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Chronology and provenance of last-glacial (Peoria) loess in western Iowa and paleoclimatic implications

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ABSTRACT

Geologic archives show that the Earth was dustier during the last glacial period. One model suggests that increased gustiness (stronger, more frequent winds) enhanced dustiness. We tested this at Loveland, Iowa, one of the thickest deposits of last-glacial-age (Peoria) loess in the world. Based on K/Rb and Ba/Rb, loess was derived not only from glaciogenic sources of the Missouri River, but also distal loess from non-glacial sources in Nebraska. Optically stimulated luminescence (OSL) ages provide the first detailed chronology of Peoria Loess at Loveland. Deposition began after ~27 ka and continued until ~17 ka. OSL ages also indicate that mass accumulation rates (MARs) of loess were not constant. MARs were highest and grain size was coarsest during the time of middle Peoria Loess accretion, ~23 ka, when ~10 m of loess accumulated in no more than ~2000 yr and possibly much less. The timing of coarsest grain size and highest MAR, indicating strongest winds, coincides with a summer-insolation minimum at high latitudes in North America and the maximum southward extent of the Laurentide ice sheet. These observations suggest that increased dustiness during the last glacial period was driven largely by enhanced gustiness, forced by a steepened meridional temperature gradient.

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Introduction

One of the most remarkable aspects of the last glacial period was the increase in overall planetary dustiness. Deep-sea cores, ice cores, lake cores, soils, and loess deposits all document greater entrainment, transport and deposition of dust over much of the Earth at the time of the last-glacial maximum, or LGM (Mahowald et al., 2006; Kohfeld and Tegen, 2007; McGee et al., 2010; Muhs, 2013). The cause of the greater global dust flux during the LGM, as well as previous glacial periods, has been hypothesized to include such factors as stronger winds, increased aridity, a decreased intensity of the hydrological cycle, decreased vegetation cover, increased source areas (such as continental shelves), and increased sediment availability (such as glaciogenic silts). In a recent review, McGee et al. (2010) speculated that of these factors, increased "gustiness," defined by them as the strength and prevalence of dust-transporting winds, was the primary driver of greater global dustiness. [We note for clarity that the definition of "gustiness" as given by McGee et al. (2010) is not identical with that of the World Meteorological Organization (2008) wherein gustiness is defined as "…the extent to which wind is characterized by rapid fluctuations, and single fluctuations are called gusts."]. Enhanced gustiness, as defined by McGee et al. (2010), is inferred to be due to a greater meridional temperature contrast during the LGM.

Western Iowa is home to some of the thickest deposits of last-glacial age (Peoria) loess in the world (Fig. 1). Peoria Loess is found in the north–south-trending, ~300 km long, Loess Hills area of western Iowa and part of adjacent Missouri, with thicknesses ranging from ~25 to ~40 m. Loess in western Iowa has attracted the attention of geologists for almost a century (Carman, 1917, 1931; Kay and Apfel, 1929; Hutton, 1947; Ruhe, 1954, 1969, 1983; Simonson and Hutton, 1954; Daniels and Handy, 1959; Daniels et al., 1960; Bettis, 1990; Forman et al., 1992; Muhs and Bettis, 2000, 2003; Forman and Pierson, 2002). Despite the many years of study, there are still uncertainties about the depositional history of loess in western Iowa. Foremost among these are the precise chronology and conflicting hypotheses about the source of the loess. Both issues are critical to modeling dust flux and its effects on climate (Mahowald et al., 2006; Kohfeld and Tegen, 2007).

Uncertainties about the timing of loess deposition in western Iowa stem largely from a lack of suitable materials for radiocarbon dating. The existing radiocarbon chronology, summarized by Bettis et al. (2003), is based primarily on ages reported by Ruhe (1969, 1983), Ruhe et al. (1971), and Forman et al. (1992). Although these ages confirm that Peoria Loess in western Iowa is indeed of last-glacial age, the

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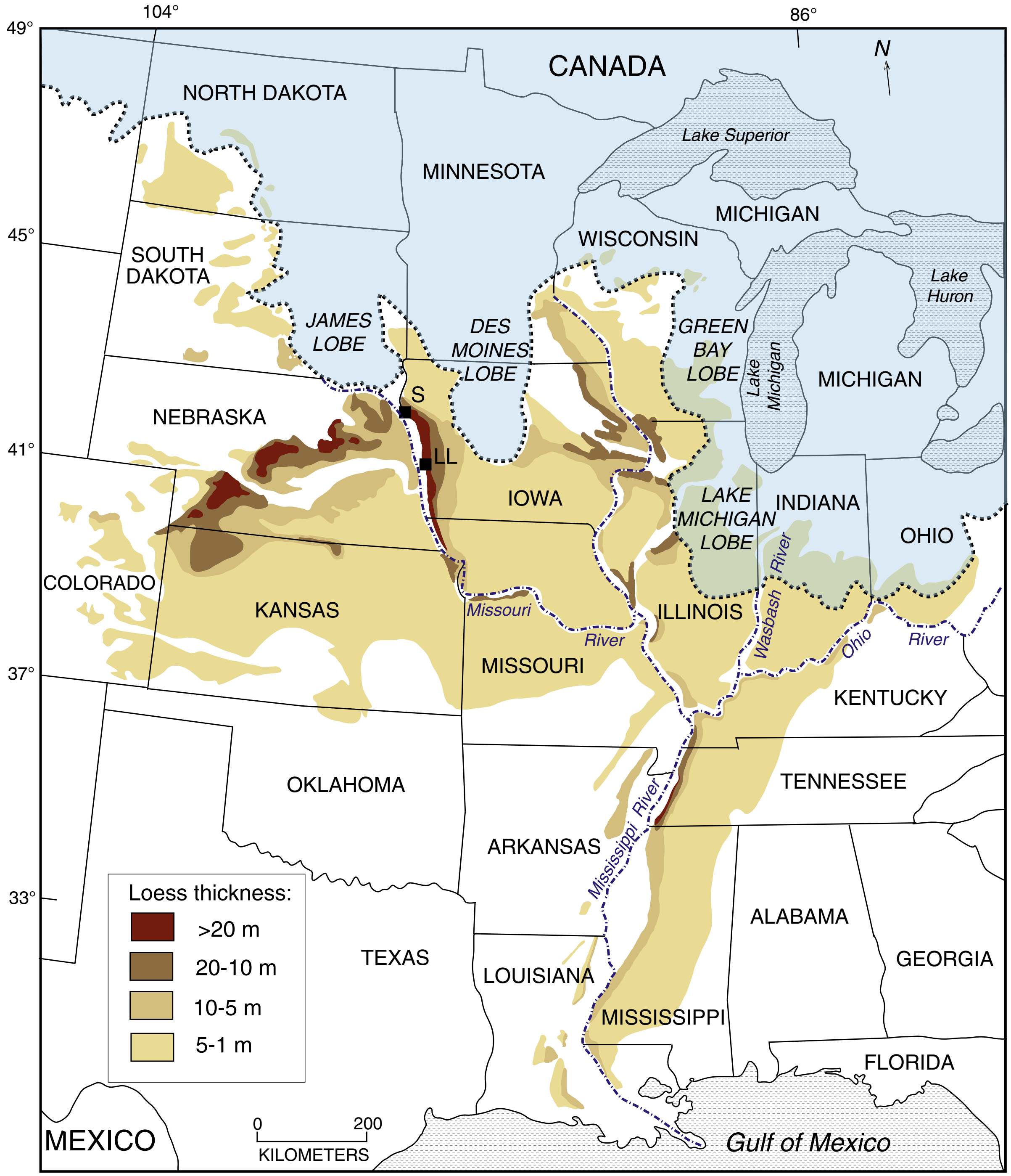

Figure 1. Distribution and thickness of loess, mostly Peoria Loess of last-glacial age, in central North America. Also shown (dashed line) is the maximum late-Wisconsin (last glacial) extent of the Laurentide ice sheet (light blue). Loess thickness and distribution taken from compilation in Bettis et al. (2003) and sources therein; Laurentide ice sheet extent generalized from Fullerton et al. (2003, 2004). LL, Loveland; S, Sioux City.

majority of radiocarbon determinations are maximum-limiting ages on organic materials in what was called the Farmdale Soil (=Farmdale Geosol) by Willman and Frye (1970), which underlies Peoria Loess. Far fewer ages are available for materials within Peoria Loess itself, and what few ages exist are mostly from disseminated organic matter of uncertain provenance.

The development of luminescence dating techniques has provided an independent means of dating eolian sediment that lacks organic materials suitable for radiocarbon dating. While early thermoluminescence (TL) dating in western Iowa yielded a number of stratigraphically inconsistent age estimates (Norton and Bradford, 1985), later work by Forman et al. (1992), using TL ages, and Forman and Pierson (2002), using infrared stimulated luminescence (IRSL) ages, gave better results. However, these studies were concerned primarily with pre-Peoria loess units, and only the oldest parts of Peoria Loess were dated.

Several studies (Daniels et al., 1960; Ruhe et al., 1971; Ruhe, 1983) have documented the existence of "dark bands," thin horizontal zones of darker color and slightly higher organic matter content, interpreted to be minimally developed soils. If this interpretation is correct, loess sedimentation was likely discontinuous, with periods slow enough for at least recognizable soil development. Furthermore, the lowermost zones of Peoria Loess in western Iowa do not contain