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Mazon Creek-type fossil assemblages in the U.S. midcontinent Pennsylvanian: their recurrent character and palaeoenvironmental significance

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[Plate 1]

Terrestrial plants, the non-marine Braidwood Fauna, and the euryhaline Essex Fauna, best known from the Francis Creek Shale Member within the Mazon Creek area of northeastern Illinois, are found to recur in analogous deltaic lithofacies elsewhere both in Illinois and in adjacent states. An important new Essex-type fossil locality is reported from deposits coeval with the Francis Creek Member in Missouri, and occurrences of Braidwood animals from additional stratigraphic units are discussed. These assemblages occur in estuarine–deltaic deposits juxtaposed on coals; the significance of the association of these fossils with transgressive inundation of coastal peat swamps is discussed and a predictive model for the occurrence of Mazon Creek-type assemblages is presented. We believe that fossil associations comparable to those at Mazon Creek, occur in certain coastal deposits ranging in age from Pennsylvanian to, at least, the Triassic.

1. Introduction

The Mazon Creek biota of Middle Pennsylvanian (Westphalian D) age is best known from localities in northeastern Illinois, and it is characterized both by diverse plants and animals preserved within sideritic concretions. These fossils, occurring in deltaic and perideltaic detrital sediments, include the most important assemblage of soft-bodied invertebrate animals from the late Palaeozoic. Moreover, the associated flora represents one of the most diverse assemblages of Pennsylvanian terrestrial plants known from North America (see Darrah 1970; Horowitz 1979).

The Mazon Creek biota consists of marine to freshwater animals, a diverse terrestrial fauna, and a rich assortment of variably disarticulated land plants. Of particular importance are medusae, crustaceans, insects, myriapods, merostomes, arachnids, holothurians, several worm phyla, hemichordates, several chordate classes, and various problematic organisms (see descriptive overview in Nitecki 1979).

Three-dimensional preservation of plant organs and soft-tissue preservation of animals is typical; preservation of jellyfish and siphonophores, yolk sacs on larval fish, colour markings on bivalves and insects, setae on worms, and delicate radulae on chitons and cephalopods occurred through rapid burial and early diagenetic concretion formation around fossils (Richardson & Johnson 1971; Baird *et al.* 1985).

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Richardson & Johnson (1971) subdivided the Mazon Creek fauna into two components. They recognized freshwater and terrestrial animal associations known collectively as the Braidwood fauna which typically occurs in association with transported and variably disarticulated land plants. They also described a marine to brackish water animal grouping known as the Essex fauna; this latter grouping contains most of the spectacular soft-bodied taxa from this deposit. We retain the above distinction, but add a third group (Danville fauna) which is intermediate between Essex and normal marine assemblages (Baird & Shabica 1980; Baird *et al.* 1985).

Ironstone concretion biotas composed of plants, freshwater animals and terrestrial taxa are reported from other parts of North America. Canwright (1959) listed a number of strip mine localities in Indiana yielding plants and occasional animals; most of these are currently inaccessible. Boneham (1975) described a significant biota of plants and Braidwood-type animals, including *Euproops*, syncarids, and insects, above Indiana Coal no. 7 in the Busseron Sandstone Member near Terre Haute, Indiana. Gastaldo (1977) described a rich concretion flora from thick deltaic facies (Energy Shale Member) above the Herrin (no. 6) Coal Member at Carterville in southern Illinois. Similarly, Condit & Miller (1951) described a concretion flora from a locality in south-central Iowa. These, plus numerous similar localities described in British literature, indicate that concretions yielding Braidwood-type fossils occur at numerous levels in the Pennsylvanian.

The Pennsylvanian Essex fauna is described solely from the Mazon Creek area and from a small strip mine area, now largely inaccessible, near Astoria, Fulton County, in western Illinois (figure 1). These two widely separated localities both yield Essex animals from the Francis Creek Shale Member (Smith 1970; Foster 1979); it is thus of no little significance that the Missouri Essex fossil occurrence described herein is also from the same stratigraphic level.

The most significant research on Pennsylvanian concretion biotas outside of Illinois is proceeding in France. Detailed census sampling of fossiliferous concretions at an open-pit coal mine at Montceau-les-Mines have revealed a diverse flora and an association of predominantly Braidwood-type animals from rocks of Stephanian age (Heyler 1980; Pacaud *et al.* 1981). Syncarid shrimps, xiphosurans, euthycarcinoids, insects, worms, and numerous amphibians occur in nodules above coal units in the mine. The fauna has a general non-marine aspect, but minor occurrence of worms and euthycarcinoid arthropods suggest some saline water incursion (Pacaud *et al.* 1981).

The principal aim of the present paper is to stress the recurrent nature of Mazon Creek-type biofacies in the context of Pennsylvanian facies cyclicity. Included herein are results of preliminary sampling of analogous Pennsylvanian concretion biotas elsewhere in the U.S. Midcontinent Region. Of particular importance is discovery of a new Essex fossil locality in western Missouri as well as additional occurrences of the Braidwood biota from other stratigraphic units within the Illinois and Midcontinent Interior Basins. The distinctive association of these fossils with estuarine–deltaic deposits juxtaposed on coals is discussed and a predictive model for recurrence of this facies is presented.

Finally, we wish to emphasize that the Essex fauna was not an aberrant biota of limited temporal value but was, apparently, a stable faunal grouping which persisted through the late Palaeozoic and across the Permo-Triassic boundary.

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2. Geological setting

Localities examined herein occur both in the Illinois Basin and Midcontinent Interior Region (figure 1); deposits in these basins record cyclic marine transgression and regression events as well as periodic development of extensive peat (coal) swamps and local deltas which bordered epeiric seas. The diverse coal floras and calcareous faunas in limestone units support results of palaeomagnetic work (Ziegler *et al.* 1979) which place the study area in the Pennsylvanian tropics.

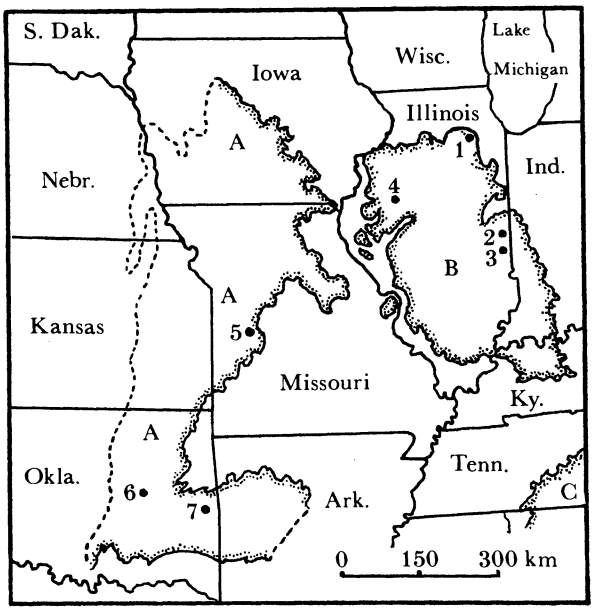

Figure 1. Distribution of localities. Solid line with stippling denotes Pennsylvanian outcrop limit. Dashed line marks edge of overlying post-Pennsylvanian units. Lettered features include: A, Midcontinent Interior Region; B, Illinois Basin; C, Appalachian Coal Basin. Localities include: 1, Mazon Creek area; 2, Danville; 3, Georgetown; 4, Astoria; 5, Windsor; 6, Henryetta-Morris; 7, Sallisaw.

Fossil-bearing sideritic concretions occur in the Francis Creek Shale Member (Middle Pennsylvanian: Westphalian D Stage) in a five-county region (Mazon Creek area) in northeastern Illinois (figure 1). Concretions typically occur in silty mudstone lithofacies within 15–25 m thick, lobate Francis Creek deposits; these lobes mark the position of deltaic distributary systems along the margin of an inland sea (Shabica 1971). The Francis Creek Member regionally overlies the economically important and widespread Colchester (no. 2) Coal Member.

3. Francis Creek depositional events: fossil distribution, burial and preservation

The Francis Creek Member and coeval mudstone deposits west of Illinois include at least four distinct lobate clastic wedges recording rapid sedimentation around distributaries (Wright 1965). These lobes, developed over the coextensive Colchester and Croweburg Coal Members, grade laterally to intervening, thin, non-deltaic deposits which lack concretions and yield

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shelly, stenotopic marine taxa typical of Pennsylvanian offshore shelf mud bottoms (Shabica 1971).

Distributary progradation is revealed by conspicuous large-scale inclined stratification in the Francis Creek, particularly near sandstone channels; these foresets record rapid offlap sedimentation associated with the filling of interdistributary bays (Baird & Shabica 1980). Similarly, an upward-coarsening trend from mudstone to sandstone is observed in Francis Creek drill-core sections and in most outcrops indicating progressive filling of water areas around distributaries. Delta progradation recorded in the Francis Creek Shale apparently followed transgressive inundation of the coal swamp as is suggested by widespread occurrence of Essex taxa in basal Francis Creek beds (Baird *et al.* 1985).

Fossil-bearing sideritic concretions occur most commonly in the basal portion of the Francis Creek Shale Member above the Colchester Coal. Concretions occur typically in laminated to weakly rippled, silty mudstone deposits which typically show little or no evidence of bioturbation. Small-scale sedimentary structures in nodule-bearing sequences include climbing ripple drift, and soft-sediment load-failure; these indicate rapid and often episodic mud deposition in interdistributary bay and prodelta settings.

Rapid fossil burial is indicated by soft-part preservation, escape burrows, sometimes associated with their entombed producers, and occasional burial of upright or nearly upright tree trunks. However, drill-cores, from the vicinity of the main strip mine fossil locality (pit 11) near Essex, Illinois, reveal a very regular pattern of alternating thick and thin graded silt laminae separated by clay partings; these repeating cycles, averaging 1 mm in thickness, are believed to record daily flood- and ebb-tide events (Kuecher 1983; Baird *et al.* 1985). Post-burial preservation of fossils was further mediated by very early diagenetic formation of sideritic concentrations which usually, but not always, formed around fossil nuclei (Woodland & Stenstrom 1979). Three-dimensional preservation of delicate insects and occurrence of jellyfish impressions indicates that concretion formation commenced immediately following fossil burial before significant compactional dewatering could start.

4. Mazon Creek biofacies: fossil associations and their palaeoenvironmental significance

(*a*) *Braidwood fauna*

The Braidwood fauna includes terrestrial and freshwater animals. Terrestrial animals include a diverse array of insects, myriapods, arachnids, merostomes, and tetrapods, all generally rare, but typically well preserved. These lived in coal swamp, flood plain, and levée habitats on the delta; their association with abundant plant parts reflects seaward fluvial transport (Richardson & Johnson 1971; Baird *et al.* 1985). Freshwater and minimally brackish Braidwood taxa include syncarid and pygocephalomorph shrimps, the xiphosuran *Euproops*, ostracodes, branchiopods, the chondrichthian egg capsule *Palaeoxyris* (McGhee 1984), larval amphibians and locally abundant small bivalves.

The Braidwood aquatic association displays low diversity and includes largely small taxa which are only locally abundant; salinity and turbidity stress in shallow bays and waterways bordering distributaries is believed to account for the restricted character of this fauna. Braidwood terrestrial and freshwater animals occur almost exclusively within a narrow belt (Baird *et al.* 1985) along the northern edge of the Mazon Creek collecting area.

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The Braidwood fauna typically occurs in close association with transported and variably disarticulated plants. Data obtained from extensive regional census-sampling of localities show a strong positive correlation between plant size, degree of articulation, diversity, and abundance between samples; there is pronounced northward (shoreward) improvement in the plant component over the entire region (Baird *et al.* 1985). Although Braidwood animals and plants occur to the south and west (seaward) in areas of marine animal occurrence, they are distinctly reduced in abundance and preservational quality owing to transport attrition.

(*b*) *Essex fauna*

This eurytopic marine fauna includes diverse medusae, polychaetes and other worm phyla, crustacea, holothurians, bivalves, a polyplacophoran, several classes of marine vertebrates, and important problematical forms including the enigmatic *Tullimonstrum gregarium*. These organisms, originally collected at pit 11 are found to occur over most of the five-county Mazon Creek area. Essex biofacies grades landward into Braidwood fossil-bearing deposits; this transition zone is typically narrow, and it is regionally aligned as a distinct boundary parallel to the inferred palaeocoast (Baird *et al.* 1985).

The Essex fauna is believed to have inhabited variably turbid, euryhaline waters in a prodeltaic setting (Baird 1979; Baird *et al.* 1985). Since the association completely lacks articulate brachiopods, rugose corals, bryozoans and is nearly devoid of crinoids, inarticulate brachiopods and cephalopods, it is believed that salinity and turbidity fluctuations regularly occurred throughout the marine part of the Mazon Creek area and probably further offshore as well; the palaeogeographic setting of Essex organisms is interpreted as a large semi-restricted estuary which formed as a result of marine transgression of an irregular, delta-dominated coast (Baird *et al.* 1985).

5. Essex–normal marine biofacies transition: Danville fauna

The seaward gradation from Essex to normal marine assemblages is not observed within the Francis Creek Member, partly owing to lack of exposure, but also for taphonomic reasons; soft-bodied organisms are not preserved in intermediate delta-margin and non-deltaic facies due to slower sedimentation rates and consequent effects of aerobic decay and bioturbation. Only in thin, offshore shelf facies near Peoria in northwestern Illinois are body fossils observed to 'reappear'. This latter, non-concretionary fauna includes chonetid and productid brachiopods, nuculid and pterid bivalves, fenestrate bryozoans, gastropods, cephalopods, and pelmatozoans (Shabica 1970, 1971).

An intermediate though chronologically younger assemblage (Danville fauna) is observed in thick, grey mudstone facies of the Farmington Shale Member above the Danville (no. 7) Coal Member at Danville in east-central Illinois (figure 1); as in the Francis Creek Member, fossils occur in sideritic concretions but the nodules contain a mixture of Essex-type organisms and normal marine taxa. Concretions yield occasional plant fossils, *Palaeoxyris*, and partly articulated holothurians. However, articulate brachiopods including rhynchonellids, and productids occur sparingly and both protobranch and pectinid bivalves are common locally. Notably lacking are the soft-bodied medusae, polychaetes, and crustaceans. Conversely, what is conspicuously present is a rich and varied suite of lebensspuren; complex three-dimensionally preserved networks of *Chondrites* are abundant, as are *Planolites* and microburrow networks

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resembling nematode traces (Baird *et al.* 1985). Burrows filled with pellets similar to those associated with the Essex echiuroid *Coprinoscolex* are particularly common.

The Danville fauna, though tantalizing, is meagre compared with the well-preserved Essex assemblages. The taphonomic overprint is not surprising owing to the inferred offshore position of this association relative to the Essex habitat; probably most deposits recording the Danville environment yield only lebensspuren due to slow deposition rates and effects of decay. It is believed that a well-preserved Danville-type fauna would require rapid burial of organisms living farther away from distributaries than Essex taxa; discovery of Danville-type Konservat Lagerstätten is deemed possible, but it would be very extraordinary.

6. Recurrent Mazon Creek-type biotas: U.S. midcontinent region

(*a*) *Braidwood- and Essex-type fossils, Windsor, Missouri*

An unnamed shale member above the Croweburg Coal near Windsor, Henry County in west-central Missouri has produced sideritic concretions yielding both Essex- and Braidwood-type animals as well as plants (figure 1). This unit comprises the lowest part of the Verdegris Formation (Howe & Koenig 1961) and the underlying coal is believed to be stratigraphically equivalent to the Colchester Member (Wright 1965). Moreover, the shale is a local clastic wedge deposit analogous to Francis Creek; it exceeds 13 m where it fills a local depression on the coal surface. Fossiliferous concretions are restricted to this thicker trough facies; these are exposed on abandoned strip mine dumps where locally thick coal was mined in the trough.

A diverse assortment of Essex animals includes the rhizostome medusoid *Essexella*, polychaetes (figure 2, plate 1), and the eocarid shrimp *Belotelson* (figure 3). As at pit 11, many *Essexella* display attached clusters of the gastropod *Strobeus*, the latter taxon being interpreted as a possible jellyfish predator (Foster 1979). Two other organisms that are locally abundant include the bivalve *Edmondia* (figure 4) and a holothurian; these both are indistinguishable from those found at Mazon Creek area localities. Notably significant are occurrences of rare Essex taxa. Several articulated chitons (figure 5) were found including one specimen which displays both the radula and spicules along the girdle margin. In addition, individuals of *Esconichthys*, an agnathan vertebrate, and *Rhabdoderma*, a coelocanth, were obtained.

Adjacent to the area of Essex animal occurrence is a 3–5 km^2 region characterized by Braidwood animals and abundant plants. Plant organs and fragments greatly predominate,

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Description of plate 1

Figure 2. Unidentified polychaete with everted proboscis. MCP 268; MCP, Northeastern Illinois University Mazon Creek palaeontology collection. Unnamed shale unit above Croweburg Coal Member, Windsor area, Henry Co., Missouri (magn. ×1.7).

Figure 3. Eocarid shrimp *Belotelson magister*. MCP 253. Unnamed shale unit above Croweburg Coal Member, Windsor area, Henry Co., Missouri (magn. ×1.7).

Figure 4. Bivalve *Edmondia* sp. MCP 249. Unnamed shale unit above Croweburg Coal Member, Windsor area, Henry Co., Missouri (magn. ×1.4).

Figure 5. Polyplacophoran *Pterochiton*. MCP 263. Unnamed shale unit above Croweburg Coal Member, Windsor area, Henry Co., Missouri (magn. ×1.3).

Figure 6. Protorthoptera (insect). Note branchiopod *Leaia* in upper right. PE 30369; PE, Field Museum invertebrate paleontology collection. Energy Shale Member. Little Vermilion River locality near Georgetown, Vermilion Co., Illinois (magn. ×2.5).

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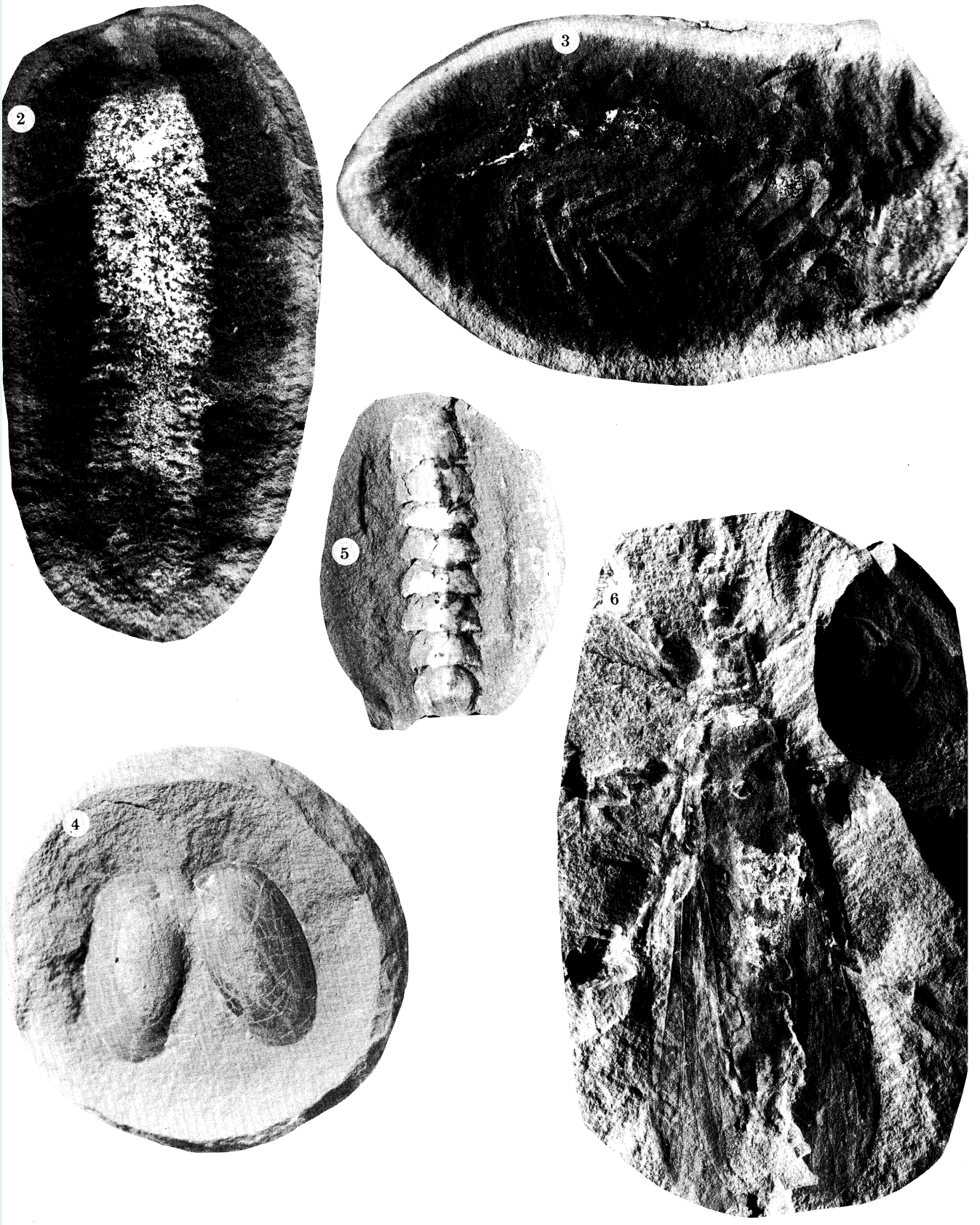

FIGURES 2–6. For description see opposite.

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with occasional occurrences of *Euproops*, syncarid shrimps, ostracodes, and *Palaeoxyris*. Thus, it is of particular significance that not only are Braidwood- and Essex-type associations identified, but that they occur in adjacent but separate areas in a pattern identical to that observed in the Mazon Creek area (Baird *et al.* 1985). Furthermore, taphonomic aspects of samples from this region are likewise identical to those at Mazon Creek.

(*b*) *Braidwood-type fauna, Henryetta and Morris, Oklahoma*

Sideritic concretions containing Braidwood-type animals and plants occur in the lower part of an unnamed mudstone–siltstone division of the Senora Formation above the Croweburg Coal in Okmulgee County in eastern Oklahoma (figure 1). As with the Windsor-area deposit, this unit is both temporally equivalent to the Francis Creek in Illinois (Wright 1965) and analogous to it as a lobate deltaic unit containing distributary and bay-fill facies.

Mine spoils both at Henryetta and nearby at Morris yield a fauna characteristic of the Braidwood association though of lower diversity and with different proportions of common taxa. *Septimyalina*, the most common animal, is the only taxon to suggest the presence of minimally saline water; it occurs along the boundary between Braidwood and Essex areas in the Mazon Creek area. These occur with small bivalves resembling non-marine forms. Branchiopods sometimes occur in clusters within concretions; both these and bivalves commonly occur broken and jumbled as hash in coprolites indicating predation. One of the most common elements is *Palaeoxyris*, the problematic structure most recently interpreted as a chondrichthyian egg case (McGhee 1984). Although not collected by the authors, rare forms including insects and arachnids were obtained from Henryetta mine dumps by the late Dr E. N. Kjellesvig-Waering.

(*c*) *Braidwood-type fauna and flora, Sallisaw, Oklahoma*

Concretions yielding abundant plants and both freshwater and terrestrial animals are found to occur in dark grey mudstone deposits above the Stigler Coal at Sallisaw, Sequoyah County, in eastern Oklahoma (figure 1). The mudstone unit is located in the McAlester Formation (Cabaniss Group) near the base of the Desmoinesian series (Friedman 1974), and it corresponds in age to Westphalian C (Harland *et al.* 1982).

Fossils obtained from abandoned strip mines in this area include an association of forms common to many Mazon Creek area non-marine localities. Animals included *Euproops*, freshwater bivalves, syncarid shrimps, millepedes, and *Palaeoxyris*. Several insects and arachnids have also been found by local collectors. All taxa are non-marine with the sole exception of one specimen of *Aviculopecten*. Plants are diverse and well preserved; these include several varieties not observed in the Francis Creek Shale.

(*d*) *Braidwood fauna and flora, Georgetown, Illinois*

Large concretions yielding plants and a non-marine fauna occur in the basal 1–5 m of the Energy Shale Member near Georgetown in Vermilion County, east-central Illinois (figure 1). This shale unit occurs above the Herrin (no. 6) Coal Member which is Westphalian D in age (Phillips & Dimichele 1981), and it is exposed in banks of the Little Vermilion River and Yankee Run. Concretions occur in grey silty mudstone which is faintly laminar; the member coarsens upward to sandstone above the interval of concretion occurrence. The Energy Member is interpreted as a lacustrine delta deposit which attains a maximum thickness of 33 m in southern Vermilion County (Jacobson *et al.* 1980).

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Although the flora at the Vermilion River and Yankee branch localities is similar to that observed in various other non-marine localities, the fauna contains exceptionally large proportions of several taxa that are uncommon in the Mazon Creek area. *Palaeoxyris* and the branchiopod *Leaia* (figure 6) greatly dominate the fauna to the complete exclusion of typical Braidwood animals. Hundreds of *Palaeoxyris* were collected; this taxon, comprising less than 1 % of Mazon Creek area samples, accounts for 78 % of all fossils recovered from the Yankee Branch locality. Rare flying insects (figure 6) were the only other animals observed, there being no other aquatic forms except vertebrates which produced coprolites. Energy Shale dumps around underground mines northwest of Georgetown interestingly yield *Euproops*, syncarid shrimps, non-marine bivalves, and a near-absence of *Palaeoxyris*; this latter assemblage is essentially indistinguishable from the typical Braidwood fauna of the Mazon Creek area.

As anticipated, these new occurrences of Braidwood animals show an unvarying close association with abundant plants. Likewise the Missouri Essex-type fauna is associated with a poorly preserved, sparse flora and soft-sediment lebensspuren. The Braidwood fauna, however, is found to be quite variable in terms of relative abundance of aquatic animal species both within and between localities as exemplified by the striking local abundance of *Palaeoxyris* and branchiopods in the Energy Member. This variability, also observed in census samples from Mazon Creek area non-marine localities (Baird *et al.* 1985), shows that the Braidwood fauna is generally low in diversity and regionally variable as to dominant taxa present. This pattern indicates that non-marine habitats were spatially and temporally variable reflecting a myriad of local conditions and short-term events.

7. Predictive facies model for recurrence of concretion biotas

Calver (1968) described several communities from the Westphalian of northern England. He recognized in seaward order: estheriid, *Planolites*, foraminiferal, *Lingula*, myalinid, and productid associations as representing a common non-marine to fully marine assemblage spectrum. One of these groupings (estheriid) is largely non-marine and roughly corresponds to part of what we call the Braidwood fauna. Calver's myalinid association, yielding *Edmondia*, *Myalina*, and small gastropods, may be the hard-part record of Essex or very similar faunas. His recognition of the myalinid association at several stratigraphic levels suggested that Essex-type faunas, though infrequently preserved as Konservat-Lagerstätten, were pervasive in Westphalian nearshore environments.

Sideritic concretions yielding plants, Braidwood animals, or the Essex fauna are commonest within thick portions of lobate deltaic–prodeltaic deposits which are juxtaposed on coals (figure 7*a*). Our studies show that the biofacies distribution within these deposits is ideally spatially radial with associations distributed in belts roughly parallel to isopach contours (figure 7*b*). Distal prodeltaic muds, seaward of the Essex belt yield the Danville fauna where burial was more rapid, but mainly lebensspuren where bioturbation predominated.

These lobate units are the expression of distributary progradation with attendant effects of overbank flooding, crevasse splays, channel avulsion, and bay-fill sedimentation (see Shabica (1971), Elliott (1974) and Fielding (1984) for discussion of Pennsylvanian distributary facies and depositional models). It appears that distributary progradation and bay-fill sedimentation timed with transgressive inundation of the peat swamp provided ideal conditions for entrapment, burial, and preservation of organisms. Distributaries prograding at such time presumably had

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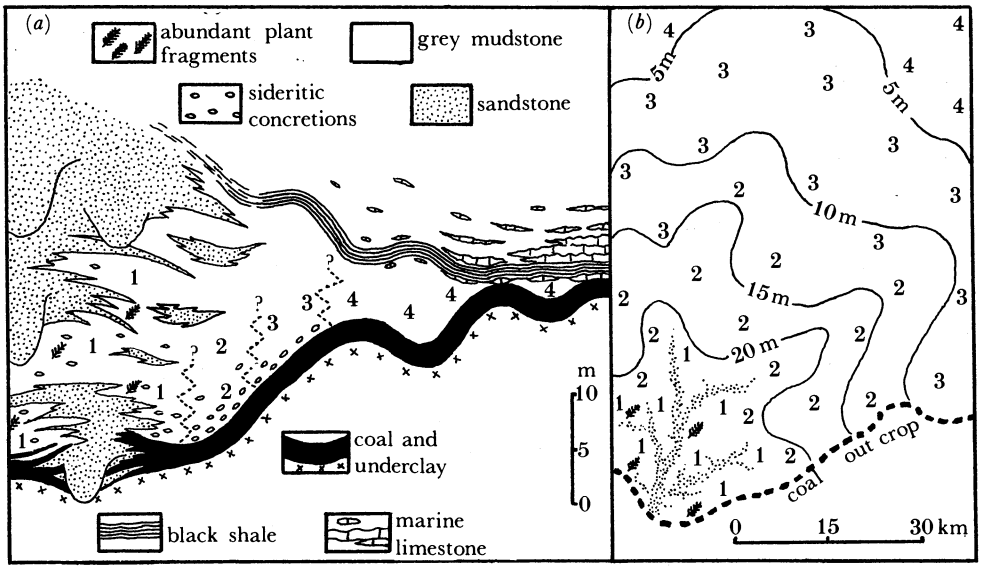

FIGURE 7. Predictive model for occurrence of Mazon Creek-type fossils in Pennsylvanian cyclic deposits. (*a*) Idealized fossil distribution within lobate distributary complex above coal. Note that biofacies distribution in upper part of wedge is unknown due to absence of fossils. (*b*) Schematic isopachous map of same lobe showing most plausible biofacies configuration. Units include: 1, Braidwood Fauna; 2, Essex Fauna; 3, Danville Fauna or shale with lebensspuren only; 4, normal–marine shelly fauna. Lateral scale same for (*a*) and (*b*).

to aggrade and maintain levées in the face of rising base level and effects of load-induced subsidence. Channel diversions and major crevasse events would have been more frequent during transgressions than during sea-level regressions or still-stands with a consequent increase in mass burial events. Much U.S. coal exploration is currently directed to occurrences of Pennsylvanian low-sulphur coal; because such coals often occur beneath lobate, deltaic deposits (Allgaier & Hopkins 1975), exposure of new concretion localities is anticipated through mining.

8. TEMPORAL SIGNIFICANCE OF MAZON CREEK-TYPE FOSSIL ASSEMBLAGES

Schram (1979) argues convincingly, from systematic study of organisms from the Mississippian Glencartholm and Bear Gulch biotas, the Mazon Creek locality, and from younger occurrences, that Mazon Creek organisms, particularly those of the Essex fauna, comprised stable associations which persisted throughout the Carboniferous. Hence, there is a predictive phylogenetic and ecological continuum into which Mazon Creek-type communities can be placed; although unusually fine preservation of these groupings is undoubtedly spotty in the rock record, their recurrence at several stratigraphic levels suggests that these associations are important, long-ranging biofacies.

Proof that Essex-type faunas are temporally persistent is shown by discovery of a diverse biota in the medial Triassic Grés-à-Voltzia deltaic deposits in Alsace (see Gall 1971, 1983); these localities yield a rich terrestrial biota of plants, insects, diplopods, arachnids, and tetrapods many of which accumulated secondarily in ponds and waterways.

Autochthonous aquatic marine animals include medusae, the brachiopod *Lingula*, eunicid polychaetes, decapod and isopod crustaceans, estheriids, euthycarcinoid arthropods, limulids, small bivalves, vertebrates, and problematica, including the form *Palaeoxyris* (McGhee 1982).

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Although these fossils are preserved as impressions in shale rather than in concretions, the overall association closely resembles that from the Mazon Creek area having components from terrestrial and schizohaline aquatic sources.

Grés-à-Voltzia fossils show evidence of seasonal mass-mortality in restricted water areas (ponds, waterways) on the delta which fluctuated cyclically from brackish to hypersaline in a subtropical setting (Gall 1983). Although the specific pattern of seasonal drying-up of ephemeral water habitats on the delta plain, invoked to explain death and preservation of these fossils (Gall 1983), differs from the subtidal burial settings envisioned for the Essex fauna (Baird *et al.* 1985), both environments are described as estuarine in character and changeable.

The association of both the Pennsylvanian and Triassic faunas with a similar inferred palaeoenvironment shows that the mutual resemblance of these assemblages is no mere coincidence. The Grés-à-Voltzia biota indicates that Essex or very similar associations apparently span the late Palaeozoic and into the early Mesozoic without dramatic changes. Essex-type faunas were clearly characteristic of certain unstable, high-stress, marginal marine environments through this interval, and such fossils should be present at numerous stratigraphic levels in the intervening Permian. Detailed study of temporal ecological replacement in these associations and examination of spatial palaeoenvironmental gradients within them remains to be done; such work will provide important information concerning the evolution of late Palaeozoic peri-deltaic and estuarine communities relative to their offshore shelf counterparts.

9. Conclusions

The terrestrial and freshwater Braidwood association and the eurytopic estuarine marine Essex fauna are found to occur at several new localities in the U.S. midcontinent region. The Braidwood fauna, found in stratigraphic units both older and younger than the classic Mazon Creek locality, is spatially variable in taxonomic composition; differences in dominant taxa and diversity of the aquatic part of the association is believed to reflect varying levels of stress in habitats and degree of connection between these waters and brackish or marine areas. The Essex fauna is reported from a new locality in Missouri; sediments yielding these fossils are stratigraphically coeval to and analogous with Mazon Creek area deposits.

Deltaic deposits occurring above coal units and within the transgressive parts of sedimentary cycles are the facies most closely associated with Mazon Creek-type fossil localities in the Pennsylvanian. This reflects the effect of increased channel-switching during base-level rise with resulting mass-mortality and burial events associated with avulsion.

Mazon Creek biofacies, including both Braidwood- and Essex-type associations comprise an important part of the larger suite of nearshore fossil assemblages in the Pennsylvanian and are believed to recur widely. Moreover, general resemblance of the Essex fauna to the Triassic estuarine–deltaic Grés-à-Voltzia aquatic fauna, independently described in France, suggests that Essex-type faunas persisted for at least 75 million years and that numerous localities of intervening age remain undiscovered or unstudied.

The authors are grateful to Carlton E. Brett of the University of Rochester for reviewing this paper and providing helpful criticism during its preparation. Gilles Pacaud and his colleagues were kind enough to show one of us (Baird) the progress of palaeoecological studies at the Montceau-les-Mines locality. Sam Friedman of the Oklahoma Geological Survey provided

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useful information on Oklahoma coal geology. Laurie Burnham supplied prints of the Energy Shale insect. This project was partly funded by National Science Foundation Grant no. EAR 257029. Theresa Dispenza typed various copies of the manuscript during its preparation.

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Discussion

A. C. Scott (*Department of Geology, Chelsea College, 552 King's Road, London SW10 0UA, U.K.*). While exceptional preservation of animals is widely reported within the Mazon Creek nodules the preservation of plants is only rarely discussed(but see Schopf 1979). The plants have also undergone rapid diagenesis so that complete compression has not taken place. While most specimens represent compression–impression fossils some are also partly permineralized and show some anatomical preservation. Fertile material has yielded beautiful three-dimensionally preserved spores (Pfefferkorn *et al.* 1971). The cuticle, however, is often absent but latex replicas of impressions often yield fine details probably due to the occurrence of a fine grained iron film which was biologically deposited on the plant surface while floating to the site of deposition (Spicer 1977). Kaolinite is widely found with such nodules at Mazon Creek and elsewhere but its origin is uncertain.

Such nodules are abundant at many levels throughout the late Carboniferous of Euramerica and represent an important (yet not fully utilized) source of data on terrestrial Lagerstätten.

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F. M. Broadhurst (*Department of Geology, The University, Manchester M13 9PL, U.K.*). I am working in collaboration with B. G. Woodland (Field Museum, Chicago) on the extent and significance of possible tidal sedimentation in the Francis Creek Shale from the evidence of its siderite concretions. Borehole cores from the Francis Creek Shale, with rhythmically bedded siltstones and mudrock couplets suggestive of tidal sedimentation (predominantly diurnal tides and spring-neap cycles), have already been studied by Kuecher (1983), who has a paper in course of preparation. We have recognized the presence of identical mudrock couplets and rhythms in siderite concretions directly associated with Mazon Creek fossils, in some cases of Braidwood (non-marine) facies, in other cases of Essex (marine and non-marine) facies.

Provided that the mudrock couplets indicate sedimentation at times of tidal slacks (high water, low water) then the environment must have been subtidal. The association of this environment with the Braidwood fossils (non-marine) would then indicate that fresh (river?) water was present, on occasion, below the low water tidal level. This suggests that the upper reaches of tidal channels (distributary or estuary) were occupied by freshwater. A modern analogue to the Francis Creek Shale environment of deposition is being sought.

Assuming that the mudrock couplets and rhythmic bedding of the Francis Creek Shale are indicative of predominantly diurnal tidal sedimentation then the rate of accumulation of the sediment was rapid, of the order of 1 m per year. The unique preservation of the Mazon Creek biota is then explained by rapid burial of organisms. Presumably they were smothered by sediment and rapidly removed from contact with the overlying (oxygenated) water. The early

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development of siderite concretions around the Mazon Creek organisms (Woodland & Stenstrom 1979) is of special significance in connection with the environment of preservation. The work of Pye (1984) on presently forming siderite concretions is of great interest in that it highlights an associated high rate of sedimentation.

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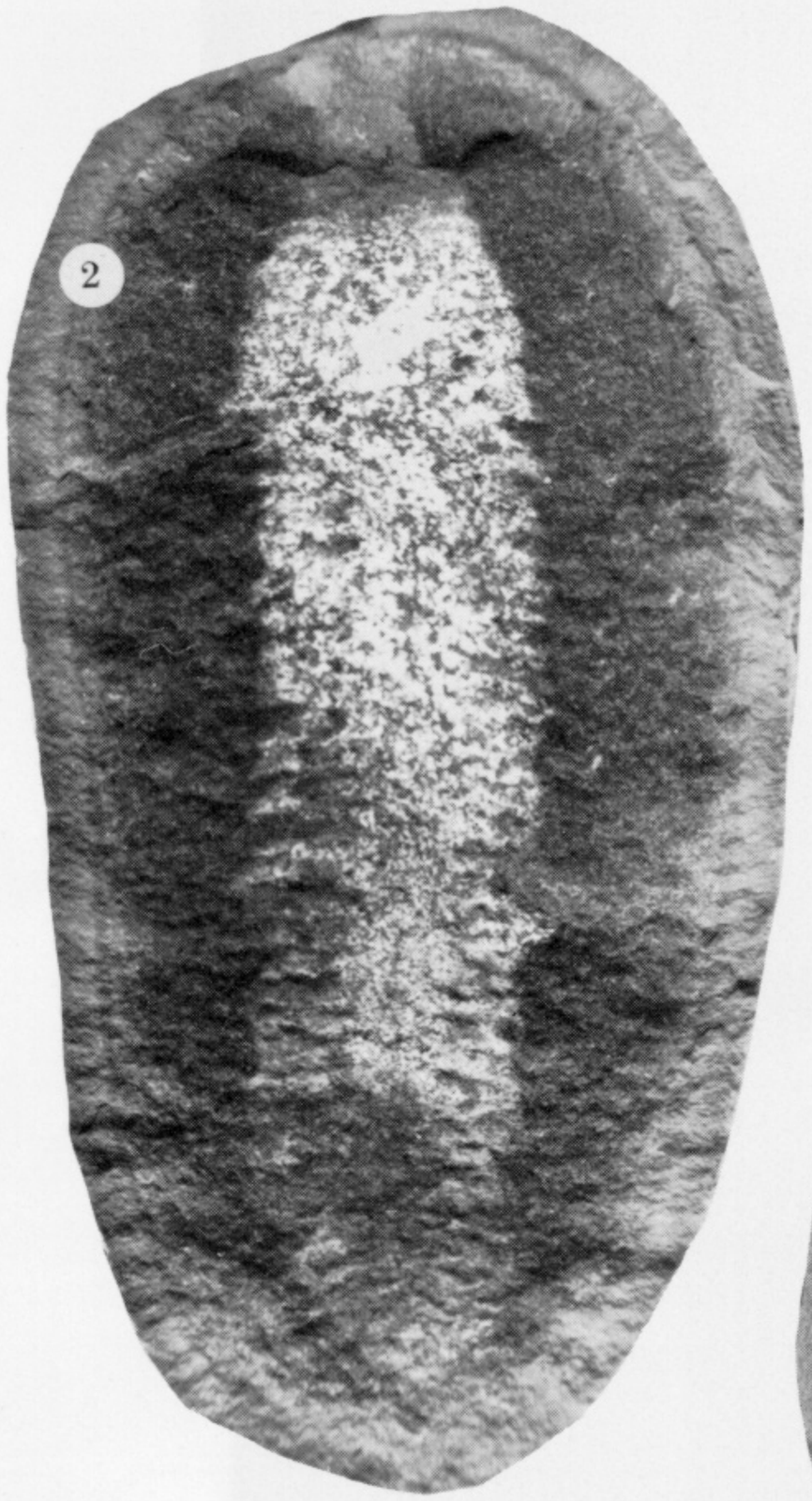

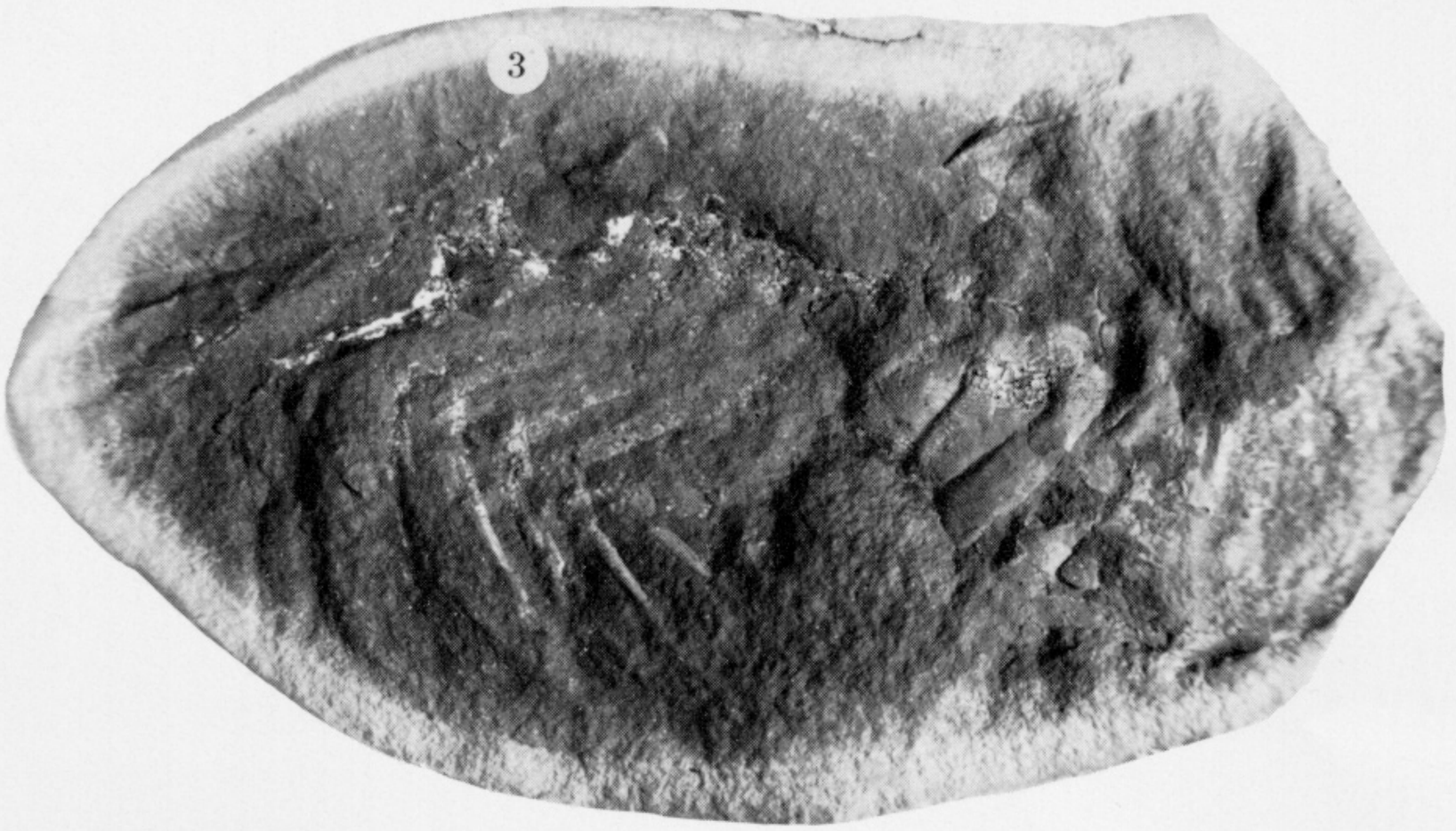

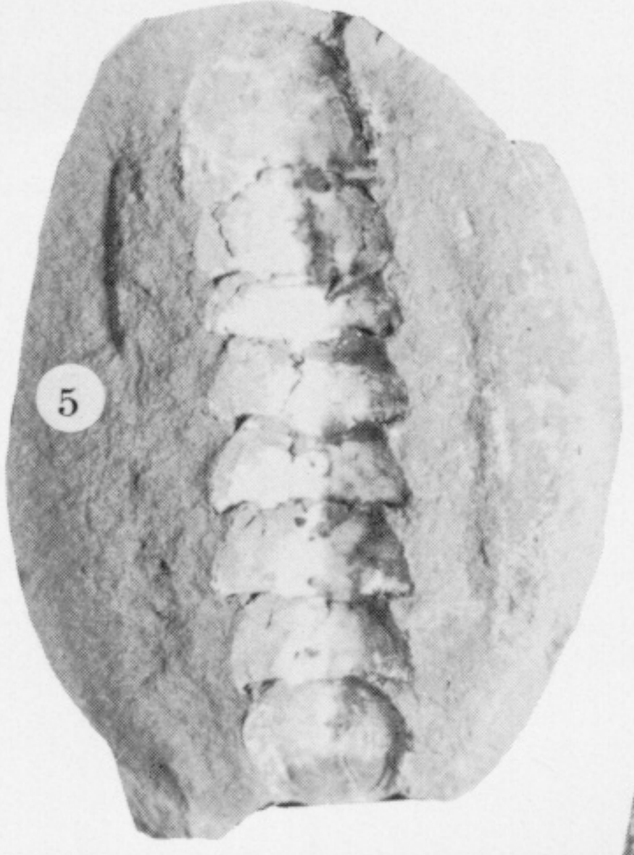

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FIGURES 2–6. For description see opposite.