Lithologic and climatic controls on regolith transformation in the Southern Sierra Nevada, CA

UC DAVIS UNIVERSITY OF CALIFORNIA

Zhiyuan Tian, Peter C. Hartsough, Anthony T. O'Geen

Department of Land, Air and Water Resources, University of California, Davis, California, USA

Background

- Climosequence studies of soils in the Sierra Nevada found that pedogenesis is limited by precipitation (P) at low altitude and cold temperature (T) at high altitude[1]. A zone of intense weathering exists at 1100 m elevation, which is located just below the rain-snow transition line.
- Hypothesis: characteristics of weathered bedrock (thickness, degree of weathering) is regulated by lithology and the temperature.

Research Questions

1. **SOIL VS. WEATHERED BEDROCK**
   Does the degree of weathering in soil relate to that of weathered bedrock?
2. **REGOLITH THICKNESS**
   Does biotite content and mineral grain size of parent material influence regolith thickness?
3. **REGOLITH CHARACTERISTICS**
   Does regolith thickness regulate temperatures in a way that influences regolith characteristics?

Site Description

Two watersheds at the southern Sierra Nevada:
- Pine oak forest, rain-dominated (1100 m)
- Mixed conifer, snow-dominated (2000 m)

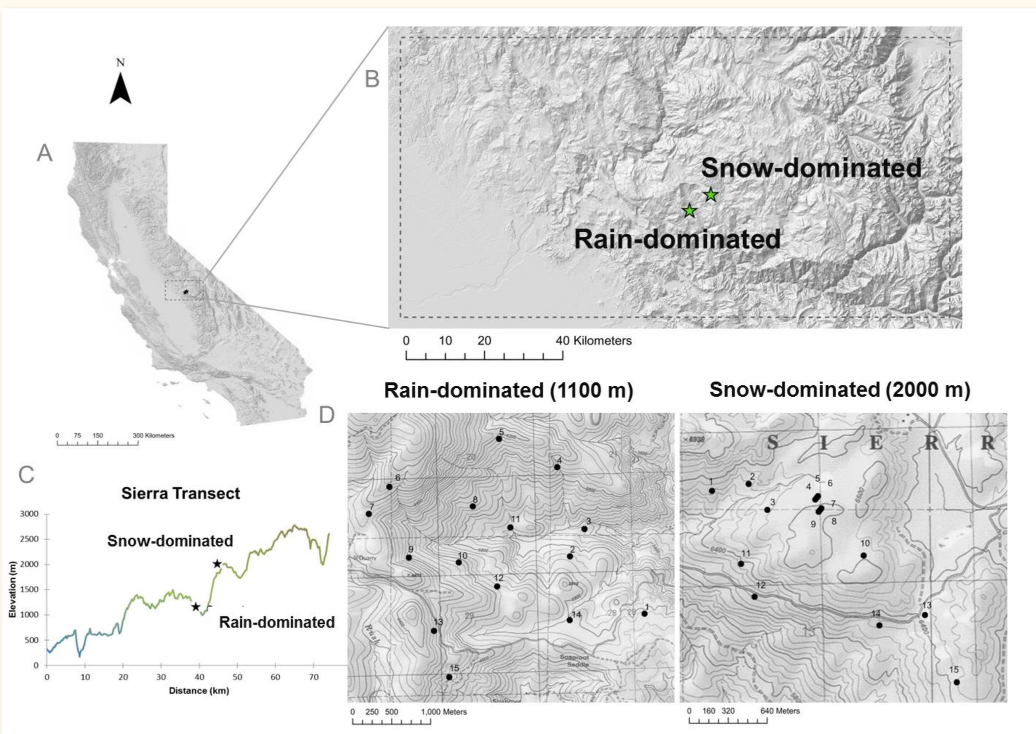


Figure 1. (A) Hillshade map of California; (B) Study area at the southern Sierra Nevada and Cross-section (C) of the elevation transect; sampling locations (D) were located in two catchments: rain-dominated (1100 m) and snow-dominated (2000 m).

Methods

Fifteen regolith cores at 1100 m and fourteen at 2000 m were collected to the depth of refusal by Geoprobe and hand-augering.
- Biotite grain counts under optical microscopy
- Particle size distribution with pipette method
- Extractable Fe by citrate-dithionite (Fe_d)

Characteristics of regolith

Table 1. Thickness of soil and weathered bedrock.

Rain-dominated (1100 m)	Soil (cm)	Weathered bedrock (cm)	Regolith (cm)
Mean thickness	153	326	434
Standard deviation	41	189	210
Snow-dominated (2000 m)	**Soil (cm)**	**Weathered bedrock (cm)**	**Regolith (cm)**
Mean thickness	154	504	658
Standard deviation	58	316	316

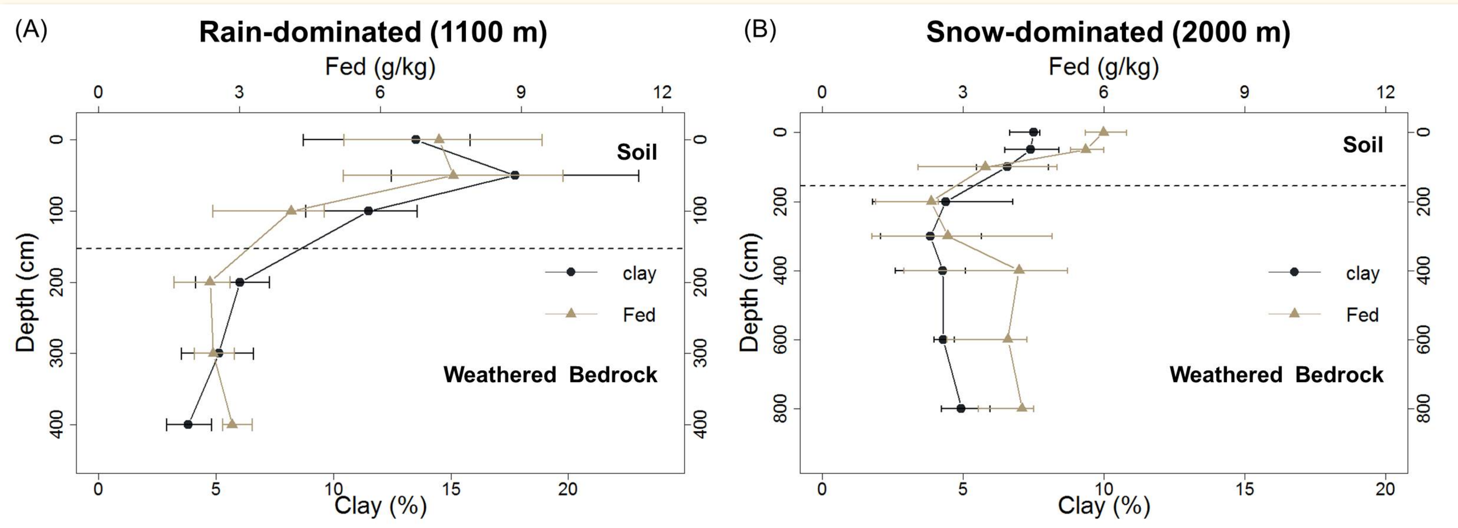


Figure 2. Clay and citrate-dithionite extractable Fe (Fe_d) of soil & weathered bedrock.

Factor 1. Mineral composition and texture control regolith thickness

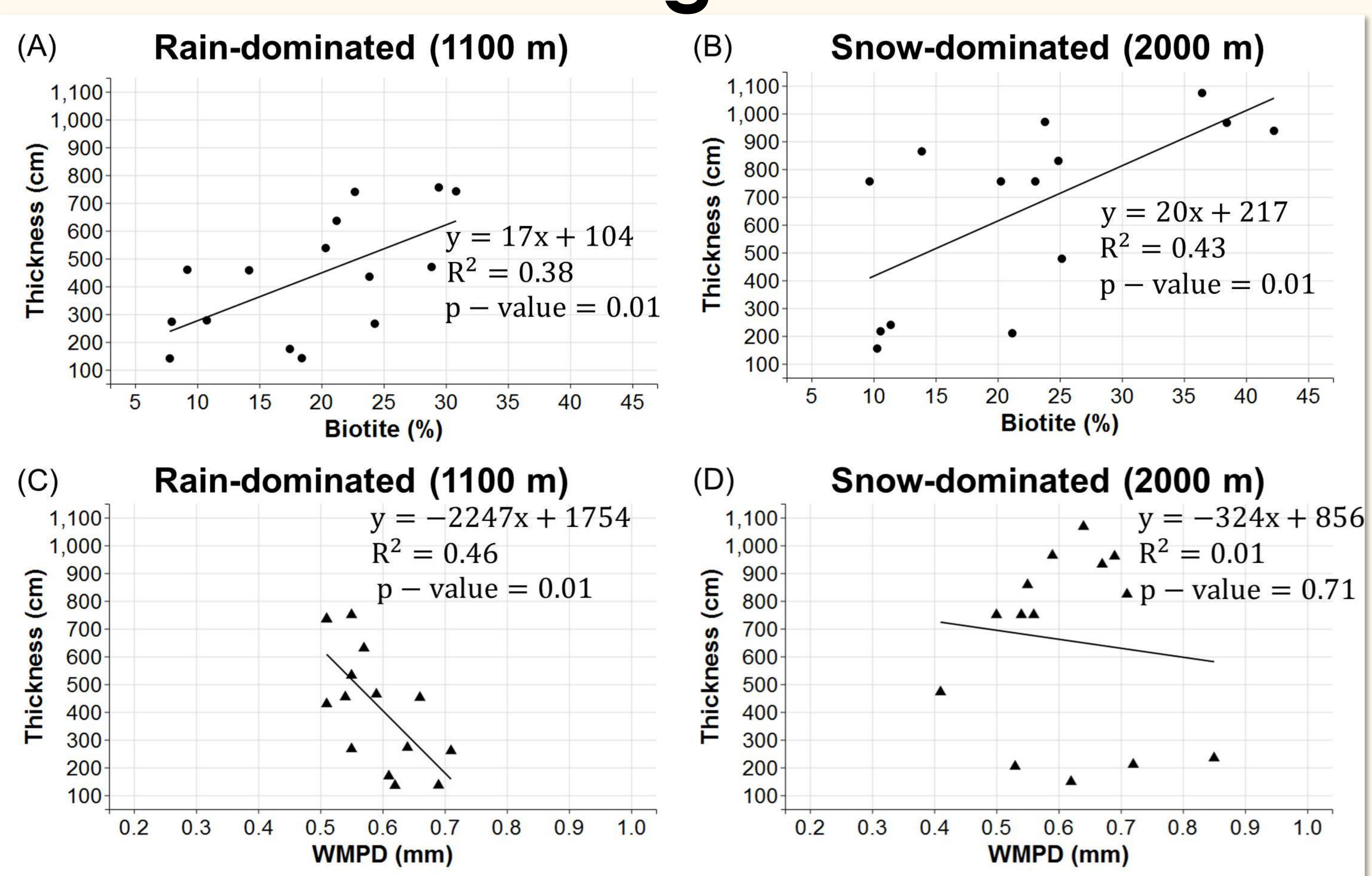


Figure 3. Relationship between biotite content and regolith thickness (A & B) and weighted-mean sand particle diameter (WMPD) as predictor of regolith thickness (C & D).

Table 2. Linear regression models to predict regolith thickness.

Models	Rain-dominated (1100 m) p-value	R^2 (adjusted R^2)
1.Depth ~ Biotite	0.01 *	0.38 (0.34)
2.Depth ~ Biotite + WMPD	0.0009 ***	0.69 (0.64)
Models	**Snow-dominated (2000 m) p-value**	**R^2 (adjusted R^2)**
1.Depth ~ Biotite	0.01 *	0.35 (0.31)
2.Depth ~ Biotite + WMPD	0.05 +	0.39 (0.29)

'***': 0< p-value <0.001; '**': 0.001< p-value <0.01;
'*': 0.01< p-value <0.05; '+ ': 0.05< p-value < 0.1

Factor 2. weathering is controlled by Annual heat energy load which is mediated by depth

Temperature model:

$$T(z,t) = T_{avg}(z) + A_0 \exp\left(-\frac{\Delta z}{d}\right)\sin\left(\omega t - \frac{\Delta z}{d}\right)$$

⇨ Heat energy: $Q = C_m \times m \times \Delta T$ where C_m is specific heat of regolith (0.25 cal g^{-1}℃ $^{-1}$); m is mass of materials (1 g); and ΔT is change in temperature from 0℃.

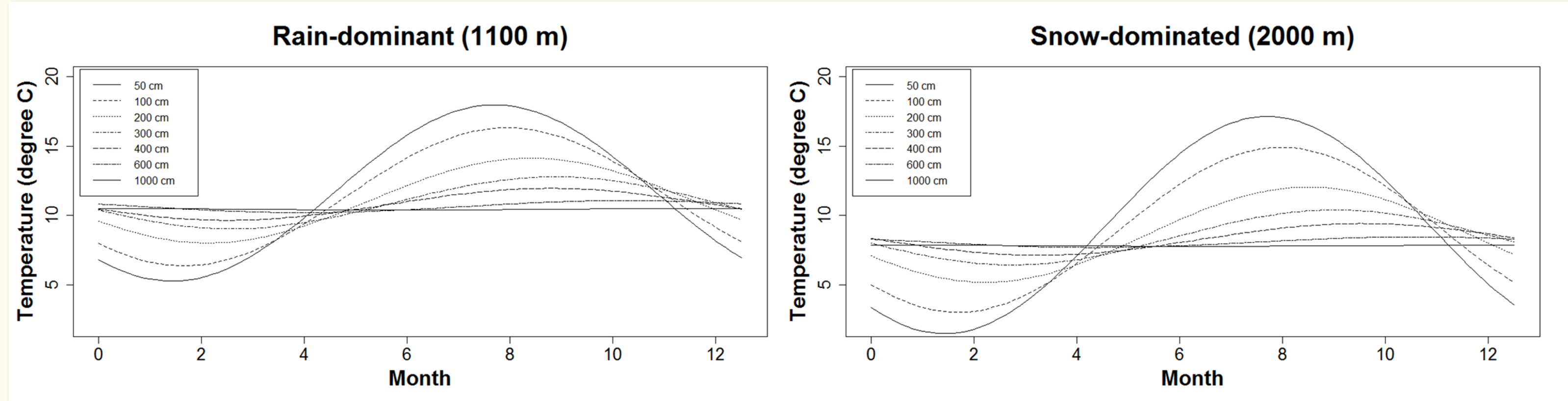


Figure 4. Modeled temperature variation with depth from 0.5 to 10 m at both rain-dominated site (1100 m) and snow-dominated sites (2000 m).

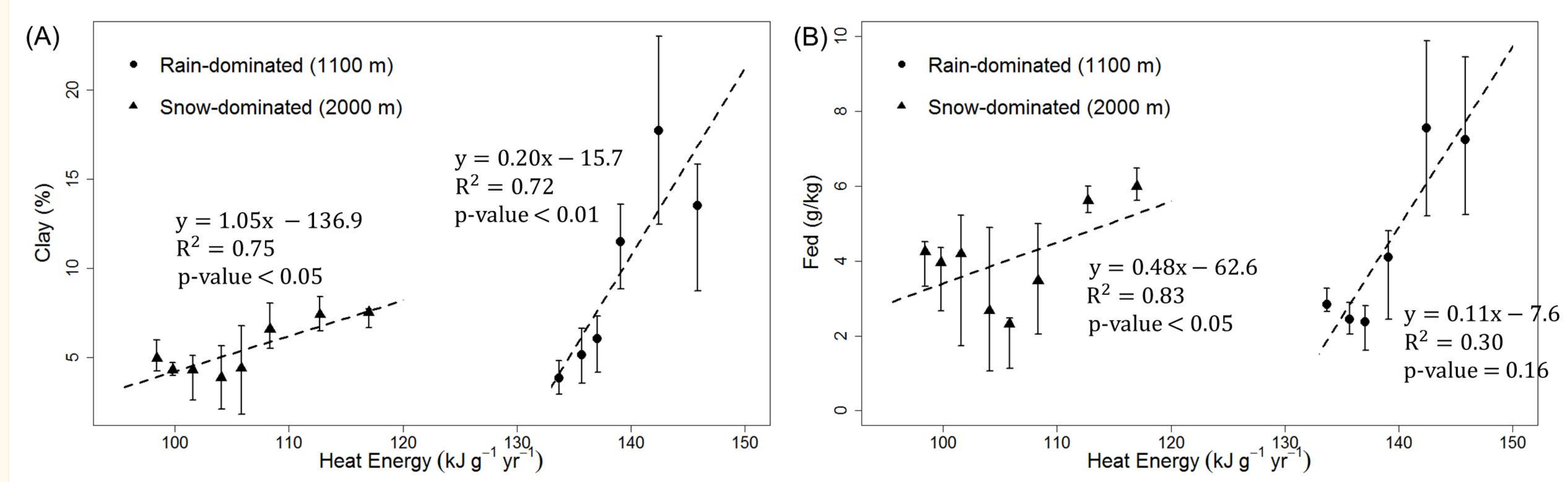
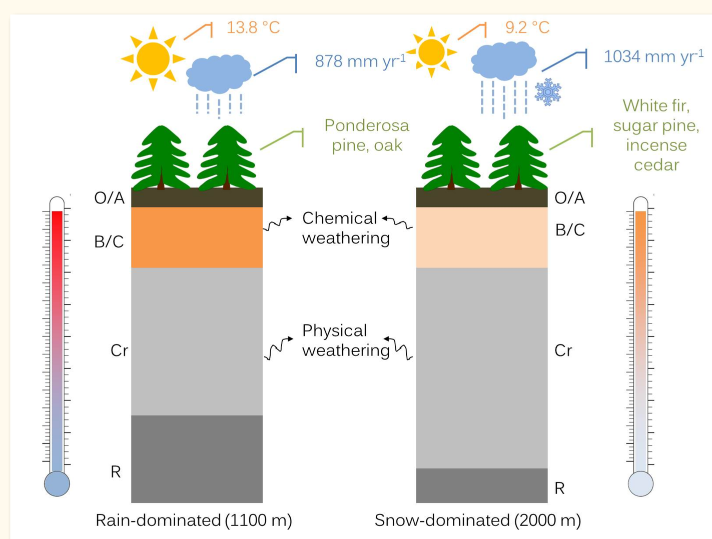


Figure 5. Relationship between annual heat energy load and weathering proxies - clay and Fed (filled circle is the mean value, error bar is between 1st and 3rd quartiles.

Summary

1. Evidence of weathering based on clay and secondary Fe oxide concentrations was intense in soils, but weak in weathered bedrock.
2. Linear regression models explain shallow to deep regolith thickness based on biotite content and mineral grain size.
3. Temperature, as regulated by depth, describes the uniformity in characteristics within deep regolith and discrepancy in characteristics among soils.



Take-home message

- **A** The more **biotite**, the deeper regolith
- **B** The larger **mineral size**, the shallower regolith
- **C** Pedogenisis increases with annual **heat energy** load

Acknowledgements

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References

[1] Dahlgren, R., J. Boettinger, G. Huntington & R. Amundson (1997) Soil development along an elevational transect in the western Sierra Nevada, California. Geoderma, 78, 207-236