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Paleoclimatic interpretations of buried paleosols within the pre-Illinoian till sequence in northern Missouri, USA

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ABSTRACT

Northern Missouri preserves shallow buried paleosols ranging in age from Early to Late Pleistocene that are developed in six pre-Illinoian tills beneath Illinoian (MIS 6) and Wisconsinan (MIS 4-2) loess. The morphology of these paleosols changes with age, reflecting a changing climate during the Pleistocene, and cosmogenic-nuclide burial dates of the respective sola provide age control on the timing of these changes.

The depth to secondary calcium carbonate nodules within the weathering profiles increases with younger age, indicating a transition to moister conditions during the Pleistocene, and these nodules are absent entirely within the modern soils. After approximately 0.4 Ma, the sola became distinctly redder, even as the time available for pedogenesis became shorter, culminating in the bright red Sangamon Geosol (MIS 5). This trend is consistent with increasing interglacial temperatures and/or precipitation. Finally, erosion rates determined from cosmogenic-nuclide concentrations within the sola also increase systematically with younger age. This increase may be due to some combination of changing climate, more-frequent glaciations and the deposition of a thick cover of unconsolidated glacial sediment above the stable residuum-dominated preglacial landscape.

1. Introduction

A sequence of buried paleosols ranging in age from Early to Late Pleistocene is preserved in northern Missouri within a sequence of pre-Illinoian (pre-MIS 6) tills and overlying loess (Figs. 1, 2). The pedology and geochemistry of these paleosols represent a potential record of paleoclimate and paleoenvironment during Pleistocene interglacial periods. In this paper, we compile and summarize data from multiple paleosols at 34 stratigraphic sections in northern Missouri (Table 1) in order to i) describe these paleosols; ii) highlight temporal variations in soil morphology, stratigraphy, and geochemistry during the Pleistocene; and iii) relate these variations to likely paleoclimatic or paleoenvironmental causes.

We focus on three striking examples of systematic temporal changes. First, pedogenic calcium carbonate (colloquially called “caliche”), which is not present in the modern soils, occurs more commonly and at shallower depths in older paleosols. As the presence and depth of secondary carbonate is related to mean annual precipitation (MAP), we propose that this records an increase in interglacial MAP during the Pleistocene. Second, the morphology of paleosols changes with age. Late Middle Pleistocene soils, although representing shorter durations of pedogenesis, have redder sola than early Pleistocene soils, culminating in the bright red Sangamon Geosol (MIS 5). Although the reasons for the distinctive red color of the Sangamon and the (somewhat older) Yarmouth Geosol have been discussed for many years, our observations place these observations in a temporal context and thus help to assess the competing hypotheses of warmer interglacial temperatures, longer weathering durations, and burial diagenesis as the dominant factor for reddening of the younger paleosols. Finally, we use cosmogenic-nuclide measurements, already carried out on these paleosols in previous research for the purposes of determining their age, to also estimate soil surface erosion rates prior to burial. Younger paleosols display higher apparent erosion rates, which may reflect either climate change or an increased frequency of landscape disturbance due to glaciation and glacial–interglacial climate change. Overall, we conclude that the Missouri paleosol sequence records a systematic increase in interglacial temperature, moisture availability and rates of erosion and landscape development during the Pleistocene.

2. Stratigraphy

Six Pleistocene tills in northern Missouri are grouped into three formal formations and three informal members (Figs. 1, 2; Rovey and Tandarich, 2006; Rovey and Balco, 2011). These tills display consistent clay loam textures, but have distinct and laterally consistent differences in lithology, thus in most cases allowing identification by lithologic characteristics alone. Four mature weathering profiles capped by argillic B horizons divide this till sequence into five major glacial sedimentary sequences corresponding to each of the named lithostratigraphic units

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Fig. 1. Location and physiography of study area in central Missouri. Numbered triangles correspond to site numbers in Table 1. The dashed line in the main panel is the southern boundary of known glacial deposits.

(Fig. 2). Informal names have been applied to some of these paleosols (Guccione and Tandarich, 1993; Rovey, 1997), but here we designate paleosols older than the Yarmouth Geosol (a paleosol buried by Illinoian deposits; Hallberg et al., 1980) simply by the lithostratigraphic name of the unit on which the soil formed; e.g., the Atlanta paleosol is the paleosol developed on the Atlanta-Formation till.

The two oldest tills (Atlanta and Moberly) have a reversed magnetic remanence, which restricts their age to the Matuyama Chron or Early Pleistocence. Cosmogenic-nuclide burial ages for these tills are 2.42 ± 0.14 Ma and 1.31 ± 0.09 Ma, respectively (Balco and Rovey, 2010). The younger three tills of the McCredie Formation are magnetically normal and underlie the 0.16 Ma Loveland Silt (Foreman and Pierson, 2002; Mason et al., 2006). The oldest of the three normal-polarity tills, the Fulton till, has a cosmogenic-nuclide burial age of 0.80 ± 0.06 Ma (Balco and Rovey, 2010). Given its normal magnetic remanence, it is most likely that the Fulton was emplaced during MIS 18 near 0.76 Ma.

The two youngest tills (Columbia and Macon) have similar lithologies, indicating that they share similar ice-accumulation and source areas, and are closer in age than the older three tills. Burial ages for the Columbia and Macon are 0.22 ± 0.15 Ma and 0.21 ± 0.17 Ma, respectively (Balco and Rovey, 2010). An argillic horizon in the Columbia paleosol suggests that deposition of the two tills was separated by at least one relatively long interglacial period. These observations, along with the fact that the Macon till underlies MIS 6 loess, suggest that the Columbia and Macon tills were emplaced during two of marine oxygen isotope stages 12 (0.48–0.42 Ma), 10 (0.37–0.34 Ma), or 8 (0.3–0.24 Ma).

The till sequence is overlain by several loess units, the oldest of which is the Illinoian (MIS 6) Loveland Silt. The Loveland began accumulating at ~0.16 Ma (Foreman and Pierson, 2002; Mason et al., 2006) and is distinguished from younger loess by pinkish hues, higher kaolinite contents, and the Sangamon Geosol at the top. The Loveland is most commonly preserved on flat uplands near the Missouri River (Guccione, 1983). However, it occurs in a variety of landscape positions and directly overlies various tills ranging in age from that of the Macon to the Moberly (Figs. 2, 3). Therefore, much of the present topographic relief developed prior to 0.16 Ma.

The Loveland Silt is buried by Wisconsinan (MIS 4-2) loess. The Early Wisconsinan (MIS 4) Roxana Silt may be present locally as a thin layer with a faintly developed A horizon of the Farmdale Geosol (Guccione, 1983; Rovey, 1997). Nevertheless, the Roxana is rarely preserved or at least distinguishable from the overlying Peoria Loess. The Peoria is the