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Early Pennsylvanian ombrotrophic mire of the Prokop Coal (Upper Silesian Basin); what does it say about climate?

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ABSTRACT

The Lower Pennsylvanian (Kinderscoutian) Prokop Coal (Coal No. 40), the erosional remnant of which covers about 5000 km^2, is the thickest seam of the Upper Silesian Basin situated along the Czech – Polish border. This basin-wide coal is unusual in its thickness and high inertinite and very low ash contents. In the Czech sector, this coal merges with the overlying Coal No. 39 into a single 9 to 15 m thick seam. Maceral analyses of an approximately 11 m thick section of these two merged coals show changes in the proportion of vitrinite (24.7 – 88.0 %) and inertinite (8.5 – 56.8 %) in cycles between 50 and 190 cm thick. The increase of inertinite in the lower part of coal cycles coincides with a dulling-upward trend, which records a drying-upward succession due to a slowing of accommodation rate relative to plant biomass productivity. This succession is interpreted as a transition from rheotrophic to ombrotrophic conditions. The brightening-upward succession in the upper part of coal cycles records a wetting-upward trend due to water table rise, resulting in restoration of rheotrophic conditions that supported humification under the regional ground water table. The sudden shift from inertinite-rich to vitrinite-rich coal at the base of brightening-upward successions points to a period of degradation and lowering of the peat dome. The coal cycles within the studied seam section probably preserve a succession of spatially overlapping but genetically independent mires bounded by degradation surfaces. The alternation between mires with contrasting hydrological regimes is interpreted as a record of base-level fluctuations of climatic causation of sub-Milankovitch periodicities. Early Pennsylvanian climate for various stages of mire development is inferred from analogy with modern tropical mires in SE Asia.

1. Introduction

Economic coal beds result from long-lived mires that formed in the geological past. As plant biomass accumulates in these habitats, permanent preservation of the peat only becomes possible after it has passed from the acrotelm above the permanent water table to the underlying, waterlogged catotelm (Ingram, 1978, 1982). The residence time of the plant material in the oxidising acrotelm determines how much of the plant material is degraded before being buried in the safety of the catotelm, thus controlling the rate of peat production (e.g. Clymo, 1983, 1984; McCabe, 1984; Moore, 1987; Teichmüller, 1989; Diessel, 1992; Taylor et al., 1998).

Space for the accommodation of additional plant biomass in the catotelm is generated by a rise in base level. An increase in base level results from the interplay between tectonic subsidence and/or compaction, and a rise in the position of the permanent water table that, in paralic environments, is driven by eustatic sea-level rise. Alternatively, in areas where precipitation outpaces evapotranspiration, the water table can rise by virtue of the low hydraulic conductivity of peat (Clymo, 1984; Jerrett et al., 2011a; Jerrett et al., 2011b). Under these latter specific circumstances, the water table domes above the regional water table (ombrotrophy) and the mire effectively "autogenerates" its own accommodation. Existing conceptual models for peat accumulation (e.g. Bohacs and Suter, 1997; Diessel et al., 2000; Diessel, 2007; Wadsworth et al., 2002; Jerrett et al., 2011b) show that, irrespective of the mechanism for generating accommodation space, a high accommodation rate that outpaces plant biomass productivity will lead to the mire being drowned and buried by marine/lacustrine sediments. A balanced accommodation rate relative to plant biomass productivity will result in the swift passage of plant material into the catotelm, resulting in humification. After coalification, the humified material becomes vitrinite-rich coal. In contrast, a low accommodation rate relative to plant biomass productivity will result in extended residency of plant material in the destructive acrotelm, leading to the formation of

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an inertinite- and liptinite-rich, highly degraded coal horizon across the mire surface. This horizon is interpreted as a residual oxidative layer that formed after the water table (base level) fell below the peat surface. An overlying vitrinite-rich banded coal thus represents re-initiation of peat accumulation in a new mire. This abrupt shift in coal facies suggests that the widespread degraded inertinite- and liptinite-rich surfaces represent periods of regional hiatus in peat accumulation. Coal benches between these bounding hiatal surfaces represent individual mires that are stacked in a single coal seam (Shearer et al., 1994; Holdgate et al., 1995; Greb et al., 1999, 2002; Lindsay and Herbert, 2002; Davies et al., 2006; Jerrett et al., 2011a, 2011b).

The formation of these hiatal surfaces is either connected to periods of lowered sea level (Diessel, 1992, 2007; Bohacs and Suter, 1997; Petersen et al., 1998; Booth et al., 1999; Diessel et al., 2000; Lindsay and Herbert, 2002; Wadsworth et al., 2002; Davies et al., 2006) or increased aridity that results in base level (water table) fall, peat cessation and degradation (Ledru et al., 1998; Webb and Webb, 1988; Hughes et al., 2000; Anshari et al., 2004; Barber et al., 2003; Hughes and Barber, 2003; Page et al., 2004; Jerrett et al., 2011a, 2011b). The climatic control on peat production relates to the amount of precipitation and its distribution throughout the year (Clymo, 1987; Cecil, 1990; Cecil et al., 1993, 2014; Wüst and Bustin, 2001; Page et al., 2006).

From the viewpoint of mire hydrology, mires are either rheotrophic and ombrotrophic (Diessel, 1992; Calder, 1993). Rheotrophic mires are supplied from both rainfall and groundwater because their planar surface corresponds to the regional ground water table. Such mires are usually nutrient rich (minerotrophic or eutrophic). The flat surface of rheotrophic mires also increases the probability of inundation by adjacent clastic depositional systems that introduce detrital minerals (Diessel, 1992; Calder, 1993; Greb et al., 2002; Jerrett et al., 2011a). Therefore, coals that result from rheotrophic mires usually have a medium to high ash content. However, some rheotrophic mires accumulate peat that is low in mineral content because clastic sources may be absent in the vicinity, the vegetation may provide a filter effect, and/or clay minerals flocculate due to the increased acidity of mire waters (Wüst and Bustin, 2001). These mechanisms may efficiently trap most of the suspended load in marginal parts of the mire, leaving its interior largely unaffected (Staub and Cohen, 1979; McCarthy et al., 1989; Calder, 1993; Mach et al., 2013). In contrast, ombrotrophic mires are solely rainfed because their surface is domed (or ombrogenous) and, except along their margins, they are poor in mineral matter; any minerals present are produced by the plants themselves or represent windborne dust. Ombrotrophic mires are considered the best modern analog to low ash coals in the geological record (Cameron et al., 1989; Calder, 1993; Cecil et al., 1993; Greb et al., 2002). A fundamentally important point is that ombrotrophic mires evolve from an initial rheotrophic state, meaning that every ombrotrophic mire always has a rheotrophic component (Anderson, 1964; Calder et al., 1993; Greb et al., 1999, 2002).

The most extensive modern tropical peatlands are in Indonesia, where they cover ~26 Mha and peat can be up to 20 m thick (Anderson, 1983; Page et al., 1999). The mires mostly occupy coastal and subcoastal lowlands, but can extend inland for more than 200 km, with most of them being ombrotrophic (Sieffermann et al., 1988; Neuzil et al., 1993; Page et al., 1999; Anshari et al., 2004). The most important requirement for the formation and preservation of ombrotrophic peat is permanent saturation by water, which is achieved where annual rainfall generally exceeds 2.5 m and the minimum precipitation during the "dry" season still exceeds evapotransporation at 100 mm/month (Whitemore, 1975; Morley, 1981; Neuzil et al., 1993; Dommain et al., 2010). Areas that receive less than 60 mm/month for two or more consecutive months do not form ombrogenous peat deposits. With regards to climatic changes and their effects on peatlands, a fen-to-bog transition occurred in northern Europe, where a major shift from rheotrophic fen to ombrotrophic bog occurred rapidly due to an increase in rainfall (e.g. Hughes et al., 2000; Barber et al., 2003; Hughes and Barber, 2003).

These examples clearly imply that climate is a crucial controlling factor on the hydrological regime of modern mires (e.g. Neuzil et al., 1993; Page et al., 1999; Jones et al., 2014), and one can assume that similar requisites constrained the development of mires in the geological past (Eble and Grady, 1993; Herbert, 1997; Greb et al., 1999, 2002).

The role of climate versus other allogenic or autogenic mechanisms is addressed in the present study of the Lower Pennsylvanian Prokop Coal in the Czech part of the Upper Silesian Basin. This thick and widespread coal exhibits a number of upward dulling and brightening trends that reflect temporal changes in maceral composition, interpreted as the product of water table/base level changes. The significance of these fluctuations is discussed in terms of their controlling mechanisms and potential implications for understanding Early Pennsylvanian climate in eastern equatorial Pangea.

2. Geological background

The Prokop Coal is the thickest coal bed of the Upper Silesian Basin that, in turn, currently is the most economically important Carboniferous hard coalfield in Europe, with annual production still attaining over 75 million tons. The approximately 7500 km^2 Upper Silesian Basin straddles the Czech-Polish border, with about 80 % situated in Polish territory (Fig. 1a). The Czech part of the basin covers 1550 km^2 and represents the largest and the only currently active hard coalfield in the country (Fig. 1b). Coal-bearing Serpukhovian to upper Moscovian strata attain a cumulative thickness of up to 8.5 km (Zdanowski and Żakowa, 1995). However, due to eastward migration of the depocentre away from an orogenic front and progressive cannibalisation of older deposits, as well as post-sedimentary erosion, maximum thickness in any part of the basin only reaches about half of the cumulative thickness (Gradziński, 1982). Paleomagnetic data of Krs et al. (1993) indicate a paleoequatorial position for the basin, near the eastern margin of Pangea.

Coal-bearing strata of the Upper Silesian Basin evolve from marine siliciclastic flysch that was deposited in a foreland setting at the contact between the Lugo-Danubian and Brunovistulian terranes, which amalgamated during the Variscan orogeny (Kumpera and Martinec, 1995). Regression around the Viséan/Serpukhovian boundary resulted in formation of a coastal lowland where deposition of the coal-bearing Ostrava Formation (= the Paralic Series in Poland) took place, interrupted by frequent glacioeustatically-driven marine transgressions (Havlena, 1964; Zdanowski and Żakowa, 1995). Major basin-wide marine bands serve to subdivide the formation into members (Fig. 1c). Radioisotopic dating of intercalated tonsteins proved that short-term eccentricity orbital forcing drove these glacioeustatic oscillations (Gastaldo et al., 2009; Jirásek et al., 2018). There are over 200 coal seams in the Ostrava Formation, of which about 90 locally reach an economical thickness of 1 m and exceptionally ~3 m (Dopita et al., 1997). In late Arnsbergian (Serpukhovian) time, the Erzgebirge tectonic event, preceding the Mid-Carboniferous glacioeustatic fall, terminated the paralic deposition recorded in the Ostrava Formation (Kędzior, 2016; Jirásek et al., 2018). After a biostratigraphically detected Chokierian – Alportian hiatus related to the Erzgebirge tectonic event (Gothan, 1913a, 1913b; Havlena, 1964; Kędzior et al., 2007), deposition in the Czech sector continued as coal-bearing continental deposits of the Karviná Formation (Fig. 1c). The formation is up to 1 km thick and spans most of the Baskhirian (Kinderscoutian – Langsettian). In the Polish part of the basin, however, accumulation of continental and mostly coal-bearing strata continued until early Stephanian times (Kędzior et al., 2007). The depositional hiatus between paralic and predominantly fluvial sedimentation is marked by a floral break and a ganister, a widespread "silcrete" horizon on top of the Ostrava Formation that formed during an interval of non-deposition (Gothan, 1913a, 1913b; Stopa, 1957; Purkyňová, 1977; Havlena, 1982; Dopita et al., 1997). The Karviná Formation contains up