

## A FOSSIL SHREW (MAMMALIA, SORICIDAE) FROM THE PIPE CREEK SINKHOLE (LATE NEOGENE: HEMPHILLIAN), INDIANA

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**ABSTRACT.** The Pipe Creek Sinkhole is one of two localities in interior eastern North America of late Neogene age (Miocene-Pliocene boundary) preserving fossils of diverse terrestrial vertebrates. This paper documents the occurrence of the sole soricid from the Pipe Creek Sinkhole, a long-tailed shrew of the genus *Sorex*. Two specimens recovered by screenwashing sediments consist of portions of lower jaws, one containing the m2 (second lower molar) and nearly complete posterior portion of the jawbone with articular condyle, and the other containing the m1 (first lower molar). The two specimens possibly represent one individual, and are not identifiable to species. Many present-day species of *Sorex* shrews exist across North America and they inhabit a wide variety of habitats, but most often moist, wooded microenvironments. Based on the fossil shrew, we infer the presence of a relatively mesic wooded environment in the vicinity of the Pipe Creek Sinkhole in the late Neogene; such an interpretation does not necessarily conflict with paleoenvironmental interpretations based on other evidence from the locality suggesting open savanna or parkland including pine, hickory, and other flowering plants.

**Keywords:** *Sorex*, Miocene-Pliocene boundary, vertebrate paleontology

The fossil locality known as Pipe Creek Sinkhole (PCS) is one of the rare places in the interior of the eastern United States yielding abundant plant and animal fossils of late Neogene age. The PCS paleobiota were recovered from the Pipe Creek Jr. Limestone Quarry, near Swayzee, Grant County, Indiana (Farlow, Sunderman, et al. 2001; Farlow & Argast 2006; Dawson et al. 2008; Shunk et al. 2009; Farlow, Chin, et al. 2010; Farlow, Richards, et al. 2010). Previous work on the geology and vertebrate paleontology at PCS indicates that the locality represents a short interval of time near the Miocene-Pliocene boundary (Farlow, Sunderman et al. 2001; Farlow, Richards, et al. 2010; Shunk et al. 2009). Biochronologically, fossil rodents from the locality indicate a latest Hemphillian or early Blancan North American Land Mammal Age (early Pliocene; Martin et al. 2002; Bell et al. 2004).

Surface collecting and screenwashing of unconsolidated fossiliferous sediment (Zone

A; Farlow, Richards, et al. 2010) from the PCS deposit has yielded an abundance and diversity of large and small vertebrates, including rhinoceros, peccary, camels, carnivorans, rodents, turtles, snakes, and frogs. Zone A sediments accumulated in a pond/wetland habitat within the sinkhole; the surrounding landscape was an open savanna or parkland (Farlow, Sunderman et al. 2001; Farlow & Argast 2006; Shunk et al. 2009; Sunderman et al. 2010). In the process of picking screen-washed matrix from PCS, two shrew specimens were recovered. This paper attempts to identify the taxon to which the shrew belongs and documents its occurrence as another mammalian member of the PCS biota.

### METHODS AND MATERIALS

Skeletal elements of the shrew were found during picking of sediment concentrate from a spot sample of Zone A sediment collected in situ in the sinkhole on 4 September 1997. The particular sediment fraction that yielded the shrew specimens (Jar 77, 9/4/97 Bag 6) was concentrated on a 1-mm mesh screen (see Farlow, Richards, et al. [2010] for details of screen-washing protocols).

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Because we could not determine if the two skeletal elements were from the same individual shrew, we chose to be conservative and gave them separate catalog numbers. The specimens were deposited in the collection of the Indiana State Museum (INSM) as INSM 71.3.144.3011 and INSM 71.3.144.3012.

The specimens were prepared for, and their images captured by, scanning electron microscopy. The samples were cleaned in alcohol, mounted on sticky tape, coated with gold, and examined with an ISI DS-130 Scanning Electron Microscope at 18.3 KeV using secondary electrons, except one image which was made using backscatter electrons.

The specimens were measured to the nearest 0.1 mm with an ocular micrometer on an Olympus SZX9 zoom stereomicroscope calibrated to an objective micrometer scale. We compared the PCS specimens with casts and published illustrations of late Neogene North American shrews, as well as with Recent specimens of the recognized genera of North American Soricidae in the collections of the Oklahoma Museum of Natural History. In particular, we consulted important diagnostic characters, terminology, and classifications of fossil soricids in the classic study by Repenning (1967) and more recently by Reumer (1998), and for North American species by Gunnell et al. (2008) and Harris (1998).

## RESULTS

The PCS specimen INSM 71.3.144.3011 consists of the posterior portion of a left dentary with m2, the empty alveoli for m3, and the complete ascending ramus and jaw condyle (Figures 1–7). The angular process is broken off this specimen. INSM 71.3.144.3012 is a small fragment of the left dentary with m1 and empty alveoli for the next forward antemolar (Figures 8–11). The mental foramen is present in the dentary bone below the anterior portion of m1. The two specimens contain no redundant parts and might actually fit together, thus representing a single specimen.

Two families of Lipotyphla, including nine genera, are known in the late Hemphillian-early Blancan in North America (Gunnell et al. 2008). These are: Plesiosoricidae with a single genus *Plesiosorex*, and Soricidae with one subfamily, Soricinae, containing three tribes (genera in parentheses), Soricini (*Sorex*, *Planisorex*, and *Petenya*), Nectogalini (*Beckiasorex*,

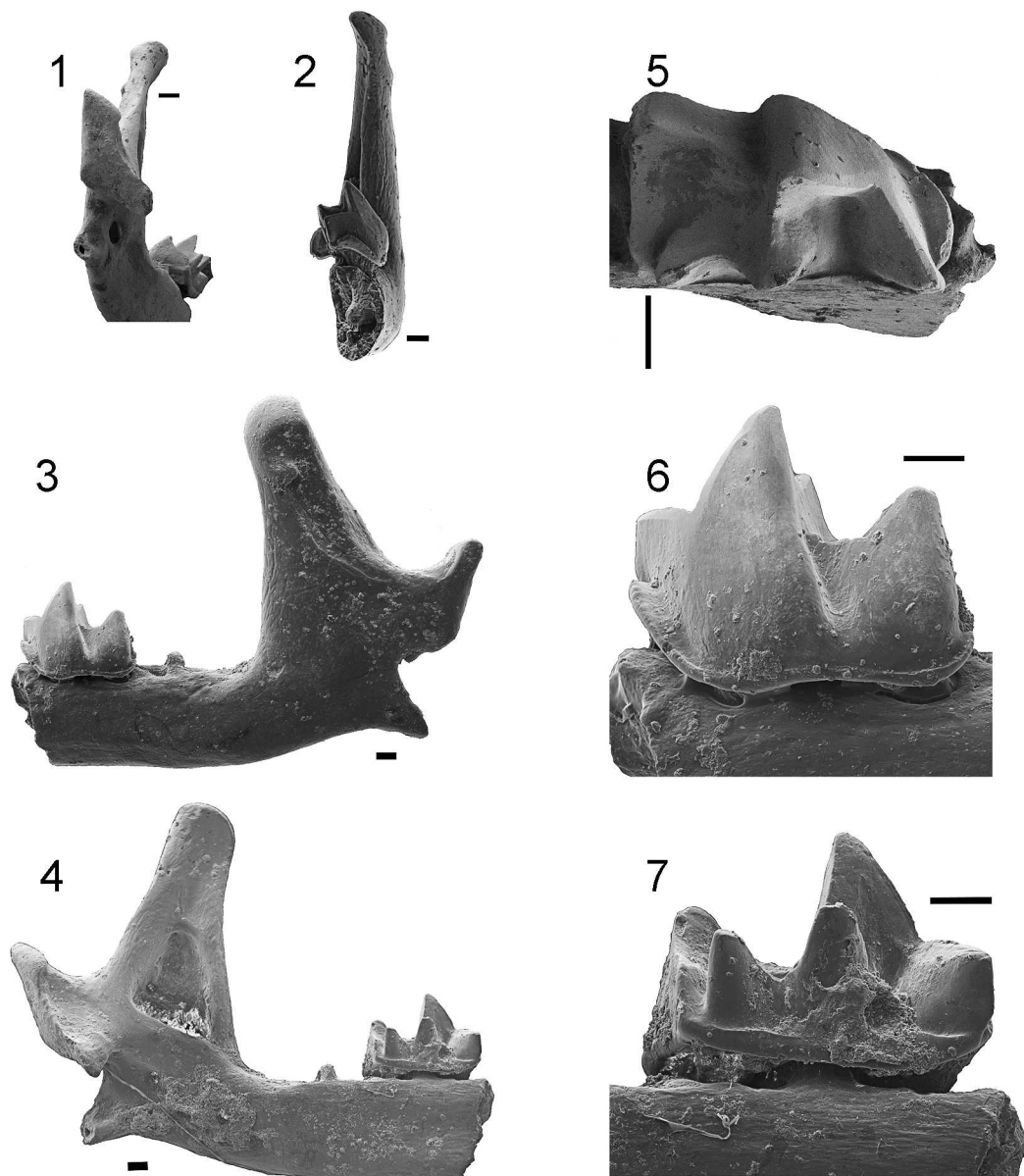
*Notiosorex*, and *Arctisorex*); and Blarinini (*Cryptotis* and *Paracryptotis*).

The PCS fossils do not have a transversely cylindrical condyle, and thus they cannot represent Plesiosoricidae. Instead they have condylar facets vertically aligned, with a slight lingual emargination between the condyles, and the internal temporal fossa is deep and pocketed. These features indicate a member of the family Soricidae (Gunnell et al. 2008).

Among the tribes of Soricinae, the PCS fossils show the characteristics of Soricini. The PCS shrew does not have an enlarged condylar process and laterally offset articular facets separated by a groove from the body of the dentary; therefore, it differs from the Nectogalini. The PCS fossils also differ from the Blarinini because they lack articular facets of the condyle that are widely separated. Additionally, the m1 and m2 possess entoconid crests. The PCS fossils agree with Soricini because the articular facets of the condyle are continuous, and m1–m2 each retain an entoconid crest that joins the entoconid to the metaconid.

Assigning the specimens to a genus was based on the position of the mental foramen. The specimens do not have the mental foramen situated beneath the talonid of m1, and thus do not represent *Petenya*. This leaves *Planisorex* and *Sorex*. We cannot eliminate *Planisorex* on qualitative characteristics because its distinguishing features require teeth that are not preserved in the PCS fossils (m3 and M1–M2; Repenning 1967; Hibbard 1972; Harris 1998). However, the PCS shrew can be identified as a *Sorex* because it has the mental foramen situated beneath m1. In addition, *Planisorex* may be larger than the PCS shrew (see below).

Gunnell et al. 2008 listed 11 species of *Sorex* in the late Miocene-Pliocene of North America, plus *Planisorex* with only one species, *P. dixonensis*. The 11 Neogene (exclusive of strictly Quaternary) species of *Sorex* are: *S. cinereus*, *S. edwardsi*, *S. hagermanensis*, *S. leahyi*, *S. meltoni*, *S. palustris*, *S. powersi*, *S. rexroadensis*, *S. sandersi*, *S. taylori*, and *S. yatkolai*. Some species of *Sorex* can be differentiated by the degree of pigmentation on the molars. Unfortunately, pigmentation is not evident on the molars of the PCS shrew. The anterior teeth (incisors and antemolars) are highly specialized in shrews (Dannelid 1998), but the molars are quite uniform in the Soricidae. As a result, there are

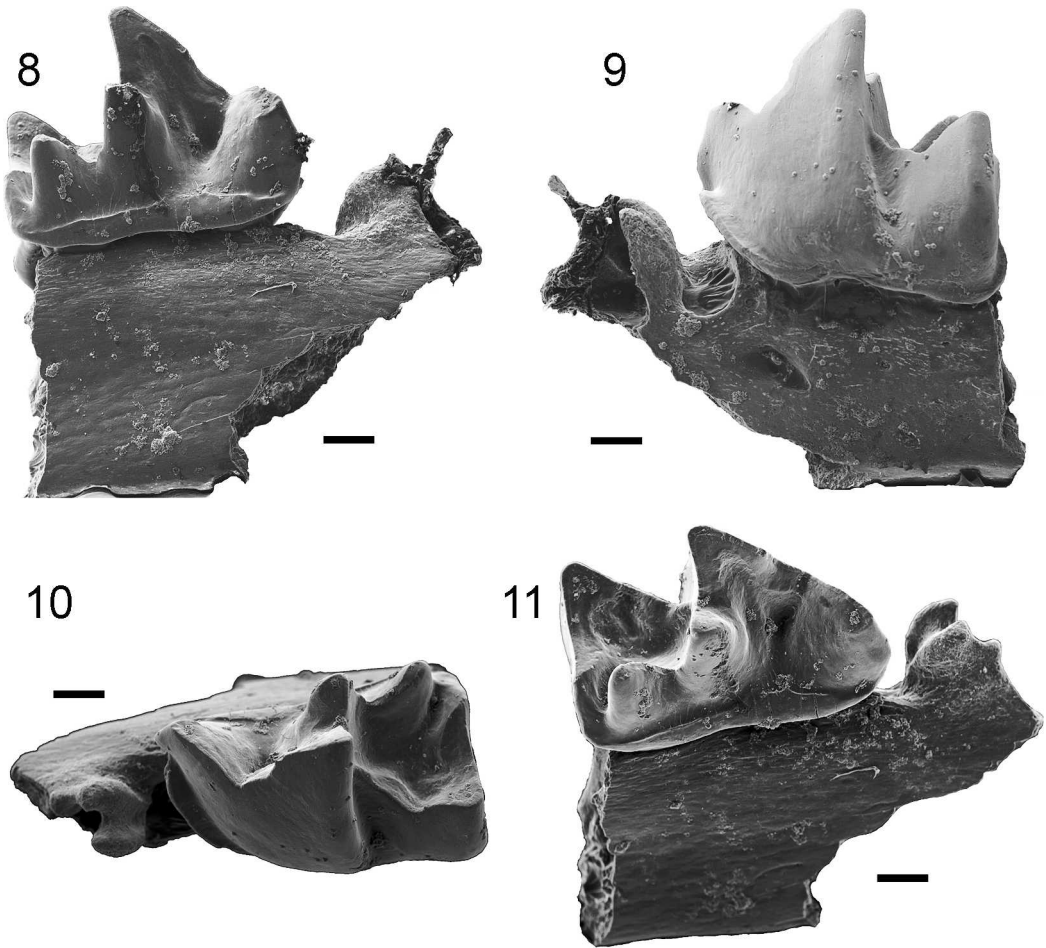


Figures 1–7.—*Sorex* sp. posterior portion of dentary with m2 (INSM 71.3.144.3011) from Pipe Creek Sinkhole, Indiana. 1. Posteroventral view showing mandibular condyles and intercondylar area; 2. Anterior view; 3. Labial view; 4. Lingual view. Close-up scanning electron micrographs of the m2. 5. Occlusal view; 6. Labial view; 7. Lingual view. Scale bars equal 200 micrometers.

few or no qualitative dental-osteological characters preserved in the PCS *Sorex* specimens that aid in identification of the species.

In terms of size, the PCS fossils represent a small species of *Sorex* (Table 1). Based on size of m2 of *Planisorex* as listed by Gunnell et al. (2008), the PCS fossils are too small to belong to *Planisorex*, because the m2 length in the only

known species *P. dixonensis* varies from 1.54–1.68 mm. Given the similar morphology in the molars and condyles and the lack of other species-diagnostic qualitative characteristics by which to distinguish *Sorex* species, size is the only criterion available in the PCS specimens by which they might be identified at present. However, many of the late Miocene and Pliocene named



Figures 8–11.—*Sorex* sp. dentary fragment with m1 (INSM 71.3.144.3012) from Pipe Creek Sinkhole, Indiana. 8. Lingual view; 9. Labial view; 10. Occlusal view; 11. Occlusal and somewhat lingual view. Scale bars equal 200 micrometers.

species of *Sorex* are based on small samples. Variability in the measurements of these species is poorly known and there would likely be much overlap in measurements if statistically valid samples of all were available. Similarly, the PCS *Sorex* sample of two, or possibly one individual, is too small for broad statistical comparisons.

#### DISCUSSION

**Paleoecology.**—Modern shrews of the genus *Sorex* are most abundant and diverse in mesic habitats, but do occur in drier situations (Getz 1961; Wrigley et al. 1979; Batzli 1985; Williams 1991; Kirkland et al. 1997; Kirkland & Findley 1999; Laakkonen et al. 2001, 2003; McShea et al. 2003; Moseley et al. 2008; Oaten & Larsen 2008). Ecologically and climatically, Recent

*Sorex* shrews generally inhabit cool, moist environments in temperate regions, retreating to higher elevations where they occur in the tropics. The reduced importance of shrews in dry habitats may have as much or more to do with the effects of dryness on the abundance of invertebrate prey as on physiological problems of water loss of the shrews themselves (Churchfield 1990; Greenberg & Miller 2004).

The presence of a long-tailed shrew at PCS, in the latest Miocene or early Pliocene continental interior of mid-latitude eastern North America, well prior to the late Pliocene initiation of glaciation in the northern hemisphere, suggests the presence of a relatively cool, moist microhabitat, probably including woodland, at least somewhere in the vicinity of



Table 1.—Measurements of the molars in specimens (INSM 71.3.144.3011 and -3012) of *Sorex* from Pipe Creek Sinkhole (PCS), Grant County, Indiana, compared with measurements of the same molars in other late Miocene-Pliocene North American species of *Sorex* for which published individual tooth measurements are available (Hibbard, 1953; Hibbard and Bjork, 1971) or were made by us. Measurements for *Sorex cinereus* (n = 1; from Recent specimen) and *Sorex taylori* (n = 1; from cast of University of Michigan Museum of Paleontology no. 41131, Rexroad 3, Kansas, Blancan age) were made by NJC. No individual molar measurements have been published for *S. edwardsi*, *S. leahyi*, *S. rexroadensis*, *S. sandersi*, and *S. yatkolai*.

	m1			m2		
	Antero-posterior length	Trigonid width	Talonid width	Antero-posterior length	Trigonid width	Talonid width
PCS <i>Sorex</i>	1.27	0.75	0.80	1.17	0.77	0.75
<i>S. cinereus</i>	1.35	0.70	0.72	1.15	0.65	0.67
<i>S. hagermanensis</i>	1.38	—	0.85	1.30	—	0.80
<i>S. meltoni</i>	1.16	—	0.64	1.02	—	0.63
<i>S. powersi</i>	1.47	—	0.83	1.31	—	0.81
<i>S. taylori</i>	1.60	0.80	0.82	1.25	0.75	0.77

the Pipe Creek Sinkhole during the latest Hemphillian land mammal age. This paleoenvironmental interpretation does not necessarily contradict previous interpretations by Farlow, Sunderman et al. (2001), Shunk et al. (2009) and Farlow, Richards, et al. (2010), based on the geochemical, palynological, and vertebrate faunal composition evidence from the locality, suggesting standing water in the sinkhole and open savanna or parkland including hickory, beech, pine, and other woody flowering plants on the surrounding landscape. Although the pine pollen could have an extralocal origin, abundant fruits and some leaf impressions of hickory and beech as macrofossils suggest proximate sources of these trees. Hickory tends to grow on more xeric uplands such as hilltops, whereas beech occurs in more mesic situations. Poplar and sycamore, present at PSC as leaf impressions, also suggest mesic or even moderately moist soil conditions. Although the somewhat dry, open conditions inferred for the regional habitat around the Pipe Creek Sinkhole may not have been prime habitat for *Sorex* shrews, wetter conditions and wooded habitat in and immediately around the sinkhole may have been more attractive to these small predators. The woodland habitat that we infer from the presence of a shrew in the fossil assemblage might even have been a localized stand growing immediately around the sinkhole itself; pieces of wood (some quite large) are abundant in the fossiliferous Zone A sinkhole sediments (Farlow, Richards et al. 2010).

**Relative abundance.**—Although a complete census of small to medium-sized vertebrates

from the Pipe Creek Sinkhole paleofauna will not be possible until all sediment samples have been processed and picked, a preliminary, semi-quantitative ranking of major groups is possible (Table 2). Fossils of frogs and pond turtles dominate the assemblage, consistent with the presence of a pond or wetland situation during deposition of the fossiliferous sediment. *Sorex* is among the rarest components of the fauna, being represented thus far by at most two individuals.

Estimates of the abundance of rodents in the PCS assemblage are based, as with the shrew(s), on the number of specimens of cheek teeth found during picking of sediment concentrate (mainly the 2-mm and 1-mm size fractions). Rodents considerably outnumber shrews in the assemblage, being represented by dozens of specimens.

The relative abundance of small rodents vs. *Sorex* in modern small-mammal communities is hard to determine, because the number of individuals captured depends on the kind of trap used (Kirkland & Sheppard 1994; Kirkland et al. 1998; Smallwood & Smith 2001) and weather conditions during the study (shrews are most active and readily captured during wet weather; Kirkland et al. 1998; Laakkonen et al. 2001, 2003), among other variables. Most data are for forest and woodland habitats (some highly altered by humans). The rodent : *Sorex* ratio in different habitats (in terms of numbers of individuals) ranges from as little as 0.3:1 (more shrews than rodents) to as high as 90:1 (many more rodents than shrews) (Aulak 1970; Yalden et al. 1973; Nagorsen & Peterson 1981;

Table 2.—Relative abundance of mesovertebrate and microvertebrate specimens (number of identifiable specimens [NISP]) from Pipe Creek Sinkhole fossiliferous (Zone A) sediments.

Group	Abundance
Anurans	Extremely abundant (90+% of NISP)
Pond turtles ( <i>Trachemys</i> , <i>Chrysemys</i> , <i>Emydoidea</i> , <i>Chelydra</i> )	Very abundant
Snakes ( <i>Thamnophis</i> , <i>Nerodia</i> , <i>Sistrurus</i> , <i>Coluber</i> , <i>Paracoluber</i> , <i>Pantherophis</i> , <i>Heterodon</i> , <i>Paleoheterodon</i> , <i>Lampropeltis</i> , <i>Opheodrys</i> )	Abundant
Rodents ( <i>Spermophilus</i> , <i>Geomys</i> , <i>Symmetrodontomys</i> , <i>Bensonomys</i> , <i>Ogmodontomys</i> , <i>Pliophenacomys</i> , <i>Dipoides</i> )	Abundant
Rabbits ( <i>Hypolagus</i> )	Uncommon
Land tortoises ( <i>Hesperotestudo</i> )	Uncommon
Fishes (small catfish and sunfish)	Uncommon
Salamanders	Rare
Moles	Rare
Shrews ( <i>Sorex</i> )	Rare

Yahner 1983, 1992; Mastrota et al. 1989; Ylonen et al. 1991; Kalko & Handley 1993; Kirkland et al. 1998; Kirkland & Findley 1999; Sullivan et al. 2000; Bellows et al. 2001; McShea et al. 2003; Kaminski et al. 2007; Oaten & Larsen 2008; Urban & Swihart 2011). Apart from the issue of how closely such numbers reflect the relative numbers of shrews in the communities being studied, there is the obvious question of whether any of the modern communities for which data are available are closely analogous to the lowland pine-parkland or savanna habitats inferred for the landscape around the Pipe Creek Sinkhole to make comparisons meaningful.

**Taphonomy.**—There are also likely taphonomic artifacts affecting the count of rodents vs. shrews in the PCS assemblage. The large-mammal component of the PCS paleofauna is thought to have accumulated attritionally rather than catastrophically (Farlow, Richards, et al. 2010). Whether the same is true for the mesovertebrate and microvertebrate components of the fauna is unknown. However, if the smaller vertebrate specimens were also contributed to the assemblage over a long interval of time, as opposed to all at once (or a few times), then the relative abundance of rodents and shrews in the fauna might reflect differences in population turnover rates (if such existed) of the two groups, and not just differences in the standing abundance at any given time. They possibly also reflect the effects of time-averaging, differential predation rates on rodents vs. shrews (if micromammal specimens were contributed to the fossil assemblage primarily via carnivore scats or raptor pellets),

and perhaps differential survivability of cheek teeth of rodents as opposed to shrews (cf. Andrews 1990). The preference of modern shrews for more mesic habitats notwithstanding, R.L. Richards (pers. comm.) noted that specimens of fossil shrews are relatively rare in Pleistocene fossil assemblages from Indiana (Whitaker & Richards 2005) that accumulated in aquatic settings, compared with the relative abundance of shrew specimens in assemblages from drier depositional settings. Consequently whether the scarcity of shrews in the PCS fossil sample accurately reflects their abundance in the living community, or is instead an artifact of preservation, is uncertain.

**Inferences about PCS Invertebrates.**—Despite their highly specialized dentition, shrews are not particularly specialized in their food habits; they are opportunistic, generalized feeders on invertebrates (Dannelid, 1998). Modern species of *Sorex* are voracious predators of terrestrial arthropods, earthworms, snails, and slugs, and also sometimes consume carrion (Churchfield 1990; Mumford & Whitaker 2008). The Pipe Creek Sinkhole species would have been close in size to many modern species of *Sorex*, and so presumably had similar food habits. Consequently its presence in the PCS paleofauna provides indirect evidence for the presence of at least some of these kinds of invertebrate prey in the paleocommunity.

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