Quaternary International 342 (2014) 186–198

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Early Holocene soil cryoturbation in northeastern USA: Implications for archaeological site formation

Gary E. Stinchcomb[a,*], Steven G. Driese[a], Lee C. Nordt[a], Lyndsay M. DiPietro[a], Timothy C. Messner[b]

[a] Terrestrial Paleoclimatology Research Group, Department of Geology, Baylor University, One Bear Place #97354, Waco TX 76798, USA
[b] Department of Anthropology, The State University of New York at Potsdam, 44 Pierrepont Avenue, Potsdam, NY 13676, USA

ARTICLE INFO

Article history:
Available online 12 July 2014

Keywords:
Pedocomplex
Early Holocene
Freeze–thaw
Northeastern USA
Archaic Period Archaeology

ABSTRACT

The study of buried soil archives in alluvial settings can be used to characterize floodplain and terrace habitats and complement other paleoenvironmental and archaeological archives. This study examines the early Holocene alluvial paleopedology along the Delaware River Valley in the northeastern USA. Chronological and alluvial stratigraphic data show that a widespread loam alluvial paleosol formed from 10.7 to 9.3 ka, herein referred to as the Jennings Lane Pedocomplex (JLP). The JLP at the Jennings Lane locality along the Delaware River, NJ, is a loam to silt loam soil that formed on mixed alluvium and windblown and/or reworked dust, likely sourced from nearby periglacial fines. This finding supports previous interpretations of late Quaternary dust deposition and reworking in the region. Fragic properties (e.g., firm peds with brittle manner of failure and rapid slaking in water) and cryogenic micromorphological features (lenticular pores, stone jacking and shattered grains) present within the JLP suggest cryoturbation. Soil mass-balance modeling suggests that the strain (ε) in immobile elements Ti and Zr show a dilation–collapse profile. These data indicate that organic matter and/or dust addition, and freeze-thaw created soil dilation at the JLP paleosurface. Mass-balance additions in Fe, K, and Mg are consistent with illuviated Fe-rich clay coatings present in thin section. The X-ray diffraction results show that these clays are illite, vermiculite, and kaolinite. Paleosol data presented here suggest that the JLP was overprinted by later pedogenic processes during the middle Holocene. $\tau_{Ti,Na}$ shows minimal loss throughout much of the profile. Although rapid thaws may have promoted downward translocation of fines, the cold environment impeded base loss through either minimal release of cations from primary minerals or negligible water flux, as suggested by $\tau_{Ti,Na}$ profiles and gains in $\tau_{Ti,K}$ and $\tau_{Ti,Mg}$. This silt-rich JLP pedofacies experienced minimal chemical depletion over the course of ~1200–3500 years. This cold-climate weathering coincides with rapid temperature fluctuations (10.5, 9.3, 8.2 ka) during the early Holocene in northeastern USA. This soil cryoturbation evidence has archaeological implications as well. The cryoturbation in this early Holocene pedocomplex suggests that vertical and lateral artifact redistribution is possible. Archaeologists should use caution when interpreting archaeological stratigraphy and intrasite artifact patterns at mid- to high-latitude archaeological sites.

1. Introduction

Soils are important modern- and paleo-environmental data archives (Yaalon, 1971; Kemp et al., 1995; Retallack, 2001; Holliday, 2004; Schaetzl and Anderson, 2005; Sheldon and Tabor, 2009) because they form as a function of five primary factors: climate, organisms, relief, parent material, and time (Jenny, 1941, 1980). Buried soils in alluvial archives are especially useful because alluvial deposition and burial minimizes overprinting. This process helps create a paleoenvironmental soil archive reflecting a discrete time period.

One such alluvial environment is the middle Delaware River valley, located in northeastern USA (Fig. 1A). Along the modern Delaware valley bottom, floodplain and alluvial terraces are composed of abundant vertical accretion deposits that have been weathered at various times during the Holocene, resulting in

* Corresponding author. Baylor University, Geology Department, One Bear Place #97354, Room E.456R.2, Waco, TX 76798, USA.
E-mail addresses: gstinch@gmail.com, Gary_Stinchcomb@baylor.edu (G.E. Stinchcomb), Steven_Driese@baylor.edu (S.G. Driese), Lee_Nordt@baylor.edu (L.C. Nordt), Lyndsay_DiPietro@baylor.edu (L.M. DiPietro), messnetc@potsdam.edu (T.C. Messner).

http://dx.doi.org/10.1016/j.quaint.2014.05.011
1040-6182/

multistory buried soil complexes (Ritter et al., 1973; Vento et al., 1989, 2008; Stewart et al., 1991; Witte, 2001; Schuldenrein, 2003; Stinchcomb et al., 2012; Gingerich, 2013). Regional geoarchaeological research has documented a late Pleistocene – early Holocene silt-rich buried soil complex (Crowl and Stuckenrath, 1977; McNett et al., 1977; Dent, 1985; Vento et al., 1989; Stewart et al., 1991; Schuldenrein, 2003; Thieme, 2003a,b). This complex corresponds with Fluvial Phase II (10.7–8 ka), a period of alluvial landscape stability (Stinchcomb et al., 2012).

Contemporaneous with this soil complex, regional palynological studies have depicted long-term, time-transgressive vegetation responses to gradually changing climatic conditions (Deevey, 1939; Davis, 1969; Webb, 1982; Shuman et al., 2004). However, recent analyses highlighted more rapid and complex changing forest structure(s) through the Holocene. Shuman et al. (2009) documented abrupt climate changes operating against the backdrop of the slower, long term trends. Their study identified large, rapid ($\leq$500 years) land cover changes – some on the magnitude of recent human disturbances at 13.25–12.75, 12.0–11.5, 10.5, 8.25 and 5.25 ka resulting from rapid shifts in temperature and moisture (Shuman et al., 2009). These abrupt declines in arboreal taxa: 1) accelerated some vegetation trends; 2) slowed or stalled regional vegetation trends; and/or 3) altered regional vegetation trends.

In conjunction with the palynological data, hydrogen isotope and paleo-lake level proxies were used to document abrupt cooling events that occurred at centennial and millennial time scales during the late Pleistocene and early Holocene (Shuman et al., 2005; Rasmussen et al., 2007; Shuman and Plank, 2011; Hou et al., 2012). These abrupt events, including the Younger Dryas, 9.3 ka, and 8.2 ka events, were caused by catastrophic drainage of glacial meltwater into the North Atlantic (Alley, 2000; Clark et al., 2001; Yu et al., 2010). These meltwater pulses likely stalled the Atlantic Meridional Overturn Current (AMOC), thereby preventing warm-moist subtropical air transfer to the higher latitudes. Paleoenvironmental anomalies that are coeval with AMOC shutdowns during the early Holocene have been documented in several lake cores in northeastern USA (Newby et al., 2011).

Despite the abundance of palynological and lacustrine studies, there are few studies that identify links between the buried soils and early Holocene climate and environment. Are the late Pleistocene and early Holocene bioclimatic changes evident in buried alluvial soils in the northeastern USA, and can they in turn provide additional environmental information to further strengthen the current observations? This study examines the paleopedology of one early Holocene buried alluvial soil complex along the Delaware River valley and documents evidence of cold-climate weathering. Possible linkages between cold-climate weathering and early Holocene climate changes are discussed along with implications for the redistribution of artifacts in soils where cold-climate weathering prevailed in the past.

2. Paleopedology methods

2.1. Physical characterization

2.1.1. Soil morphology

Early Holocene alluvial soil formation within the middle Delaware River Valley was assessed using a multiproxy paleopedology approach (e.g., Driese et al., 2008) within a predefined alluvial stratigraphic framework (Stinchcomb et al., 2012). The early Holocene buried soil complex was temporally constrained using a radiocarbon (^{14}C) ages from previous work (Table 1; Stinchcomb et al., 2012 and references therein).

The early Holocene buried soil morphology in the Delaware River Valley was described using U.S. Department of Agriculture (USDA) soil nomenclature (Schoeneberger et al., 2002) with modifications (see Holliday, 2004 – Appendix 1). The color, texture, consistency, and ped/void features were described for each sample. The slaking test was applied to representative air-dried aggregates in the lab (NRCS, 2009). The application of soil horizon nomenclature in the USA is used in field description and as a starting point towards identifying diagnostic horizons for taxonomy (Birkeland, 1999). We used the field descriptive approach when describing soils and no diagnostic horizons were identified. Sediment overlying an alluvial soil was the criterion used to designate buried soils ("b" horizon designation) (Schaetzl and Anderson, 2005). This approach should not be confused with criteria for designating a buried soil using USDA Soil Taxonomy.

2.1.2. Particle-size analysis

Bulk soil and sediment samples collected in approximately 10 cm intervals were analyzed for particle size using a Malvern 2000E laser granulometer with the HydroMU dispersion unit (Arriaga et al., 2006). Malvern quality audit standards (QAS3002, 15–150 μm glass spheres) were run and the results show a standard error less than 1%. Results are shown in cumulative weight percent of sand, silt, and clay, using the Udden-Wentworth (geological) grain-size scale (Wentworth, 1922). The Wentworth scale precludes genetic interpretations of soil development and is primarily used for sedimentological interpretations.

2.1.3. Bulk density estimates

The estimated bulk density (ρ_{est}) of soil and sediment samples was calculated using a pedotransfer function developed by Saxton and Rawls (2006). The model uses particle size and % organic matter, salinity and compaction to estimate bulk density. The values were compared with modern Delaware Series measured bulk density values to help determine the validity of the approach (National Cooperative Soil Survey, 2013).

2.1.4. Soil micromorphology

Soil micromorphology was used to identify pedogenic processes, evidence of overprinting, and mineralogical composition. Undisturbed, oriented thin-section samples were recovered from all horizons, air dried, epoxy impregnated, and then prepared for commercial fabrication (Spectrum Petrographics Inc.). Soil micromorphological features were described using the terminology developed by Fitzpatrick (1993) and Stoops (2003). Thin sections from buried soils were point counted using a PELCON automatic point counter to identify mineral and ped/void feature concentrations that indicate specific pedogenic processes. The point-count concentrations were based on a total of 300 point counts from the combined sand and silt fraction for each thin section to achieve a large sample size.

2.2. Chemical characterization

Buried soils were chemically characterized to determine parent material uniformity and the presence and magnitude of pedogenic processes (Birkeland, 1999). Bulk geochemical samples were analyzed commercially (ALS Chemex) using ICP-MS and major and trace elements were reported in weight percent. The concentrations of immobile elements (Ti and Zr) were used to evaluate the parent material composition. Mobile elements (Na, Mg, K, Ca, Fe, Mn, C, P, Pb) were used to determine elemental addition and/or depletion due to pedogenic processes.

2.2.1. Parent material uniformity

Lithologic discontinuities were identified using the Ti and Zr concentrations and clay-free particle-size distribution obtained