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Stratigraphy, morphology, and geochemistry of late Quaternary buried soils on the High Plains of southwestern Kansas, USA

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ABSTRACT

This study investigated two stratigraphic sequences that record the complex interplay of sedimentation and pedogenesis over the past ca. 84 ka on the High Plains of southwestern Kansas. Up to eight eolian sand and loess units with associated soils were identified in two cores collected from an upland setting. Soil morphological and geochemical data were used to quantitatively assess and compare soil development between multiple buried soils. Chronostratigraphic relationships indicate that 1) loess and eolian sands were episodically deposited during late Marine Isotope Stage (MIS) 5 (ca. 84–70 ka), 2) the Sangamon soil at this site formed between MIS 3/4 (ca. 70–52 ka), which is consistent with age estimates for renewed Sangamon pedogenesis in the Mississippi River valley, and 3) soil development in the Gilman Canyon Formation began at ca. 44 ka and continued until at least 29.2 ka. Multiple lines of evidence, including grain-size distributions, structure, clay content, and chemical weathering index data, indicate that the morphology and chemistry of the Ak horizon developed in the Gilman Canyon Formation is a product of cumulization by slow loess additions. Similar evidence suggests that cumulization processes are also responsible for the morphology and chemistry of other buried soils in the stratigraphic sequence. Overall, loess inputs during pedogenesis complicate the quantification of weathering processes in these soils.

1. Introduction

Many investigations of Quaternary loess-paleosol sequences, particularly in Europe and China, have utilized chemical weathering indices to investigate weathering intensity and paleoclimatic change (e.g., Yang et al., 2004; Jeong et al., 2008; Buggle et al., 2011; Schatz et al., 2015). In the Midwestern USA, the application of weathering indices has mostly been directed to glacigenic loess and associated intercalated paleosols (e.g., Muhs et al., 2001; Grimley et al., 2003). In the central Great Plains of North America, however, where loess deposits are non-glacigenic (e.g., Aleinikoff et al., 2008), weathering indices have typically been employed as an indicator of sediment provenance (e.g., Muhs et al., 1999, 2008; Jacobs and Mason, 2007). In addition to chemical weathering, pedogenic processes also result in the formation and accumulation of secondary minerals (e.g., clay, Fe oxides, and $CaCO_3$), which are commonly reflected in the morphological properties of the soil. Relatively few sediment-paleosol studies, however, have attempted to quantitatively compare morphological development with the intensity of chemical weathering. Together, such data allow for a more complete assessment of 1) the relative contributions of pedogenic and sedimentary processes, 2) the relative morphological differences among sequences of buried soils, and 3) regional differences and comparisons.

In this paper we investigate two sediment-paleosol sequences that record soil formation and the episodic deposition of loess and eolian sands during the late Quaternary on the High Plains of southwestern Kansas. A 98 m-deep core (HP1A) was collected from an upland setting approximately 25 km south of the Arkansas River (Fig. 1) as part of the High Plains Ogallala Drilling Program at the Kansas Geological Survey. Here, we present the stratigraphy, geochronology, soil morphology, and geochemistry of the upper 14 m of this core. The stratigraphy, numerical ages, and soil morphology from the upper 20 m of a similar core (CMC) collected from an upland setting just north of the Cimarron River valley (Fig. 1) are also presented. The HP1A and CMC cores provide ca. 77 and 84 ka records, respectively, of eolian sedimentation and soil formation on the High Plains surface. By correlating eolian units with regionally extensive loess units and quantifying the morphological development and weathering intensity of buried soils, this study

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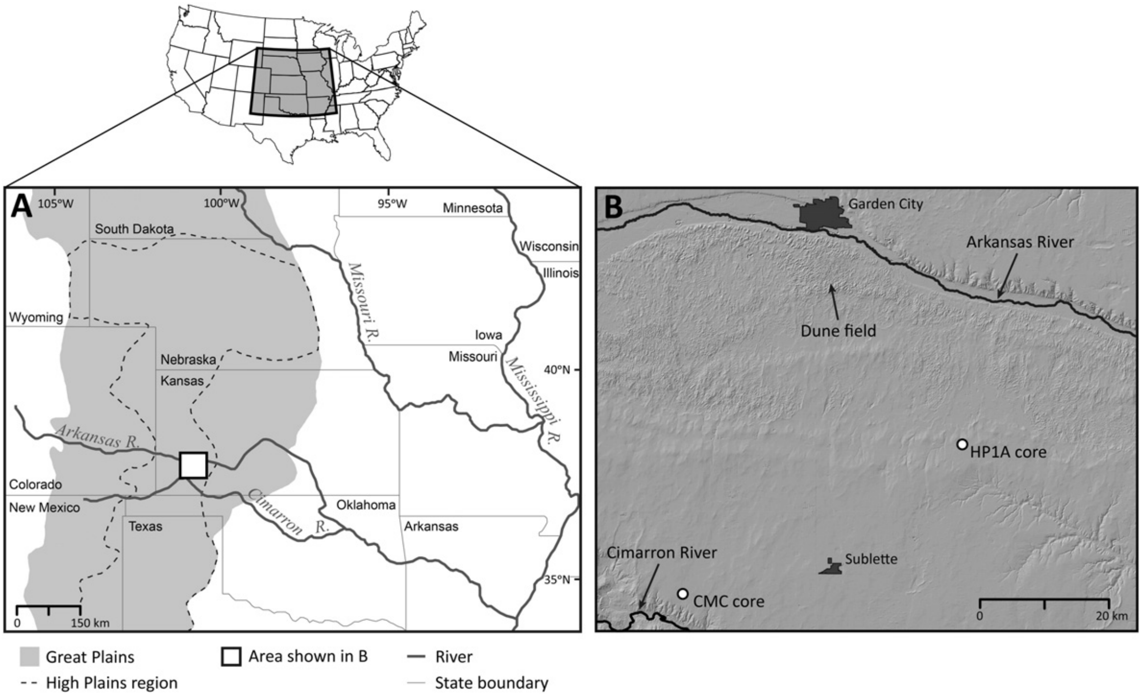

Fig. 1. A) Regional map showing study area location on the High Plains of southwestern Kansas. B) Lidar image showing location of the HP1A and CMC cores.

provides a better understanding of late-Quaternary landscape evolution as well as the complex interplay between eolian sedimentation and pedogenesis in the central Great Plains of North America.

2. Background

2.1. Study area

The study area is located in southwestern Kansas and is part of the High Plains region of the Great Plains physiographic province (Fig. 1; Fenneman, 1931). The High Plains region represents the remnant of a vast alluvial plain (Ogallala Formation) formed by sediments deposited by streams discharging from the Rocky Mountains during the late Miocene-early Pliocene epochs. The High Plains surface is relatively flat and featureless and is mantled by <5 m of loess in southwestern Kansas (Welch and Hale, 1987; Bettis et al., 2003); however, river valleys, dune fields, and numerous small playa basins provide some topographic relief (5–15 m).

Southwestern Kansas is dominated by short grass prairie and has a semiarid continental climate. Mean annual temperature and precipitation are 12.5 °C and 490 mm, respectively, for the period of record (1947–2015 CE) at Garden City, Kansas (High Plains Regional Climate Center, 2015). Most precipitation falls during the early summer due to frontal activity where cold, dry polar air masses collide with warm, moist air masses from the Gulf of Mexico. Also, periodic intensification of the North American Monsoon brings peak summer rainfall to southwestern Kansas (e.g., Higgins et al., 1997). Droughts are common in the region due to the development of upper level anticyclones, which inhibit frontal activity and are driven primarily by sea surface temperature anomalies in the tropical Pacific Ocean (e.g., Cook et al., 2007; Hoerling et al., 2014).

2.2. Late-Quaternary stratigraphy

The late-Quaternary stratigraphic framework for the Great Plains includes at least three superimposed loess units: the Loveland Loess, Gilman Canyon Formation, and Peoria Loess (e.g., Feng et al., 1994; Bettis et al., 2003). These loess units are regional in extent and thus provide a means to stratigraphically correlate more localized units.

The Loveland Loess typically is the oldest loess unit in the Great Plains and usually is only a few meters thick (Bettis et al., 2003). Studies suggest that the Loveland Loess was deposited during the penultimate glaciation (Marine Isotope Stage (MIS) 6) (e.g., Forman et al., 1992; Maat and Johnson, 1996; Forman and Pierson, 2002), although there is evidence of intermittent deposition throughout MIS 5 in some locations (e.g., Rodbell et al., 1997; Markewich et al., 2011). The Loveland Loess is commonly recognized by the well developed, rubified soil formed in its upper part. This soil, referred to as the Sangamon Geosol, has been documented in the Great Plains (e.g., Frye and Leonard, 1952; Schaetzl, 1986; Feng et al., 1994) and throughout the Midwestern USA (e.g., Willman and Frye, 1970; Ruhe, 1974; Follmer, 1978; Jacobs and Knox, 1994; Grimley et al., 2003). The Sangamon Geosol typically is 1–2 m thick with silt loam or silty clay loam textures, 7.5YR to 5YR hues, thick Bt horizons, and well-developed prismatic or angular blocky structure. Based on studies in the Mississippi River valley, Sangamon pedogenesis occurred between ca. 130–90 ka (most of MIS 5) with renewed pedogenesis from ca. 74–54 ka (MIS 4) (Markewich et al., 2011).

The Gilman Canyon Formation (GCF) mantles the Sangamon Geosol and is usually <2 m thick on the Great Plains (Bettis et al., 2003). The GCF is the stratigraphic equivalent of the Pisgah Formation in western Iowa (Bettis, 1990) and the Roxana Silt of the Mississippi River valley (Follmer, 1983; Leigh and Knox, 1993). The GCF is typically noncalareous with dark brown to grayish brown coloration and silt loam textures. The GCF has often been modified by pedogenesis, commonly with two or more soils (e.g., Reed and Dreeszen, 1965; Mandel and Bettis, 1995; Johnson et al., 2007). In Kansas and Nebraska, the GCF has yielded calibrated ^{14}C ages ranging from ca. 45 to 24 ka (Johnson et al., 2007; Muhs et al., 2008).

The Peoria Loess overlies the GCF and is the thickest and most areally extensive loess deposit in the Great Plains (Bettis et al., 2003). This loess unit typically is calcareous, massive, light yellowish tan to brown in color, and has silt loam textures. Peoria Loess accumulated in the Great Plains between ca. 25–11 ka (Bettis et al., 2003; Mason et al., 2007). The Brady Geosol, developed in the Peoria Loess but only