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Geochemistry and Detrital Zircon Geochronology of Upper Paleozoic Loessite within the Ancestral Rocky Mountains: Implications for Paleoclimate

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Introduction:

There is a growing recognition of the presence and significance of loessite adjacent to and within the greater Ancestral Rocky Mountains (ARM) (Murphy, 1987; Johnson, 1989; Soreghan, 1992; Kessler, et al., 2001; Soreghan, et al., in press; Tramp, et al., in review;). These upper Paleozoic loessites commonly form thick, highly cyclic deposits that have been interpreted to record climate fluctuations on a glacial-interglacial scale (e.g., Johnson, 1989; Soreghan et al., 1997; Kessler et al., 2001; Soreghan, et al., in press). Their presence at equatorial latitudes of the western margin of the Pangean supercontinent is significant, because Pangea's size and cross-latitudinal orientation have led many to suggest extreme climatic conditions for the Pangean interval. Pangea's size and cross-latitudinal orientation would have produced cross-equatorial pressure contrasts in both seasons, with a low-pressure cell in each summer hemisphere and a high-pressure cell in each winter hemisphere. Clearly, the circulation models generated for late Paleozoic/early Mesozoic Pangea provide us with testable hypotheses for atmospheric circulation; but at a relatively crude spatial resolution. Further, the actual geologic data from eolian sandstone paleocurrents yield excellent indications of the sand-transporting winds, but (1) are somewhat noisy for Pennsylvanian and early Permian time (Parrish and Peterson, 1988), (2) do not necessarily record subordinate winds (and potentially, seasonality), and (3) yield no data for the truly equatorial ($<5^{o}$) region.

The primary objective of this study is to utilize whole-rock geochemistry and detrital zircon geochronology to characterize the provenance of several ancient loessite and eolian-marine siltstone deposits of the ARM region (western equatorial Pangea) in order to delineate paleodispersal and thereby paleoatmospheric circulation in late Paleozoic time. The age spectra of detrital zircons from four loessite sections representing Middle Pennsylvanian (Desmoinesian) to Early Permian (Wolfcampian) times vary significantly, reflecting changing provenances attributable to temporal and spatial shifts in winds. Our preliminary geochemical data also suggests that a significant volume of the loess was derived from basement sources within the ARM region itself.

The Nature of Upper Paleozoic Loessite

The origin of the silt-sized material that composes loess(ite) and reworked loess(ite) remains somewhat controversial. Assallay et al. (1998) suggested that large-scale production of silt is attributable primarily to glacial processes and intense weathering in high, cold, mountainous regions (cf. Smalley 1966); however, others have noted the possibility of significant silt production via, for example, salt weathering and eolian abrasion in deserts (e.g., Goudie et al., 1979), and chemical weathering in tropical regions (Nahon and Trompette, 1982). One significant consequence of the possible silt formation mechanism(s) is that silt can be generated directly from basement sources (first-cycle; Pye, 1985), or can be recycled from pre-existing silt-bearing strata. Thus, *in situ* weathering products can be directly deflated to produce silt, although an intermediate stage of fluvial transport is commonly involved (Pye, 1996).

Detrital Zircon Geochronology: Preliminary findings

We have studied four upper Paleozoic loessitic sections within the ARM region: 1) Naco Group (Pedregosa basin, Arizona); 2) Hermosa and Cutler Groups (Paradox basin, Utah; 3) Maroon Formation (Eagle basin, Colorado) 4) Abo Formation (Bravo dome, New Mexico). All four sections represent significant (>100 m) accumulations of lithified loess that have been dated and studied previously (Johnson, 1989; Soreghan, 1992; Kessler et al., 2001; Soreghan, et al., in press; Tramp et. al., in review). Each section has been logged in detail to discern the sedimentologic character of the siltstone and define its depositional setting and degree of (paleo)pedogenic overprinting. Samples for detrital zircon U-Pb geochronology were collected from stratigraphically discrete (50 cm) horizons, and were processed and analyzed at the Geochronology Laboratory of the Geological Survey of Canada (GSC) using the Sensitive High-Resolution Ion Microprobe (SHRIMP II). The mounted zircon grains were chosen at random for ion-probe analysis and over 500 grains were analyzed in total.

Zircons from two Desmoinesian samples (Naco Group, Arizona, Hermosa Group, Utah) show a dominant mode between 1800-1600 Ma, reflecting the Yavapai/Mazatzal terranes coring the Ancestral Rockies uplifts and suggesting northeasterly winds for both localities. Both samples also contain a secondary cluster of Grenville-age grains (1000-1300 Ma) and grains ranging in age from 440-370 Ma, reflecting a south-southeasterly source (e.g. Mexico/Texas). Age spectra for the seven Wolfcampian samples (three from the Abo Formation, New Mexico, three from the Maroon Formation, Colorado, and one from the Lower Cutler Beds, Utah) differ both temporally and spatially. The New Mexico loessite exhibits a temporal change from exclusively 1340-1400 Ma zircon grains near the base of the section, reflecting local basement sources (e.g. Southern Granite-Rhyolite province), to a large mode of 1800-1600 Ma grains at the top of the section, reflecting derivation from the Yavapai/Mazatzal terrane. Significantly, the one Wolfcampian Utah sample analyzed thus far lacks the 1800-1600 Ma zircon population, whereas the three samples from Colorado show a variable number of grains in this age mode. The difference in the abundance of the Paleoproterozoic zircon grains may reflect the locations of these loessites on opposing sides of the "core" Ancestral Rockies uplifts within a strong westerly wind regime. Inferred easterly winds for Middle Pennsylvanian time matches predictions of zonal circulation models, and the presence of both northerly and southerly directions may reflect time-averaged fluctuation of the inter-tropical convergence zone (ITCZ). In contrast, our data indicate that monsoonal circulation and attendant westerly winds were established by earliest Permian time, but evolved during the Wolfcampian.

Whole-rock geochemistry: Preliminary findings

Samples for whole-rock geochemistry were collected from three of the four loessite study sections from intervals that were interpreted as pedogenically unmodified loesites using sedimentologic and rock magnetic characteristics. The powders were analyzed for major-element oxides and selected trace elements using x-ray fluorescence spectrometry (XRF) after being treated with a 1 N solution of HCl in order to remove the carbonate phases.

The major-element abundances of the loessites show temporal and spatial differences that can be attributed to changes in source material. However, deciphering whether the changes in source material are attributable to changes in source lithology or in degree of weathering of source material is complicated. Nevertheless there are several generalizations that can be made. First, the loess appears to be highly unweathered in terms of bulk composition. For example, the loessite exhibits a low chemical index of alteration (CIA, Nesbitt and Young, 1982) of 59.2±3.3. The CIA is an index of chemical maturity calculated from the ratio of Al_2O_3 to the sum of Al_2O_3, CaO, Na_2O, and K_2O. By comparison, unweathered granite and granodiorite yield CIA values of 45-55, whereas average shales yield CIA values of 70-75 (Nesbitt and Young, 1982). Therefore the whole-rock geochemistry of the loessite is indicative of minimal weathering and more reflective of derivation from crystalline basement source rather than derivation from recycled sedimentary rocks or significant weathering of basement prior to accumulation. In detail, the Utah loessite from the Lower Cutler Beds exhibits a higher CIA relative to the Maroon Formation loessite (Colorado) or to the Abo Formation loessite (New Mexico). This may reflect slightly higher degree of weathering in Utah relative to Colorado or New Mexico and is consistent with westerly winds during the Wolfcampian. Alternatively the sources for the loess in the Lower Cutler Beds during the Wolfcampian may have been less dominated by basement sources of the ARM region, again consistent with our interpretations based on the detrital zircon data. Other geochemical indicators, such as the ratio of K_2O/Al_2O_3 vs. Na_2O/Al_2O_3 also reveal compositional differences between the Utah and the other two sites that may be attributable to differences in source material.

Conclusions:

The combined detrital zircon and geochemical data for the Upper Paleozoic loessites, which accumulated within the ARM region, suggest that the ARM basement uplifts were the source of much of the silt. In terms of paleoclimate, during Desmoinesian (Middle Pennsylvanian) time, our data are consistent with the inference that atmospheric circulation was zonal within low northern latitudes of western Pangea and comprised dominant northeasterly winds and attendant southeasterly winds. The southerly flow may reflect seasonal fluctuations of the ITCZ. For Wolfcampian (Early Permian) time, we infer a change in atmospheric circulation, marked by a significant westerly provenance signature, particularly in the Utah and New Mexico sections. However, the signature of this westerly flow in the detrital-zircon age spectra is different between the two Wolfcampian sections because of their respective locations on opposing sides of the Ancestral Rocky Mountains. The whole-rock geochemistry of the loess appears consistent with these interpretations. These explanations generally support previous models of paleowind patterns in western Pangea based on eolian cross-bed data. Unlike eolian sandstone, however, loessite preserves a record of both weak and strong winds, as evidenced in the multiple source directions within the zircon data. Moreover, unlike eolian sandstones, upper Paleozoic loessites occur at equatorial latitudes and offer the potential of high-resolution records of atmospheric circulation because they commonly form thick, highly cyclic records of climate fluctuations on a glacial-interglacial scale (e.g., Johnson, 1989; Soreghan et al., 1997; Kessler et al., 2001; Soreghan, et al., in press).

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