
An Overview of the Upper Carboniferous Fossil Deposit at Linton, Ohio¹

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ABSTRACT. The cannel coal that underlies the Upper Freeport coal (Westphalian D, Upper Carboniferous) at Linton in Jefferson County, Ohio, has yielded a remarkable fossil assemblage of at least 10 invertebrate taxa and nearly 40 vertebrate taxa. Spirorbid worms, crustaceans (primarily syncarids and conchostracans), and fishes (coelacanth, haplolepid palaeoniscoids, and xenacanth sharks) are the most abundant fossils in the deposit; small aquatic amphibians (including neotriton, temnospondyl, and aistopod species) are also common. Other arthropod and tetrapod taxa are exceedingly rare and possess obvious adaptations for terrestrial existence.

The fossiliferous cannel originated as the sapropelic filling of an approximately 15-m-deep abandoned river meander within an alluviated delta plain setting. Remains of animals that lived in and near the freshwater oxbow accumulated in this anaerobic, scavenger-free lake bottom. The assemblage is autochthonous at the scale of the floodplain lake and its margins and represents a lowland biocoenose. Previous paleoecological interpretations of the Linton assemblage and similar Westphalian vertebrate deposits cannot be upheld because they are based largely on paleontological inferences and incorrect paleoenvironmental diagnoses.

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INTRODUCTION

The remarkable abundance and diversity of fossil vertebrates from a once-active underground coal mine at Linton, Ohio, have attracted the attention of paleontologists for over 130 years. As a much-collected source of Upper Carboniferous fishes, amphibians, and reptiles, the Linton assemblage includes highly specialized members of fish-tetrapod associations first encountered in Lower Carboniferous freshwater deposits, as well as elements of a terrestrial biota more commonly sampled in younger continental sequences. Recent paleoenvironmental investigation of the Linton area has further established this important fossil deposit as an autochthonous record of a complex animal community that thrived in and near an oxbow lake within an alluviated delta plain

setting. The purpose of this overview is to summarize paleontological and geological information pertaining to the Linton locality. Detailed review of previous literature and full presentation of primary data cannot be provided here but can be found in a series of recent papers (Hook and Baird 1986, Hook and Ferm 1988, Hook and Hower 1988).

HISTORICAL BACKGROUND

The following information is abstracted from our more complete presentation of historical details related to various aspects of the Linton area (Hook and Baird 1986). The village of Linton, located at the mouth of Yellow Creek in northeastern Saline Township, Jefferson County, was the site of the Diamond Coal Mine, a drift mine that was open from 1855 to 1921 (Fig. 1). Shortly after this mine opened, Newberry (1856) described several fish taxa from the site and forwarded Linton tetrapod specimens to J. Wyman for study (Wyman 1857). As State

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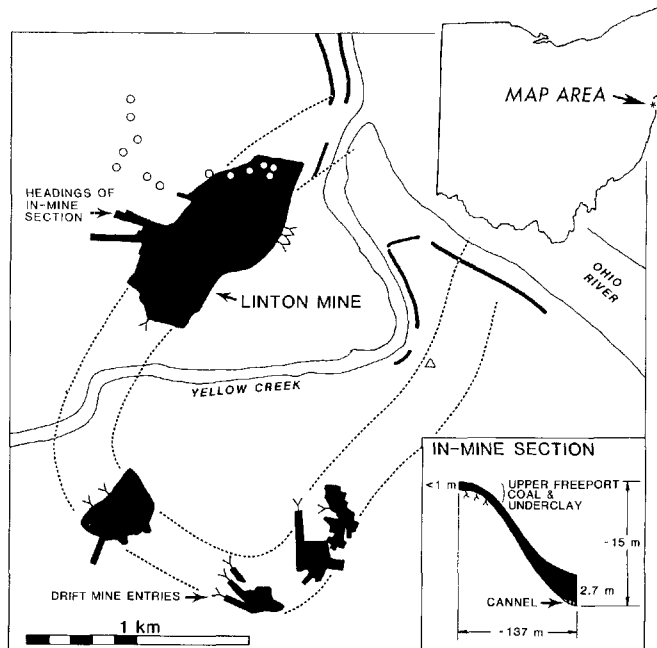


FIGURE 1. Linton, Jefferson County, Ohio. Area enclosed by dashed lines is the inferred original distribution of the fossiliferous cannel based on maps of drift mines in thick Upper Freeport coal (blackened areas) immediately above cannel, boreholes (circles), road and railway cuts (heavy lines) and a surface section (triangle, Ohio Geological Survey file no. 940). Inset shows generalized in-mine cross section within the western headings of the Linton mine (described by Orton 1884).

Geologist during the Second Geological Survey of Ohio from 1869 to 1882, Newberry authored additional descriptions of Linton fishes and facilitated the publication of a landmark summary by Cope (1875) on the locality's tetrapods. These and other early descriptive efforts have been extensively revised, however, because of improved methods of preparation and analysis and the discovery of similar vertebrate remains elsewhere.

Although the details of Newberry's activities at Linton may never be known, the thousands of fossils he obtained within the mine, from the mine dump, and from local collectors attest to many visits to the locality. His collections reflect little bias for particular types of vertebrate remains, and despite intensive modern-day collecting from the mine dump, only one or two new vertebrate taxa have been found since Newberry's time. Inventory of nearly 7000 vertebrate specimens from Linton indicates that fishes are at least 10 times more abundant than tetrapod remains, and that less than 100 specimens, most of which were collected by Newberry, account for over half the taxonomic variation within the tetrapod assemblage (Fig. 2). The existing collections, therefore, comprise a reasonably complete record of the vertebrates preserved in the deposit.

Reports of the Second Ohio Survey also include in-mine and areal descriptions of the fossil deposit (Newberry 1871, 1878, Orton 1884). The mine has been inaccessible for nearly 70 years, but since the 1960s, highway roadcuts in the Linton area have offered a wealth of sedimentological data by which the paleoenvironmental setting of the deposit can be addressed.

PALEONTOLOGY

PLANTS. Fossil plant remains in the Linton deposit have not been systematically collected or studied. The

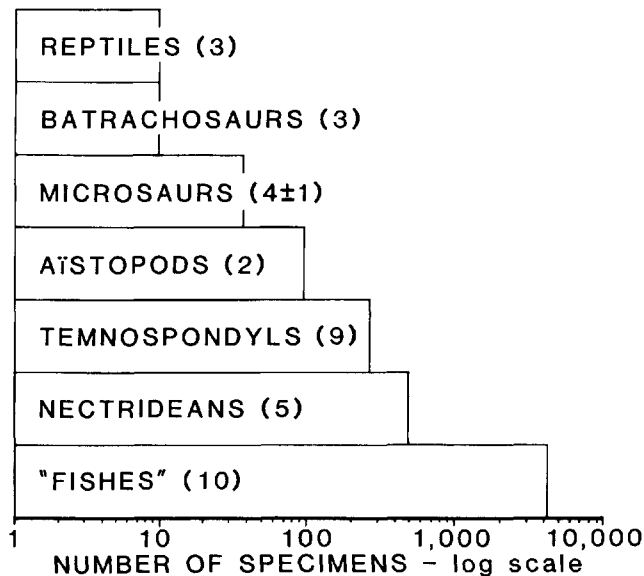


FIGURE 2. Relative abundance of Linton vertebrate taxa based on inventory of major collections. Genera per taxon shown in parentheses. Batrachosaurs are embolomeres and gephyrostegids; temnospondyls include loxommatid counts (from Hook and Baird 1986).

following notes are based primarily on our own observations and should only be considered preliminary. The preservation of megascopic plant remains ranges from poor to excellent, largely in relation to the nature of original plant tissues. Resistant parts, such as resin-bearing structures, cuticles, and fructifications, are generally well preserved and easily recognized; outstanding among these are complete lycopod fructifications that bear trilete megaspores (Hamilla and McComas 1984). Fusinitized plant remains are common but rarely identifiable to specific taxa. Stems and leaves appear infrequently as faint impressions or compressions.

Unpublished data indicate that tree fern spores comprise over half the palynomorph assemblage of the fossil-bearing rock with lycopod spores second in abundance (D. A. Willard, Univ. of Illinois, pers. comm.). These analyses also evidence poor preservation of spores, possibly related to the deleterious activities of anaerobic bacteria (Elsik 1971), and the presence of fungal remains comparable to those found in other cannel coals (Sullivan 1959).

INVERTEBRATES. Prior to recent collecting from the Diamond Mine dump, the record of invertebrates at Linton was embarrassingly poor. Our knowledge of the invertebrate assemblage has been greatly advanced by the diligent collecting and preparation efforts of D. S. Hamilla and G. A. McComas. Much of the following information was reported originally by Hamilla and McComas (1984).

The serpulid worm *Spirorbis* is the most abundant invertebrate in the deposit, sometimes occurring "in millions" (Newberry 1874:180) within aggregations that measure up to 20 mm in thickness and that include at least two varieties of podocopinid ostracods. Spirorbids are also found attached to plant remains, as commonly seen in fresh- to brackish-water, plant-bearing deposits throughout the Carboniferous.

Conchostracan branchiopod and palaeocaridacean syn-carid crustaceans are also common and usually found in substantial concentrations. An eocarid crustacean, *Pygo-*

cephalus dubius, has been reported (Brooks 1962) but is rarely preserved. Schram (1976) noted syncarids and a pygocephalomorph in material collected by Lund, but asserted incorrectly that no invertebrates had been identified previously from Linton and that the poor preservation of these specimens prevented more detailed analysis. The "Tail of a Crustacean" illustrated in Newberry (1873, Pl. 38, Fig. 5) was prepared recently and shown to be a pelvic fin of a male xenacanth shark (Hook and Hansen 1985).

In contrast to most of the crustaceans, Linton myriapods are very well preserved but exceedingly rare. Two spirobolid diplopods, *Xyloius bairdi* and *Plagiascetus lateralis*, were described by Hoffman (1963). Other diplopods, including an oniscormorph, a spinose archipolypod, and a form of uncertain affinity, and possible arthropleurid remains have been collected by Hamilla. A large spineless diplopod that measures over 100 mm in length is currently being described by J. E. Almond (Cambridge Univ., pers. comm.).

Despite exhaustive study of recently collected samples, glaring omissions remain in the Linton invertebrate record. The complete absence of molluscs noted by Newberry (1874) persists to this day. No unequivocal insect remains, including those of the otherwise commonplace blattoids, have been discovered. Neither arachnids nor chilopods, which are admittedly rare but certainly present in other Upper Carboniferous deposits (Rolfé 1985), are known, although scorpion cuticle and other previously unrecorded arthropod fragments may be recovered if the fossiliferous matrix is appropriately macerated and the residues are thoroughly examined (Bartram et al. 1987).

VERTEBRATES. Tables 1 and 2 enumerate the fish and tetrapod species presently recognized from Linton; Table 3 divides these taxa into frequency-of-occurrence categories. We have recently provided a taxonomic revision of the vertebrate assemblage and notes on existing systematic problems (Hook and Baird 1986). The outline below follows gross ecological adaptations and approximate abundances of the vertebrate genera, nearly all of which are monospecific.

Remains of a coelacanth, *Rhabdoderma*, and of certain haplolepid palaeoniscoids are truly plethoric at Linton.

TABLE 1
Linton fish taxa.

Chondrichthyes
<i>Orthacanthus arcuatus</i> (Newberry)*
<i>Orthacanthus compressus</i> (Newberry)
<i>Xenacanthus gracilis</i> (Newberry)*
Osteichthyes
Coelacanthini
<i>Rhabdoderma elegans</i> (Newberry)
Dipnoi
<i>Conchopoma exanthematicum</i> (Cope)
<i>Sagenodus serratus</i> (Newberry)
Palaeoniscoidea
<i>Elonichthys peltigerus</i> Newberry
<i>Haplolepis corrugata</i> (Newberry)
<i>Microhaplolepis ovoidea</i> (Newberry)
<i>Microhaplolepis serrata</i> (Newberry)
<i>Parahaplolepis tuberculata</i> (Newberry)
<i>Pyritocephalus lineatus</i> (Newberry)

*Based on cephalic spines; may be synonymous with *O. compressus*.

TABLE 2

Linton tetrapod taxa. No equivalency of higher taxa implied.

Amphibia
Aistopoda
<i>Ophiderpeton amphiuminum</i> (Cope)
<i>Phlegethonia linearis</i> Cope
Nectridea
<i>Ctenerpeton remex</i> (Cope)
<i>Ptyonius marshii</i> (Cope)
<i>Sauropleuria pectinata</i> Cope
<i>Diceratosaurus brevirostris</i> (Cope)
undescribed scincosaurid
Microsauria
<i>Cocytinus gyrimoides</i> Cope
<i>Molgophis macrurus</i> Cope
<i>Pleuroptyx clavatus</i> Cope
<i>Tuditonus punctulatus</i> Cope
<i>Odonterpeton triangulare</i> Moodie
Temnospondyli
<i>Colosteus scutellatus</i> (Newberry)
<i>Erpetosaurus radiatus</i> (Cope)
<i>Saurerpeton obtusum</i> (Cope)
<i>Gaudrya</i> cf. <i>G. latistoma</i> Fritsch
<i>Macrerpeton huxleyi</i> (Cope)
<i>Amphibamus lyelli</i> (Wyman)
<i>Stegops newberryi</i> (Cope)
Loxommatoidea
<i>Baphetes lineolatus</i> (Cope)
<i>Megalocephalus enchodus</i> (Cope)
Embolomeri
<i>Leptophractus obsoletus</i> Cope
undescribed archeriid
Gephyrostegoidea
<i>Eusauropleuria digitata</i> (Cope)
Reptilia
Captorhinomorpha
<i>Anthracodromeus longipes</i> (Cope)
<i>Cephalerpeton</i> aff. <i>C. ventriarmatum</i> Moodie
Pelycosauria
<i>Archaeothyris</i> sp.

Isolated teeth of a xenacanth shark, *Orthacanthus compressus*, are likewise very abundant, but the relative infrequency of cephalic spines, which regrettably stand under two additional xenacanth species, indicates that these large

TABLE 3

Abundance of Linton vertebrate taxa: abundant, >25 specimens; common, 25-11 specimens; rare, ≤10 specimens. Counts exclude specimens of diagnostic but isolated scales.

Abundant	Common	Rare
<i>Rhabdoderma</i>	<i>Sagenodus</i>	<i>Elonichthys</i>
<i>Microhaplolepis</i> spp.	<i>Conchopoma</i>	<i>Haplolepis</i>
<i>Parahaplolepis</i>	<i>Pyritocephalus</i>	<i>Ctenerpeton</i>
<i>Orthacanthus</i> *	<i>Phlegethonia</i>	scincosaurid
<i>Sauropleuria</i>	<i>Cocytinus</i>	<i>Pleuroptyx</i>
<i>Ptyonius</i>	<i>Erpetosaurus</i>	<i>Molgophis</i>
<i>Diceratosaurus</i>	<i>Amphibamus</i>	<i>Odonterpeton</i>
<i>Ophiderpeton</i>		<i>Tuditonus</i>
<i>Colosteus</i>		<i>Stegops</i>
<i>Saurerpeton</i>		<i>Macrerpeton</i>
		<i>Gaudrya</i>
		<i>Baphetes</i>
		<i>Megalocephalus</i>
		<i>Leptophractus</i>
		archeriid
		<i>Eusauropleuria</i>
		<i>Anthracodromeus</i>
		<i>Cephalerpeton</i>
		<i>Archaeothyris</i>

*Based on total count of xenacanth spines.

predators were certainly less common than most of the fishes and aquatic tetrapods upon which they preyed. Two strikingly different lungfish genera are known; three palaeoniscoid genera, *Elonichthys*, *Haplolepis*, and *Pyritocephalus*, are rare.

The small aquatic neotridaeans, *Sauroplorea*, *Ptyonius*, and *Diceratosaurus*, are the most abundant tetrapods in the assemblage. *Colosteus* and *Ophiderpeton*, two heavily scaled aquatic amphibians with elongate bodies and little or no limb development, are also common. Taken as a group, the lysorophoids represent another stock of reduced-limbed, aquatic amphibians that are fairly common. However, *Pleuroptyx* and the problematical *Molgophis*, as delimited by Wellstead (1985), are known from very few specimens. Other common to abundant tetrapods, such as the temnospondyls *Saurerpeton* and *Erpetosaurus* and the aistopod *Phlegethontia*, may have been capable of a more amphibious existence with increased size.

The dentitions and skull morphologies of the embolomeres and, less certainly, the loxommatids and the temnospondyl that we have referred to as *Gaudrya*, suggest that these rarely occurring amphibians were large piscivores. This interpretation is supported indirectly by the more frequent appearance of similar embolomeres and loxommatids in other fish-dominated Carboniferous deposits (Milner 1980, 1987, Boyd 1984). Most of the remaining Linton tetrapods, many of which are known from an average of only five specimens, possess skeletal characters that indicate an active, nonaquatic existence. The temnospondyl *Amphibamus*, the microsauro *Tuditanus*, the gephyrostegid *Eusauroplorea*, and the reptiles represent generalized terrestrial forms, whereas the temnospondyls *Stegops* and *Macrerpeton* show bizarre cranial features that are poorly understood at present.

GEOLOGY

DEPOSITIONAL ENVIRONMENT AND TAPHONOMIC CONTROLS. The physical and chemical factors that influenced the accumulation and preservation of the Linton assemblage have been evaluated on the basis of surface and subsurface data at both local and regional scales (Hook and Ferm 1985, 1988) and petrographic analysis of the fossiliferous deposit (Hook and Hower 1988). These findings are summarized below and integrated in a number of hypotheses, which, although not predicated directly upon paleobiological inferences, complement available paleontological data.

Linton fossils are preserved in a thin deposit of cannel coal that immediately underlies a locally thick bituminous seam, known as the Upper Freeport coal, at the top of the Allegheny Group. The Upper Freeport is the No. 6 coal of Newberry (1871, 1874, 1878) or the No. 7 coal of subsequent Ohio Geological Survey reports, and is taken to be correlative to the top of the Westphalian D Series of Europe. The cannel is composed primarily of miospores and other resistant plant parts dispersed within a very fine-grained, pyrite-rich matrix of organic detritus. Together with the types, completeness, and fidelity of animal remains found in the deposit, the petrographic attributes of the cannel indicate that it originated as a subaqueous sapropelic peat that formed under neutral to moderately alkaline, anoxic conditions.

The fossiliferous cannel is more widespread in the Yellow Creek area than reported by Newberry (1871,

1878) and Orton (1884). The U-shaped cross section, oxbow-like plan-view geometry, and lateral lithic relationships of the cannel and overlying thick Upper Freeport coal indicate that the deposit occurs at the bottom of an approximately 15-m-deep abandoned river meander (Fig. 1). Analyses of borehole and mine-map data, previously measured surface sections, and extensive road and railway cuts in the vicinity of Yellow Creek show that the erosive-based, fining-upward, sandstone-dominated sediment body that includes the Linton channel fill was deposited by a highly sinuous, single-channel fluvial system. The multistory and locally entrenched nature of this sediment body resulted from lateral migration of a major channel across an alluviated delta plain, and point-bar and channel-fill deposits of individual stories record meander development and abandonment.

The geometry and organic-rich character of the fossiliferous channel fill suggest that the Linton meander was closed rapidly by neck cutoff (Fig. 3A). In the absence of significant clastic influx, plant debris derived from the surrounding levees formed a peaty muck in the bottom of the oxbow and, after a brief period of aerobic decomposition, degenerated into an anoxic, scavenger-free sapropelic peat (Fig. 3B). Because excessive water depth precluded immediate plant growth and humic peat accumulation, a prolonged period of anaerobic bottom conditions insured the preservation of abundant and diverse animal remains introduced from overlying oxygenated waters. A conservative estimate of this time period based on sedimentation rates in oxbow lakes along the modern-day Mississippi River (Gagliano and Howard 1984) is on the order of 1000 years.

Extensive stigmarian root traces in the top of the cannel and the existence of the Upper Freeport coal above the deposit indicate that water depth in the lake eventually became shallow enough for in-place growth of peat-forming vegetation (Fig. 3C). Besides the likely absence of an aquatic fauna in such a setting, significant remains of terrestrial vertebrates probably would not have survived in the uppermost aerobic peat layers of this appar-

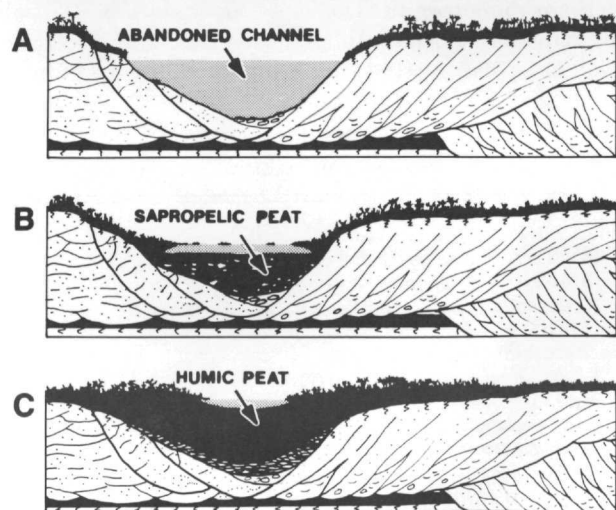


FIGURE 3. Generalized cross section of the Linton deposit before, during, and after accumulation of animal remains. 3A, abandoned river meander approximately 15 m deep; 3B, sapropelic filling of oxbow lake in absence of clastic influx; 3C, humic peat accumulation representing Upper Freeport mire (modified from Hook and Ferm 1985).

ently acidic mire. Thus, the primary controls on the origin of the Linton fossil deposit appear to be the high sinuosity of the fluvial system, which promoted rapid isolation of the meander by neck cutoff, and the substantial depth of the original channel, which resulted in an extended episode of sapropelic bottom conditions upon abandonment.

REGIONAL PALEOENVIRONMENTAL SETTING. The Linton locality has been traditionally referred to as a "coal swamp" deposit, a term that does not characterize accurately the paleoenvironment as evidenced by recently evaluated sedimentological data. The oxbow was situated in the meander belt on a large, contemporaneously active river. As sediment supply within this system diminished, peat-forming mires expanded over floodplain deposits, and where no clastic sediments intervened, humic peat accumulated directly above sapropel-filled abandoned channel segments. At this scale of resolution, the Linton depositional setting resembles those of Joggins and Florence, Nova Scotia, where remains of predominantly terrestrial animals are preserved within upright tree stumps encased in overbank sandstones. Although the taphonomy of the tree-stump assemblages is different, all three examples originated in floodplain or proximal flood-basin environments.

Milner (1987) has suggested recently that the Linton paleoenvironment was influenced by marine waters. Sedimentological data clearly establish, however, that the locality was at least 3 km removed from brackish-water bays or lakes, and that no contemporaneous distributary or barrier systems existed in the general region of Yellow Creek. There is also no paleontological evidence of a marine influence. The aquatic invertebrates of the deposit are all non-marine, as are the fishes. Of particular significance is the occurrence of *Orthacanthus compressus* teeth, which represent a xenacanth shark that is restricted to freshwater deposits on the basis of systematic sampling and microscopic analysis of over 250 Upper Carboniferous fish-bearing units in the Pittsburgh Basin (Hansen 1986). Furthermore, the complete lack of rhipidistian crossopterygians, acanthodians, and sharks characteristic of brackish to marine assemblages within the region reinforces a freshwater diagnosis of the Linton deposit. Milner's suggestion of marine influence at Linton is untenable. The Mid-continent work that inspired it (Schultze 1985) appears to be based primarily on ecological interpretations that are grounded in cyclothem dogma, not closely spaced sedimentological data. In the Ohio Valley and other areas where extensive surface exposures and abundant mining data can be used to assess depositional conditions, simplistic models of cyclic sedimentation have been falsified *in toto* (Ferm and Horne 1979).

DISCUSSION AND CONCLUSIONS

The census-like sampling of the Linton deposit conducted by Newberry and several recent collectors provides a high fidelity record of the vertebrate remains preserved in the channel fill. Although the predominance of aquatic taxa has led workers to conclude that amphibious to terrestrial forms are "wash ins" or "erratics," the petrography of the channel and the high degree of completeness exhibited by most specimens demonstrate that animal remains were derived from the oxbow lake and its

immediate surroundings. Post-mortem transport was essentially downward into the sapropelic milieu, not laterally across an environmental transect that supposedly ranged from "upland" and "open water" to "swamp lake," as depicted by Milner (1980) and suggested by others. In short, the assemblage is autochthonous at the scale of the oxbow lake and its margins.

In some fossil-bearing channel fills, animal and plant assemblages are segregated vertically into discrete rock units that record successive environmental conditions (Hook, unpubl. data). If sampled randomly, such deposits yield ecologically mixed assemblages that are interpreted reasonably, but incorrectly, as thanatocoenoses. At Linton, however, remains of aquatic animals are preserved adjacent to the most terrestrial of both invertebrate and vertebrate taxa, a notable example being the holotype specimen of the protorothyridid reptile, *Anthracodromeus longipes*, which Romer (1930) mistook for a fish on the basis of coelacanth remains that accompany the articulated tetrapod skeleton (Carroll and Baird 1972). Thus, for all intents and purposes, the Linton vertebrate assemblage is a biocoenose, and recognition of discrete terrestrial and lacustrine communities within it is largely artificial.

Taxonomic studies have noted a preponderance of juvenile and subadult aquatic forms relative to a paucity of larger individuals of the same species at Linton. Such observations have been used repeatedly to depict the paleoenvironment as a "breeding pond" where single-age classes of subadults would perish in catastrophic "seasonal kills." While ignoring the probability that the largest growth forms of any one species constitute a small absolute percentage of a population, these suggestions also discount the existence of aquatic taxa that are known from a continuum of growth forms or primarily from large specimens. Pending statistical analysis of *all* aquatic to amphibious taxa, we dismiss the notion of a Westphalian "nursery pool" as paleontological conjecture.

The paleoecology of the Linton vertebrate assemblage has been discussed directly or indirectly in numerous papers. With the notable exception of observations made by Newberry (1871, 1874, 1878), these accounts have relied heavily upon paleobiological inferences that are fraught with circular reasoning. Constrained by little, if any, sedimentological data, previous interpretations have regarded the Linton assemblage as an allochthonous "coal swamp" accumulation, not an autochthonous floodplain deposit. As a result, the absence of particular tetrapod remains, such as large diadectid amphibians or the diversity of pelycosaur reptiles known from somewhat younger deposits, has been "explained" by *ad hoc* scenarios that are grounded in paleoenvironmental misinterpretations.

Recent discussions of the vertebrate assemblages from Linton and other Westphalian tetrapod sites have fostered the reconstruction of "Coal Measure" food webs or chains (Scott 1980, Milner 1980, Boyd 1984, Olson 1984, 1985). Although these diagrams convey the essence of a detritivore-based ecosystem that lacks primary herbivores and large land-dwelling predators, they grossly oversimplify complexities within and between trophic levels. A detailed understanding of feeding habits, locomotion, and life histories is also suggested by these exercises. Such information does not exist, however, in the case of

most vertebrate species. At Linton, for example, the only positive evidence for predator-prey relationships is a single specimen of a coelacanth (*Rhabdoderma*) preserved with a palaeoniscoid (*Parahaplolepis*) in its gullet (Princeton University 19299). Critical examination of these food webs reveals that they are little more than faunal lists arrayed according to the conjectured habits of various taxa.

We suggest that paleoecological problems can be considered more profitably if the meager amounts of data that bear directly on trophic relationships are not inflated to manufacture untestable food webs. Before complex interactions within or between "faunas" can be elucidated, topical hypotheses must be developed and evaluated for particular species or morphotypes that recur in Permo-Carboniferous deposits. Furthermore, irrespective of how abundant the fossils may be at a certain locality, depositional environments and events must be defined on a factual, non-anecdotal basis if paleoecological interpretations are to have scientific currency.

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