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A paleopedologic and ichnologic perspective of the terrestrial Pennsylvanian landscape in the distal Appalachian Basin, U.S.A.

Daniel I. Hembree *, Gregory C. Nadon

Department of Geological Sciences, Ohio University, 316 Clippinger Laboratories, Athens, OH 45701, United States

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ABSTRACT

The Conemaugh Group of southeastern Ohio contains numerous ichnofossil-bearing paleosols in both the lower Glenshaw and upper Casselman formations, which were deposited during the Kasimovian and Gzhelian (305–301 Ma) along the distal edge of the Appalachian basin. This study examined the small-scale (<1 km) lateral variability in some of these paleosols and the role of organisms in the soil-forming processes during the Late Pennsylvanian.

Twenty four stratigraphic sections were measured from ten sites in Athens County, Ohio from which thirty paleosols were identified and described. Detailed field descriptions allowed differentiation of four distinct pedotypes; one in the Glenshaw Formation and three in the Casselman Formation. The Glenshaw Pedotype (GPT) is a Vertisol that formed on a proximal to distal floodplain. The three Casselman pedotypes represent Entisols/Inceptisols (CPTI) Alfisols (CPTII) and Vertisols (CPTIII). All four types contain evidence of alteration by post-pedogenic processes such as 'drowning' by migrating river channels or rising sea level or a gradual transition from one alluvial subenvironment to another as a result of channel migration.

Eight morphologically distinct ichnofossils were observed in the Conemaugh Group paleosols including three types of rhizoliths, lined and unlined, vertical to subhorizontal shafts, chambers, sinuous burrows with and without bioglyphs, and general burrow mottling. These ichnofossils occur in distinct assemblages that form unique ichnocoenoses within each of the four pedotypes. They were produced by various plants, arthropod detritivores, carnivores, and herbivores as well as amphibians and early reptiles as temporary to permanent members of complex soil ecosystems.

Pedogenic properties combined with ichnofossil diversity, abundance, and distribution increase the understanding of the complexity of Late Pennsylvanian soil ecosystems and provide details on the small-scale variations in paleosols due to short-term autogenic changes in alluvial environments. Although broad, regional studies across 10^2–10^3 of kilometers are important, small scale variations over less than 1 km are needed to understand the effects of localized changes in hydrology, topography, organisms, and sedimentary processes on soil formation and soil biodiversity. Consideration of these types of localized studies is also vital when attempting to interpret regional to global-scale aspects of environment such as climate from paleosols.

1. Introduction

Terrestrial landscapes are highly complex surfaces with soil types that vary with even minor changes in parent material and topography. Variations in drainage as a result of these changes can occur over a distance of meters resulting in very different soil-forming conditions (Birkeland, 1999; Buol et al., 2003; Schaetzl and Anderson, 2009; Aslan and Autin, 2010). In addition, both permanent and temporary occupants of the soil ecosystem play a fundamental role in soil development by altering soil composition, density, drainage, and chemistry (Bardgett, 2005; Lavelle and Spain, 2005). Understanding the physical and biological controls on landscape development requires a spatially restricted approach with closely spaced stratigraphic sections.

Previous studies have depicted the landscape of the Appalachian basin during the Pennsylvanian from different spatial and temporal scales based on paleontology, sedimentology, and paleopedology. Paleontological investigations have primarily focused on marine invertebrates (Donahue and Rollins, 1974; Saltsman, 1986; Merrill, 1993; Lebold and Kammer, 2006) and plants (Phillips and Peppers, 1984; DiMichele et al., 1996a, 2001, 2007) with rare exceptions (Archer and Maples, 1984; Labandeira et al., 1997). Coal studies vary from those examining the evolution of plants through the Pennsylvanian of North America to detailed examinations of individual coal beds (Phillips and Peppers, 1984; DiMichele et al., 1985; DiMichele and Phillips, 1994; Heckel, 1995; Chestnut, 1996; Milici, 2005). Regional and local studies of the sedimentology of the basin fill have described both overall patterns and local variations (Donaldson, 1974; Cecil et al., 1985; Cecil,

* Corresponding author.
E-mail address: hembree@ohio.edu (D.I. Hembree).

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1990; Chestnut, 1991, 1994; Cecil et al., 2003; Heckel, 2008). Sedimentology, and more recently paleopedology, has provided a depositional framework on an equally large variation of spatial and temporal scales (Ferm, 1970; Cox et al., 1984; Presley and Donaldson, 1984; Donaldson et al., 1985; Gardner et al., 1988; Retallack, 1994; Slucher and Rice, 1994; Joeckel, 1995; Robinson and Prave, 1995; Nadon and Kelly, 2004; Driese and Ober, 2005). The paleosol studies in particular both enrich the understanding of the depositional environments and provide valuable data on paleoclimate.

The scale of investigation and the bias of the different biological components are of paramount importance. Terrestrial geomorphology is self-similar over a large range of scales (Birkeland, 1999; Buol et al., 2003; Migon, 2010). Whereas detailed studies of closely spaced exposures can be applied to regions; the converse does not apply because of the data lost with the coarser spatial filter. The biological component of the Pennsylvanian terrestrial landscape, and the climate inferences made from them, has been mainly restricted to plants, especially flora preserved within coal beds (Phillips and Peppers, 1984; Schutter and Heckel, 1985; Winston, 1990; Parrish, 1993; DiMichele and Phillips, 1994, 1996; DiMichele et al., 1996b, 2006; Gastaldo et al., 1996; Falcon-Lang, 2004). Although useful both locally and regionally, the formation and preservation of coal requires a very specific set of circumstances that are not necessarily representative of the average Pennsylvanian landscape (Presley and Donaldson, 1984; DiMichele et al., 1985; Tandon and Gibling, 1994; Joeckel, 1995; Johnson et al., 1997). Continental vertebrate and invertebrate fossils can provide useful information, but the fossil record suffers from the effects of the taphonomic filter that limits the preservation of body fossils. As with the marine record, ichnology provides a data set that reveals more of the Pennsylvanian biota than the rare body fossils (Miller, 1984; Wright, 1987; Pickerill, 1992; Bromley, 1996; Keighley and Pickerill, 1997, 2003; Retallack, 2001; Lucas et al., 2004; Hasiotis, 2007). The integration of continental ichnological data with paleopedology provides a richer set of paleoenvironmental and paleoclimatic data than either used in isolation.

This study uses paleopedologic and ichnologic data from 24 closely spaced sections from 10 localities of an interval within the middle of the Late Pennsylvanian Conemaugh Group (Kasimovian–Gzhelian). The data illustrate that the lateral changes in landscape are more rapid and complex than have been previously depicted. These data also provide important constraints on the climate affecting deposition in the low accommodation region of the distal Appalachian basin.

2. Geologic setting

The study area is primarily within the boundaries of the city of Athens and includes units directly above and below the last major marine transgression in the Appalachian basin (Figs. 1, 2). The Pennsylvanian age sediments in southeastern Ohio were deposited between the depo-center of the Appalachian basin to the east and the positive Cincinnati Arch to the west while the whole region was located at a paleolatitude of between 5° and 10° S (Opdyke and DiVenere, 1994; Scotese, 1994). In Ohio, the record of Late Pennsylvanian sedimentation is divided into the Allegheny, Conemaugh, and Monongahela Groups (Fig. 1). Each group contains a complex assemblage of lithofacies, but the marine record is largely absent above the middle of the Conemaugh Group (Condit, 1912; Sturgeon, 1958; Presley and Donaldson, 1984; Joeckel, 1995; Nadon and Kelly, 2004). Commercial coal deposits occur within the Allegheny and, to a lesser extent, in the Monongahela Groups; none are present in the Conemaugh Group (Sturgeon, 1958; Milici, 2005). Deposition within the basin shifted from under-filled with an axial drainage system during deposition of the Middle Pennsylvanian (Pottsville, New River and Pocahontas Groups) to a broadly transverse pattern with a northwest paleoflow during deposition of the Middle to Late Pennsylvanian (Donaldson et al., 1985).

The climate of the western portion of the Appalachian basin was wet-humid to moist subhumid, but was affected by the episodic presence of seaways and the adjacent Appalachian Mountain range to the south. Inferences on paleoclimate drawn from paleosols (Joeckel, 1995; Caudill et al., 1996; Driese and Ober, 2005) and coal beds (Cecil et al., 1985; Cecil, 1990; DiMichele et al., 2010) suggest that the region shifted from tropical and ever-wet during deposition of the Allegheny Group to strongly seasonal with extended dry periods recorded within the Conemaugh Group.

The study area was affected by large amplitude, high frequency, fourth-order, glacio-eustatic sea level fluctuations (Heckel, 1994, 1995, 2008; Rygel et al., 2008). While the exact connections of the Appalachian basin with the Illinois and Midcontinent basins are unknown, conodont biostratigraphy shows that all of these basins shared a common marine connection at different times (Heckel, 1994). Data from the Midcontinent, where the section is more complete, shows an overall third-order rise in sea level from the Middle to Late Pennsylvanian reaching an apex during deposition of the Oread cyclothem (Ross and Ross, 1987; Heckel, 2008). The presence or absence of higher order marine transgressions in the study area was controlled by variations in tectonic subsidence and eustatic sea level change (Heckel, 1994; Nadon and Kelly, 2004; Heckel, 2008). The last major marine transgression deposited the Ames Limestone, which divides the Conemaugh Group into the lower Glenshaw and upper Casselman formations (Sturgeon, 1958). Conodont biostratigraphy correlates the Ames Limestone with the Shumway Cyclothem of the Illinois Basin and the Heebner Shale of the Oread Cyclothem of the Midcontinent (Heckel, 1994).

The Conemaugh Group in Ohio consists of a complex assemblage of fluvial and marine lithofacies (Condit, 1912; Stout et al., 1923; Sturgeon, 1958). The initial correlations of the marine bands within the Conemaugh suffered from an acknowledged lack of biostratigraphic control. The development of the cyclothem concept, although challenged by some (e.g., Stout et al., 1923), was used by others to propose very detailed lateral correlation of the Ohio Pennsylvanian System to the thicker sections in Pennsylvania and West Virginia (e.g., Sturgeon, 1958). Confidence in these simple physical correlations was eroded by the increased understanding of the complexity of the depositional systems in the region (e.g., Ferm, 1970). Later, others (e.g. Heckel et al., 1998; Nadon and Heckel, 2004) showed that that the variations in relative sea level within the interval require conodont biostratigraphy to properly correlate detailed sections.

Two studies have attempted to illustrate the lateral variations in the landscape of the Appalachian Basin during the Pennsylvanian. Both correlated sections using high-resolution biostratigraphy and both drew conclusions from variations in paleosols. Cecil et al. (2003) amassed data from the interval of the Middle Kittanning Coal (Middle Pennsylvanian, Allegheny Formation) from Pennsylvania to southern California. That study correlated a paleosol horizon, interpreted as a single landscape surface, across the North American craton from the eastern edge of the Appalachian basin to eastern Nevada. Their stratigraphic sections indicated a trend from deeply weathered paleosols containing high alumina clay minerals, iron, organic matter, and weakly developed crosscutting fractures with slickensides in the east to poorly developed paleosols with rhizoliths, calcareous cement, and pedogenic calcite in the west (Cecil et al., 2003). These data were used to interpret a spatially variable paleoclimate across North America from one that was seasonal and ranged from humid to subhumid to one that was dry subhumid to semiarid (Cecil et al., 2003).

Joeckel (1995) used the Ames Limestone to correlate underlying Upper Pennsylvanian paleosols (Conemaugh Group) within the Appalachian basin. The data used in the Joeckel (1995) study incorporated 24 sections, including two sections from within the current study area, which occurred across 400 km with an average distance of 50 km between sections. These data were used to conclude that the