brown, D.L., 1969, Stratigraphy of the Fort Pillow test well, Lauderdale County, Tennessee: Tennessee Division of Geology, Report of Investigations 26, 2 sheets.

Nichols, D.J., and Ott, H.L., 1978, Biostratigraphy and evolution of the Momipites-Caryapollenites lineage in the Early Tertiary in the Wind River Basin, Wyoming: Palynology, v. 2, p. 93-112.

Olive, W.W., 1980, Geologic maps of the Jackson Purchase region, Kentucky: U.S. Geological Survey Miscellaneous Investigations Map I-1217, scale 1:250,000.

Palmer, J.R., and Hoffman, David, 1993, Possible late Quaternary faulting in the Benton Hills, southeastern Missouri (abs.): Geological Society of America, Abstracts with Programs, v. 25, no. 3, p. 72.

Palmer, J.R., and Hoffman, David, 1994, Collaborative research (USGS-BGRA and MO DNR-DGLS): Shallow seismic reflection survey in the Benton Hills, southeast Missouri: National Earthquakes Hazards Reduction Program, Summaries of Technical Reports, v. 30.

Potter, P.E., 1955a, The petrology and origin of the Lafayette Gravel: Part 1. Mineralogy and petrology: The Journal of geology, v. 63, p. 1-38.

Potter, P.E., 1955b, The petrology and origin of the Lafayette Gravel: Part 2. Geomorphic history: The Journal of Geology, v. 63, p. 115-132.

Pryor, W.A., 1960, Cretaceous sedimentation in upper Mississippi embayment: American Association of Petroleum Geologists Bulletin, v. 44, no. 9, p. 1473-1504.

Pryor, W.A., and Glass, H.D., 1961, Cretaceous-Tertiary clay mineralogy of the upper Mississippi embayment: Journal of Sedimentary Petrology, v. 31, no. 1, p. 38-51.

Pryor, W.A., and Ross, C.A., 1962, Geology of the Illinois parts of the Cairo, LaCenter, and Thebes quadrangles: Illinois State Geological Survey Circular 332, 39 p.

Ross, C.A., 1963, Structural framework of southernmost Illinois: Illinois State Geological Survey Circular 351, 27 p.

Ross, C.A., 1964, Geology of the Paducah and Smithland quadrangles in Illinois: Illinois State Geological Survey Circular 360, 32 p.

Russell, E.E., and Parks, W.S., 1975, Stratigraphy of the outcropping Upper Cretaceous, Paleocene, and lower Eocene in western Tennessee (including descriptions of younger fluvial deposits): Tennessee Division of Geology Bulletin 75, 53 p.

Safford, J.M., 1864, On the Cretaceous and Superior formations of West Tennessee: American Journal of Science, 2nd Series, v. 37, p. 360-372.

Self-Trail, J.M. and Bybell, L.M., 1995, Cretaceous and Paleogene calcareous nannofossil biostratigraphy of New Jersey:

Geological Association of New Jersey, Contributions to the paleontology of New Jersey, p. 102-139.

Sigleo, W.R., and Reinhardt, Juergen, 1985, Cretaceous paleosols from the eastern Gulf Coast Plain: Southeastern Geology, v. 25, p. 213-223.

Sims, J.D., 1972, Petrographic evidence for volcanic origin of part of the Porters Creek Clay, Jackson Purchase region, western Kentucky: U.S. Geological Survey Professional Paper 800-C, p. C39-C51.

Smith, E.A., and Johnson, L.C., 1887, Tertiary and Cretaceous strata of the Tuscaloosa, Tombigbee, and Alabama Rivers: U.S. Geological Survey Bulletin 43, 189 p.

Stearns, R.G., 1957, Cretaceous, Paleocene, and lower Eocene geologic history of the northern Mississippi embayment: Geological Society of America Bulletin, v. 68, p. 1077-1100.

Stearns, R.G., and Marcher, M.V., 1962, Late Cretaceous and subsequent structural development of the northern Mississippi embayment area: Geological Society of America Bulletin, v. 73, p. 1387-1394.

Stewart, Dan, 1942, The Mesozoic and Cenozoic geology of southeastern Missouri: Missouri Geological Survey, unpublished manuscript, 122 p.

Stewart, Dan, and McManamy, Lyle, 1944, Early Quaternary or late Tertiary folding in the vicinity of Commerce, Scott County, southeastern Missouri: Missouri Academy of Science, Rolla, Missouri.

Sugarman, P.J., Miller, K.G., Bukry, David, and Feigenson, M.D., 1995, Uppermost Campanian-Maestrichtian strontium isotopic, biostratigraphic, and sequence framework of the New Jersey Coastal Plain: Geological Society of America Bulletin, v. 107, no. 1, p. 19-37.

Tschudy, R.H., 1975, Normapolles pollen from the Mississippi embayment: U.S. Geological Survey Professional Paper 865, 42 p.

Weller, J.M., 1940, geology and oil possibilities of extreme southern Illinois: Illinois State Geological Survey Report of Investigations 71, 71 p.

Willman, H.B., and Frye, J.C., 1970, Pleistocene stratigraphy of Illinois: Illinois State Geological Survey Bulletin 94, 204 p.

Willman, H.B., and Frye, J.C., 1975, Mesozoic Erathem; *in* Willman, H.B., Atherton, Elwood, Buschbach, T.C., Collinson, Charles, Frye, J.C., Hopkins, M.E., Lineback, J.A., and Simon, J.A., eds., Handbook of Illinois stratigraphy: Illinois State Geological Survey Bulletin 95, p. 201-206.

Wolfe, J.A., 1976, Stratigraphic distribution of some polen types from the Campanian and lower Maestrichtian (Upper Cretaceous) of the Middle Atlantic States: U.S. Geological Survey Professional Paper 977, 18 p.

Appendix A.

Drill-hole log BH-1.--Location: abandoned gravel quarry on Leonard Weber farm, SW 1/4, SW 1/4, NW 1/4 sec. 34, T. 29 N., R. 14 E., Scott County, Missouri; collar elevation: 459 ft; inclination at collar: -90°; length: 233 ft; drilled: 9/16/93-9/22/93.

Unit	Depth (feet)
Tertiary System	
Pliocene or Miocene? Series	
Mounds Gravel (in part):	
Gravel, cobble to very coarse pebbles; poorly sorted; subrounded to subangular; clasts of brown and gray chert, and orthoquartzite; brown patina on clasts-------------------------------------	0.0-0.3
Eocene\Paleocene Series	
Holly Springs Formation of the Wilcox Group:	
Sand, very coarse to fine grained; about 10% granule to very coarse gravel; poorly sorted; rounded to subrounded; in part cemented by reddish-brown iron oxides; grains of clear, white, and reddish quartz, black and gray chert, and orthoquartzite---------	0.3-5.2
Gravel, granule to very coarse pebble; about 30% very coarse- to fine-grained sand; poorly sorted; rounded to subrounded; unconsolidated; clasts of gray, black, yellowish-white, and reddish-brown chert, orthoquartzite, and clear, white, and red quartz------------------------------------	5.2-6.9
Sand, reddish-brown; fine to coarse grained; <5% granule gravel; moderately sorted; rounded to subrounded; heavy iron oxide; clasts dominantly clear and white quartz, lesser pink quartz and orthoquartzite------	6.9-8.7
Gravel, coarse pebble to granule; about 15% fine- to very coarse-grained sand; poorly	

sorted; rounded to subrounded; in part indurated with an iron oxide cement; clasts of white to clear quartz, gray, black, and white chert, and minor orthoquartzite----------8.7-10.0

Ackerman Formation of the Wilcox Group:

Clay, mottled bright yellow, pink, and tan; very silty, slightly sandy (dominantly very fine-grained clear quartz, lesser dark opaques)very plastic------------------------ 10.0-15.2

Clay, light gray and yellowish brown; very silty; plastic------------------------------ 15.2-18.5

Porters Creek Clay:

Clay, light to medium gray (dark gray when wet); silty; micaceous; lignite common, especially from 25 to 40 ft; abundant conchoidal fractures when dry; very slightly plastic; expandable; 1/4 in. pyrite nodule at 32.3 ft; rare glauconite grains; sharp lower contact------------------------ 18.5-55.2

Cretaceous System

Maastrichtian Series

Owl Creek Formation:

Silt and clay, interbedded; dark gray plastic clay and white micaceous silt; thinly bedded; quartz, dark opaques, and muscovite in silt fraction; lignite scattered throughout; local bioturbation; possible silt-filled molds of marine invertebrates; pyrite and sulfates after pyrite common---- 55.2-59.4

Silt, mottled gray, brown, and white; clayey; strong bioturbation; abundant limonite and goethite; grains of quartz, dark opaques, and muscovite; lignite throughout, seam at 60.9 ft------------------------------------- 59.4-60.9

Silt, yellowish brown and brownish gray; moderate bioturbation; grains of quartz,

dark opaques, and muscovite---------------- 60.9-61.8
Silt, yellowish brown and greenish gray; subangular grains of quartz, dark opaques, muscovite, and glauconite?----------------- 61.8-62.7
Silt, mottled yellow, gray, and pink; grains of quartz, muscovite, and dark opaques----- 62.7-65.0
Silt, yellow to tan; about 20% gray clay in irregular shapes; lithologies similar to above-- 65.0-65.5
Sand, yellow and brown; very fine grained; locally well-indurated iron-oxide-cemented clots and layers; well sorted; subangular; dominantly quartz, lesser dark opaques, and very rare muscovite, gradational lower contact------------------------------------- 65.5-66.3

McNairy Sand:

Sand, white to light tan; very fine grained; well sorted; subangular; very rare iron oxides; grains of quartz, muscovite, and dark opaques------------------------------- 66.3-74.2
Silt, pinkish tan; rare iron oxides; lithologies similar to above; abundant sand-sized muscovite--------------------------- 74.2-74.8
Silt, yellow, brown, white, and gray; abundant well-indurated iron-oxide-cemented clots and layers; strong bioturbation; lithologies similar to above-------------------- 74.8-75.3
Silt, yellow and brown; abundant well-indurated iron-oxide-cemented layers, 1/4 in. seam at 76.1; finely laminated; no bioturbation; lithologies similar to above--------------- 75.3-76.1
Silt and clay, very finely laminated grayish white quartz-muscovite silt and medium gray clay; fine specs of lignite throughout; no iron oxides---------------------------------- 76.1-83.6
Clay, light to medium gray; silty (quartz-muscovite grains); massive; plastic-------- 83.6-84.2
Silt and clay, alternating horizontal beds of white quartz-muscovite silt and medium-gray silty plastic clay; beds 1/8 to 1.0 in.

thick-- 84.2-86.3

Clay, medium to dark gray; very silty (quartz-muscovite grains); numerous lens and partings of quartz-muscovite silt; specks of lignite throughout, 1/2 in. seam at 92.9 ft; plastic-- 86.3-94.6

Zadoc Clay Member of McNairy Sand:

Clay, dark gray; slightly to moderately silty; relatively massive; few quartz-muscovite silt seams; plastic; sharp, wavy lower contact-- 94.6-103.2

Clay and sand, interlayered medium-gray silty clay and pinkish tan to yellow very fine-grained quartz sand; layers 1/8 to 3/4 in. thick and contorted from bioturbation; transition zone------------------------------ 103.2-103.4

Sand, white, yellow, and brown; very fine grained; well sorted; subrounded; almost exclusively quartz grains, rare opaques, very rare muscovite; iron-oxide concentration at 107.2 ft----------------------------- 103.4-108.4

Silt, white, yellow, and pink; fine horizontal laminations; grains of quartz, abundant muscovite, and dark opaques; minor iron oxides-- 108.4-118.4

Sand and silt, dominantly yellow, lesser pinkish red and brown; very fine grained; relatively massive, few horizontal bedding surfaces; well sorted; subrounded; grains of quartz, muscovite, and dark opaques----- 118.4-135.7

Sand and silt, variegated yellow, pinkish red, and brown, common liesegang bands; very fine grained; dominantly quartz grains, minor muscovite and dark opaques; low amplitude cross bedding defined by hairline to 1/8 in. white clay intervals----------- 135.7-164.9

Sandstone, yellow, brown, and tan; poorly sorted; fine- to coarse-grained, subrounded to rounded, clear and white quartz; sparse muscovite; 5-10% matrix-supported coarse pebbles of various-colored chert, iron-cemented quartz sandstone, orthoquartzite, and argillic-altered fragments; pebble amounts and size increase downward; slightly calcareous clay cement; transition zone-- 164.9-171.9

Gravel, heterolithic clasts in dark-gray clay matrix; very coarse to fine pebbles; clasts of various-colored chert, banded chert, fine- and medium-grained orthoquartzite, iron-cemented quartz sandstone, and argillic-altered pyritic rock; older, iron-oxide-cemented matrix partially coats some clasts-------------------------------------- 171.9-175.0

Campanian Series

Coffee Sand:

Clay, medium to light gray; lignite rich; very sandy, fine grains of dominantly quartz and lesser chert; rare fine-pebble clasts of gray chert; micaceous------------ 175.0-180.3

Clay, very light gray; lignite common; very rare fine-grained quartz sand-------------- 180.3-180.5

Clay, medium gray; lignite rich; silty; micaceous---------------------------------- 180.5-185.3

Clay, light to medium gray; lignite rich; variable quartz sand content, from slight to abundant; rare granule to fine-pebble clast of chert; 1.5 in. pyrite nodule at 189.6 ft; specs of white clay (kaolinite?) common throughout; tubular Foraminifer identifiable locally------------------------------------ 185.3-194.8

Clay, dark gray; very silty; massive; lignite common, but less than above; common gypsum bloom upon drying; 1/2 in. pyrite nodule at 197.3 ft; silt grains of dominantly clear quartz------------------------------------- 194.8-198.2

Post Creek Formation:

Gravel, heterolithic clasts in a buff sandy matrix; very coarse pebbles to cobbles; subangular to subrounded; clasts of light-to dark-gray chert; rounded to subrounded frosted quartz sand------------------------ 198.2-205.0

Sand and gravel, medium to dark gray; about 50-50% mixture; massive, no apparent bedding; subrounded to rounded, fine-grained, well-sorted, frosted-quartz sand; angular, matrix-supported, coarse- to fine-pebble, light- to dark-gray chert gravel; gravel fines downward; gray clay coats all clasts; sparse pyrite; common gypsum bloom- 205.0-212.5

Clay, silt, and gravel, medium to dark gray; lithologies similar to above, only finer grain sizes; about 15% fine-pebble to granule gravel, decreases in amount downward; spotty very coarse pebble; rounded, frosted-quartz silt; common gypsum bloom--- 212.5-222.0

Lower Cretaceous Series?

Little Bear Formation:

Clay, silt, and gravel, dark to light gray and brownish yellow; transition zone; lithologies similar to above mixed with brownish yellow clay---------------------- 222.0-222.4

Clay, brownish yellow, brown, and tan in swirly patterns; slightly silty; < 5% angular, granule chert fragments; common platelets and pods of limonite and goethite; 2 in. gray and black chert fragment at 226.9 ft---------------------------------- 222.4-227.0

Ordovician System

Mohawkian Series

Joachim Dolomite or uppermost Dutchtown Formation:

Limestone, brownish gray; finely crystalline; no chert; subhorizontal fine laminations; numerous subhorizontal stylolites; hairline vertical (tectonic stylolite) from 228.1-228.7 ft; upper 3 in. strongly broken; angular breccia (fault?) from 230.7-231.0; iron oxide coatings along fractures-------- 227.0-233.0

Appendix B.

Drill-hole log BH-2.--Approximately 300 ft north of Route E and English Hill Road intersection on Leonard Weber farm, center W1/2, sec. 34, T. 29 N., R. 14 E., Scott County, Missouri; collar elevation: 371 ft; inclination at collar: -90°; length: 195 ft; drilled: 9/23/93-9/28/93.

Unit	Depth (feet)
Quaternary System	
Holocene Series	
Alluvium:	
Silt, tan to light brown; very slightly sandy; common twig and root debris----------------	0.0-3.0
Sand, tan to light brown: silty; very fine to fine grained; coarsens downward; dominantly subrounded clear quartz-------------------	3.0-3.6
Gravel and sand, brown and tan; poorly sorted; subrounded to subangular, granule to coarse pebbles of brown, yellow, red, and black chert, and orthoquartzite; fine- to very coarse-grained sand of clear, white, pink, and yellow quartz, and various-colored chert; commons ion- and manganese-oxide stains--------------------------------------	3.6-5.3
Silt, tan to light brown to brownish white; micaceous; locally sandy; isolated granule to fine pebbles of various-colored cherts throughout; common iron oxide stains-------	5.3-11.0
Sand and gravel, yellowish brown; silty; fine- to coarse-grained sand and granule to very coarse pebbles of subrounded to subangular clear and white quartz, and various-colored cherts; abundant iron oxides---------------	11.0-15.0
Sand, gravel, and clay; light tan and gray; transition zone; lithologies similar to above interval mixed with micaceous, silty clay from below---------------------------	15.0-15.2

Cretaceous System

Maastrichtian Series

McNairy Sand (in part):

Clay and silt, light gray and yellow brown; very micaceous; finely laminated; slightly bioturbated----------------------------------	15.2-15.5
Silt, white to light gray; very micaceous; cross bedding defined by muscovite concentrations; 1½ in. almond-shaped iron concretion 15.8 ft-------------------------	15.5-16.8
Clay, light to medium gray; silty; micaceous; lignite rich; cross bedding (as much as 30° from horizontal) defined by muscovite concentrations-----------------------------	16.8-25.0
Clay and gravel, light gray; silty; micaceous; rounded to subrounded, fine to medium pebbles of various-colored cherts and white quartz; massive; no cross bedding; sparse lignite-------------------------------------	25.0-26.1
Silt, light to medium gray and brownish yellow; clayey; locally sandy; very micaceous; low amplitude cross bedding defined by muscovite concentrations; isolated granules of chert and locally small concentrations along bedding surfaces-----------------------------------	26.1-27.9
Silt, yellow; clayey; slightly sandy; micaceous; 1/4 in. iron-oxide cemented `hard pan' at upper contact---------------------	27.9-35.0
Sand, white, yellow, pink, and orange; very fine grained; dominantly subangular clear quartz, much lesser muscovite and dark opaques; rare iron and manganese oxides----	35.0-46.2

Zadoc Clay Member of the McNairy Sand

Clay, dark to medium gray; silty; micaceous; plastic; massive, few silt lens and partings; gypsum bloom upon drying---------	46.2-54.6
Clay and sand, dark gray and brownish yellow; transition zone; lithologies similar to above interval mixed with lithologies	

similar to interval below------------------ 54.6-55.2

Sand, yellowish brown, white, and pink; very fine grained; clay matrix; dominantly sub-angular quartz grains, minor muscovite; 1/8 in. iron-oxide `hard pan' at lower contact------------------------------------- 55.2-57.6

Sand, orange and yellowish brown; very fine grained; clean, virtually all subangular to subrounded quartz, very rare muscovite, no clay; iron oxide concentration at lower contact------------------------------------- 57.6-57.8

Sand, white and yellowish brown; very fine grained; clean quartz grains; very rare muscovite except in 1/2 in. iron-oxide layer at 58.1 ft; fine subhorizontal beds-------- 57.8-59.5

Sand, white and yellowish brown; very fine grained; dominantly quartz grains, but muscovite rich; 1.0 in. layer of iron-oxide concentration at 59.9 ft------------------- 59.5-60.8

Silt, white, yellowish brown, orangish brown, and pink; slightly sandy; grains of subangular quartz, muscovite, and dark opaques------------------------------------- 60.8-83.3

Sand, yellow, yellowish brown, pink, and orange; very fine grained; well sorted; sub-angular to subrounded grains of quartz, muscovite, and dark opaques; variable clay content, relatively abundant in yellowish-brown-colored intervals, almost absent elsewhere---------------------------------- 83.3-99.3

Sand, yellowish brown and tan; fine to very fine grained; moderately sorted; clayey; dominantly subrounded to rounded quartz, rare muscovite, very rare opaques---------- 99.3-103.9

Sand, yellowish brown and pink; very fine grained; clayey; dominantly quartz, but abundant muscovite; streaky clay lens from 103.9 to 104.0 ft; sharp lower contact----- 103.9-105.6

Silt and clay, yellowish to pinkish brown and light gray; alternating 1/8 to 1/4 in. layers of clay and clayey, muscovite-rich silt--------------------------------------- 105.6-105.7

Sand, tan and yellowish brown; fine grained; well sorted; subrounded to rounded grains of quartz, rare muscovite; slightly clayey- 105.7-106.3

Sand, yellowish brown and tan; very fine grained; subrounded quartz grains, no muscovite; clayey-------------------------- 106.3-107.3

Sand, yellowish and reddish brown, and tan; fine to medium grained; poorly sorted; dominantly subrounded quartz, rare muscovite; isolated fine pebbles of gray chert from 108.5 to 108.9 ft--------------- 107.3-108.9

Clay, medium to dark gray; silty; micaceous; massive; plastic; gypsum bloom upon drying; sharp upper contact, gradation lower------- 108.9-111.5

Sand, tan and yellowish tan; fine grained; well sorted; subrounded to rounded quartz, no muscovite; rounded fine pebbles of chert (some oolitic) isolated and scattered throughout---------------------------------- 111.5-115.2

Clay and sand, tan, yellowish brown, and gray; transition zone; lens of sand similar to above interbedded with silty, sandy, micaceous clay; finely layered------------- 115.2-115.5

Clay, medium to dark gray; silty; micaceous; muscovite concentrated on partings; massive; plastic-------------------------- 115.5-116.3

Sand and gravel, yellowish and reddish brown, and light gray; fine-grained, well-sorted, rounded to subrounded quartz sand; no muscovite; clayey; subrounded granule to coarse pebbles of various-colored cherts; percentage of pebbles increases with depth- 116.3-118.0

Gravel, heterolithic clasts in a medium-gray clay matrix; coarse pebbles to cobbles; clasts of various-colored cherts and fine-grained orthoquartzite (6% recovery)------- 118.0-125.0

Clay and gravel, dark gray; transition zone; granules and coarse pebbles of chert embedded in lignite-rich clay------------- 125.0-125.2

Campanian Series

Coffee Sand:

Clay, dark to medium gray; lignite rich; silty; micaceous-------------------------- 125.2-128.1

Clay, light gray; lignite rich, 1½ in. layer at 129.3 ft; silty; quartz grains, but no mica; common pyrite replacing organic material throughout, 1 in. pyrite nodule at 129.5 ft, 1 in. pyrite layer at 135.5 ft; common gypsum bloom upon exposure to air-- 128.1-138.5

Clay and sand, light gray and yellowish brown; transition zone; lithologies similar to above interval mixed with lithologies similar to below; 1 in. pyrite nodule embedded in sand------------------------- 138.5-138.8

Sand, yellowish to reddish brown and light tan; clayey; fine to very fine grained; subangular to subrounded grains of clear and white quartz, black and gray chert; gradational lower contact------------------ 138.8-144.8

Post Creek Formation:

Gravel, heterolithic clasts in a yellowish-brown to brownish-gray sandy and silty matrix; coarse pebbles to cobbles; sub-rounded clasts of black and light to dark gray chert, and pyrite nodules------------- 144.8-165.0

Gravel and clay, light to dark gray, brown, and reddish brown; subangular to subrounded granules and coarse pebbles of gray and black chert, and iron-cemented sandstone; matrix of silty to sandy clay------------- 165.0-166.5

Clay, brownish gray and yellowish brown; very slightly silty; massive; sparse coarse pebbles of black chert; iron oxides and very fine-grained sulfides concentrated at 173.5 ft (replacing organic material?); common gypsum bloom; gradational upper contact; sharp and irregular lower contact; lignite and fine-grained pyrite concentrated near lower contact----------- 166.5-174.6

Lower Cretaceous Series?

Little Bear Formation:

Clay and claystone, pale yellowish brown and yellowish gray; angular laminated claystone fragments in a massive clay matrix; very fine liesegang bands---------------------- 174.6-175.0

Clay, brownish and reddish gray, and yellow; slightly sandy; common lignite and very fine-grained pyrite, also 1.o in. pyrite nodule; scattered and isolated medium to coarse pebbles of black chert; gypsum bloom upon exposure to air---------------------- 175.0-175.3

Clay, pale yellowish green, reddish brown, and pale white, swirly color pattern; numerous fragments of angular claystone; iron and manganese oxides replacing lignite fragments-----------------------------------175.3-177.0

Gravel, heterolithic clasts in yellow-brown clay matrix; medium to very coarse pebbles; subrounded; clasts of light to dark gray and black chert-------------------------- 177.0-192.0

Clay, brownish yellow, yellowish green, black brown streaks, contorted and swirly color patterns; massive and dense; scattered and isolated coarse to medium pebbles of chert; common iron oxides replacing lignite------- 192.0-194.0

Clay, yellowish white; powdery---------------- 194.0-194.3

Clay, yellowish brown, brown, and gray, swirly color patterns; massive and dense; sparse sand grains of quartz and chert; common iron oxides replacing lignite; medium to coarse pebbles of chert and dolomite concentrated at lower contact-------------- 194.3-194.6

Ordovician System

Mohawkian Series

Joachim Dolomite or uppermost Dutchtown Formation:

Dolomite, medium to dark gray; finely crystalline, irregular, contorted bedding; strongly fractured and broken; iron-oxide coatings along fractures------------------- 194.6-195.0

Appendix C.

Drill-hole log BH-3.--Location: field on Leonard Weber farm, approximately 800 ft southeast of Route E and English Hill Road, SW¼, NE¼, SW¼ sec. 34, T. 29 N., R. 14 E., Scott County, Missouri; collar elevation: 335 ft; inclination at collar: -90°; length: 119 ft; drilled: 11/3/93-11/8/93.

Unit	Depth (feet)
Quaternary System	
Holocene Series	
Alluvium\Colluvium:	
Clay, yellowish brown and brownish gray; very silty; slightly sandy; common plant debris-	0.0-1.5
Pleistocene Series	
Alluvium:	
Sand, brown to tan; fine to very fine grained; moderately to well sorted; subrounded to rounded; grains of clear, white, and pink quartz, various-colored cherts, dark opaques, and sparse igneous and metamorphic rocks; coarsens downward slightly; arbitrary lower contact-------------------	1.5-12.5
Sand, brown to tan; very fine to very coarse grained; scattered granules; moderately sorted; lithologies similar to above interval and includes some muscovite and orthoquartzite; arbitrary lower contact----	12.5-19.4
Sand, brown to tan; very fine to very coarse grained; abundant granules and fine pebbles; scattered medium to coarse pebbles; slightly silty; poorly sorted; lithologies similar to above and includes a 1.0 in. clast of pebble conglomerate at 19.4 ft; arbitrary lower contact----------	19.4-27.0
Sand and gravel, brown to tan; very fine sand to very coarse pebbles; silty; very poorly sorted; lithologies similar to above	

interval; gradational lower contact--------	27.0-37.5
Sand, brown to tan; very fine to coarse grains; scattered very coarse sand, and granule and fine pebbles; very silty; poorly to very poorly sorted; lithologies similar to above; sooty organic material at 37.9 ft; gradational lower contact---------	37.5-38.4
Sand and gravel, brown to tan; fine- to coarse-grained sand and granule gravel; scattered fine to very coarse pebbles; lithologies similar to above; organic material at 39.0 ft------------------------	38.4-50.6
Sand, gravel, and clay, brown to tan to light gray; transition zone; material similar to above mixed with clay similar to below-----	50.6-50.9
Sand, clay, and gravel, greenish brown, pale green, and whitish green; very poorly sorted; fine- to medium-grained sand and clay matrix; matrix-supported granules to very coarse pebbles of subrounded to subangular, various-colored cherts and rare igneous and metamorphic rocks; 1.0 in. diameter rounded lignite fragment at 59.3 ft----------------------------------	50.9-69.0
No recovery----------------------------------	69.0-74.0

Cretaceous System

Campanian Series?

Post Creek Formation?:

Clay and gravel, medium gray and pale greenish gray, swirly color patterns; slightly sandy; matrix-supported granules to very coarse pebbles off various-colored (dominantly pale whitish gray) cherts; sparse organic material-------------------	74.0-79.0
Sand, clay, and gravel, grayish green; fine- to very coarse-grained sand of subrounded polished quartz, chert, sparse brown silicified siltstone, and rare pyrite; fine to coarse pebbles of various-colored cherts; abundant interstitial clay---------	79.0-79.3
Clay, pale greenish gray, brownish black, and	

brown, irregular and swirly color patterns; massive and dense; scattered granules and medium pebbles of whitish-gray chert; spars sand; irregular patches of brown iron-oxide concentrations from 81.2 to 82.0 79.3-82.0

Lower Cretaceous Series?

Little Bear Formation:

Gravel and clay, whitish gray, pale green, and brown; sandy clay matrix; matrix-supported granules to cobbles of dominantly white to light gray weathered chert, some brown silicified siltstone? or chert? from 88.7 to 89.0 ft; fine to medium sand grains of polished quartz and various colored cherts-- 82.0-89.4

Clay, light greenish gray and brown; slightly calcareous; <10% matrix-supported, rounded very fine sand grains of exclusively reddish-brown quartz?--------------------- 89.4-90.1

Gravel, clay, and sand, light gray to brownish gray; very fine to fine sand grains of reddish-brown quartz? and polished clear quartz; subangular granules to coarse pebbles of white and whitish gray chert; matrix supported at top grading into clast supported at base; very slightly calcareous 90.1-99.0

Gravel, whitish gray and brownish gray; matrix, if existing, washed away during drilling; monolithic, angular to subangular, coarse and very coarse pebbles of whitish-gray chert in upper portion; monolithic, subangular, very coarse pebbles of brown, finely crystalline dolomite in lower portion; 10% recovery--------------------- 99.0-107.0

Ordovician System

Mohawkian Series

Joachim Dolomite or uppermost Dutchtown Formation:

Dolomite, medium gray to brownish gray; finely crystalline; abundant very thin subhorizontal laminae defined by dark intraformational solution surfaces; some irregular cross laminae; common fine bioturbation; near vertical (tectonic) stylolites from 107.0 to 108.0 ft----------107.0-109.0

Dolomite, medium gray to brownish gray; finely crystalline; laminae dip at about 40° and are disrupted then above; hairline stylolite at 55° to bedding at 110.1 ft; very fine-grained crystalline pyrite on laminae surface at 110.2 ft, also horizontal striations indicating strike-parallel movement; strongly broken from 110.4 to 113.0 ft---------------------------------- 109.0-113.0

Dolomite, medium gray to brownish gray, finely crystalline; laminae dip at 15° to 20°; abundant hairline to 1/16 in. lens and streaks of very fine-grained sulfides, dominantly subparallel to laminae, but some cross cut laminae (outlining bioturbation?); fracture dipping 70° (perpendicular to laminae) filled with fine-grained carbonates and scattered very fine-grained galena from 112.0 to 112.3 ft; fracture with similar orientation and mineralization from 112.8 to 113.1 ft; subhorizontal striations and smeared galena and pyrite on several laminae surfaces from 113.1 to 113.4 ft; strongly broken and fractured rock (several fractures striated) from 113.4 to 117.0 ft; 1.0 in. horizontal gouge and breccia interval at 116.9 to 117.0 ft and containing horizontally striated surfaces and coarse-sand-sized grains of clear to brown quartz, some with unidentified gray-black sulfide mineralization-- 113.0-117.0

Dolomite, medium gray to brownish gray; finely crystalline; laminae dip from 10° to 20°; lens, streaks, and pods of very fine-grained sulfides parallel to and cross cutting laminae; very fine-grained sulfides along vertical (tectonic) stylolite with 1/2 in. amplitude from 117.0 to 117.3 ft, also sulfides along smaller vertical stylolites from 117.9 to 118.2; 1/2 in. interval of strong bioturbation accented by sulfides at 117.8 ft; sulfide concentrations increase to about 30% of rock from 118.0 to 118.2--- 117.0-118.2

Gouge and breccia? and\or solution-altered material, light gray to light brownish gray; sharp subhorizontal contact with above interval; soft altered dolomite fragments; minor sulfide disseminations; sparse polished, rare fine- to coarse-sand-sized grains of quartz--------------------- 118.2-119.0