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WHAT HAPPENED TO THE COAL FORESTS DURING PENNSYLVANIAN GLACIAL PHASES?

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ABSTRACT

Sequence stratigraphic analysis of Pennsylvanian coal-bearing strata suggests that glacial-interglacial fluctuations at high latitudes drove cyclic changes in tropical biomes. A literature review of plant assemblages in this paleoclimatic context suggests that coal forests dominated during humid interglacial phases, but were replaced by seasonally dry vegetation during glacial phases. After each glacial event, coal forests reassembled with largely the same species composition. This remarkable stasis implies that coal-forest refugia existed across the equatorial landscape during glacial phases, expanding to repopulate lowlands during and following deglaciation. One possibility is that refugia comprised small pockets of wetland forest strung out along valleys at some sites, but data are currently insufficient to test this hypothesis. The model presented here, if accepted, dramatically alters our understanding of the coal forests and helps explain aspects of their dynamics.

INTRODUCTION

Cyclic patterns of sedimentation in Pennsylvanian coal-bearing strata (cyclothems) have long been attributed to glacial-interglacial cycles (e.g., Wanless and Shepard, 1936). Although demonstrating a direct link with Gondwanan icecap dynamics (Fielding et al., 2008a, 2008b; Rygel et al., 2008) is beyond the resolution of present studies, the strongest evidence for glacioeustatic origin is the fact that cyclothems show evidence for coupled fluctuations in climate and sea level (Tandon and Gibling, 1994) within the Milankovitch band (Maynard and Leeder, 1992). These glacial-interglacial cycles profoundly affected Pennsylvanian tropical landscapes and vegetation as shown by fossil floras (Falcon-Lang, 2004) and computer simulations of paleoclimate (Poulsen et al., 2007).

The best-known Pennsylvanian tropical ecosystems were the so-called coal-swamp forests that formed widespread peatlands (now coal). Dominated at different times by lepidodendrids, cordaitaleans, and marrattialean tree ferns (e.g., Phillips et al., 1985), these communities are often referred to as coal forests. Sequence stratigraphic studies show that most coal forests were established during the glacial-to-interglacial transition and, to a more limited extent, during interglacial phases (Tandon and Gibling, 1994; Flint et al., 1995). Continent-wide peat (now coal) formation was triggered by a combination of climate change from seasonally dry (semiarid to subhumid) to ever-wet (humid to perhumid) and a coeval rise in sea level, which elevated the regional water table. Sea-level rise also created the initial accommodation space to preserve the resultant peats (Bohacs and Suter, 1997), which ultimately required the creation of tectonically generated accommodation space for long-term preservation. In marked contrast, successions that occur between coal-bearing intervals commonly include deeply developed paleosols with vertic and calcic characteristics, incised by paleovalleys. These are interpreted as the deposits of intervening glacial phases during which tropical climate was seasonally dry, and locally semiarid (Tandon and Gibling, 1994; Cecil et al., 2003).

Thus, the Pennsylvanian cyclothems of North America define a generalized climate framework of glacial-interglacial cycles. On the one hand, vertic and calcic paleosols locally incised by paleovalleys (Falling Stage and Lowstand Systems Tracts, FSST and LST) demonstrate that climate was seasonally dry when sea level was falling during the progression to glacial maxima (Gibling and Wightman, 1994; Tandon and Gibling, 1994; Feldman et al., 2005). On the other hand, overlying economic coal seams suggest a shift to ever-wet climate (Cecil et al., 2003). In addition, brackish-marine sediments of the Transgressive and Highstand System Tracts (TST and HST) suggest sea-level rise during deglaciaton (e.g., Hampson et al., 1999; Heckel, 2008; Fischbein et al., 2009; Falcon-Lang et al., 2009). This glacial-interglacial signature is, of course, complicated by local tectonics and sediment supply.

While we generally agree on this paleoclimate framework (Fig. 1), we disagree about the exact sequence stratigraphic position of economic coals. WAD's view is that Pennsylvanian coals with well-developed underclay paleosols dominantly comprise late LST deposits. They most often lie below the ravinement surface of a major transgressive marine unit (usually a marine black shale in the midcontinent United States) that marks the TST (Demko and Gastaldo, 1992; Archer et al., 1994). In this model, peat formation occurs as a consequence of base-level rise driven by non-seasonal rainfall, originating from confinement of the Intertropical Convergence Zone close to the equator or its intensification due to increased Hadley Cell turnover during the late LST (Cecil et al., 2003; Poulsen et al., 2007; Elrick and Nelson, 2010).

In contrast, HFL's position is that coals dominantly comprise mid- to late-TST deposits (Flint et al., 1995) because brackish fauna and estuarine facies locally occur below coal seams within expanded valley-fill successions (e.g. Gibling and Wightman, 1994; Feldman et al., 1995), indicating that sea level had risen significantly prior to the onset of peat (coal) formation. In this latter model, peats kept pace with rising sea level and may represent, in part, time-transgressive units, albeit rapidly transgressive. Marine roof shales above coals demonstrate that the rate of sea level then accelerated, outpacing peat formation and resulting in marine flooding, as full interglacial conditions were approached.

TROPICAL VEGETATION DURING GLACIAL PHASES

Compared to our knowledge of coal forests, relatively little is known of the vegetation that covered Pennsylvanian tropical landscapes during seasonally dry glacial phases between the times of coal formation. To date only eight well-documented sites in North America have yielded fossil assemblages representative of this part of the climate cycle (Fig. 2). Most of these assemblages come from valley fills incised into lowstand seasonally dry paleosols (Cridland and Morris, 1963; McComas, 1988; Cunningham et al., 1993; Falcon-Lang, 2003, 2004; Feldman et al., 2005; Falcon-Lang et al., 2009). Where they are

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