

Dust Input to Regolith and Chemical Erosion of Carbonate Hillslopes: A Mass Balance Approach

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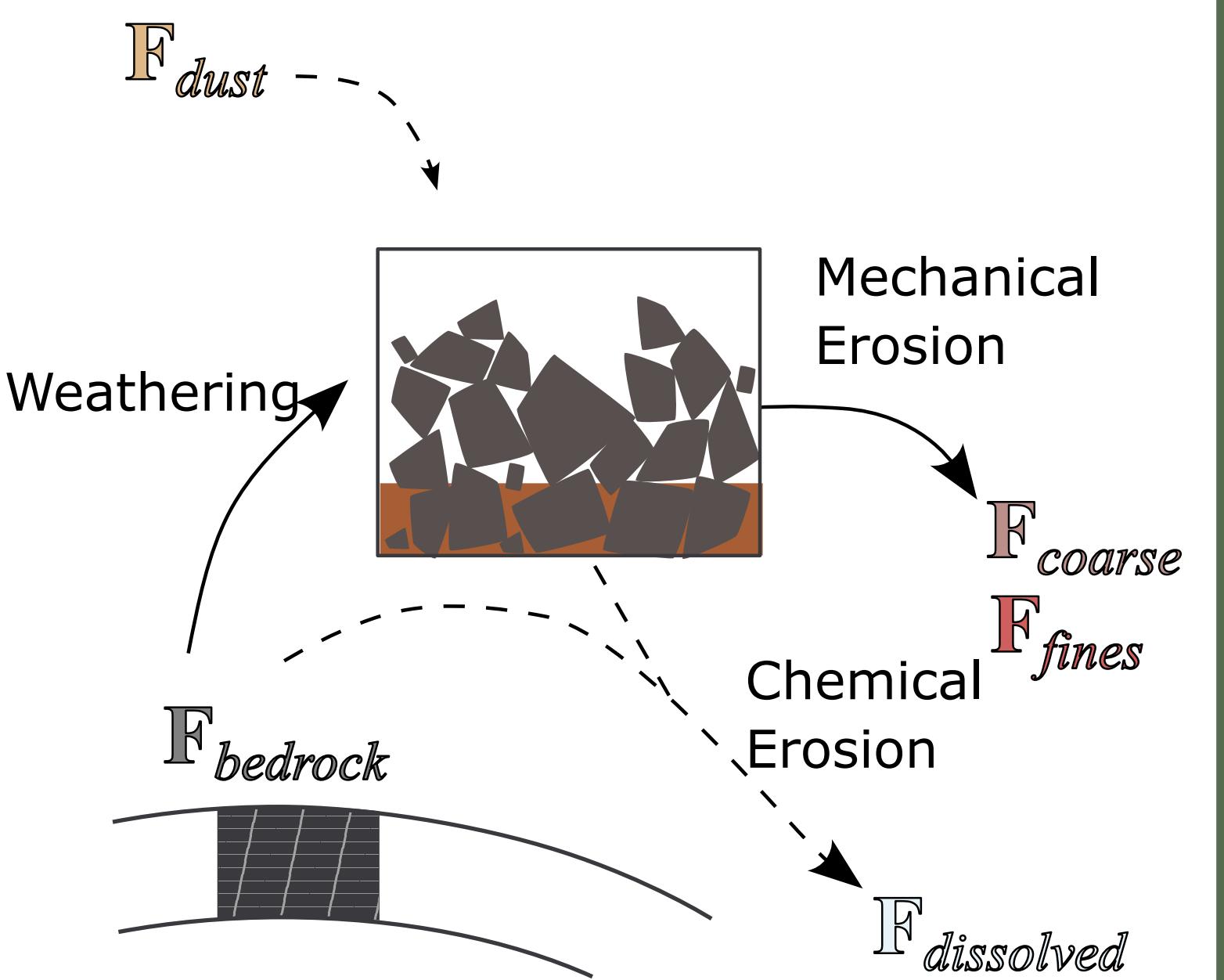
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Introduction

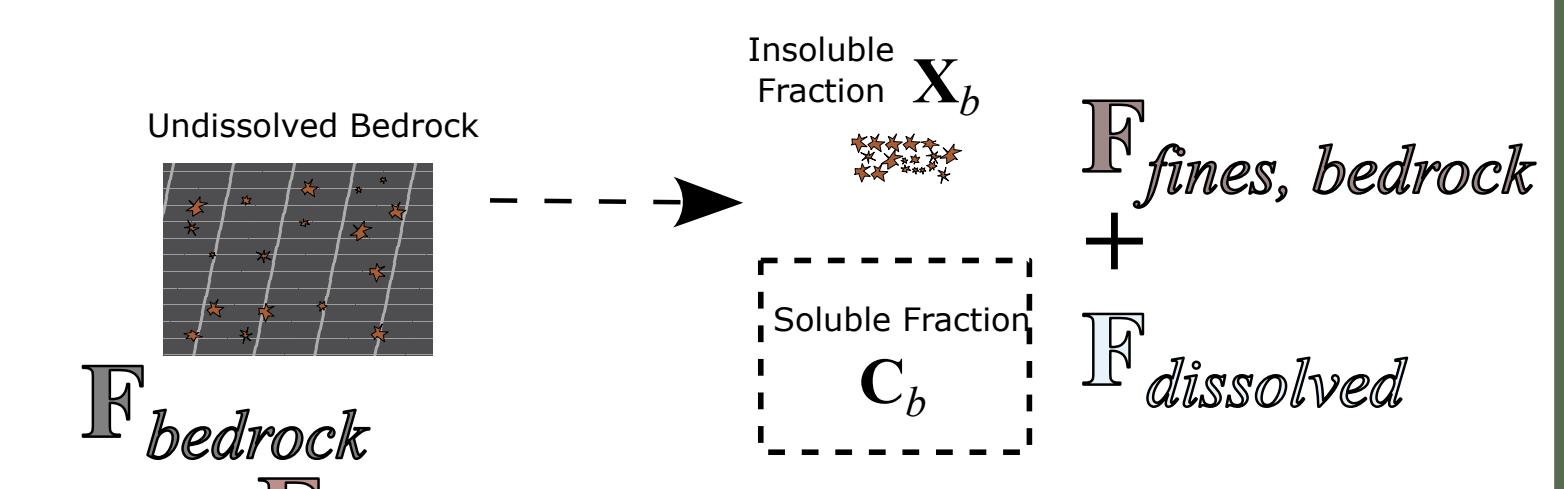
Carbonate rocks can erode mechanically and through dissolution. In humid environments, carbonate rocks form landforms unique to chemical erosion. However, the extent to which chemical erosion acts in semi-arid and arid environments is poorly understood. Significant chemical erosion may reduce sediment flux, decoupling it from bedrock erosion. Another important factor in arid environments, windblown dust may enhance sediment flux as it accumulates. This study quantifies the mass fluxes of hilltop regolith to test whether chemical erosion and dust accumulation are necessary to reconcile the mass balance.

Methods

A mass balance quantifies each component into and out of the volume of interest; here, a unit-volume patch on a hilltop. In this work we consider the fluxes that compose regolith, the layer of mobile sediment on hillslopes. Flux, F (g/m²/yr), represents the amount of material moving across the boundaries of the unit-volume hilltop patch of regolith.



Mechanical weathering of bedrock produces coarse (>2 mm) lithic clasts. Windblown dust, accumulating in the regolith, adds to the fine sediment fraction ($F_{fines} = F_{dust} + F_{fines, bedrock}$).



Chemical weathering of a portion of bedrock yields fine, insoluble non-carbonate sediment ($F_{fines, bedrock}$) and carbonate minerals in solution ($F_{dissolved}$).

Mass Balance

In the formulation to the right, the only unknown quantity is dust flux. The other fluxes can be determined using a combination of field measurements, analysis of ³⁶Chlorine in bedrock and clasts, meteoric ¹⁰Beryllium in the fine fraction of regolith, and geochemical analysis of bedrock and regolith.

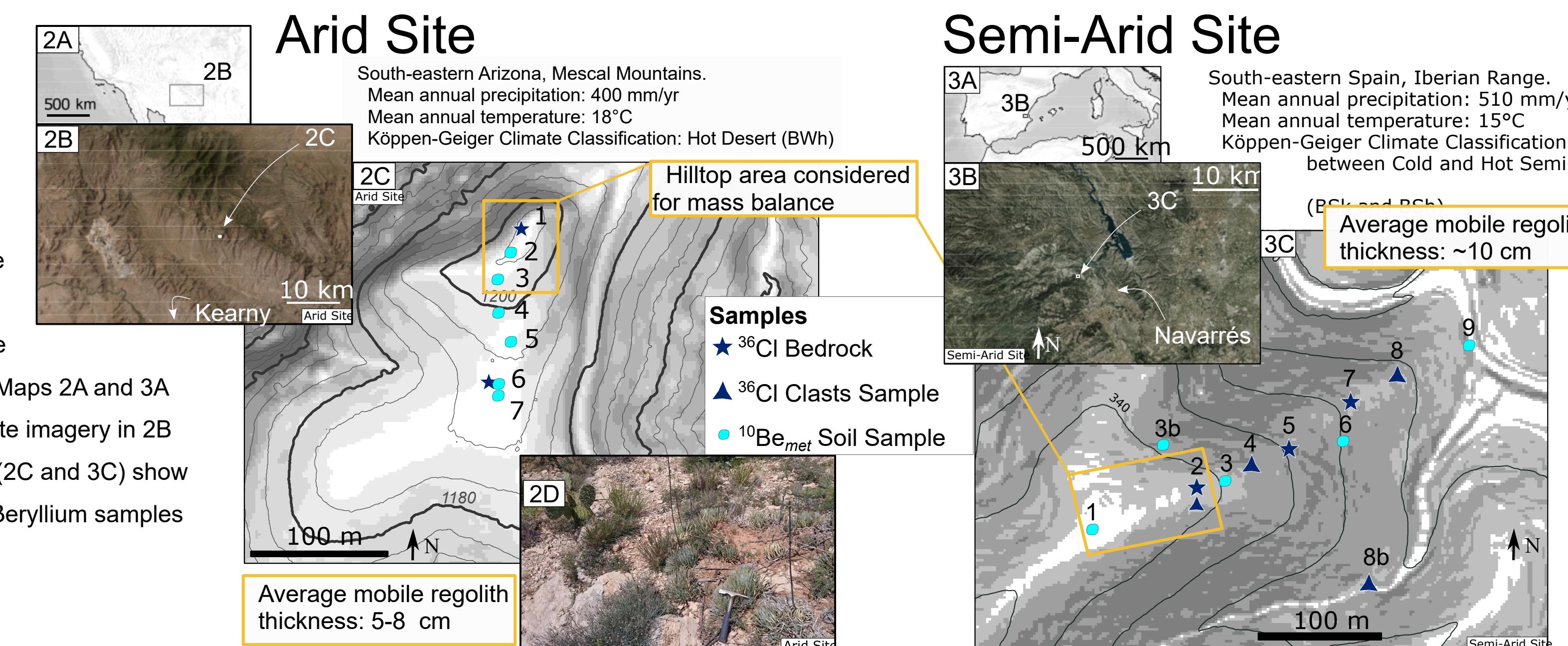
$$F_{dust} = F_{fines} + \frac{F_{coarse} - F_{bedrock}}{(1 + C_b/X_b)}$$

The mass percent of bedrock that is soluble, C_b , and the mass percent of bedrock that is insoluble, X_b , can be determined from geochemical analysis.

For more details on the derivation and use of this mass balance model, please see the link under Further Information.

Field Locations

Two carbonate hillslopes were chosen: one in arid south-eastern Arizona and one in semi-arid zone south-eastern Spain. The map above (1) places the field locations on a global map. Maps 2B and 3A show regional extents of field areas with satellite imagery in 2B and 3B. Slope-shaded maps of each field site (2C and 3C) show where cosmogenic ³⁶Chlorine and meteoric ¹⁰Beryllium samples were collected.



Data

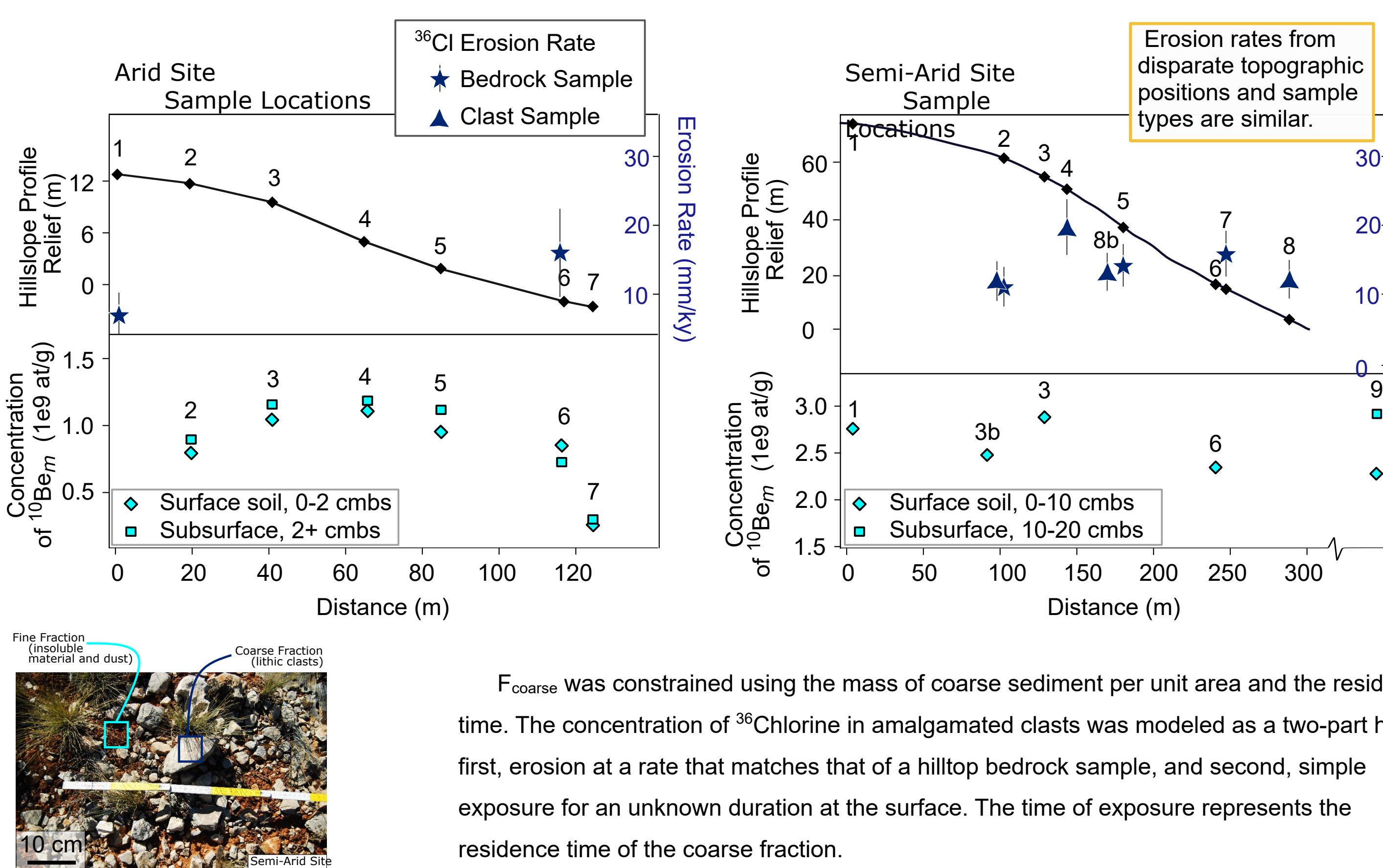
The flux of bedrock into regolith and solution is simply the bedrock erosion rate (E_b , Length/Time) times the rock density (ρ_b , Mass/Volume).

$$F_{bedrock} = E_b \rho_b$$

Regolith thickness can be described as the formation rate times its residence time (t_f , Time), which is the average duration a particle remains in the regolith. The residence time of the fine sediments (t_f) is calculated using meteoric ¹⁰Beryllium, which forms in the atmosphere and accumulates in soils over time.

We calculate F_{fines} (assuming steady-state conditions, where flux in equals flux out) using the residence time, soil depth (h_f , Length), and fine sediment density (ρ_f , Mass/Volume).

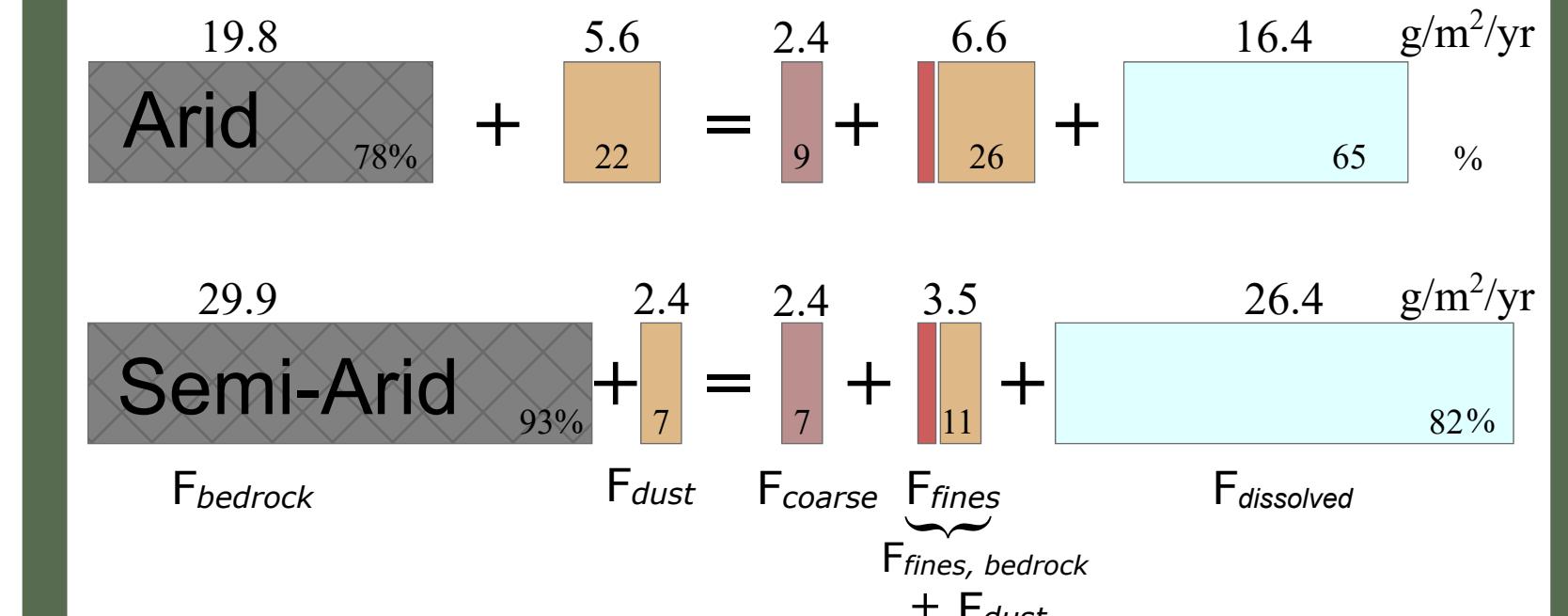
$$F_{fines} = h_f \rho_f / t_f$$



F_{coarse} was constrained using the mass of coarse sediment per unit area and the residence time. The concentration of ³⁶Chlorine in amalgamated clasts was modeled as a two-part history: first, erosion at a rate that matches that of a hilltop bedrock sample, and second, simple exposure for an unknown duration at the surface. The time of exposure represents the residence time of the coarse fraction.

Results and Conclusions

$$F_{bedrock} + F_{dust} = F_{coarse} + F_{fines} + F_{dissolved}$$



For both sites, the total mass flux is composed of more than 60% dissolved material.

→ Even in arid and semi-arid regions, carbonate rocks may be subject to significant chemical erosion.

Future work could identify whether additional chemical erosion occurs during clast transport, or if mineral precipitation inhibits transport out of the hillslope system (McFadden, 2013).

The proportion of dissolved flux at the arid site is less than at the other site.

→ Supports a direct correlation between chemical erosion and climate. More work quantifying chemical erosion in carbonate soils across aridity gradients would help test this hypothesis.

Dust flux was greater at the arid site. Besides climate, different local and regional dust sources, as well as variations in topography, might affect local dust accumulation (McClintock et al., 2015).

Further Information



My dissertation is available at
<https://hdl.handle.net/2286/R.2.N.195269>
or the QR code at left.

Literature Cited

Jungers, M. C., Bierman, P. R., et al. (2009). Tracing hillslope sediment production and transport with in-situ and meteoric ¹⁰B. Be. Journal of Geophysical Research: Earth Surface, 114. <https://doi.org/10.1029/2008JF001086>

McClintock, M. A., Brocard, G., et al. (2015). Spatial variability of African dust in soils in a montane tropical landscape in Puerto Rico. Chem. Geol., 412, 69–81.

McFadden, L. D. (2013). Strongly dust-influenced soils and what they tell us about landscape dynamics in vegetated aridlands of the southwestern United States. The web of geological sciences: Advances, impacts, and interactions (pp. 501–532). Geological Society of America.

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