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Origin and significance of loess in late Paleozoic western Pangaea: A record of tropical cold?

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ABSTRACT

Loess is abundant today, primarily in mid- to high-latitude regions, and is well recognized as a high-fidelity archive of terrestrial climate change. Much of this 'Quaternary' loess is linked either directly or indirectly to glacial and associated cold-weathering processes, as such processes are highly effective in generating the silt size so characteristic of loess. Loess deposits have been poorly documented in the pre-Quaternary record, but are increasingly well recognized in the late Paleozoic of western equatorial Pangaea, particularly in and surrounding the region of the Ancestral Rocky Mountains of western North America. Siltstone deposits here range from true 'loessite' to eolian silt that ultimately accumulated in a variety of continental and marine environments. These strata include the thickest 'dust' deposits yet documented in the geologic record. Following the lower to middle Paleozoic record of carbonate deposition that prevailed over much of western equatorial Pangaea, silt first appeared in the latest Devonian, became widespread in the late Carboniferous (Pennsylvanian), and persisted, but with diminishing importance, through the Permian. Atmospheric 'dustiness' clearly varied on a high-frequency scale as well, evinced by, e.g. loessite-paleosol couplets or by variations in silt content of (glacioeustatic) stratigraphic 'cycles' that formed isolated from all but atmospherically derived detrital influx. Silt-rich units of this time interval are well sorted and blanket-like, with a mineralogical and geochemical composition that is, in many regions, characterized by immaturity. Detrital zircon data from several silt-rich (loessitic) accumulations within the Ancestral Rocky Mountains indicate significant first-cycle derivation from Precambrian basement composed of remarkably coarse-grained protoliths. The great volume, mineralogical and geochemical immaturity, basement derivation, and the timing that coincides with pulses of major Gondwanan cold (glacial) episodes are all most readily reconciled with silt genesis via glacial and associated cold-weathering processes, a hypothesis consistent with emerging indications of glacial and cold-weathering phenomena in the low-latitude Ancestral Rocky Mountains region. Such a concentration of loess in the tropics is remarkably nonuniformitarian and, we hypothesize, reflects a tropical climate system that was at times oddly cold and semi-arid. Beyond its importance as a climatic archive, eolian 'dust' also acts as a potentially potent agent of climate change, e.g. through effects on radiative forcing, cloud and storm formation, and through the biogeochemical repercussions of dusting marine and terrestrial ecosystems with such a large volume of highly chemically reactive and nutrient-bearing material. The late Paleozoic interval may well rank as the dustiest in Earth history, and thus yield important insights to the causes and consequences of mineral aerosols on Earth System processes and feedbacks of our most recent pre-Quaternary icehouse.

1. Introduction

Loess, or terrestrial eolian silt, covers a substantial area of Earth's mid- to high-latitude surface today and is well recognized as a high-fidelity archive of terrestrial climate change and atmospheric circulation for the Plio–Pleistocene (e.g., Kukla et al., 1988; Porter, 2001; Muhs and Bettis, 2003). In addition to its role as a climatic archive, eolian 'dust' (including silt and finer sizes) can be an *agent* of climate change, via both direct and indirect effects on radiative forcing and atmospheric moisture, and through feedbacks involving, e.g. nutrient delivery, productivity and atmospheric CO_2 (e.g., Martin, 1990; Tegen et al., 1996; Ridgwell, 2003; Mahowald et al., 2006). Until recently, pre-Pliocene examples were rare, but loess and associated eolian silt are increasingly well recognized in the late Paleozoic record, especially in what was western equatorial Pangaea (western North America). The concentration and distribution of silt(stone) here is remarkable, especially given the challenge of making silt in large volume (references below) and its 'nonuniformitarian' distribution within the tropics. In this paper, we begin by reviewing lessons from the recent loess and silt record, focusing on the fundamental issue of silt generation. We then summarize both new and published data on

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stratigraphic, sedimentologic, geochemical, and detrital zircon analyses of several upper Paleozoic loessite accumulations to investigate the history of loess(ite) and associated eolian silt(stone) deposition in the Carboniferous–Permian record of western equatorial Pangaea. Our findings address the origin of silt in this system, its paleoclimatic significance and implications for its broader effects on the late Paleozoic tropical Earth system. We hypothesize that the remarkable abundance of silt in western equatorial Pangaea derives fundamentally from icehouse conditions, accentuated by large-scale orogeny and evolving monsoonal circulation.

2. Methods

Qualitative assessment of the volume and age of loess- and eolian silt-rich strata of western equatorial Pangaea was accomplished through a literature search to identify (1) units of confirmed (published) loessitic or eolian silt origin, and (2) 'anomalously' silt-rich units, i.e. those for which silt forms a predominant proportion, commonly to the exclusion of other clastic grains. A loessitic interpretation for many upper Paleozoic silty units of the western U.S. is a relatively recent development, with Murphy (1987) applying the first explicit interpretation of 'loess' for an upper Paleozoic silty unit. Since this interpretation, many other units of this region and age have been reinterpreted to be of loessitic origin or ultimate loessitic derivation (see later discussion). However, many analogous silty units of late Paleozoic age remain of suspect origin. Hence, in the literature compilation provided here, we include these 'suspect' units and use the phrase 'silt-rich' to indicate that the published lithologic description noted silt as a predominant proportion of the unit, i.e., 'silt' is used prominently in the description (indicating >50% siliciclastic silt). Furthermore, we have restricted this compilation to silt-rich units that are neither associated with known clastic wedges (i.e., fluviodeltaic feeders), nor with systems characterized by a full spectrum of siliciclastic grain sizes. In the case of predominantly carbonate successions that are included in this compilation, silt forms the only (or greatly predominant) siliciclastic grain-size present. Age designations for many of these commonly nonfossiliferous units are poorly constrained. Ages used here are those of the cited sources, and/or are derived from stratigraphic correlation charts (Ballard et al., 1983; Hills and Kottlowski, 1983; Childs, 1985; Hintze and coordinator, 1985; Adler, 1987; Mankin, 1987; Kent et al., 1988; Baars, 1990; Kues and Giles, 2004), and thus should be taken as provisional.

Framework mineralogy for units reported here were determined by point counts of thin sections using an automated point-count stage affixed to a standard petrographic microscope. These counts were done using polished thin sections that were slightly etched to highlight plagioclase feldspar, and stained for potassium feldspar. Each sample represents 400 framework grains (>2000 points in some carbonate-rich samples) counted by a single operator (G.S. Soreghan), using the Gazzi–Dickinson method (Ingersoll et al., 1984) as modified to include grains as fine as the lower limit of visual identification (effectively <10–15 μm).

Detrital zircons for provenance analysis were concentrated from loessite samples using standard crushing, grinding, shaking (Wilfley) table, heavy liquid and magnetic separation techniques. Zircons from two Cutler Formation siltstones (CUT04-VI-5.5 and CUT04-XII-133) were analyzed using conventional isotope dilution-thermal ionization mass spectrometry (ID-TIMS) methods at the Jack Satterly Geochronology Laboratory at the University of Toronto. Representative grains from each sample were selected from non-paramagnetic separates by hand-picking under a binocular microscope and were air-abraded to reduce surface-correlated Pb-loss, according to the method of Krogh (1982). Detailed analytical methods are provided in the footnote to Table 4. Uncertainties for the ID-TIMS data are presented in the table, plots and text at the 95% (2σ) confidence level.

Detrital zircons from one sample (Bravo Dome loessite, P41.25) were analyzed using *in situ* ion probe methods, with the sensitive, high-resolution ion microprobe (SHRIMP II) at the Geological Survey of Canada, Ottawa. Detailed analytical and data-reduction procedures are provided in the footnote to Table 4 and in M. Soreghan et al. (2002b). Uncertainties for the SHRIMP data are presented at the 68% (1σ) confidence level.

Decay constants used in U–Pb age calculations are those of Jaffey et al. (1971). Graphical data presentation and quoted ages were generated using the Microsoft Excel Add-in Isoplot/Ex v. 3.00 of Ludwig (2003).

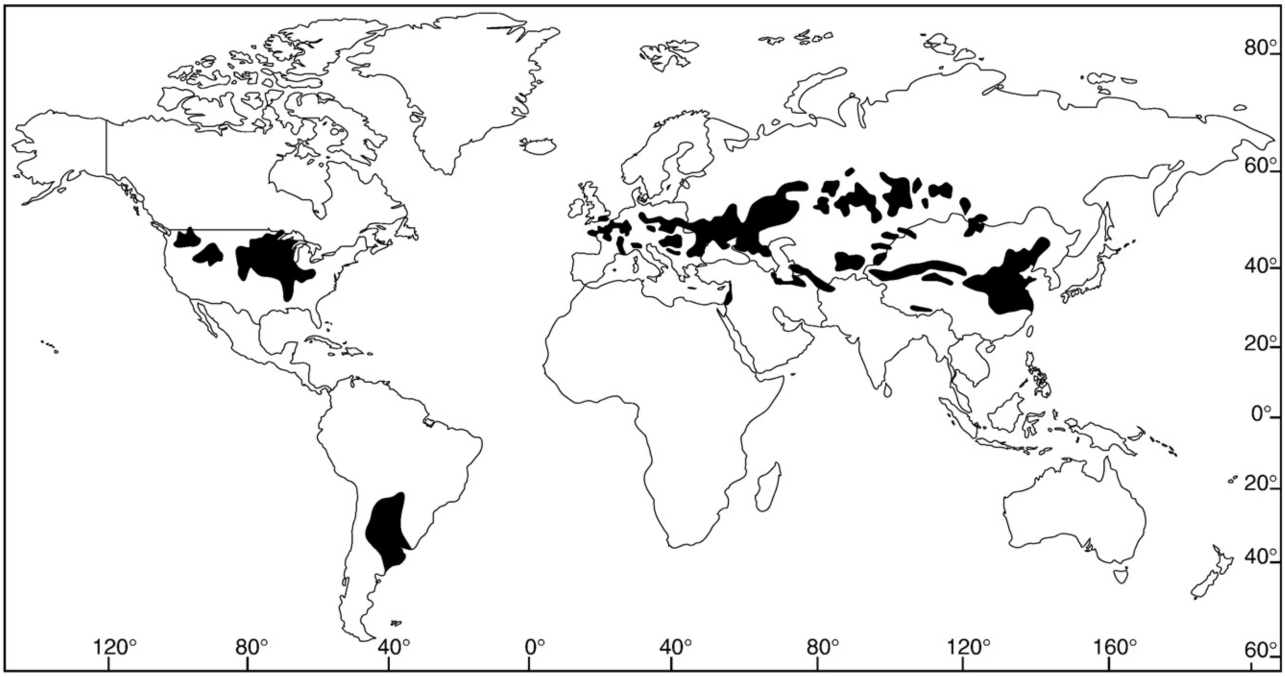

Fig. 1. Global distribution of 'modern' (Plio–Holocene) loess (modified from Pécsi, 1990).