Appendix 1. Additional methodological details for palynological counts and ordination analyses.

**Table A2.** Palynomorph taxa and groups sorted by morphological categories as employed throughout this paper. Note the finer taxonomic divisions for PKHB-1 Count 1. Taxa in bold have been employed herein for regional palynostratigraphic correlation. Morphological categories are based on those of Traverse (2007). “Spp.” includes only other species not already listed.

**Table A3.** Abundance tables of palynomorph groups. All percentages are calculated as a proportion of the respective total palynomorph sample count (N). Average counts for PHKB-1 are calculated from the abundances of both counts 1 and 2. Dashes indicate samples included only in PHKB-1 Count 2. Palynomorph concentration per gram of dried sediment (C) derived by the following calculation (modified from Benninghoff, 1962):

\[ C = \frac{N \times L_t}{L \times M} , \]

where \( N \) = total palynomorph sample count, \( L_t \) = estimated *Lycopodium* spores per spiked sample (\( = 9666 \); standard deviation = 671; Maher, 1981), \( L \) = *Lycopodium* spores counted, and \( M \) = mass of processed dried sediment.

**Table A4.** Abundance tables of palynofacies groups. All percentages are calculated as a proportion of the respective palynofacies total, either category subtotal (n) or total palynofacies count (N = 500). Palyn = palynomorphs, phyto = phytoclasts, miospores = spores + pollen, - = samples in which *Lycopodium* spore tablets were not included during processing. PHKB-1 palynofacies data are from Fielding et al. (2019).

**Table A5.** Palynomorph categories for ordination analysis applied to all palynomorph count data. Categories employed in this study are numbered.

**Table A6.** Stable carbon isotope data for PKHB-1 and CCC-27. PHKB-1 data are from Fielding et al. (2019).

**Table A7.** List of specimens in Figs 7 and 8, including taxon authorities, sample numbers, slide numbers and England Finder coordinates (Eng. Find. coords); K = kerogen slide.
APPENDIX 1: ADDITIONAL METHODS and REFERENCES CITED

Palynology count methods

Of the 52 palynological samples from PHKB-1, we provide the full palynomorph count data sets of the 44 samples presented by Fielding et al. (2019), including additional data categories that were excluded from that study for brevity; taxa assigned to each taxonomic/morphological category are outlined in Appendix 2. Twenty-four of these samples were counted a second time by CM (‘Count 1’; the remaining specimen counts constitute ‘Count 2’; see Appendix 3) for the purpose of verifying the original results of Fielding et al. (2019). The remaining eight samples from PHKB-1 (S014107, S014111, S014112, S014115, S014121, S014122, S014123, S014149), and four samples from CCC-27 (S014165, S014168, S014169, S014171), were barren of palynomorphs, and excluded from the palynomorph counts. All palynomorph counts incorporated ≥250 individual specimens, except for six samples from PHKB-1 (S014097, S014099, S014100, S014105, S014116 and S014141) and three samples from CCC-27 (S014158, S014166, S014167), which failed to meet the prescribed specimen count. Full palynomorph count data are presented in Appendix 3.

Pollen diagrams of PHKB-1 (Figs. 3 and 4) were produced from a composite data set of counts 1 and 2; in samples where both count data were available, an average was calculated and used. Where only Count 2 data were available, these data were employed. Count 2 did not include monolete spores other than *Thymospora* spp. and zonate monolete spores (= *Aratrisporites* spp.). As such, all values of ‘other monolete spores’ for Count 2 were assigned to zero for the purposes of the pollen diagrams.

Kerogen slides of all 78 samples were produced for palynofacies analysis. Palynofacies data were compiled from counts of 500 individual grains (minimum grain diameter = 5 μm). The following palynofacies categories and subcategories were included in the counts (following the classification of Tyson, 1995): 1, palynomorphs ([a] plant spores, [b] pollen, [c] phytoplankton, [d] fungal remains); 2, phytoclasts ([e] opaque including charcoal, [f] tracheids/rays, [g] other translucent phytoclasts, [h] cuticles/membranous tissues); and 3, amorphous organic matter (AOM; [i] particulate, [j] resin). Full palynofacies count data are presented in Appendix 4.

To estimate productivity (a measure of absolute abundance) per sample, a standardized quantity of an exotic marker spore species was added to the samples during palynological processing (Stockmarr, 1971). For these estimates, selected samples were dried, weighed and one spore tablet of extant *Lycopodium clavatum* per sample was added prior to acidification (for specific samples and lycopodium counts, see appendices 3 and 4). Spore tablets were from Batch 3862, as prepared by the Department of Geology, Lund University (2014); estimated number of spores per tablet = 9,666 ± 6.94% (confidence estimations follow Maher, 1981). These extrinsic *Lycopodium* spores were counted in addition to the total counts for palynofacies and palynomorphs outlined above. By counting these standard markers in parallel with the palynological counts, we employed the relative changes in palynomorphs or palynofacies as a proxy of palynomorph production or total organic production, respectively, for a given time horizon. Specifically, there is an inverse relationship between the *Lycopodium* count and total palynomorphs/palynofacies count; hence, an interval of higher palynomorphs/palynofacies productivity should be reflected by a relatively low *Lycopodium* count. Fluvio-deltaic systems are characterized by variable depositional rates and hydraulic sorting of sediments, including palynomorphs and other organic matter (Brown et al., 2007). Thus, productivity estimates should
only be compared between assemblages from lithofacies of similar grain-size (e.g., claystone, siltstone, or fine sandstone), because these should reflect comparable flow conditions at the site of deposition. In order to control for this variable, siltstone and claystone facies were selected for palynological processing, reflecting minimal depositional transport (Folk, 1980), except where indicated in appendices 3 and 4. Palynomorph concentrations for each sample spiked with *Lycopodium* were calculated by employing the method outlined by Benninghoff (1962; see Appendix 3); however, owing to the low concentrations of counted *Lycopodium* spores, absolute palynomorph concentrations could not be determined reliably for most samples in PHKB-1.

**Ordination data treatment and indices**

For nMDS, the abundance data needed to be standardized across both well successions, and this was conducted in a series of stages. Firstly, within PHKB-1, Count 1 was selected where possible (because of the higher sample counts), and Count 2 data for the remaining samples in that well. Secondly, data categories shared by both successions could be compared without regrouping, whereas more finely-partitioned data required amalgamation into broader morphological categories (‘lumping’) which could then be compared across all count data sets. Thirdly, samples were excluded if they failed to meet the minimum palynomorphs count number of 250, including functionally barren samples (14 samples in total from PHKB-1, seven from CCC-27; see Appendix 3). Finally, palynomorph categories that were recorded from single samples (‘singletons’) were excluded in order to decrease statistical noise.

Ordination analyses were conducted on two versions of the compiled data: 1, relative abundance; and 2, presence/absence. Relative abundances were calculated as a proportion of the total count of each sample, thus standardizing for different count sizes. NMDS ordination analyses were conducted on these relative abundance data, and on two types of transformed fossil data sets: 1, a logarithmic function (e.g., Spicer and Hill, 1979; Slater and Wellman, 2015); and 2, a square root function. These transformations were performed to compress the abundance ranges, without altering their relative rank-orders. The Bray-Curtis similarity index was employed for all variants of the relative abundance data; this is algebraically equivalent to the Bray-Curtis dissimilarity index (Bray and Curtis, 1957). The combination of nMDS and Bray-Curtis index has been demonstrated to be a reliable ordination method for quantitative ecological data (Minchin, 1987). For the presence/absence ordination, all palynomorph group abundances were converted to binary, where the absence of a palynomorph group = 0, and presence = 1. The Jaccard index of similarity was chosen for the presence/absence ordination because it has consistently proven reliable for intergroup differences in binary ecological data (Hubálek, 1982). Ordination analysis was conducted on a binary variant of the data set because, although anomalously high taxon abundances can greatly influence the ordination of abundance data sets, binary data are immune to this effect. A comparison of presence/absence and relative abundance ordinations should reveal which samples are contributing inordinately to the dissimilarity between palynomorph assemblages. Furthermore, both ordination techniques were included in this study because temporal differentiation (biozones) was probably a major factor controlling the differences between assemblages, and these zones are defined partly on taxon acmes and partly on taxon first appearances. Relative abundance ordination is more relevant for differentiating the former, whereas presence/absence ordination should reveal the latter.
REFERENCES CITED


