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The Pipe Creek Sinkhole Biota, a Diverse Late Tertiary Continental Fossil Assemblage from Grant County, Indiana

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ABSTRACT.—Quarrying in east-central Indiana has uncovered richly fossiliferous unconsolidated sediment buried beneath Pleistocene glacial till. The fossiliferous layer is part of a sedimentary deposit that accumulated in a sinkhole developed in the limestone flank beds of a Paleozoic reef. Plant and animal (mostly vertebrate) remains are abundant in the fossil assemblage. Plants are represented by a diversity of terrestrial and wetland forms, all of extant species. The vertebrate assemblage (here designated the Pipe Creek Sinkhole local fauna) is dominated by frogs and pond turtles, but fishes, birds, snakes and small and large mammals are also present; both extinct and extant taxa are represented. The mammalian assemblage indicates an early Pliocene age (latest Hemphillian or earliest Blancan North American Land Mammal Age). This is the first Tertiary continental biota discovered in the interior of the eastern half of North America.

INTRODUCTION

Abundant late Tertiary continental biotas have been described from the Far West, Great Plains and coastal margins of North America (Janis *et al.*, 1998), but have hitherto been unknown from the interior of the eastern half of the continent. Here we report a diverse assemblage of plants and animals (mainly vertebrates) from a buried sinkhole deposit in east-central Indiana. The vertebrate fossils indicate a latest Hemphillian or earliest Blancan (Early Pliocene; 4–5 million years B.P.; Tedford *et al.*, 1987) age.

The sinkhole deposit was discovered by employees of Irving Materials, Inc. at the Pipe Creek Jr. limestone quarry near Swayzee, Grant County, Indiana (Fig. 1). Workers stripped away a cover of Wisconsinan till while expanding the quarry and unexpectedly found unconsolidated sediments beneath the till. Most of the sinkhole sediments were dumped on

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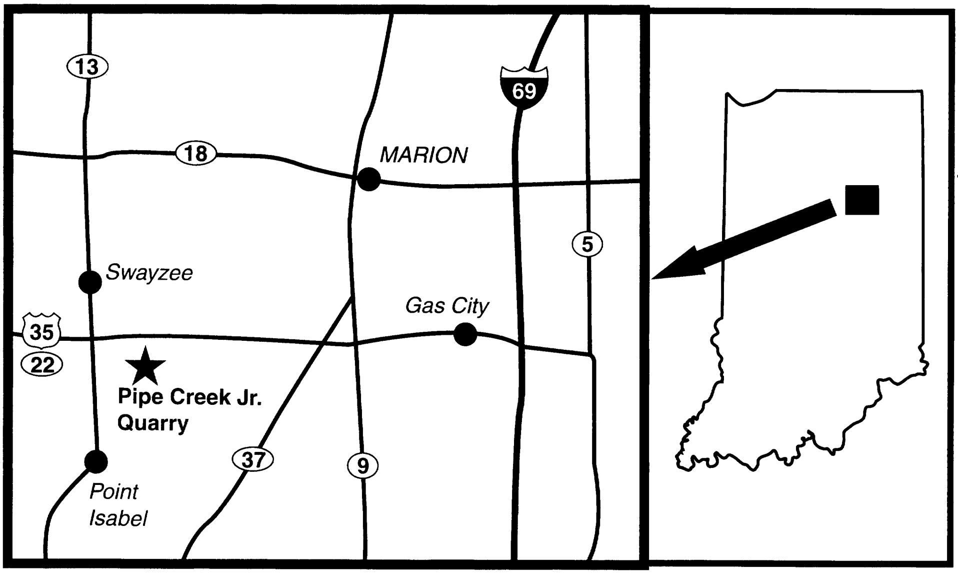

FIG. 1.—Map of Grant County, Indiana, showing location of the Pipe Creek Jr. quarry (star). The site is at latitude 40°27′16″N, longitude 85°47′31″W; NE 1/4, NW 1/4, SE 1/4, Sec. 12, T23N, R6E, Point Isabel Quadrangle, Indiana, U.S. Geological Survey 7.5 Minute Series Topographic Map

a spoil pile at the edge of the quarry, but enough material remained in situ in the sinkhole to permit reconstruction of a significant part of its history.

Because the Pipe Creek Sinkhole has yielded a fossil assemblage that is unique for this part of the continent, it is the focus of a multidisciplinary study. Detailed accounts of the site's stratigraphy, sedimentology and paleontology are in preparation. The present paper puts the site on record and summarizes geological and paleoecological interpretations to date (Farlow *et al.*, 1997, 1998, 1999; Sunderman *et al.*, 1997, 1998; Holman, 1998; Swinehart *et al.*, 1999).

Processing of sediments from the Pipe Creek Sinkhole is on-going, and additional taxa may be discovered as work proceeds, but the currently known Pipe Creek Sinkhole biota sheds much light on a previously unsampled portion of the North American late Tertiary fossil record.

GEOLOGIC SETTING OF THE PIPE CREEK SINKHOLE

The sinkhole developed in flank beds of the Pipe Creek Jr. reef (named for the quarry), a 1.6-km wide feature of Late Silurian age (Shaver and Sunderman, 1982). The sinkhole is about 75 m long by 50 m wide by 11 m deep (Fig. 2) with steep sides. It probably originated as a small cave whose roof eventually collapsed. Stream sediment was then deposited in the sinkhole, forming an alluvial fan with rubble beds containing large clasts of limestone and chert derived from the surrounding bedrock, and rounded quartzite pebbles of distant origin. Fan sediments also include reworked saprolite derived from local limestones, as well as clays and silts derived from nearby paleosols (Sunderman *et al.*, 1997). These fan sediments periodically plugged the sinkhole, at least once producing a small ephemeral pond or wetland, in which the fossils accumulated (Sunderman *et al.*, 1998). The Tertiary sedi-

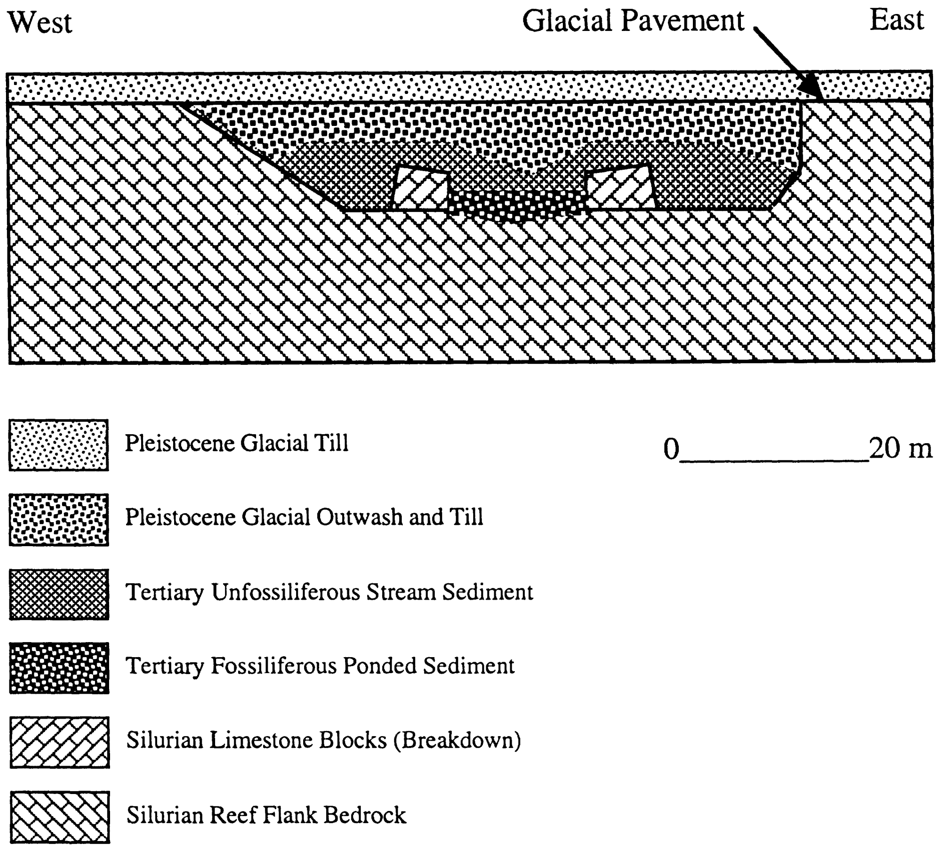

FIG. 2.—Diagrammatic cross section of the Pipe Creek Sinkhole (J. A. Sunderman, pers. obs.)

ments were eventually buried beneath Pleistocene glacial outwash and till. The total volume of sinkhole sediments was about 30,000 m^3, about one-third of which were Tertiary deposits.

The fossiliferous layer was near the base of the sinkhole deposit and was about 2 m thick before most of it was removed by quarrymen; the total volume of the fossiliferous layer was 50–100 m^3. This layer is mostly unconsolidated, but contains numerous nodules cemented with calcite and iron/manganese oxides (Sunderman *et al.*, 1998). Leaf impressions and other plant materials, and bones identical to those found in unlithified sediment, occur in some nodules. Neither nodules nor abundant fossils have thus far been found in any sinkhole sediments other than the fossiliferous layer.

The land surface surrounding the sinkhole during the late Tertiary was low-relief, and crossed by a single major west-flowing stream, the Teays River (Tight, 1903; Bleuer, 1991; Gray, 1991), which passed about 23 km northeast of the sinkhole. Incision of the Teays produced a bedrock canyon that extends about 123 m below the present level of the sinkhole rim (Wayne, 1956; Gray, 1982; Bruns *et al.*, 1985a, b; Sunderman *et al.*, 1998). Quartzite pebbles found in the sinkhole probably were transported to this area by a pre-incision version of the Teays (Sunderman *et al.*, 1998). Wisconsinan glaciers eventually eroded the surrounding bedrock surface to a smooth glacial pavement and removed some Tertiary sediment from the sinkhole. The latest Wisconsinan ice advance covered the sinkhole's Tertiary sediments with sandy and bouldery outwash and about 4 m of clay till (Gray, 1983, 1989; Sunderman *et al.*, 1997).

PLANT AND ANIMAL FOSSILS FROM THE PIPE CREEK SINKHOLE

Most of the fossils collected thus far (Figs. 3, 4) were found in the spoil pile, and so are no longer in stratigraphic context, but several fossils have been recovered from the part of the deposit that remains in situ in the sinkhole. Many of the more common taxa identified were recovered from both the spoil pile and the in situ deposit.

By far the most abundant fossil materials are plant fragments. Large conspicuous plant fossils were collected by hand from the surface of the in situ deposit, or by limited digging with hand trowels. Small plant remains were recovered from in situ and spoil pile sediment samples in the laboratory (with sieve mesh sizes down to 0.25 mm). A minimum of 26 plant taxa occurs at Pipe Creek Sinkhole (Table 1): 6 trees, 3 shrubs, 1 vine, 1 aquatic macrophyte, 13 terrestrial or wetland herbs, a moss and an alga.

Seeds and wood fragments regularly occur in both the unconsolidated material and in nodules. Although wood pieces are abundant, none is well enough preserved to permit identification. Some plant fragments are carbonized in a manner that suggests that they had burned. Leaf imprints, although abundant, are often highly fragmented. *Platanus* is the most common taxon in our leaf sample. Diatoms have not yet been found, a surprising result given our paleoenvironmental interpretation (*see* below).

No macroinvertebrates have been found in our samples apart from a few small gastropod internal molds and partial beetle elytra. Ostracodes are more abundant, represented by *Candona cf. C. crogmaniana, Candona aff. C. elliptica, Cypridopsis aff. C. okeechobei, Cypridopsis cf. C. vidua* and *Potamocypris aff. P. unicaudata.*

Hibbard (1958: 3) defined "local faunas" as assemblages "commonly named after a geographic locality, [that] consist of an association of identifiable remains of animal life of the same age which have been collected in a restricted geographical area," usage that has been followed by subsequent workers (*e.g.*, Tedford, 1970; Graham and Semken, 1987). The Pipe Creek Sinkhole vertebrate assemblage clearly meets the criterion of coming from a restricted geographic region. As best we can tell, all or most of our vertebrate fossils probably came from the above-described fossiliferous layer in the sinkhole deposits, but because much of the fauna was recovered from a spoil pile, we cannot be certain if all taxa were contemporaneous. However, there are no obvious discrepancies in the fauna that suggest significant diachrony, and consequently we feel justified in designating it as the Pipe Creek Sinkhole local fauna (Table 2).

Vertebrate bones are very common in the Pipe Creek Sinkhole assemblage; although not yet counted, the number of bones and bone fragments collected to date is in the thousands. Bones were found by surface collecting and by picking screen-washed (mesh size 2, 1 and 0.5 mm) concentrate from both the in situ deposit and the spoil pile. With the exception of some turtle shells, bones are disarticulated. The remains of frogs (particularly leopard frogs [*Rana pipiens* complex]) and pond turtles are considerably more abundant than all other vertebrate remains combined.

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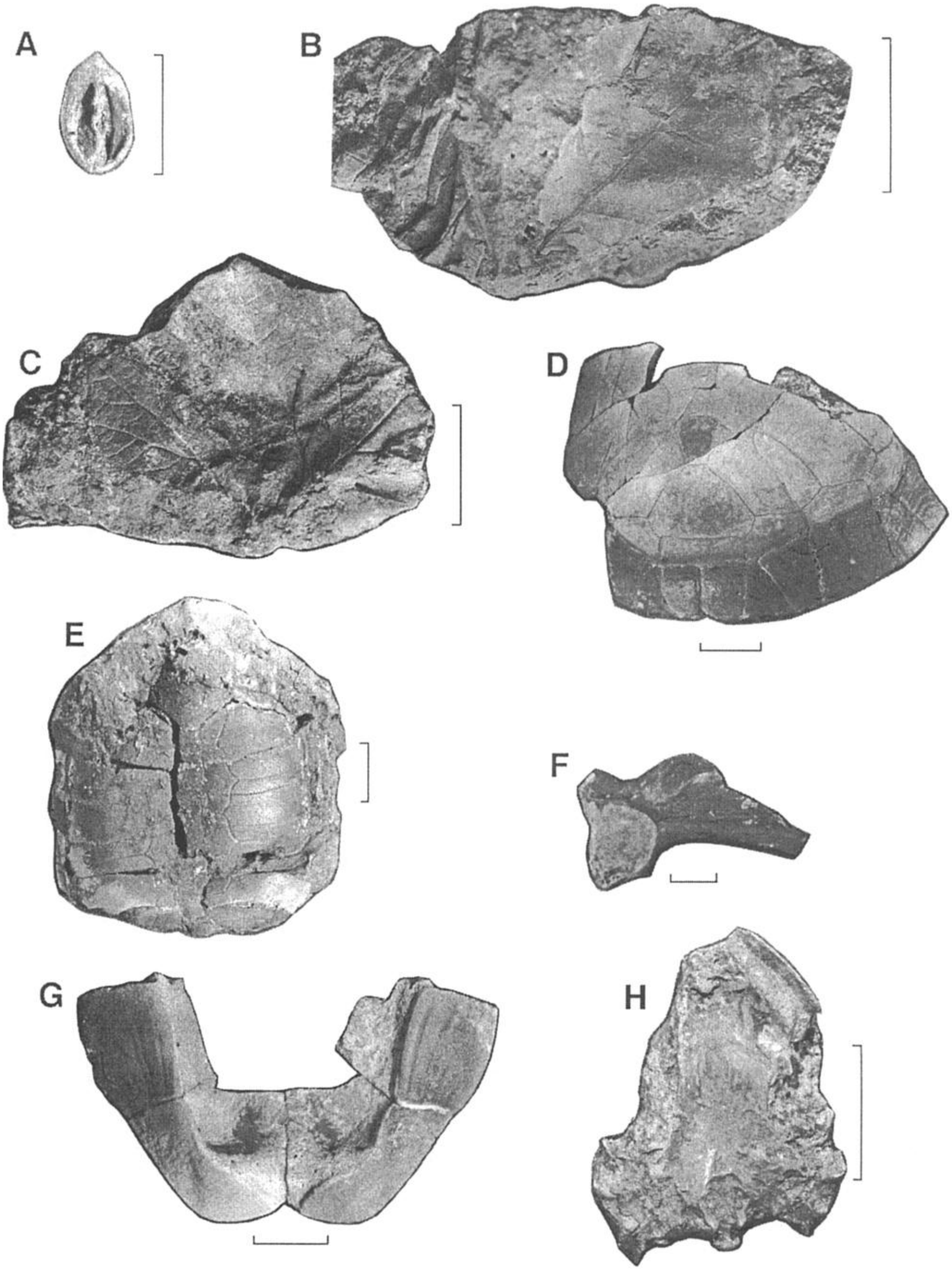
FIG. 3.—Plant and lower vertebrate fossils from Pipe Creek Sinkhole. Scale bars = 2 mm (F) or 20 mm (A–E, G, H). (A) Indiana State Museum (INSM) 71.12.2902.117, *Carya* sp. pericarp. (B) INSM 71.12.2902.7, *Fagus* sp. (C) INSM 71.12.2902.2, *Platanus* sp. (D) INSM 71.3.144.501, partial carapace



of *Hesperotestudo* sp. (E) INSM 71.3.144.502, carapace of *Chrysemys cf. C. picta,* partly encrusted in nodular material. (F) INSM 71.3.144.503, right ilium of a frog of the *Rana pipiens* complex. (G, H) *Emydoidea cf. E. blandingii.* (G) INSM 71.3.144.505, partial plastron in dorsal view. (H) Cincinnati Museum Center (CMC) VP5412, skull in palatal view

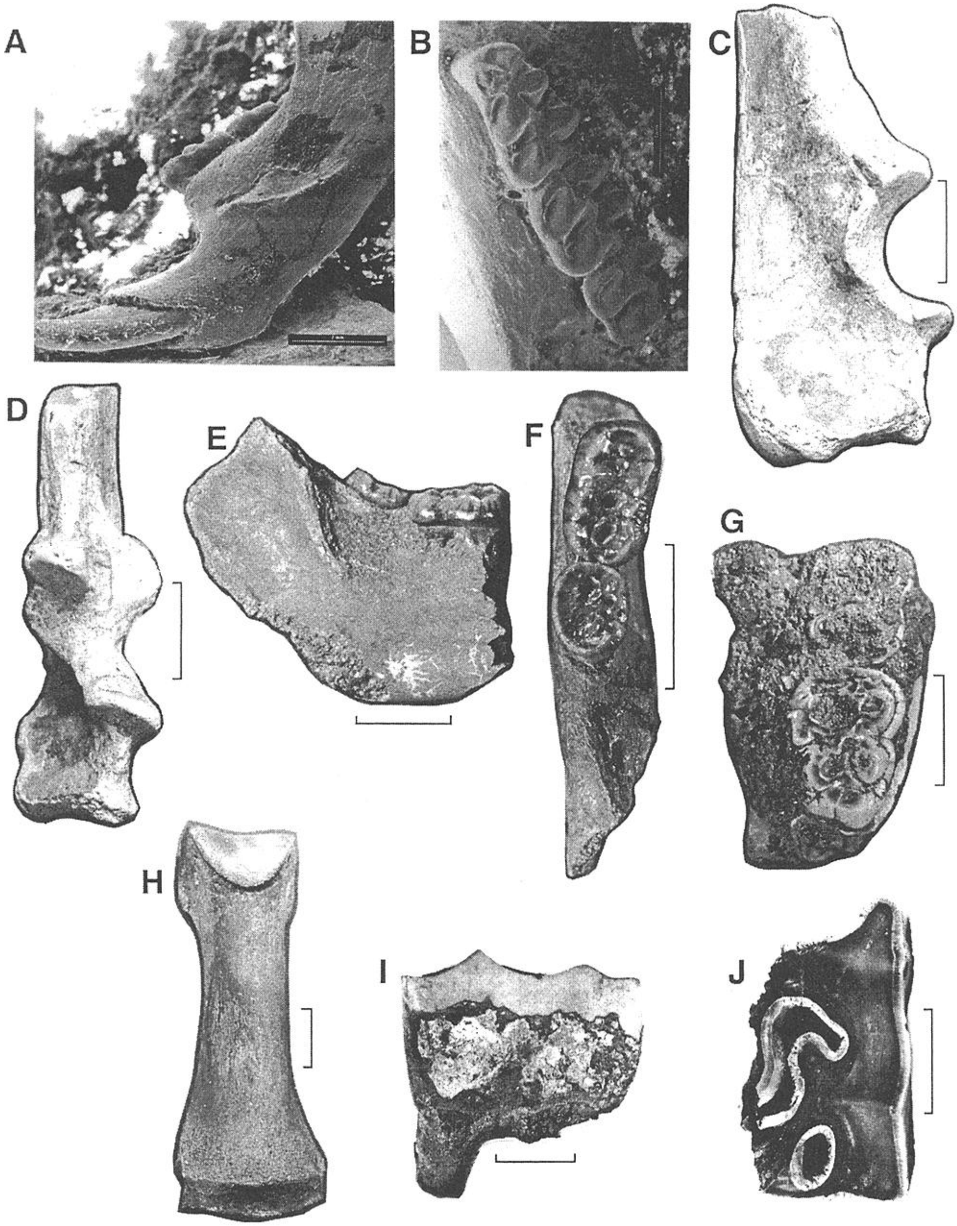


FIG. 4.—Mammalian fossils from Pipe Creek Sinkhole. Scale bars = 1 mm (B), 2 mm (A) or 20 mm (C-J). (A, B) Left mandible of INSM 71.3.144.1, *Symmetrodontomys* sp. (A) Lateral view. (B) Occlusal view of cheek tooth row; cranial (anterior) end toward top of page. (C, D) Partial right ulna of INSM 71.3.144.2001, *Borophagus* sp. (C) Medial view. (D) Cranial view. (E, F) Partial right mandible of INSM 71.3.144.2002, *Plionarctos edensis.* (E) Lateral view. (F) Occlusal view; cranial end of preserved tooth row toward top of page. (G) INSM 71.3.144.2003, jaw fragment of large peccary with two molar teeth in occlusal view; the specimen is partly encrusted by nodular material. (H) INSM 71.3.144.2004, prox-

TABLE 1.—Plant fossils identified from Pipe Creek Sinkhole. Plant habitat preferences from Deam (1940) and Gleason and Cronquist (1963)

Group	Taxon	Occurrence	Habitat
Charophytes:	*Chara* sp. (stonewort)	common oogonia	Aquatic
Mosses:	*Bryum* sp. (moss)	common leaf and other fragments	Indeterminable
Monocots:	*Potamogeton* sp. (pondweed)	single achene	Aquatic
	Indeterminate grasses	three leaf impressions	Indeterminable
	Scirpus sp. (bulrush)	single achene	Wetlands
	Cyperus sp. (sedge)	single achene	Wetlands
	Carex sp. (sedge)	achenes	Indeterminable
Dicots:	*Populus cf. P. deltoides* (cottonwood)	leaf impression	Wetlands or moist soil
	Salix sp. (willow)	leaf impressions	Wetlands
	cf. *Comptonia* (sweetfern)	leaf impression	Mesic woods or dry clearings
	Carya sp. (hickory)	several pericarp fragments	Indeterminable
	Fagus cf. F. grandifolia (beech)	leaf impressions	Moist soil
	Indeterminate Caryophyllales	numerous seed fragments	Indeterminable
	Rumex sp. (dock)	single achene	Indeterminable
	Polygonum sp. (smartweed)	single achene	Indeterminable
	Viola sp. (violet)	seed fragment	Indeterminable
	Platanus occidentalis (sycamore)	many leaf impressions	Wetlands or moist soil
	Potentilla sp. (cinquefoil)	numerous achenes	Indeterminable
	Acer sp. (maple)	leaf impressions	Indeterminable
	Oxalis sp. (wood sorrel)	part of a seed coat	Indeterminable
	Vitis sp. (grape)	complete seed and numerous seed fragments	Indeterminable
	cf. Lyonia (stagger-bush)	leaf impression	Wetlands or moist soil
	Indeterminate Boraginaceae	two or three fruit fragments	Indeterminable
	Verbena sp. (vervain)	numerous achenes	Indeterminable
	Indeterminate Compositae	achenes and achene fragments	Indeterminable
	Xanthium sp. (cocklebur)	several fruit fragments	Indeterminable

Peccary and camelid bones dominate the large-mammal assemblage, but probably constitute only a few individual animals. Each carnivoran species is represented by a single individual. Surprisingly, given the composition of later Tertiary faunas elsewhere in North

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imal phalanx of large camel (cf. *Aepycamelus*) in cranial view. (I, J) CMC VP5399, partial left upper molar of *Teleoceras* sp. (I) Labial view. (J) Occlusal view; cranial end of tooth toward top of page

TABLE 2.—Vertebrate taxa of the Pipe Creek Sinkhole local fauna; # indicates an extinct genus, * an extinct species of an extant genus, and n. sp. indicates a new species

Group	Taxon
Fishes:	Unidentified small teleost(s)
Amphibians:	*Rana cf. R. catesbeiana* (bullfrog)
	Rana pipiens complex (leopard frog)
	Rana sp. indet. (true frog)
	Bufo sp. (toad)
	Unidentified plethodontid salamander
Turtles and tortoises:	*Chelydra cf. C. serpentina* (snapping turtle)
	Chrysemys cf. C. picta (painted turtle)
	Trachemys cf. T. scripta (slider turtle)
	Emydoidea cf. E. blandingii (Blanding's turtle)
	#*Hesperotestudo* sp. or spp. (land tortoise)
Snakes:	*Coluber constrictor* (racer)
	#*Paracoluber storei* (extinct racer)
	Elaphe sp. (ratsnake)
	#*Paleoheterodon tiheni* (extinct hognose snake)
	Nerodia cf. N. erythrogaster (water snake)
	Nerodia sp. (water snake)
	Thamnophis sp. (garter or ribbon snake)
Birds:	Unidentified small passerine
Talpids:	Unidentified taxon
Castorids:	*Castor* or #*Dipoides* sp.
Sciurids:	*Spermophilus nr. S. howelli**
	Spermophilus sp.
Geomyids:	*Geomys cf. G. adamsi**
Cricetids:	#*Ogmodontomys* n. sp.
	#*Pliophenacomys* n. sp.
	#*Symmetrodontomys* n. sp.
	Peromyscus sp.
Lagomorphs:	#*Hypolagus cf. H. fontinalis*
Carnivorans:	*cf. Canis*
	Vulpes sp.
	#*Borophagus* sp.
	#*Plionarctos edensis*
Artiodactyls:	Unidentified large peccary
	cf. #*Hemiauchenia*
	cf. #*Titanotylopus* or #*Gigantocamelus*
	cf. #*Aepycamelus*
	Unidentified *Odocoileus*-sized cervoid
Perissodactyls:	#*Teleoceras* sp.

America (Janis *et al.*, 1998), no horse remains have yet been found. *Hypolagus, Ogmodontomys,* and *Symmetrodontomys* are the most common small mammals.

The Pipe Creek Sinkhole plants and ostracodes are all extant taxa. Most of the herpetofauna are likewise modern taxa, indicating a post-Middle Hemphillian age (Holman, 1995; Parmley and Holman, 1995). However, *Hesperotestudo* is now extinct and *Paleoheterodon* ranges from the Barstovian-Hemphillian and *Paracoluber* from the Hemingfordian-Hemphillian (Holman, 2000).

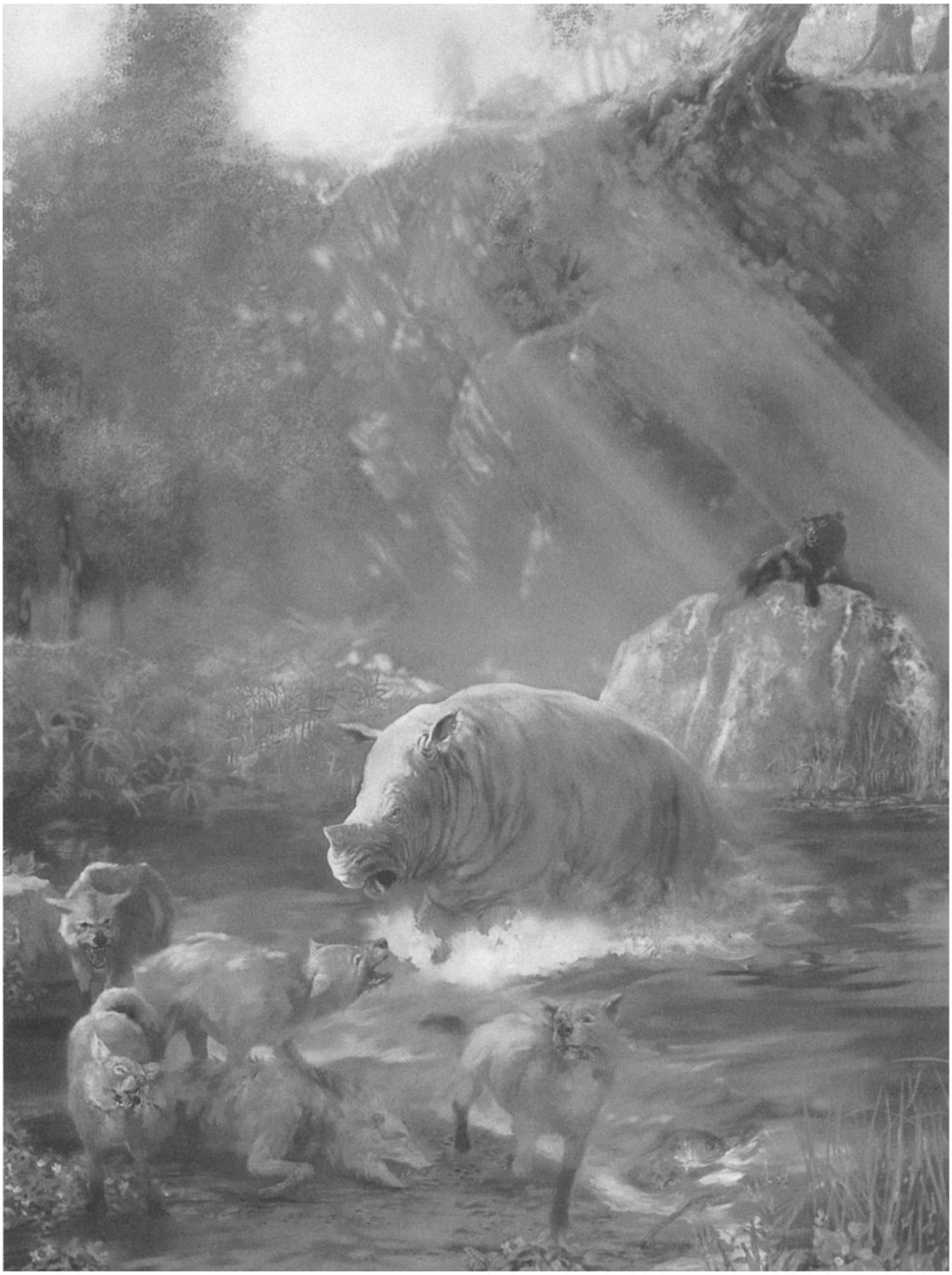

FIG. 5.—Restoration of the Pipe Creek Sinkhole biota. An aggressive *Teleoceras* splashes across a shallow sinkhole pond toward a group of *Borophagus* feeding on the carcass of a peccary, while in the background a lazy *Plionarctos* watches proceedings in a detached manner. Sycamore trees grow around the margin of the sinkhole. Painting by Karen Carr

The identified mammalian taxa indicate a late Tertiary age, based on comparison with faunas from other parts of North America. *Hypolagus fontinalis* was originally described as being Clarendonian in age (Dawson, 1958). The presence of *Teleoceras* suggests that the deposit cannot be younger than latest Hemphillian or very earliest Blancan (Prothero, 1998) and *Plionarctos edensis* is no younger than Early Blancan (Hunt, 1998). The rodent assemblage collectively suggests an Early Blancan age (Hibbard, 1941, 1956, 1967; Hibbard and Zakrzewski, 1967; Lundelius *et al.*, 1987; Repenning, 1987; Martin *et al.*, 2000).

On balance, a latest Hemphillian or earliest Blancan age for the fossil assemblage seems reasonable. Because the Pipe Creek Sinkhole local fauna comes from a region where late Tertiary biotas were previously unknown, it is possible that the temporal ranges of some of the taxa may have been slightly different here than in previously studied vertebrate faunas.

Interpretation of the depositional environment of the fossiliferous deposit is somewhat ambiguous. Bullfrog (*Rana cf. R. catesbeiana*), snapping turtle (*Chelydra cf. C. serpentina*), painted turtle (*Chrysemys cf. C. picta*), slider turtle (*Trachemys cf. T. scripta*), Blanding's turtle (*Emydoidea cf. E. blandingii*) and water snake (*Nerodia* spp.) suggest an aquatic habitat, while leopard frog (*Rana pipiens* complex) and *Thamnophis* are more indicative of a grassy or marshy area. The ostracodes match what would be found in a sinkhole pond or spring.

Although water plants are present, most of the flora (eight of the ten taxa for which environmental preferences could be identified) consists of wetland and even upland taxa (Table 1). Upland taxa presumably represent fossils that were blown or washed into the sinkhole, whereas the wetland/aquatic forms indicate environmental conditions within the sinkhole itself. The absence of diatoms, and the scarcity of fishes and molluscs, are surprising if a large body of standing water had existed at the site for significant lengths of time. Possibly the sinkhole environment was a wetland that flooded at least once to form an ephemeral pond, providing temporary habitat for the aquatic frogs and turtles (Fig. 5). The flora of the sinkhole floor probably was open, and dominated by herbaceous species with the occasional *Salix* and *Populus.*

The environment around the sinkhole was warm, as indicated by the presence of *Hesperotestudo.* The flora in aggregate suggests a dry, open, perhaps prairie-like or savanna regional vegetation, but with trees nearby (*Platanus, Fagus*), an interpretation congruent with the herpetofauna and the large-mammal assemblage, and broadly consistent with habitat reconstructions for the late Tertiary of the Great Plains (MacGinitie, 1962; Thomasson *et al.*, 1990). Indiana in the Early Pliocene might aptly be nicknamed "East Nebraska."

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