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The sedimentary record of Carboniferous rivers: Continuing influence of land plant evolution on alluvial processes and Palaeozoic ecosystems

Neil S. Davies *, Martin R. Gibling

Department of Geology and Soil Science, Ghent University, Krijgslaan 281 s.8, B-9000 Ghent, Belgium

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Evidence from modern rivers and the deep-time geological record attests to the fundamental importance of plant life for the construction of physical habitats within fluvial environments. Data from an extensive literature review and original fieldwork demonstrates that many landforms and geomorphic features of modern river systems appear in the Palaeozoic stratigraphic record once terrestrial vegetation had adopted certain evolutionary advances. For example, stable point bars are associated with the onset of rooted plants in the Siluro-Devonian and avulsive and anabranching fluvial systems become common at the same time as extensive arborescent vegetation in the Carboniferous. In this paper, we demonstrate a correlation between the diversification of physical fluvial environments and the expansion of terrestrial fauna and flora, with an emphasis on the culmination of these trends within Carboniferous alluvial systems. Many extrinsic factors have been considered as possible controls on the evolutionary timelines of terrestrialization for organisms. However, a fundamental prerequisite for achieving terrestrial biodiversity was the variety of physical habitats, especially riparian systems, available for newly evolved organisms. In association with abundant lowland meandering systems, the widespread appearance across Carboniferous alluvial plains of fixed-channel and anabranching reaches created further physical landforms for colonization and would have promoted increasingly complex hyporheic flow regimes. Furthermore the associated increase in arborescent vegetation and supply of large woody debris to inland and coastal rivers would have created a wealth of microhabitats for continental organisms. We argue that the expanding extent and diversity of physical alluvial niches during the Palaeozoic is an underappreciated driver of the terrestrialization of early continental life. The study of the deep-time fossil and stratigraphic record also illustrates that vegetation is a fundamental prerequisite for the creation of biogeomorphic alluvial landforms and physical habitats and microhabitats.

Contents

* Corresponding author at: Department of Earth Sciences, Cambridge University, Downing Street, Cambridge, CB2 3EQ, United Kingdom. Tel.: +32 9264 4680; fax: +32 9264 4943.
E-mail address: nsd27@cam.ac.uk (N.S. Davies).

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1. Introduction

Recent research across a number of scientific disciplines has begun to identify fundamental feedback loops and mutual adjustments that exist between biological and physical processes within alluvial systems. Studies of alluvial geomorphology, sedimentology, ecology, palaeontology, and both analogue and numerical modelling have all yielded data that suggest intrinsic linkages between the physical processes and products of river systems and the ecological traits of the organisms, particularly plant life, that inhabit them (e.g., Corenblit et al., 2007; Fisher et al., 2007; Tal and Paola, 2007; Murray et al., 2008; Braudrick et al., 2009; Corenblit and Steiger, 2009; Francis et al., 2009; Corenblit et al., 2010, 2011; Collins et al., 2012; Rice et al., 2012). In a geological context, surveys of Cambrian through Devonian strata have demonstrated that alluvial facies exhibit a stepwise stratigraphic evolution that closely mirrors significant evolutionary developments in early land plants, as apparent in their fossil record (Davies and Gibling, 2010a, 2010b, 2011; Davies et al., 2011b). This review extends this survey of earlier Palaeozoic alluvial successions to the Carboniferous Period, an interval of 60 million years, and discusses geological evidence for biotic–abiotic feedback loops in Middle Palaeozoic riverine settings, through reference to modern analogues.

The Carboniferous Period is closely associated with its abundant and diverse vegetation, familiar from museum dioramas and textbook illustrations of “coal age” equatorial wetlands. Whilst the sedimentological changes promoted by ongoing plant evolution during the Cambrian to Devonian are readily apparent and quantifiable, Carboniferous changes are more subtle. The history of vegetation in Carboniferous alluvial landscapes is not one of the colonization of formerly barren landscapes by increasingly ubiquitous plant life, but one in which the early forests and plant communities that developed during the Devonian continued to diversify, encroach into new terrestrial ecospace, expand their areal extent, and operate on a global scale as mediators for climate. As these changes took place, many characteristics of modern river systems were enhanced or appeared for the first time: sediment transport changed dramatically as woody debris entered streams in significant quantities; large log-jam deposits appeared; avulsion frequency increased; a perennial anabranching fluvial style became possible; complex and sturdy rooting strategies increased the stability and promoted the aggradation of alluvial islands and banks; and, perhaps most importantly, new opportunities for colonization and evolution were presented by an explosion of available riparian habitats. This latter effect, which created new niche space within which flora and fauna could evolve and diversify, is arguably one of the most significant global changes induced by terrestrial plants as ecosystem engineers.

1.1. Evolutionary biogeomorphology of pre-Carboniferous rivers

The notion that river systems operating prior to the evolution of terrestrial vegetation were significantly different from modern systems was first propounded by Schumm (1968) in a discussion that centred on modern river systems with varying degrees of vegetation cover. This hypothesis was tested by Cotter (1978), who demonstrated a paucity of literature describing meandering alluvial facies prior to the Siluro-Devonian expansion of embryophytes. This notion of a different facies and planform style for pre-vegetation river systems subsequently found support from research on Precambrian river systems. Precambrian rivers were mainly wide gravel- and sandbed channels that experienced frequent high flow-strength conditions (Long, 2011) and their floodplains, where preserved, were poorly baffled and unbioturbated, resulting in well-laminated successions with ubiquitous soft-sediment deformation, intraformational rip-up clasts, and rippled sand horizons (Fralick and Zaniewski, 2011).

The Lower Palaeozoic record of the interaction between evolving land plants and alluvial systems has been discussed in detail by Davies and Gibling (2010a, 2010b), Davies et al. (2011b) and Gibling and Davies (2012). Through an analysis of published literature and original fieldwork, these studies identified characteristics of alluvial facies, the origination or rise in abundance of which were in close stratigraphic alliance with the macrofossil record of land plants. A summary of these advances is presented in Table 1, and the original references contain further details. The earlier Palaeozoic evolution of alluvial successions implies that there is arguably a greater difference between the alluvium of Cambrian rivers and their Devonian counterparts than between that of Devonian and modern rivers. Nonetheless, some significant vegetative features were only beginning to take hold by the latest Devonian, and this paper considers their effects on alluvial landscapes and sedimentation during the Carboniferous: a period of expanding forests, increasing arborescence, and, for the first time in Earth history, a widespread global coverage of diverse, climatically attuned flora.

2. Carboniferous fluvial database

The literature review conducted for this paper is a stratigraphic continuation of that presented in Davies and Gibling (2010a) and uses similar methods. In this previous study, the Cambrian through Devonian periods were divided into five ‘vegetation stages’, the boundaries of which correspond to significant evolutionary milestones in the embryophyte fossil record. Within this framework, 144 Cambrian–Devonian formations were grouped into vegetation stages. The presence or