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A depositional model for the Linton tetrapod assemblage (Westphalian D, Upper Carboniferous) and its palaeoenvironmental significance

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A palaeoenvironmental study indicates that fossils from the famous Upper Carboniferous vertebrate deposit of Linton, Ohio, are preserved in an allochthonous organic filling of an abandoned river channel. A depositional model developed from this analysis is corroborated by other Coal Measure vertebrate localities in Europe that also appear to represent abandoned channels. Additional vertebrate occurrences were discovered in the Ohio Valley by prospecting coal-bearing intervals for similar channel deposits. These results suggest that environmental models based on study of geological controls influencing fossil concentrations, combined with information on collecting histories of classic sites, offer an improved understanding of seemingly extraordinary assemblages and a means by which further fossiliferous deposits may be located.

1. Introduction

Both sedimentary geologists and palaeontologists have routinely considered the occurrence of vertebrate fossils unusual. Geologists typically find such remains difficult to recognize or collect properly in the field and vertebrate palaeontologists generally seek fossils at sites that have produced significant specimens in the past. As a result, certain types of animals or even entire assemblages are known from single localities that are regarded as exceptional or unique. Although these sites are sometimes considered in palaeoecological studies, physical and biological factors responsible for such occurrences are seldom documented. This lack of detailed information on the geology of prolific fossil deposits virtually precludes all but chance discoveries of similar concentrations elsewhere and perpetuates the notion of extraordinary or rarely occurring assemblages.

We have analysed the palaeoenvironmental setting of a famous fossil vertebrate locality and present here a depositional model based on palaeontological, petrographic, and stratigraphic data derived from this productive site. We outline our procedures and briefly discuss the implications of this model relative to similar localities to illustrate a method by which other outstanding fossil occurrences may be considered. Our findings lead us to conclude that sedimentologically oriented investigations that serve to establish why specific deposits appear to be remarkable are prerequisites to the development of viable hypotheses that incorporate these exceptional records.

2. The Carboniferous vertebrate assemblage of the Linton diamond mine

The focus of our study is the Diamond Coal Mine of Linton, Ohio, a long-abandoned drift mine that is one of four Upper Carboniferous mining localities that yielded rich concentrations of fossil vertebrates during the latter half of the 19th century (figure 1). The tetrapod assemblages from these sites are of particular interest because they include a diverse array of aquatic to terrestrial amphibians and, in some cases, important records of early reptiles (see Carroll 1984). A considerable body of descriptive literature exists on the vertebrates of these classic Coal Measure localities, and a number of papers offer palaeoecological scenarios for coal-swamp vertebrate faunas (see, for example, Case 1917; Romer 1930; Westoll 1944, 1968; Panchen 1977; Milner 1980; Boyd 1984). Rayner (1971) and Boy (1977) have summarized the geological information reported previously on Carboniferous tetrapod-bearing deposits, but primary sedimentological data have never been fully presented to document the physical factors responsible for such vertebrate occurrences, and little emphasis has been placed on the significance of extensive collecting at these sites. Together with the unsettling fact that no Carboniferous vertebrate assemblages of comparable wealth have been discovered in recent time, these shortcomings lead us to initiate a comprehensive investigation of the Linton deposit.

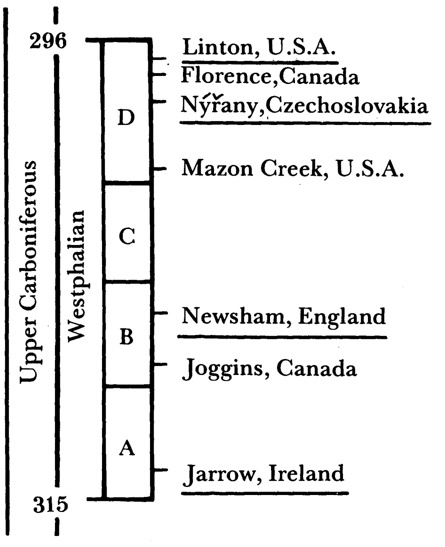

Figure 1. Principal Upper Carboniferous tetrapod localities; those associated with 19th century mining activities are underlined. Modified from Carroll (1984) with time increments from Harland *et al.* (1982).

A taxonomic summary of the complex vertebrate assemblage at Linton, accompanied by a history of collecting activities at the locality, has been completed recently by Hook & Baird (1986). A survey of all major Linton collections, comprising over 6000 specimens, demonstrates that fish remains are nearly ten times more abundant than tetrapods (figure 2). Coelacanth and certain palaeoniscoid fishes are abundant, whereas lungfish, other palaeoniscoid species, and xenacanth sharks are less common. Of the approximately 26 monotypic tetrapod genera, the most frequent are aquatic amphibians of small to intermediate size. Larger aquatic amphibians, as well as terrestrial forms and reptiles, are exceedingly rare.

The diversity of the Linton assemblage appears to be attributable to the collecting efforts of J. S. Newberry, who visited the locality regularly over a 20-year period during the last century to collect fossils within the active mine and from the tip heap. Although substantial amounts of material have been acquired by subsequent collectors from the existing tip heap, only one or two additional vertebrate taxa have been discovered at Linton in the last 100 years. Furthermore, less than 100 specimens, nearly all of which were obtained by Newberry, account for nearly 60% of the taxa within the vertebrate assemblage (figure 2). These data indicate that the striking diversity seen among the tetrapods is a direct reflection of the exhaustive, census-like collecting of Newberry. Similar sampling histories can be cited for other extraordinary fossil deposits (for example, Mazon Creek: Pfefferkorn 1979) and cannot be discounted when considering prolific localities.

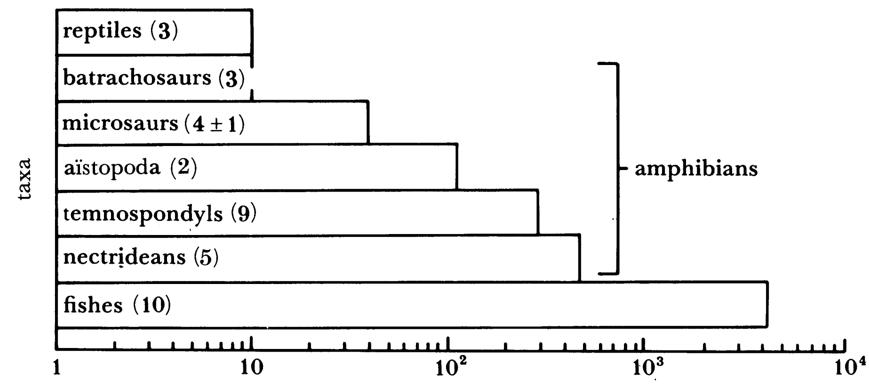

Figure 2. Relative abundance of Linton vertebrate taxa based on approximate minimum number of individuals. Genera per taxon shown in parentheses. Modified from Hook & Baird (1986).

3. Sedimentological analysis

Acknowledging a correlation between the recognized diversity of some renowned fossil assemblages and intensive collecting efforts following an initial discovery of unusual fossils, we considered what chemical and physical factors may have influenced the preservation of uncommon forms, namely vertebrates, at Linton. Chemical controls were identified primarily through analysis of representative samples of the fossiliferous matrix, whereas physical controls were inferred mainly from the documented lateral and vertical relationships of the vertebrate-bearing deposit to surrounding rock bodies.

The Linton fossils occur in a cannel coal that appears characteristically massive with a subconchoidal fracture in unweathered samples. Petrographic study indicates that this material consists of spores and variously degraded plant remains dispersed within a dense, pyrite-rich matrix of fine-grained organic detritus. Humic components (vitrinites) characteristic of *in situ* coal deposits are neither abundant nor well preserved. These petrographic attributes suggest that the vertebrate-bearing cannel represents an allochthonous deposit of sapropelic plant materials that accumulated under reducing, anaerobic conditions.

Previous geological studies of coal-bearing rocks in the Upper Ohio Valley indicate that the Linton cannel is part of a fluviodeltaic sequence (Ferm 1970, 1975), but earlier reports established neither the shape nor extent of the fossiliferous deposit. All pertinent geological data from prior work within a 30 km radius of Linton were collated and field investigations were conducted in areas where critical information was lacking. Because of past development of mineral resources, a substantial amount of unpublished data was available in the form of mine maps, in-mine coal seam sections, mine inspectors' reports, and a variety of borehole records. Combined with measured surface sections obtained from the files of the Ohio Geological Survey and detailed scale drawings of continuous exposures along highway and railroad cuttings, these data provided information on the physical characteristics of the 50 m rock interval that included the horizon of the vertebrate-bearing cannel. In addition, all existing tip heaps and appropriate exposures were examined for vertebrate fossils.

The geometries of the fossiliferous cannel and associated rock bodies are most evident in the immediate vicinity of the Diamond Mine (figure 3). The cannel averages 30 cm in thickness and directly underlies an anomalously thick body (up to 3 m) of banded humic coal. In plan view, the cannel and overlying thick coal are restricted to an approximately 300 m wide

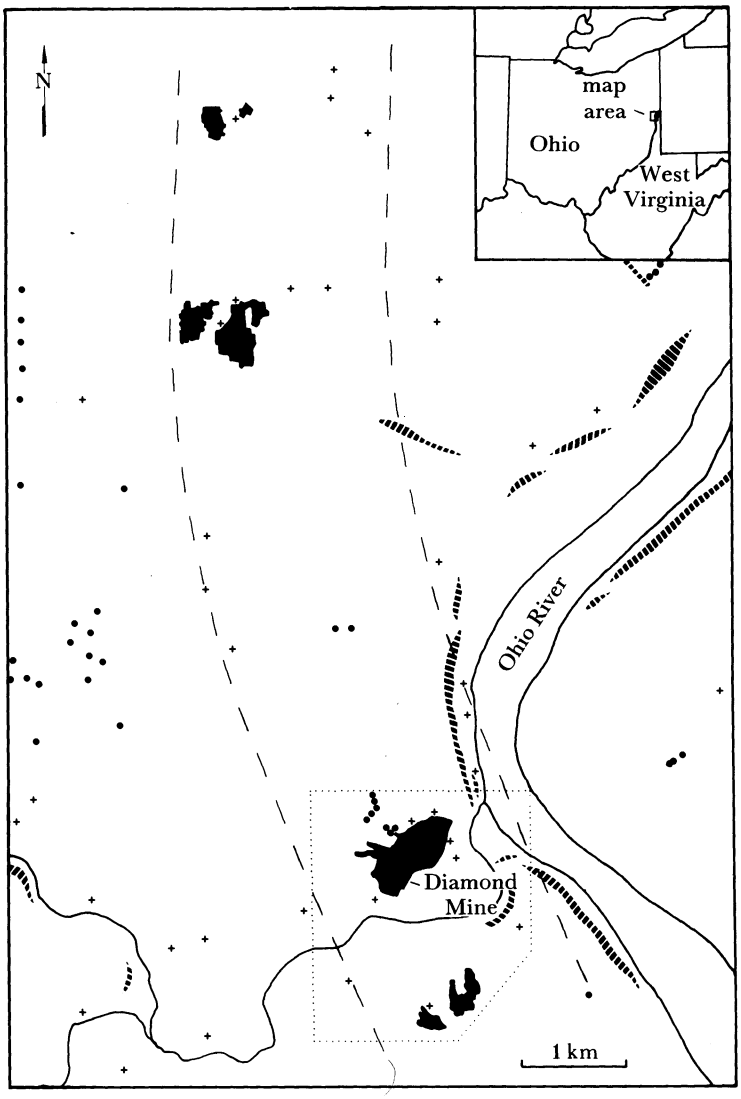

FIGURE 3. Map of Linton study area with locations of boreholes (dots), measured sections (crosses), and surface cuttings (stripe pattern) indicated. Blackened areas within north-northwest trending belt represent workings in channel-fill coal immediately above fossiliferous cannel. Area within dotted lines depicted on figure 4.

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curvilinear deposit. At right angles to the axis of this deposit, the humic coal thins and slopes upward approximately 20 m over a horizontal distance of less than 140 m and, near the base of this incline, the cannel pinches out. In areas other than the trough-like depression that contains the cannel, the humic coal is less than 1 m in average thickness and is underlain by a root-penetrated seatearth.

The deposit of cannel and thick humic coal lies within a 20–30 m thick, fining-upwards sequence of clastic rocks. Erosional basal contacts and other sedimentary features indicate that this sandstone-dominated interval is fluvial in origin. As exposed in extensive roadcuttings, the channel geometries preserved in these fluvial accumulations resemble the dimensions of the cannel body, and the flat-lying cannel bed is locally underlain by upturned slump blocks that represent collapsed river bank deposits.

In conclusion, these geological relationships suggests that the Linton deposit originated as an organic infilling of a deep and fairly sinuous abandoned channel (figure 4). Similar organic-rich channel fills, as well as bank-collapse or slump structures comparable to those found beneath the cannel, have been described from other coal fields (for example, Elliot 1965; Williams *et al.* 1965). Six additional occurrences of the vertebrate-bearing cannel underlying abnormally thick humic coal in association with channel deposits were located within an approximately 10 km long by 2 km wide area that trends north-northwest from the Linton area (figure 3). Because palaeocurrent data obtained from channel sandstones indicate that the fluvial system was flowing in the same north-northwest direction, these additional cannel sites may be interpreted either as extensions of the Linton deposit or as discrete but roughly contemporaneous abandoned meanders.

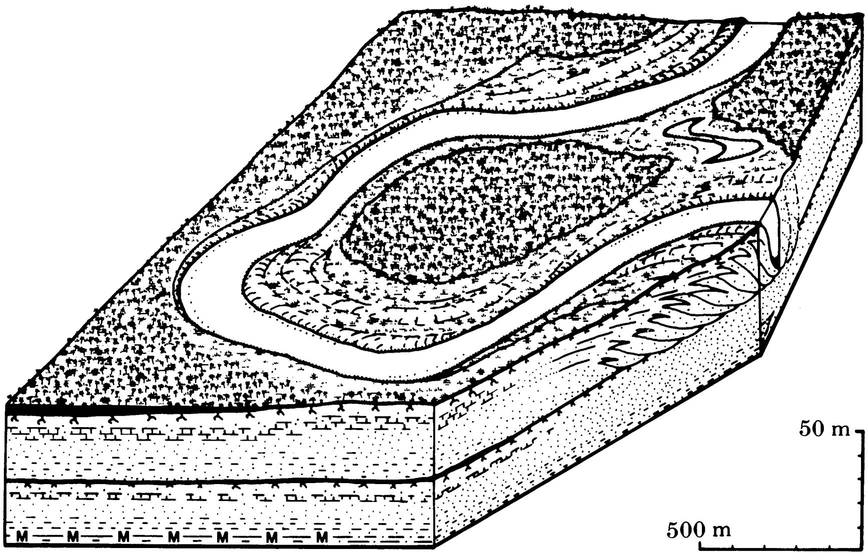

FIGURE 4. Block diagram of Linton area at initial stage of channel abandonment prior to filling. See figure 3 for location.

4. The abandoned channel model and model testing

The documentation of vertical and lateral rock relationships in the Linton area leads to a model for the occurrence of vertebrate remains in sapropelic coals. Upon abandonment of the river channel in part or whole, normal plant growth and peat accumulation would have been inhibited by excessive water depths (figure 5*a*). Macerated plant debris from surrounding levées accumulated within the channel and, in the absence of clastic influx, degenerated into a gyttja-like bottom sludge (figure 5*b*). The reducing, anaerobic characteristics of this material were conducive to the preservation of animal remains that were introduced from the upper oxygenated portion of the water column; given the length of time required to fill such a body of water, a relatively diverse collection of animals, including amphibious to terrestrial forms, would be represented in the death assemblage. As marginal vegetation encroached upon the progressively shallower water, *in situ* peat accumulation would occur and the former river course would become incorporated in the swamp complex (figure 5*c*). The organic materials filling the channel would compact more than subjacent clastic sediments, thus producing a deposit characterized by a marked U-shaped cross section and greatest coal thickness with cannel development in the lowest parts of the coal horizon (figure 5*d*).

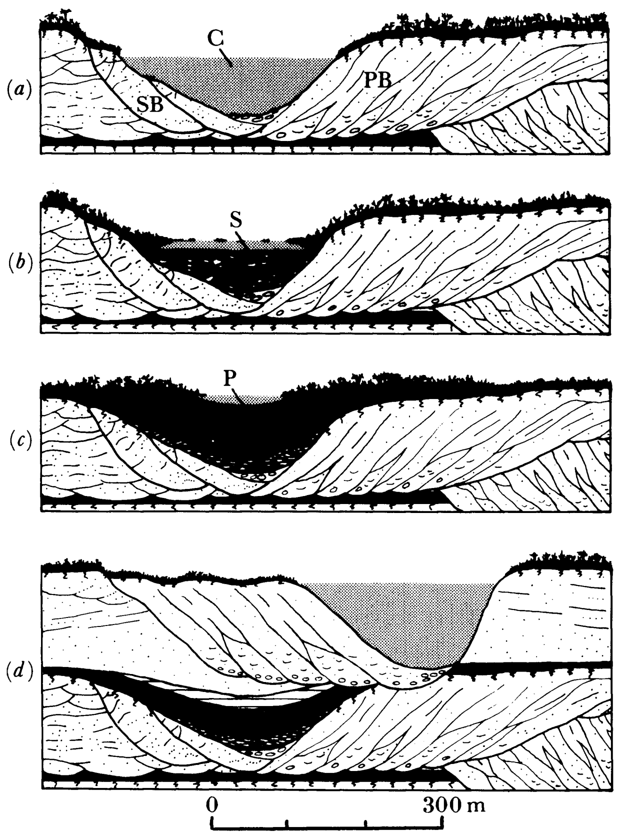

FIGURE 5. Abandoned channel model for the occurrence of vertebrate remains. (*a*) Abandoned river channel (C) flanked by point-bar deposits (PB) and slumped cut bank (SB); (*b*) allochthonous sapropelic fill (S) from contemporaneous swamps; (*c*) autochthonous humic fill (P) by *in situ* peat accumulation; (*d*) subsequent sedimentation and compaction. Vertical exaggeration approximately five times.

The abandoned channel model was tested by reviewing geological data from other Coal Measure vertebrate localities. With the exception of the patently different tree stump assemblages of Nova Scotia (Carroll *et al.* 1972) and ironstone concretions of Illinois (Baird *et al.* 1985), all prolific Westphalian localities for which adequate information exists appear to be similar to the Linton example. That is, fossils representing predominantly aquatic animals are preserved in pyrite-rich sapropelic coals or coaly shales that are associated with locally thick deposits of humic coal that exhibit channel-like geometries. These abandoned channel sites include Jarrow (County Kilkenny, Ireland: see Rayner 1971), Newsham (Northumberland, England; see Boyd 1984), and possibly Nýřany (western Bohemia, Czechoslovakia; see Milner 1980). Although the fossiliferous horizon occurs at the top or in the middle of the accompanying humic coal at some localities, the overall similarities suggest that the channel hypothesis may serve as a general model for predicting the occurrence of vertebrate remains in fluvial-dominated, coal-bearing sequences.

A second test of the abandoned channel model was performed in the field by examining other sapropelic coals at lower stratigraphic intervals in the Ohio Valley. Cursory sampling of three deposits yielded a variety of vertebrate fossils, including freshwater fishes and sharks and amphibians. The geology of two of these deposits appears to corroborate the channel model, but the geometry of the third, an extensive cannel occupying an area of approximately 120 square km, clearly suggests an alternative model for the preservation of vertebrates in coal-forming environments. Even though amphibians comprise a small part of the material from these deposits, their mere occurrence is very significant and not quantitatively different from the fish:tetrapod ratios known from Linton.

5. Palaeoecological implications and significance

The development of depositional models based on the geology of apparently unique fossil assemblages promotes a better understanding of the palaeoecological significance of such deposits. Previous interpretations of coal-swamp tetrapod assemblages have relied mainly on palaeobiological inferences, such as abundance and adaptations of recognized species, to frame specific localities within environmental transects that range from 'upland' to 'deep water'. Furthermore, the preservation of various animals has been attributed to rather complex events, including flooding of shallow ponds and overturn of deep, thermally stratified lakes. Our diagnosis of several Upper Carboniferous tetrapod deposits, however, suggests that successive ecological settings may be recorded in the filling of abandoned channels. With little sedimentological evidence of dramatic taphonomic influences, the known diversity and abundance of animal remains found in these deposits may be explained more reasonably by the considerable length of time over which preservational conditions existed, combined with the intensive efforts of fossil collectors. In conjunction with recent work on the taphonomy and palaeoenvironments of Coal Measure plant assemblages (see, for example, Pfefferkorn *et al.* 1975; Scott 1978; Eggert & Phillips 1982; Scheihing & Pfefferkorn 1984), environmental analyses of vertebrate concentrations should contribute to comprehensive yet testable palaeoecological hypotheses for Carboniferous biotas.

If improved palaeoenvironmental diagnoses of classic localities can be applied successfully to the discovery of additional assemblages that are considered at present to be exceptional, perhaps those fossil deposits that are truly extraordinary because of geological or biological phenomena, not historical factors, may be recognized. The feasibility of this approach depends on the amount and quality of available data and the critical synthesis of information into coherent models. By establishing relationships between geological controls and the occurrence of organic remains, significant aspects of ancient biotas may be assessed more readily and palaeontologists will be less disposed to offer interpretations that other earth scientists disqualify as 'just-so' stories.

We thank Dr Donald Baird of Princeton University for assistance in summarizing the Linton assemblage and for enthusiastic support of our palaeoenvironmental study. We have also benefited from the recent collecting efforts of Mr David S. Hamilla and Mr Gregory A. McComas which have documented vertebrate occurrences at several new Carboniferous localities in the Ohio Valley. Mr Michael J. Boyd has kindly shared with us the findings of his continuing study of the Newsham assemblage. Our work would not have been possible without the generous cooperation of the Ohio Division of Geological Survey. Mt Savage Refractories Company assisted our investigation by making available borehole records in their possession. Unpublished data on the Jarrow deposit was provided by the Geological Survey of Ireland. Study of the Linton vertebrate assemblage was aided by the Sylvester–Bradley Award of the Palaeontological Association to Hook. This material is based upon work supported by the National Science Foundation under grant EAR-8212499.

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