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# Wind-Strength Variations Inferred from Quartz Grain-Size Trends in the Maroon Formation Loessite (Pennsylvanian-Permian, Colorado, U.S.A.)

K.M. Moreland, School of Geology and Geophysics, University of Oklahoma, 100 E. Boyd Street, Norman, OK 73019 (kmmorel@ou.edu)

M.J. Soreghan, School of Geology and Geophysics, University of Oklahoma, 100 E. Boyd Street, Norman, OK 73019 (msoreg@ou.edu)

G.S. Soreghan, School of Geology and Geophysics, University of Oklahoma, 100 E. Boyd Street, Norman, OK 73019 (lsoreg@ou.edu)

## Introduction

Understanding past climates of the Earth is of fundamental importance in predicting and managing future climate change. Late Paleozoic Pangea, in particular, is of significant interest to paleoclimatologists because the configuration of this supercontinent is hypothesized to have greatly perturbed Earth's climatic system. The pole-to-pole land distribution and cross-latitudinal orientation of Pangea have led many to suggest extreme monsoonal circulation and strong seasonality for the Pangean interval (e.g. Robinson, 1973; Parish, 1993). The initiation and temporal evolution of Pangea's megamonsoon was also likely modulated by higher frequency glacial-interglacial climate fluctuations that are well preserved in the upper Paleozoic loess-paleosol sequences of the western U.S. (Soreghan et al., 2002). Previous studies have shown that similar sequences present in the Chinese Loess Plateau serve as high-resolution records of Plio-Pleistocene climate change. Grain-size analysis of the quartz fraction in particular (Porter et al., 1995; Xiao et al., 1995) has been used as a proxy indicator of monsoon wind strength, while increases in magnetic susceptibility values represent times of pedogenesis during interglacials (Maher and Thompson, 1992). This study attempts to extend such techniques to very ancient loess successions of the Late Paleozoic to assess atmospheric circulation patterns (wind strength and variation) in western equatorial Pangea.

The Pennsylvanian Maroon Formation loessite is located within the eastern Eagle basin (northwest Colorado) and consists of approximately 700 m of lithified loess (eolian silt) punctuated with numerous interbedded paleosols. It accumulated during the Late Pennsylvanian-Early Permian (ca. 300 Ma) in western equatorial Pangea at paleolatitudes of approximately 5°-10° N (Johnson, 1989). The loess-paleosol sequences exposed in this unit exhibit significant variations in magnetic susceptibility and record glacial-interglacial climate fluctuations of Pangea (Soreghan et al., 1997; Tramp et al., in review). The loess units represent relatively arid glacial periods marked by high dust influx, whereas paleosols record more humid interglacials with decreased silt influx and enhanced pedogenic activity. In this study, we present preliminary data on variations in quartz grain-size within several loessite-paleosol (glacial-interglacial) couplets and of the Maroon Formation, and we assess their possible paleoclimatic significance.

## Methods

The loessite of the Pennsylvanian Maroon Formation is well lithified and not easily disaggregated, making standard grain-size analysis inappropriate. Consequently, we analyzed apparent grain-size using backscattered electron (BSE) microprobe images. For this study, cores of approximately 2.5 cm in diameter were drilled from the Maroon Formation using a portable gas-powered and water-cooled drill. Samples were collected from 3 consecutive loessite-paleosol couplets at the base, middle, and top of the 700 m section, for a total of 9 couplets and 69 samples. We prepared polished microprobe rounds and collected 10 BSE images for each sample (Fig. 1a); and, minerals were identified by their gray levels (intensities) and textures. The digital images were then imported into Adobe Photoshop 5.5 for image processing designed at isolating quartz grains, with a target of 800 quartz grains per sample. Owing to its resistance to chemical weathering, which is common in both pedogenic and diagenetic environments, quartz constitutes a more reliable proxy for paleowind strength (cf. Porter and An, 1995; Xiao et al., 1995). A series of filtering steps, including noise reduction, edge finding, and thresholding were employed to create binary images in which quartz grains were highlighted (Fig. 1b). Overall, this filtering routine worked relatively well but in some cases it was necessary to manually separate grain-to-grain contacts created by authigenic silica, and remove spurious pixels.

Each binary image was then imported into the National Institute of Health's (NIH) freeware software, NIH Image v. 1.62, for grain-size analysis. This program measures characteristics of individual grains, such as area, perimeter, and major and minor axes. The software allows the user to predefine a minimum quartz grain area for analysis (8 μm), eliminate grains touching edges, and fill in interior holes. Text file results were imported into Microsoft Excel for statistical analysis and, ultimately, for the determination of apparent (2D) quartz grain-size trends in single profiles as well as throughout the entire section.

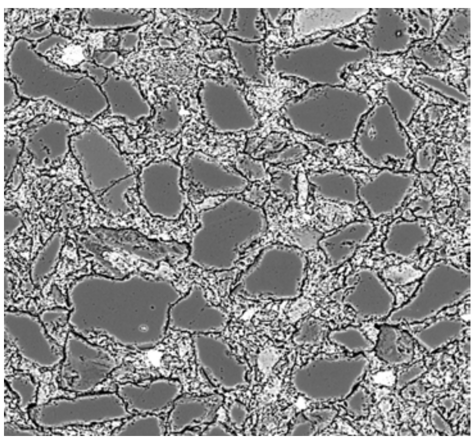

Figure 1a. BSE image for L28.9E

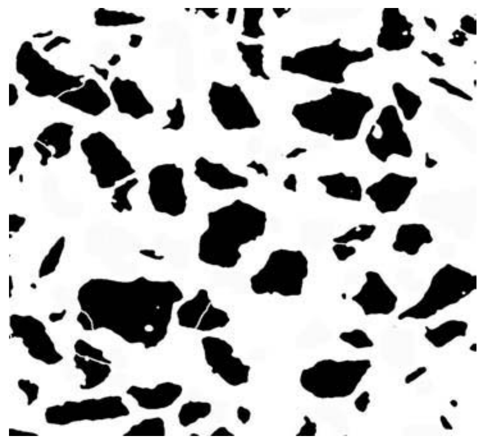

Figure 1b. Filtered binary image for L28.9E

## Results and Discussion

In general, median quartz grain area decreases both up through the entire Maroon Formation and from parent loessite to pedogenically altered loessite within any given loess-paleosol couplet (Fig. 2). Following the findings of Porter and An (1995) and Xiao et al. (1995), we relate the upwardly fining trends within individual couplets to decreased wind speeds during interglacials. We are still investigating the long-term temporal variation in quartz grain-size throughout the entire Maroon Formation, but we suggest that it may reflect the initiation and evolution of the megamonsoon in western equatorial Pangea during the Late Paleozoic. Additionally, the grain-size data also inversely tracks ($r^2 = 0.916$) previously collected magnetic susceptibility values throughout the section, such that finer quartz grain-size corresponds to higher magnetic susceptibility values, a result similar to that reported by Porter et al. (2001) for the Chinese Loess Plateau. Magnetic susceptibility varies in synchrony with glacial-interglacial cycles in this study, which is a relationship implying a dominant climatic control (G. Soreghan et al., 2002). We feel that this correlation ultimately allows us to extend the use of quartz grain-size as a proxy index for wind strength to this very ancient system.

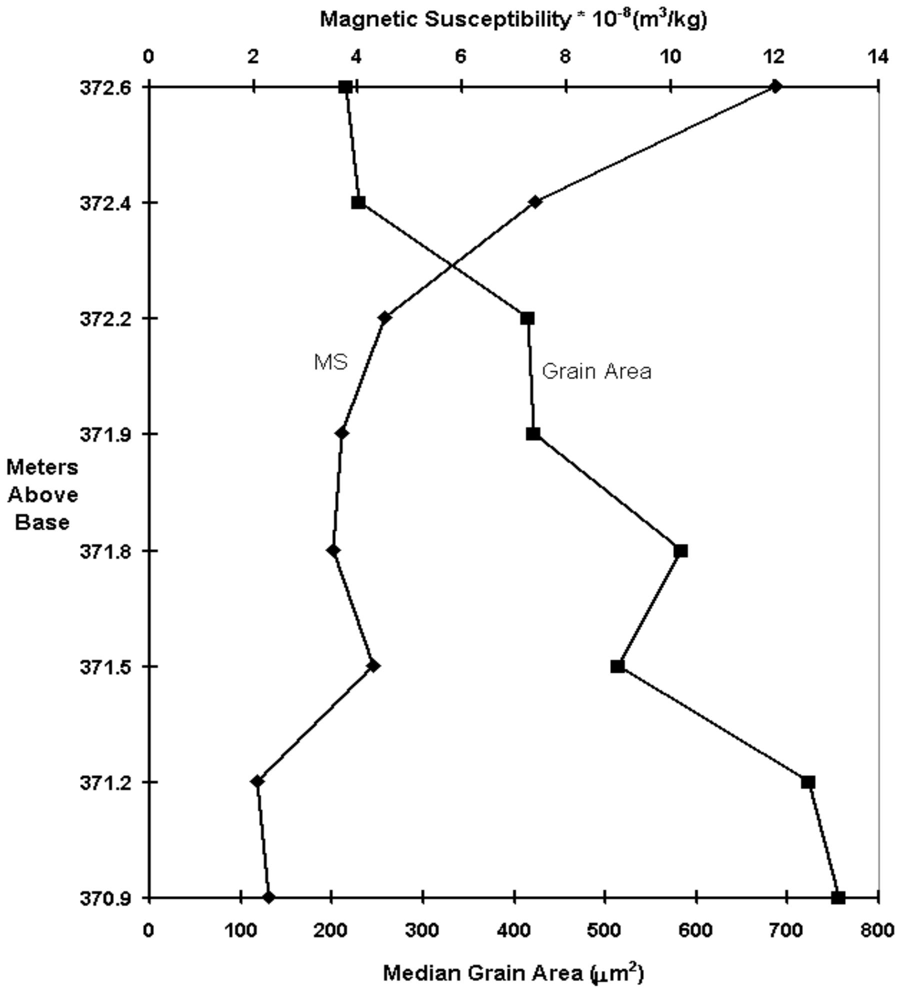


Figure 2. Median grain area (squares) and magnetic susceptibility (diamonds) versus stratigraphic position for middle section

## Conclusions

(1) Grain-size analysis of lithified loessite can be performed by applying filtering routines to 2D backscattered electron (BSE) images.

(2) In the Pennsylvanian Maroon Formation, apparent quartz grain-sizes decrease upward within individual loess-paleosol couplets, reflecting a decreased wind strength associated with the transition from glacial to interglacial conditions.

(3) Quartz grain-size and magnetic susceptibility are inversely correlated, suggesting a primary climatic control on both parameters.

(4) This study suggests that techniques utilized for Plio-Pleistocene paleoclimatic analysis are also applicable to very ancient loessite successions.

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