Small-Scale Spatial Heterogeneity in Pennsylvanian-Age Vegetation from the Roof Shale of the Springfield Coal (Illinois Basin)

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An underground mine in southern Illinois exposes the spatial composition of the final forest of the Springfield (No. 5) Coal swamp. The area studied is within 600 m of the Galatia channel, contemporaneous deposits that mark the course of a river that periodically flooded the surface of the adjacent peat-forming forest. A nearly pure stand of Sigillaria mamillaris *is flanked on the south, the side farthest from the channel, by a pteridosperm-calamite vegetation from which* Sigillaria *is absent. The ecotonal contact of these two assemblages may be as narrow as 2 m wide. On the north end, the side closest to the channel, the* Sigillaria *stand grades over a 40 m wide ecotone into a mixed lycopod-calamite vegetation with minor pteridosperms. Tree ferns and ground cover are nearly absent from all assemblages. This exposure provides a rare look at the short-term spatial heterogeneity of a Pennsylvanian-age peat-forming forest, and reveals an unexpected degree of patchiness, which is not demonstrable from most outcrop or coal-ball exposures.*

INTRODUCTION

Modern tropical forests display an enormous range of heterogeneity in tree composition, from nearly monotypic stands spread over many hectares to the tens of species per hectare typical of many lowland rain forests. The factors controlling this heterogeneity are complex, but the physical habitat appears to play a large part. This clearly is true where dramatic edaphic differences occur over short distances, such as at the contact between periodically flooded and nonflooded areas. Plants of the geological past appear to have responded to variation in the environment in ways similar to those we see today, suggested by lithofacies specificity of many species and marked differences between plants of peat-forming and non-peat-forming environments (e.g., Scott, 1978; DiMichele, Phillips and Peppers, 1985; Gastaldo, 1987b; Wnuk and Pfefferkorn, 1987; Spicer and Hill, 1979; Hickey and Doyle, 1977; Wing, 1984; Burnham, 1987; DiMichele and Phillips, 1988). Understanding the details of such variability in ancient communities is important in the search for ecological generalities that apply to past as well as modern biotas, and if paleoecological comparisons are to be drawn between different times and places.

The fragmentation and transport of plants prior to burial and especially the limited areal exposure offered by most outcrops severely limit our abilities to interpret the spatial distribution of plants in ancient landscapes. Opportunities do exist, however, particularly in the artificial exposures created by coal mining. Recently, several studies of two dimensional exposures of *in situ* Pennsylvanian-age plant communities have appeared (Wnuk and Pfefferkorn, 1987; DiMichele and DeMaris, 1987; Gastaldo, 1986, 1987b), suggesting a range of community organization, from monotypic stands to mixed stands varying in composition along an environmental gradient from swamp to levee. In this report we describe the nature of the contacts of a nearly pure stand of the lycophyte tree *Sigillaria* cf. *mamillaris* with vegetation dominated either by pteridosperms and calamites, or by mixed lycopods, calamites, and pteridosperms, within an area of 25,000 m^2. This occurrence, exposed in the roof of an underground mine, demonstrates both a sharp ecotonal contact (approximately 2 m wide) and a gradational contact (> 40 m wide). It is within 600 m of a river channel contemporaneous with peat formation, and suggests that this coal swamp was marked by considerable areal patchiness. This patchiness probably was a response to microtopographic variation in the peat swamp.

GEOLOGICAL SETTING

Plant fossils were exposed in the roof of the Springfield (No. 5) Coal Member in the AMAX Coal Company Wabash Mine, Wabash County, Illinois (7-1/2 Keensburg Quad. Sec. 9, T. 2 S., R. 13 W.). The coal in this area is overlain by a gray shale roof (Dykersburg Shale Member) and is split locally by gray shale partings. These shales represent freshwater overbank flood or splay deposits from the Galatia channel (Hopkins et al., 1979), part of a larger complex of such channels in southern Indiana and Illinois (Eggert, 1982). The study area is approximately 600 m from a no-coal area of sandstones and shales deposited in the Galatia channel. Over most of the Illinois Basin, away from the Galatia channel, the Springfield Coal is overlain by the marine, black, fissile Turner Mine Shale Member and/or the marine St. David Limestone Member. These rocks onlap the Dykersburg Shale, which is present only in the vicinity of paleochannels.

The Dykersburg Shale exposed in the study area is medium dark gray and silty, between 30 cm and 40 cm thick, and planar to ripple-laminated. This suggests deposition in shallow, relatively quiet water.

The plant fossils in the gray shale appear to be an *in situ* accumulation derived from the final forest of the peat swamp. This contention is supported by the following observations. There is no rooting in the roof shale, indicating no colonization by plants after the onset of deposition of clastics. Scattered tree stumps appear to be *in situ* and in

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contact with the top of the coal seam. Most of the plant fossils are horizontal axis fragments, trunks, and leaf parts, compressed flat, and criss-crossing in a disordered manner. The fossils are not sorted by size, they show no preferential orientation, and there are distinct patterns of association among constituent taxa. Flooding from the channel probably drowned the swamp forest and formed standing bodies of water along the channel margin. An analogy may be the lakes containing drowned forests flanking channels in the Orinoco Delta, described by Scheihing and Pfefferkorn (1984). In the case of the Dykersburg Shale, such flooding was not merely seasonal, but appears to have been associated with long-term inundation, brought on by delta platform subsidence or rising sea level.

The great size range of plant debris preserved throughout the study area, the lack of preferential orientation of axes, and the mostly planar lamination in the roof shale suggest that plant debris was autochthonous to hypautochthonous (sensu Gastaldo, 1987a). Thus the original taxonomic composition and physical distribution of plants in the final swamp forest are reflected in the roof shale flora. Assemblages very similar to those described here occur in coal balls from the Wabash Mine (Eggert et al., 1983). This further suggests that this particular roof-shale flora represents a kind of assemblage that existed within the larger peat-forming vegetation of the Springfield coal swamp.

PLANT DISTRIBUTION

Core Area

The study area and distribution of major floristic units are shown in Figure 1. The core area is 7,000 m^2 as mapped, with the eastern limits not exposed. It is dominated almost exclusively by *Sigillaria* cf. *mamillaris*, as trunks, branches, and occasional upright stumps. The largest stumps observed are approximately 1 m in diameter. Trunks are as wide as 60 cm and as long as 12.7 m, with neither end exposed. *Sigillaria* branches as small as 10 cm wide are intermixed with trunks, as are leaves of lycophytes and unidentifiable organic detritus. These remains are layered densely in the lower 30–40 cm of shale without preferred orientation. Only one non-sigillarian tree trunk was identified in the core area, a trunk fragment of *Lepidodendron aculeatum* that was 14 cm in diameter. Thus, we interpret this to have been a nearly pure stand of relatively large *S.* cf. *mamillaris* trees.

Narrow Ecotone

The southern edge of the core area is marked by an abrupt contact between the *Sigillaria* cf. *mamillaris* stand and a mixed vegetation dominated by pteridosperms and calamites. The contact zone, or ecotone, was traceable for approximately 210 m, and was about 2 m wide. No detectable change in roof-shale lithology accompanied the abrupt floristic change. We cannot account for the lack of *Sigillaria* trunks crossing this contact in view of the fact that *Sigillaria* trees could be over 10 m tall. Considering that two kinds of very distinct vegetation were adjacent to each other, the ecotone could appear narrow because it was detectable best at the outer limit of *Sigillaria* tree falls. These falls may have masked the actual breadth of the contact zone, which was obscured and crossed by fallen trunks. Our observations in the mine do suggest a narrow contact zone. In any event, the compositional overlap of the two assemblages is minimal, indicating that the two vegetation types were segregated rather sharply on some basis.

The pteridosperm remains were largely leaf fragments, rachises, and petioles, comprising finely striated axes often showing the characteristic branching patterns of pteridosperm fronds. A few pteridosperm stems, up to 33 cm wide and bearing recurved leaf bases 6 cm wide, were found. Laminate foliage of any type was extremely rare. Where it occurred such foliage typically was in thin layers, consisted mostly of isolated pinnules or terminal rachis segments, and most closely resembled *Neuropteris parvifolia* (*sensu* Laveine, 1967). Other kinds of *Neuropteris* pinnules, not identifiable to a single species, also were present, suggesting that several species of pteridosperms made up this stand.

Calamites were assignable to *Calamites* cf. *suckowii*. Most of the calamite remains were pith casts, infilled with shale similar to that of the Dykersburg Shale roof, but with an organic rind. In some instances the outer rind appeared to be a compression of the outer surface of the plant. Basal segments of aerial stems, tapered to a point, were common. The largest axes were about 20 cm wide, but most of the calamite remains were relatively small axes, < 10 cm wide. These remains were totally intermixed with those of the pteridosperms in a dense organic accumulation, reflecting the relatively small size of the detritus produced by such plants.

Scattered lycopod tree trunks and upright stumps occurred within 30 m of the ecotone. Trunks were up to 60 cm wide, and stumps were up to 1 m in diameter. These were decorticated (lacking taxonomically characteristic bark patterns) but also lacked all evidence of ribbing or paired parichnos (aerating) strands typical of *Sigillaria*. They probably were trunks of *Lepidodendron* or *Diaphorodendron*. Noteworthy is the lack of any identifiable ground cover, such as *Sphenophyllum* or small ferns, and lack of tree-fern remains. This suggests periods of standing water in the area, sufficient to prevent the growth of ground cover and plants requiring extended periods of substrate exposure to reproduce, such as tree ferns.

Several hundred meters south of the ecotone, an area not shown in Figure 1, the plant detritus became more highly fragmented and contained remains of tree-fern stems (*Caulopteris*) and foliage (*Pecopteris* spp.), as well as pteridosperms, calamites, and lycopod trees. The gradual decline in quality of plant preservation occurs elsewhere in the mine away from the Galatia channel.

Broad Ecotone

The west and north sides of the core area have similar floristic characteristics. The ecotonal area widens along the west side toward the north. At its widest, on the north side, the transitional contact is over 40 m wide and has no clear northern limit. The floras to the east and west are dominated by pteridosperms with subordinate calamites. Lycopod trees, *Lepidodendron aculeatum* and *Diaphorodendron (Lepidodendron) rimosum* (*sensu* Wnuk, 1985), are progressively more abundant through the ecotone to the north.

Along the western edge, which is irregularly lobate, we also identified single fragmentary specimens of the tree-fern laminate foliage *Pecopteris* sp., and *Pecopteris (Senftenbergia) plumosa*, a possible ground-cover filicalean fern (Jennings and Eggert, 1972). Along the northeastern edge we identified one fragment of *Asolanus camptotaenia*, another lycopod tree.

The northern ecotonal contact contrasts sharply with that of the southern edge of the core area. Through 40 m it grades from almost entirely *Sigillaria*, to a mixture of *Sigillaria* and calamites with some pteridosperms, to increasing abundance and dominance of *Lepidodendron* and *Diaphorodendron*. As far as we were able to trace this broad zone, *Sigillaria* remained a decreasing but recognizable component of the flora, but other lycopod trees became the dominant elements. Thus, we found it impossible to mark a clear northern terminus to the transitional vegetation. In this flora calamites become second in abundance to lycopods, with pteridosperms third. Still notably absent are tree ferns and ground cover.

Other Areas of the Mine

Plant fossils occur in the roof shale throughout this mine and were mapped in three other areas, about 1,000 m to the east of the study area and within 900 m of the Galatia channel (no-coal area). Assemblages were variable, but the patterns observed in these other areas were not marked as clearly as in the main study area. In the first area plants were layered densely and the flora was dominated by a pteridosperm very similar to *Neuropteris dussarti* (Laveine, 1967). Lycopod trunks and upright stumps assignable to *Lepidodendron aculeatum* were common; *Sigillaria* sp. occurred rarely. In a second area *Sigillaria* sp. trunks and trunk fragments occurred in great density in a friable organic shale several centimeters thick between the top of the coal and a gray siltstone. No other plants were identified in the *Sigillaria* deposit. The gray shale included abundant calamites and stems of *Diaphorodendron (Lepidodendron) rimosum*, and rare *Lepidodendron aculeatum*. In this instance the lateral spatial pattern detected in the main study area is expressed in a vertical relationship; a *Sigillaria* assemblage is overlain by a lycopod-calamite stand similar to that north of the core area at the main study site. However, the incomplete and superposed nature of the exposures prevent estimation of the areal relationships of these additional assemblages. In the third area the flora was dominated by *Lepidodendron aculeatum*, both fallen trunks and upright stumps.

DISCUSSION

Small-scale patchiness of the coal-swamp flora, at least in the vicinity of a contemporaneous channel, is the most important finding of this study. This demonstrates that coal-swamp vegetation could be extremely heterogeneous, with assemblages of different dominance-diversity structure but overlapping taxonomic composition coexisting within relatively small areas. That zones of contact between these intraswamp assemblages could be gradational or abrupt probably reflects the distribution of abiotic conditions (habitat factors) within the swamp. In this instance, the areal coverage of the different assemblages, their juxtaposition, and the taxonomic composition (especially *Sigillaria*, *Lepidodendron aculeatum*, and *Calamites*, which are far more common in clastic than in coal-ball deposits) reflect the nearness of the contemporaneous channel. This channel probably created a more nutrient-rich environment than that found in the many parts of the swamp that rarely were flooded by stream water. In areas more distant from channels in other coals, *Lepidophloios* and *Psaronius* abundances were higher (Eble et al., 1985; Phillips and DiMichele, 1981; DiMichele and Phillips, 1988).

The existence of distinctive plant assemblages or "communities" in Pennsylvanian-age lowlands has been documented in numerous studies, both on levee and floodplain vegetation preserved in clastic rocks (see Scott, 1977, for review of the extensive literature; Pfefferkorn and Thomson, 1982; Gastaldo, 1987b), and on vegetation from peat swamps preserved in coal balls (Schopf, 1939; Phillips et al., 1977; Phillips et al., 1985). However, with rare exceptions (e.g., Gastaldo, 1987b), these workers had to infer the spatial relationships of distinct plant assemblages by looking for repeated patterns of taxonomic association based on isolated samples. An "average" of the many studies of Westphalian (Lower and Middle Pennsylvanian) lowland plants finds three major plant associations (Oshurkova, 1974, 1978; Scott, 1977): lycopod-dominated, calamite-dominated, and pteridosperm-dominated. Whereas such patterns of dominance may be recognizable in a very broad and general sense (e.g., Westphalian coal swamps are, if time averaged within and between coals, lycopod-dominated: Phillips et al., 1985), clearly there is a large degree of ecological overlap among species within these major plant groups. Real understanding of the ecology of Pennsylvanian plants will come from additional detailed studies of associations of genera and species, within the context of depositional environment.

The nearly total lack of tree ferns and ground-cover ferns and sphenopsids is unusual for floras associated with the generally tree-fern rich Springfield Coal (Peppers, *in* Eggert et al., 1983). This suggests prevalence of conditions throughout the study area that selected against plants requiring substrate exposure for growth or reproduction, most likely periodic or long-term flooding. Assemblages depauperate in ground cover have been documented in both the Herrin (No. 6) Coal and the Springfield Coal in Illinois and Indiana (Phillips and DiMichele, 1982; DiMichele and Phillips, 1988; Eggert et al., 1983).

The three assemblages in the main study area of the Wabash Mine are largely variations on the same floristic-taxonomic theme. They suggest a single complex of species, each with slightly different microhabitat preferences, too slight to be reflected in, or unrelated to, the sediments deposited on the peat surface. These tolerance differences lead to differing proportions

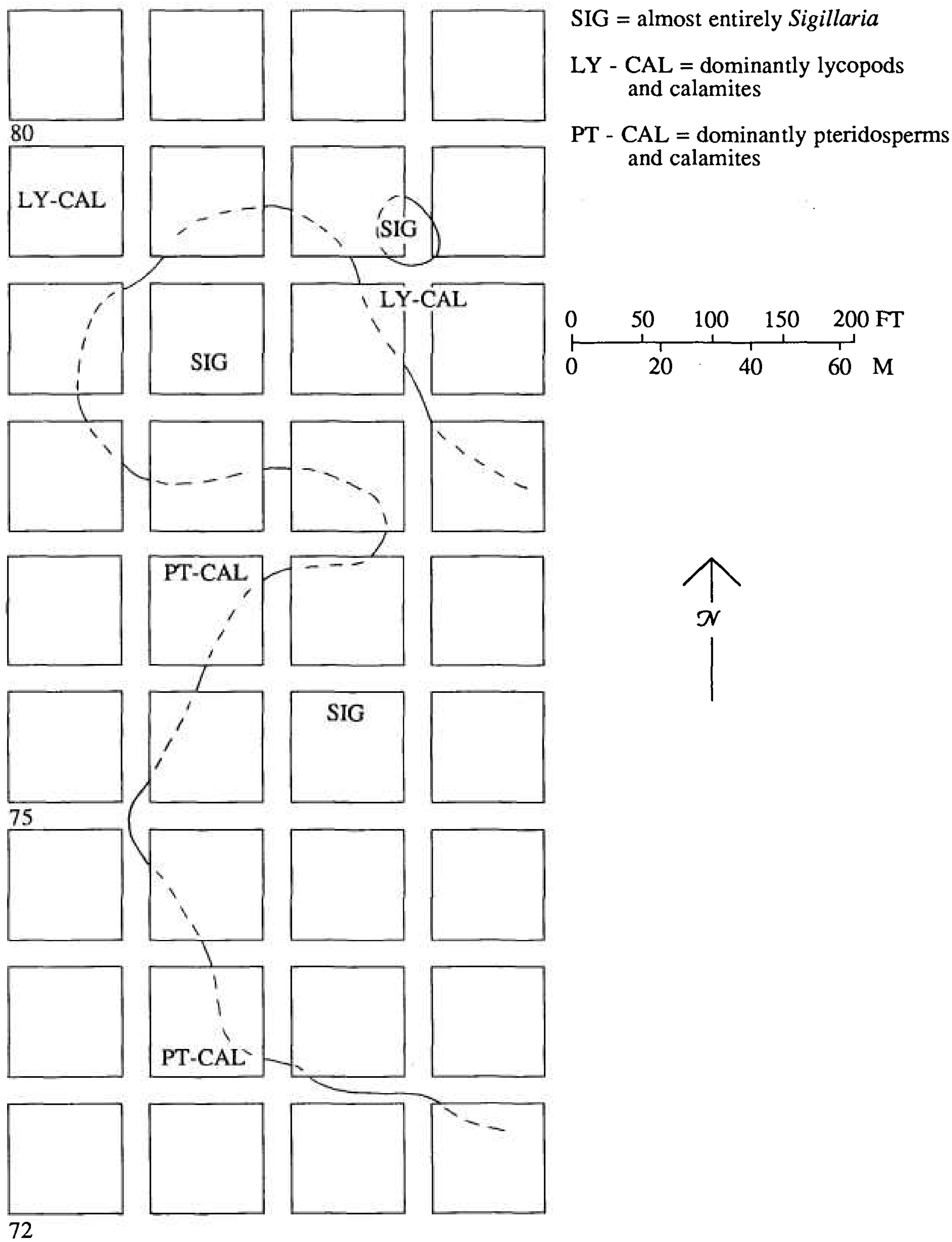

FIGURE 1—Map view of study area in AMAX Wabash Mine. Channel deposits lie to north of the plant exposures.

of species in a patchy array about the nearby channel. Sharp vs. gradational contacts most probably reflect differences in water depth or duration of standing water in a local area. However, details of the controls on specific aspects of this heterogeneity elude us at present, and may lie in aspects of species-level autecology that will prove most difficult to ascertain.

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