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Sedimentological, geochemical, and magnetic analyses of pedogenesis in Maroon Formation loessite with paleoclimatic implications

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Paleosols developed on loess of the Chinese Loess Plateau preserve measurable magnetic susceptibility and geochemical trends linked to Plio-Pleistocene glacial-interglacial climate change (Heller and Liu, 1984; Kukla et al., 1988). We apply this modern analog to the late Pennsylvanian Maroon Formation loessite (lithified loess) of central Colorado (Fig 1) which contains approximately 200 interbedded paleosols within a nearly 1000 m section. The clastic late Pennsylvanian Maroon Formation was deposited in the Eagle basin surrounded by the Uncompaghre, Front Range and Sawatch uplifts. Interbedded fluvial channels and eolian sandsheet deposits provided a sediment source for a thick section of loess abutted against the Sawatch uplift. The loess accumulated intermittently with soils forming during periods of diminished loess deposition. In order to better understand the paleoclimate signal that the loess-paleosol couplets preserve, we identified and classified the paleosols using several pedogenic indicators including field and micromorphological description, and petrographic, geochemical, and rock magnetic analyses. First, we logged 700 m of the exposed section at centimeter scale noting individual paleosols including color, texture, structure, and other features (Retallack, 1988). Over 1500 samples were collected at an average spacing of 0.5 to 1.0 m in the parent loessite and 0.5 to 10 cm in paleosols. Magnetic susceptibility was measured and recorded on each sample (Fig 2).

Based upon the field descriptions and macroscopic ranking system (table 1), nine paleosols which span the range of pedogenic development were chosen for petrographic, micromorphological, and geochemical analysis. Pedogenic development is manifested by carbonate and clay enrichment in distinct zones and culminates as horizons in well developed paleosols. Pedogenic clay originated predominantly as allochthonous dust inputs as evidenced by normalizing major oxides to ZrO₂ as opposed to in situ weathering of labile grains (Mason and Jacobs, 1998; Reheis, 1990). These analyses allowed us to classify the paleosols into three types based upon degree of development and include Protosols with calcic and argillic modifiers, Argillisols, calcic Argillisols, and argillic Calcisols (following Mack et al., 1993). The magnetic susceptibility signal shows definite trends with high values in paleosols and low values in parent loessite (Fig 3). Rock magnetic analysis shows that the magnetic susceptibility signal is derived from ultra-fine grained magnetite (c.f. Soreghan et al., 1997) whereas the remnant magnetism resides in hematite. Peak magnetic susceptibility values were plotted against our macroscopic rank, micromorphological rank, and maximum carbonate value of the paleosol profile. Positive correlations suggest that magnetic susceptibility tracks degree of pedogenesis.

Additionally, magnetic susceptibility correlates positively with Al_2O_3 , K_2O , and clay-sized material and negatively with SiO_2 and quartz, which further bolsters the magnetic susceptibility-pedogenesis link.

The paleosols interbedded with the loessite of the Maroon Formation preserve sedimentologic, geochemical, and magnetic susceptibility trends. These signals can be used to evaluate level of pedogenic development from weakly developed (Protosols) to well developed (Calcisols). Additionally, the Maroon Formation paleosols formed under at least two fundamentally different climatic conditions characterized by Argillisols and Calcisols. They also potentially record high-frequency paleoclimate oscillations during the late Pennsylvanian superimposed on a regional semi-arid climate. Understanding frequency, intensity and nature of paleoclimate change in the Eagle basin of the Ancestral Rocky Mountains may help to answer questions about reservoir distribution, quality at both a regional and prospect scale, in addition to fundamental questions about local and regional paleoclimate.

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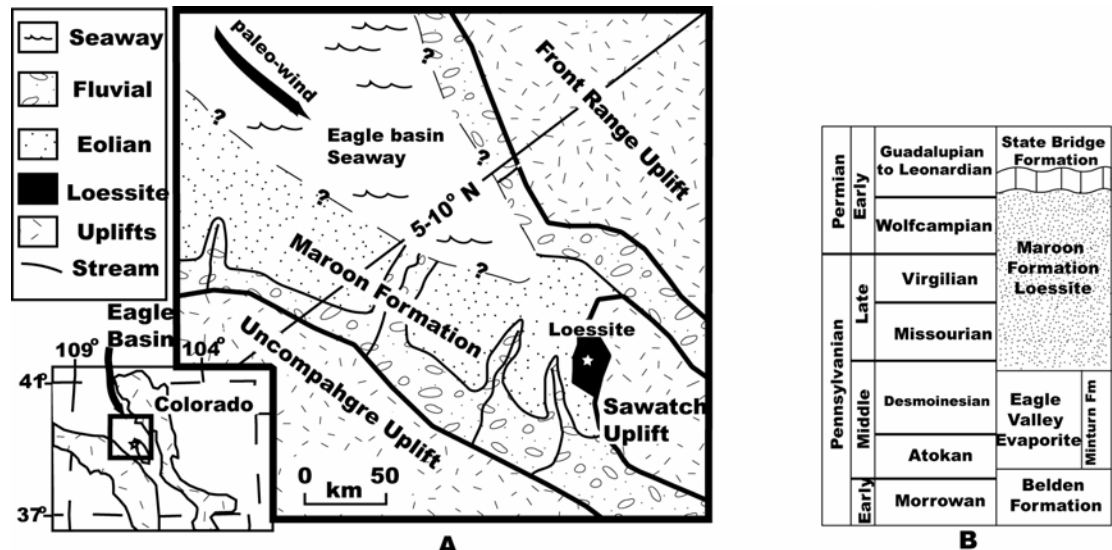


Figure 1. Paleogeography (A) and stratigraphic column (B) of late Paleozoic Eagle basin in the vicinity of the western Sawatch uplift. Insert places the Eagle basin in modern coordinates. The Maroon Formation loessite was deposited downwind of MaroonFormation eolian sandsheet deposits (Johnson,1989). Figures are modified from Mallory (1960,1972); De Voto (1972,1980); Johnson (1987); Johnson et al. (1993).

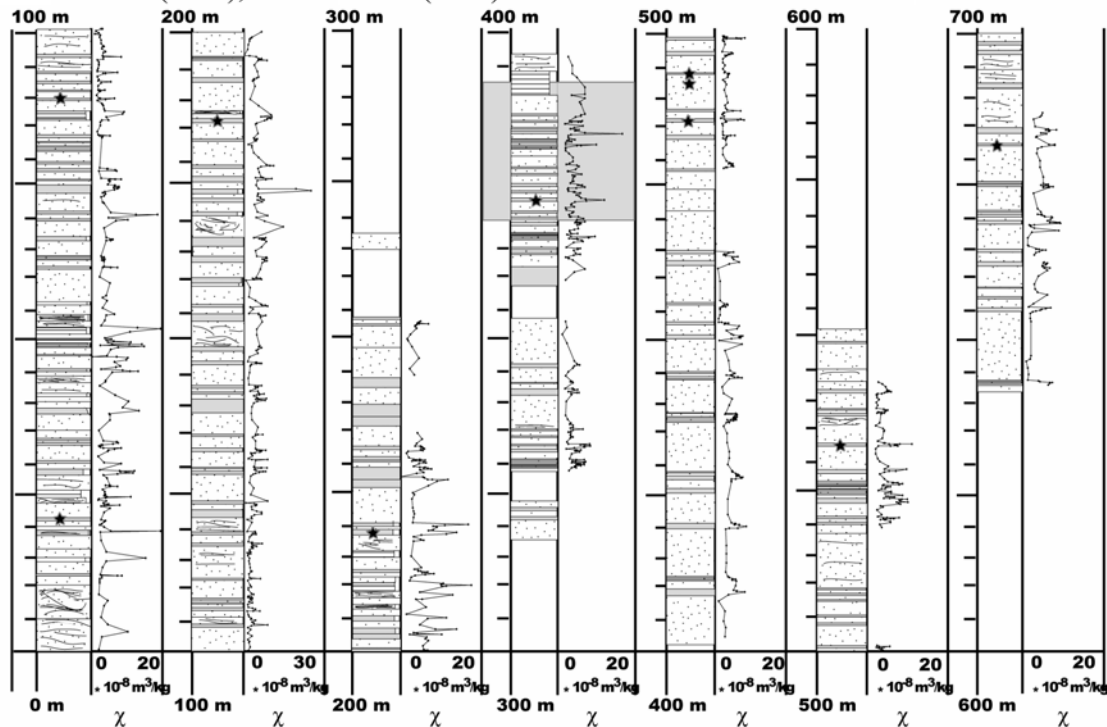


Figure 2. Magnetic susceptibility (c) of the studied section. Magnetic susceptibility exhibits high values in paleosols and low values in parent material loessite. Bottom is on the lower left and top of section on upper right. Stars indicate paleosols profiles chosen for detailed study. Large gray box indicates section described by Soreghan et al. (1997). Error bars are less than symbol size.

Field description	Macroscopic rating	Magnetic Susceptibility	Point counts	Micromorphology	Key geochemical data	Zr,Al,Ti ratios	Class**
	(points)	(m3/kg)	volume %	description	weight %		
Type I Reddish brown (10R 4/6) siltstone with gradational (0-0.5m) lower contact . Slight preserved pedogenic structure and/or root traces. Original sedimentary fabric intact.	range 1 to 5	range 4 to 5 * 10 ⁻⁸	carbonate rich zone (~10%) underlying clay rich zone (~30%)	Argillasepic to insepic ferriargillans in an intertextic fabric Rating = 1 to 2	MgO (~1.7-2.5%) peak; K ₂ O (~0.7-1%) peak	<1 s from mean parent material	Protosol, calcic Protosol, argillic Protosol
Type II Reddish brown(10R 4/6) siltstone with gradational lower contact up to 0.5 m. Possible preserved pedogenic structure and/or root traces. Original sedimentary fabric intact.	range 2 to 7	range 7.5 to 11 * 10 ⁻⁸	carbonate rich zone (~10-20%) underlying clay rich zone (~30-50%)	Agglomeroplastic to porphyroskelic fabric with skelsepic ferriargillans Rating =3 to 5	MgO (~2-3%) peak; K ₂ O (~2-5%) peak	1.6 to 4 s from mean parent material	Argillisol, calcic Argillisol
Type III Dark reddish-brown clayey siltstone with preserved pedogenic structure, reduction halos, and root traces, and gradational lower contact up to 1.0 m. Original sedimentary fabric obscured.	range 7 to 11	range 10 to 12 * 10 ⁻⁸	carbonate rich zone that ranges from 30 % to 80 %	Micritic, microsparite dolomite rich zone. Clayey micritic groundmass/floating skeletal grains. Rating = 6	MgO (~4.5%) peak; K ₂ O (~6.5%) peak	> 5 s from mean parent material	argillic Calcisol

Table 1. Brief description and classification of paleosols types. ** Classification based on Soil Survey Staff (1975) and Retallack (1990) and (Mack et al., 1993) ⁺ Dolosol is an adaptation of Mack et al., 1993 calcisol for paleosols in which dolomite is the only carbonate material