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Supplement of

Comparison of soil production, chemical weathering, and physical erosion rates along a climate and ecological gradient (Chile) to global observations

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Supplemental Material

1 Calculation method for soil production rate models discussed in text

Three theoretical considerations of soil production rates were addressed in the main text and described in more detail below. In order to simplify the considerations, only the exponential function for soil production rates with soil depth is addressed. The humped function for soil production rates was not considered.

A) Norton et al. (2014)

Based on mass balance considerations and steady-state, maximum soil production rate SPR_{max} (t/(km^2 yr)) on hillslopes under different climatic conditions is calculated by:

$$SPR_{max} = 0.42\, MAP\, exp\left(\frac{-77}{8.3144598 \times 10^{-3}}\left(\frac{1}{(MAT + 278.15)} + \frac{1}{278.15}\right)\right) \quad \text{(S1)},$$

where MAP (mm/yr) and MAT (°K) are mean annual precipitation and temperatures. For further details see Eqn, 7 in Norton et al. (2014). As the maximum soil production rate SPR_{max} is reduced under soil cover (e.g., Heimsath et al., 1997; Gilbert, 1877), soil production rate SPR can be calculated following:

$$SPR = SPR_{max}\, exp^{(-\alpha h)} \quad \text{(S2)},$$

where h is the soil depth (m) and α a rate constant (/m) considered to be 3 /m in this study (see Table 1 in Norton et al., 2014). In addition to our calculation of SPR under 0.5 and 1.0 m of soil, we assumed a linear increasing soil depth with increasing precipitation. The linear increase of soil depth is based on the correlation of soil depth (mm) with MAP (mm/yr) in our study area (see Table S1). The equation used is: y = 311.7 + 0.292x (R^2 = 0.62).

B) Pelletier and Rasmussen (2009)

Calculation of soil production rate SPR_0 (m/kyr) is suggested to be a function of:

$$SPR_0 = a\, exp^{(b\, EEMT)} \quad \text{(S3)},$$

where EEMT ($m^2/(kJ\ yr)$) is the "Effective energy and mass transfer" of Rasmussen and Tabor (2007) and a (m/kyr) and b ($m^2/(kJ\ yr)$) are empirical coefficients. The coefficients are calibrated for granitoid lithologies to be: a = 0.037 m/kyr and b = 0.00003 $m^2/(kJ\ yr)$ (Pelletier and Rassmussen, 2009). EEMT is given by:

$$EEMT = 347134\, exp\left\{-0.5\left[\left(\frac{MAT-21.5}{-10.1}\right)^2 + \left(\frac{MAP-4412}{1704}\right)^2\right]\right\} \quad \text{(S4)}$$

where MAT (°C) and MAP (mm/yr) are mean annual temperature and precipitation, respectively (Rassmussen and Tabor, 2007). As EEMT is an empirical function of MAT and MAP, biotic controls on EEMT are included in Eqn. S4. Based on Eqns, S3 and S4, soil production rates can be calculated.

C) Pelak et al. (2016)

Whereas Pelletier and Rassmussen (2009) and Norton et al. (2014) address soil production rate in the light of MAP and MAT, Pelak et al. (2016) approach calculation of soil production rates as influenced by plant biomass density b (kg/m^2) and soil depth h (m). The so called soil production rate $P_{(h.b)}$ of Pelak et al. (2016) is given by:

$$P_{(h,b)} = \left(P_0 + P_v b_{(h)}\right) exp(-k_s h) \quad \text{(S5)},$$

where P_0 (mm/yr) is the abiotic soil production rate in the absence of vegetation and soil, P_v ($mm^3/(yr\ kg)$) the sensitivity of soil production to vegetation, and k_s (/m) a rate for the decoupling of soil production from surface weathering processes due to increasing soil depth. Typical suggested model parameters are P_0 = 0.05 mm/yr, P_v = 0.4 $mm^3/(yr\ kg)$, and k_s = 0.8 /m (see Table I in Pelak et al., 2016); note unit adjustments were needed). The plant biomass density b (kg/m^2) is a function of soil depth h (m) and is calculated with:

$$b_{(h)} = \frac{r}{m}\left[1 - exp\left(-k_g\, h\right)\right] \quad \text{(S6)},$$

where r (/yr) is the vegetation growth rate, m ($m^2/(yr\ kg)$) the vegetation turnover rate, and k_g (/m) the vegetation growth response to soil depth. In Pelak et al. (2016) the ratio r/m is given as 4 kg/m^2 and k_g = 0.2 /m. The soil production rates presented in our study reach values up to ~1000 $t/(km^2\ yr)$. To reach the full range of soil production rates reported, we show r/m values of 50, 100, and 150 kg/m^2 in Figure 3C. Furthermore, we convert plant biomass density $b_{(h)}$ into LAI based on the relationship shown in Fig. 4 of Gratani and Crescente (2000):

$$LAI = \frac{\left(10 b_{(h)} - 2.217\right)}{71.813} \quad \text{(S7)}.$$

Observed LAIs (Table S5) of ~8 $m^2/\ m^2$ then results in plant biomass values of ~60 kg/m^2. This is in agreement with observed values of about 50 kg/m^2 (Brown and Lugo, 1982).

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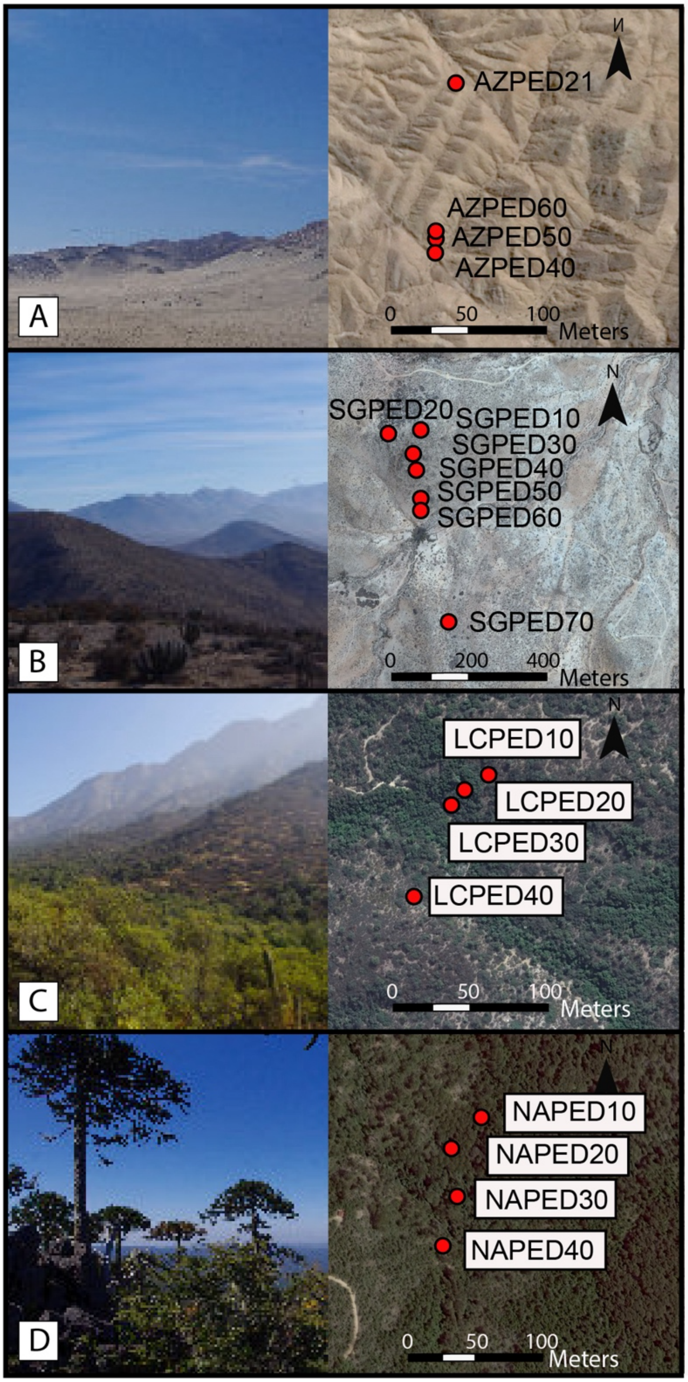

Figure S1: Photographs of study areas and satellite images (Data source: Google Earth©) with sample locations: A) Pan de Azúcar. B) Santa Gracia. C) La Campana. D) Nahuelbuta.

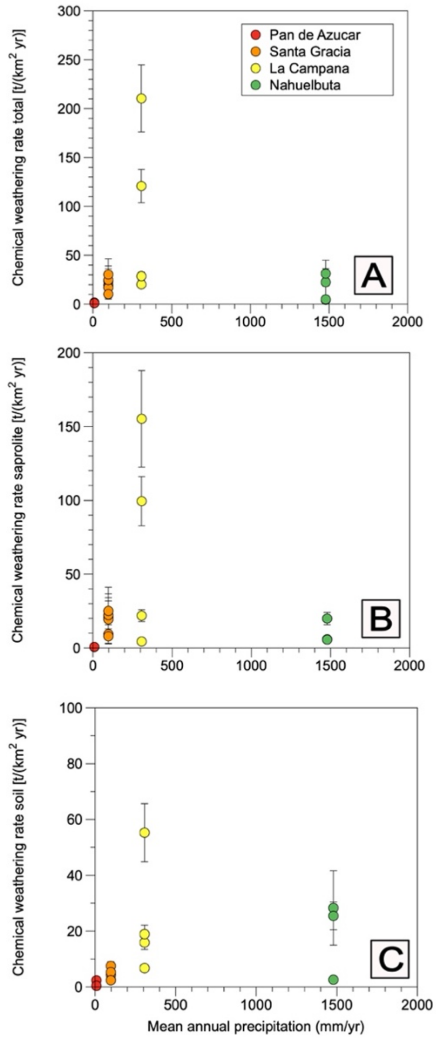

Figure S2: Chemical weathering rate versus mean annual precipitation for the four Chilean study areas: A) Total weathering rate. B) Weathering rate in soil. C) Weathering rate in saprolite.

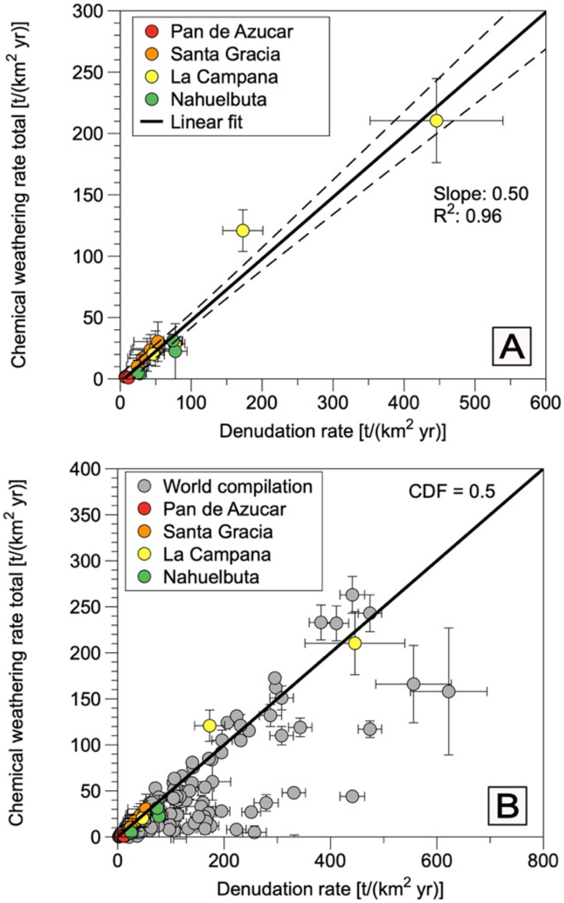

Figure S3: Total weathering rate W_{total} versus total denudation rate D_{total}: A) Four study areas investigated in this study. The weathering rate can be approximated by the linear function $W_{total} = 0.5\ D_{total}$ ($r^2 = 0.96$; black line). The stippled line shows the 95% confidence interval. B) Compilation of published data from hillslopes located in granitoid lithologies. The black line represents a CDF value of 0.5.

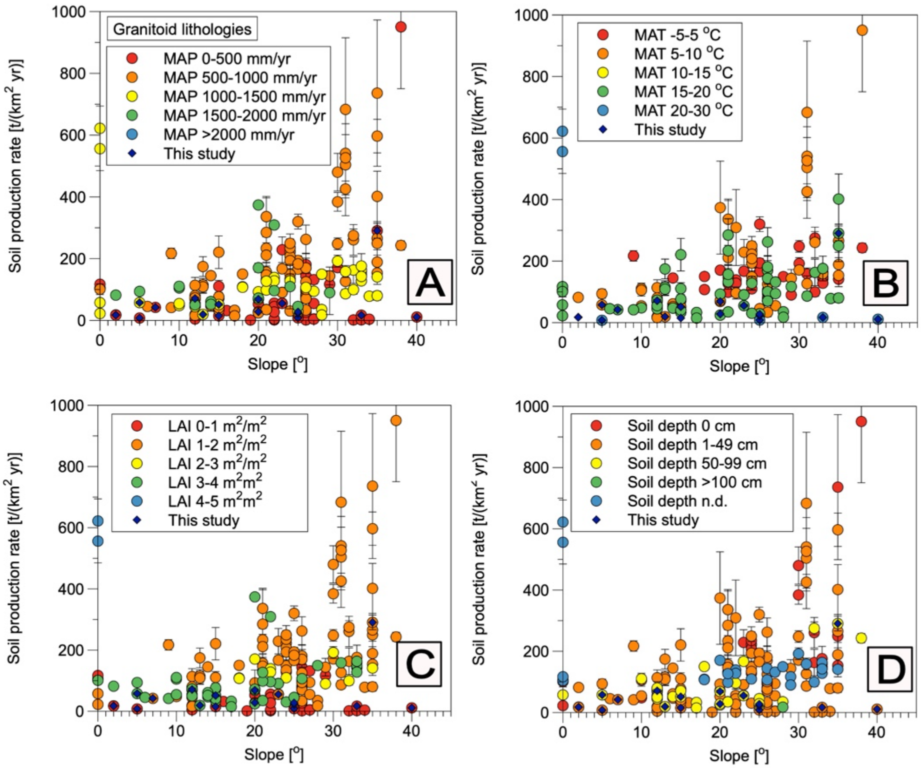

Figure S4: Soil production rates SPRs versus slope: A) SPRs are in mean annual precipitation bins. B) SPRs are in mean annual temperature bins. C) SPRs are in bins for leaf area indices. D) SPRs are in bins of soil depth.

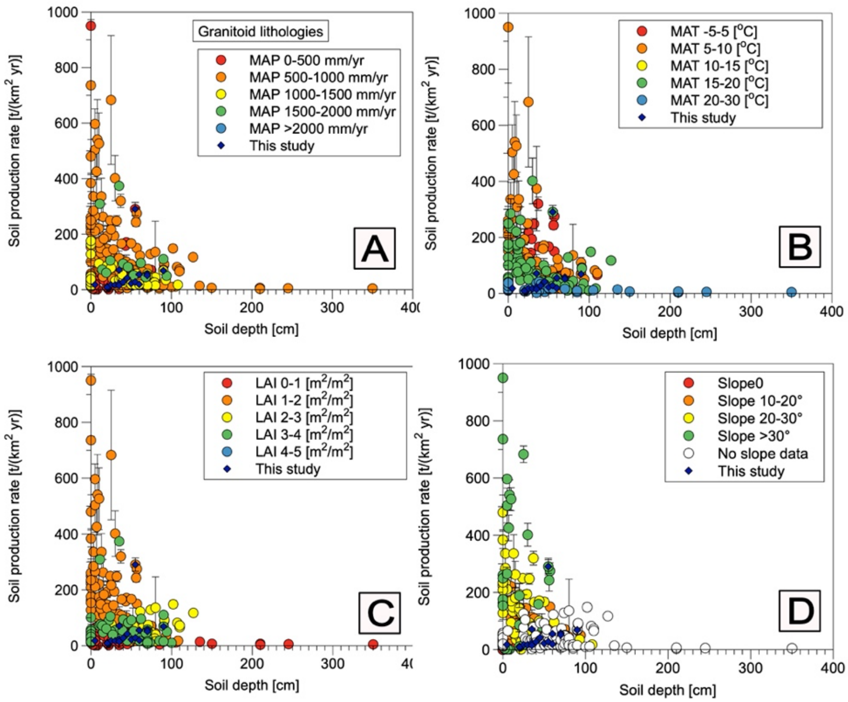

Figure S5: Soil production rates SPRs versus soil depth: A) SPRs are in mean annual precipitation bins. B) SPRs are in mean annual temperature bins. C) SPRs are in bins for leaf area indices. D) SPRs are in slope bins.

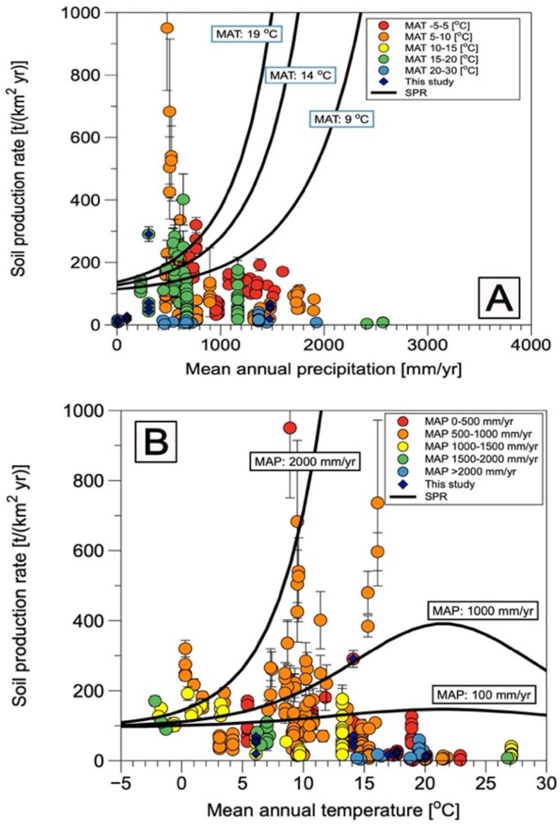

Figure S6: Soil production rates SPRs versus: A) Mean annual precipitation. B) Mean annual temperature. Black lines indicate calculated SPRs for different mean annual temperatures and mean annual precipitations based on Pelletier and Rasmussen (2009).