Does Phosphorus Limit the Growth of Pine Trees in Volcanic Ash Soils?

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Introduction

Phosphorus (P) is a major plant nutrient, however its availability in soil is often small, since it is easily immobilized. Soil P is estimated to become the primary growth limiting nutrient for crops in the next decades, so it is important to understand the behavior of soil P fractions in time under different land use scenarios.

We analyzed distinct P fractions in volcanic ash soils of different age in Central Mexico following the fractionation method of Tiessen and Moir (1993). We did so to investigate how the different P fractions change along a soil chronosequence of Regosols, Andosols and Lixisols (60 to 100,000 years BP), and to discover if P availability limits growth of pine trees at a particular development stage.

Methods

General characteristics of the analyzed soil samples:

Soil type*	Location	Hz	Age Years	Bulk density kg dm⁻³	pH H₂O	Corg %	Al o mg g⁻¹	Fe o mg g⁻¹	Fe d mg g⁻¹	Al p mg g⁻¹	P Bray mg kg⁻¹
R	Paricutin	AC	60	0.82	7.18	1.70	0.50	1.32	2.82	0	16.8
R	Popocatépetl	Ah1	1000	0.85	5.48	6.35	2.57	2.30	15.08	4.24	119.8
A	Guespalapa	Ah1	3800	0.64	5.80	6.62	15.96	13.00	15.98	3.79	8.5
A	Guespalapa	Bw1	3800	0.81	6.88	1.22	17.53	16.05	13.01	1.22	4.0
A	Tlaloc	Ah1	6200	0.44	5.65	8.72	18.30	9.16	20.66	5.81	3.0
A	Tlaloc	2Bw	6200	0.47	6.52	3.49	41.86	16.11	12.28	3.34	n.d.
A	Pelado	Ah1	10000	0.45	5.67	14.52	17.60	10.05	20.18	6.84	5.1
A	Pelado	Bw	10000	0.73	6.66	1.81	38.51	14.90	11.13	1.43	0.3
A	Quinto Barrio	Ah	100000	0.52	5.24	13.24	22.17	5.08	27.93	9.86	0.9
A	Quinto Barrio	Bw1	100000	0.78	5.71	1.41	10.51	4.91	20.98	2.04	1.2
L	Las Trojes	Ah	>100000	0.84	5.34	9.48	9.76	3.86	32.00	3.72	4.3
L	Las Trojes	Bt	>100000	1.07	5.79	1.03	2.61	1.50	2.82	0.31	0.2

*R= Regosol, A=Andosol, L= Lixisol
Hz: soil horizon
pH: measured potentiometrically in a soil-water suspension 1:2.5 (wt:vol).
Total C : measured in an C N H S autoanalyzer, Perkin Elmer 2400.
Al₀, and Fe₀: Al and Fe extracted with ammonium oxalate at pH 3.25 in the dark (Blume and Schwertmann, 1969).
Al_p: Al extracted with sodium pyrophosphate (van Reeuwijk, 1995).
Fe_d: Fe extracted with bicarbonate dithionite (Blume and Schwertmann, 1969).
P Bray: Plant available P extracted with acid NH₄F (Bray and Kurtz, 1945).

P Sequential extraction method proposed by Tiessen and Moir (1993)

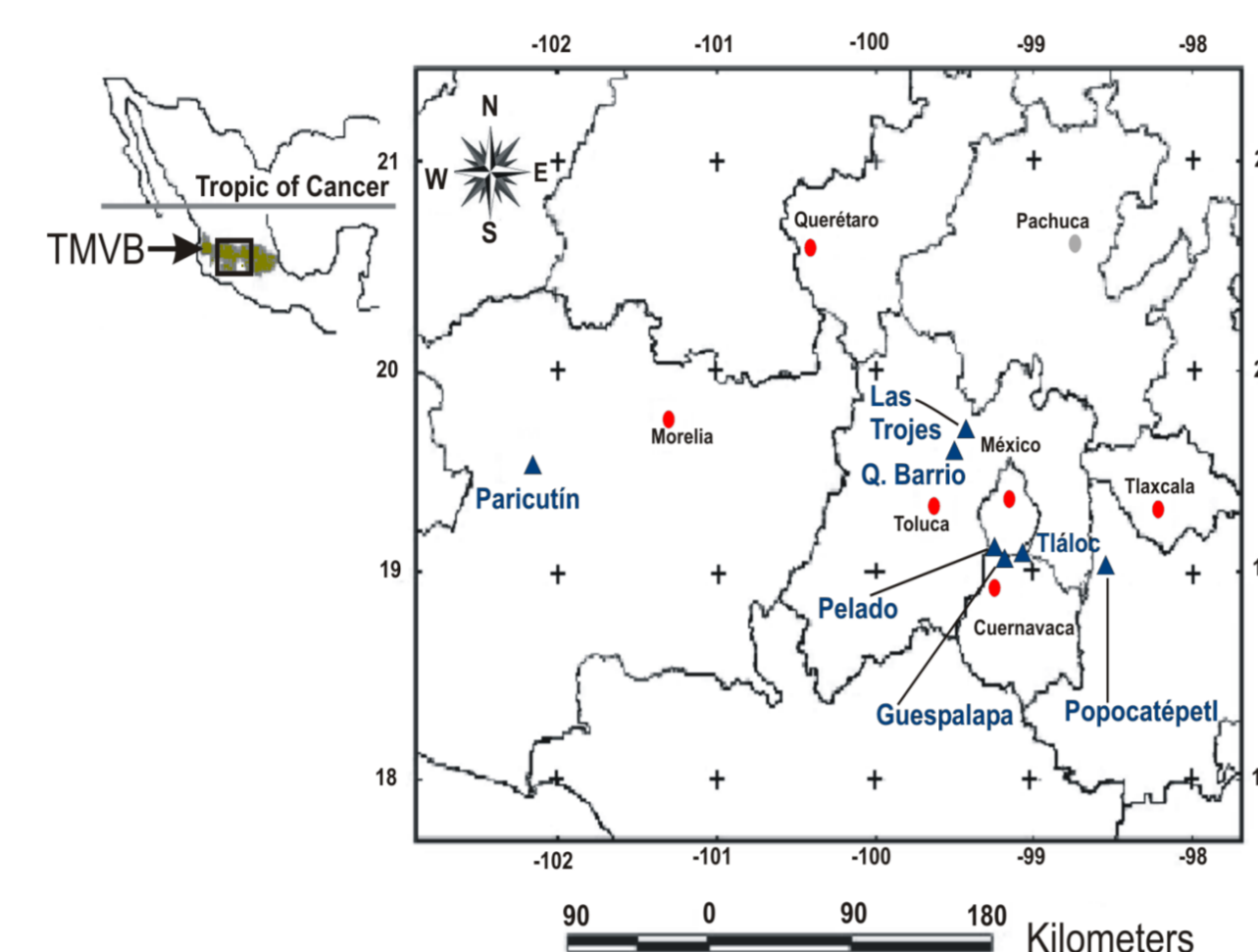| Step	P fractionation	P Fraction
1	0.5 g of sample + IER + 30 ml of H₂O/ 20ml of 0.5M HCl	non occluded P (P Non Occ)
2	30 ml of 0.1M NaHCO₃ *	organic P and non occluded P (P₀, P Non Occ)
3	30 ml of 0.1M NaOH *	organic P and non occluded P (P₀, P Non Occ)
4	30 ml of 1M HCl	P associated to primary minerals (P Ca)
5	15 ml of concentrated HCl *	organic P and occluded P (P₀, P Occ)
6	10 ml of H₂O +5ml concentrated H₂SO₄/ Digestion at 360°C/ 0.5 mL of 30% H₂O₂	occluded P (P Occ)

IER: ion exchange resins (IRA-410 Merck)
* Pt (total P) and Pi were quantified separately in these extracts as follows:
Pt = Extract + H₂SO₄ 0.9 M+ (NH₄)₂S₂O₈
Pi = Extract + H₂SO₄ 0.9 M, and Po = Pt – Pi

The determination of P in each extract was done by ICP-OES (inductive coupled plasma optic emission spectroscopy). This does not allow to distinguish unequivocally between inorganic and organic P, so additionally we calculated organic P fractions as the difference between P extracted from burned and unburned samples. Estimated Po contents correlated well with Corg contents (r = 0.81).

To validate the plant available fraction we collected pine needles from 5 trees at each site. The needles were dried at 60°C, ground and pressed to tablets mixing 0.5 g of sample with 0.5 g of C micropowder binder (Hoechst Wax). The total P content in these samples was also determined by XRF.

1) Guespalapa
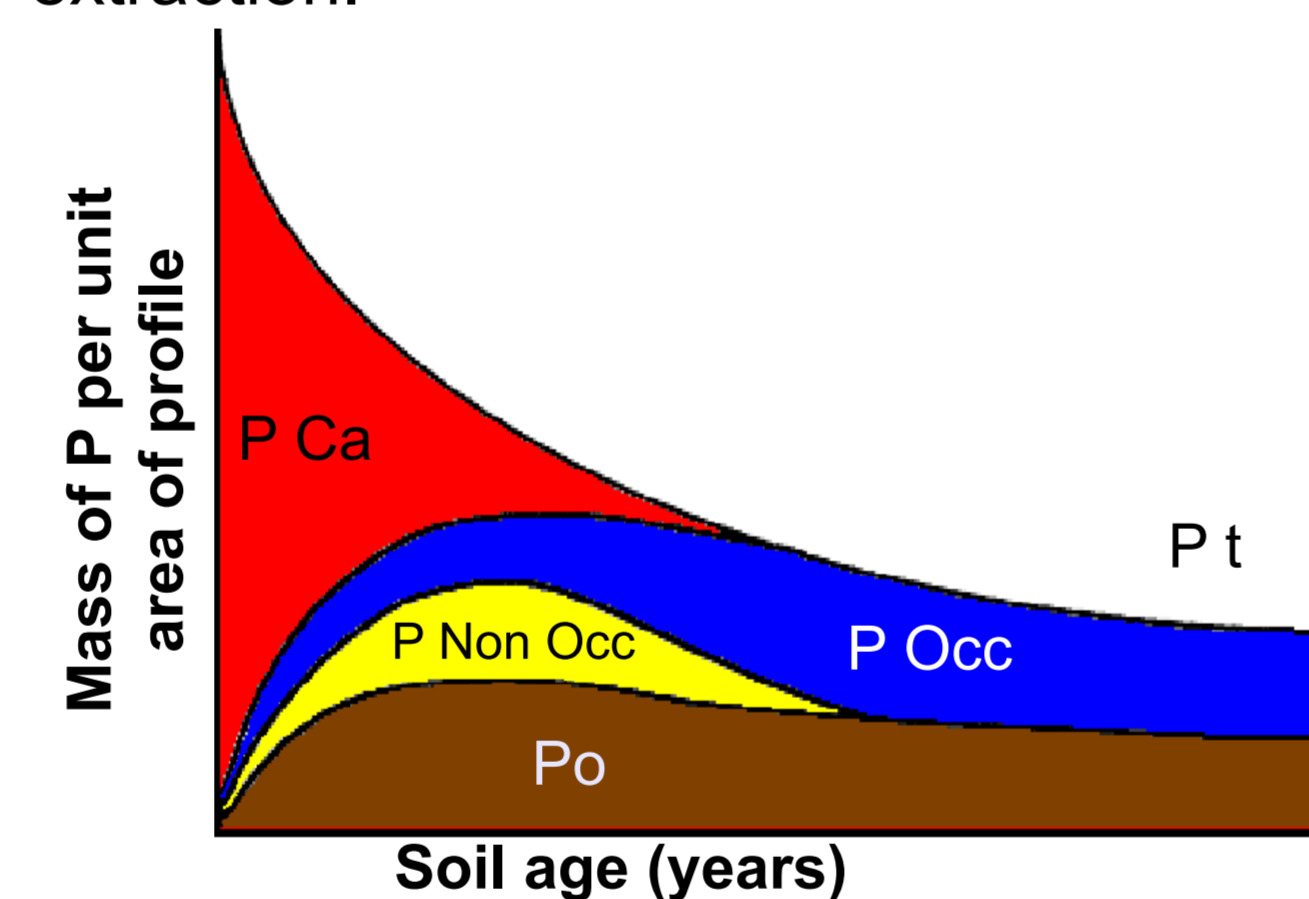2) Tláloc
3) Pelado

Sample site locations:

Sample pre-treatments:
Subsamples of each location were either:
a) Preserved at field moisture content at 4° C
b) Air dried to simulate desiccation
c) Burned at 300 °C in a muffle oven.

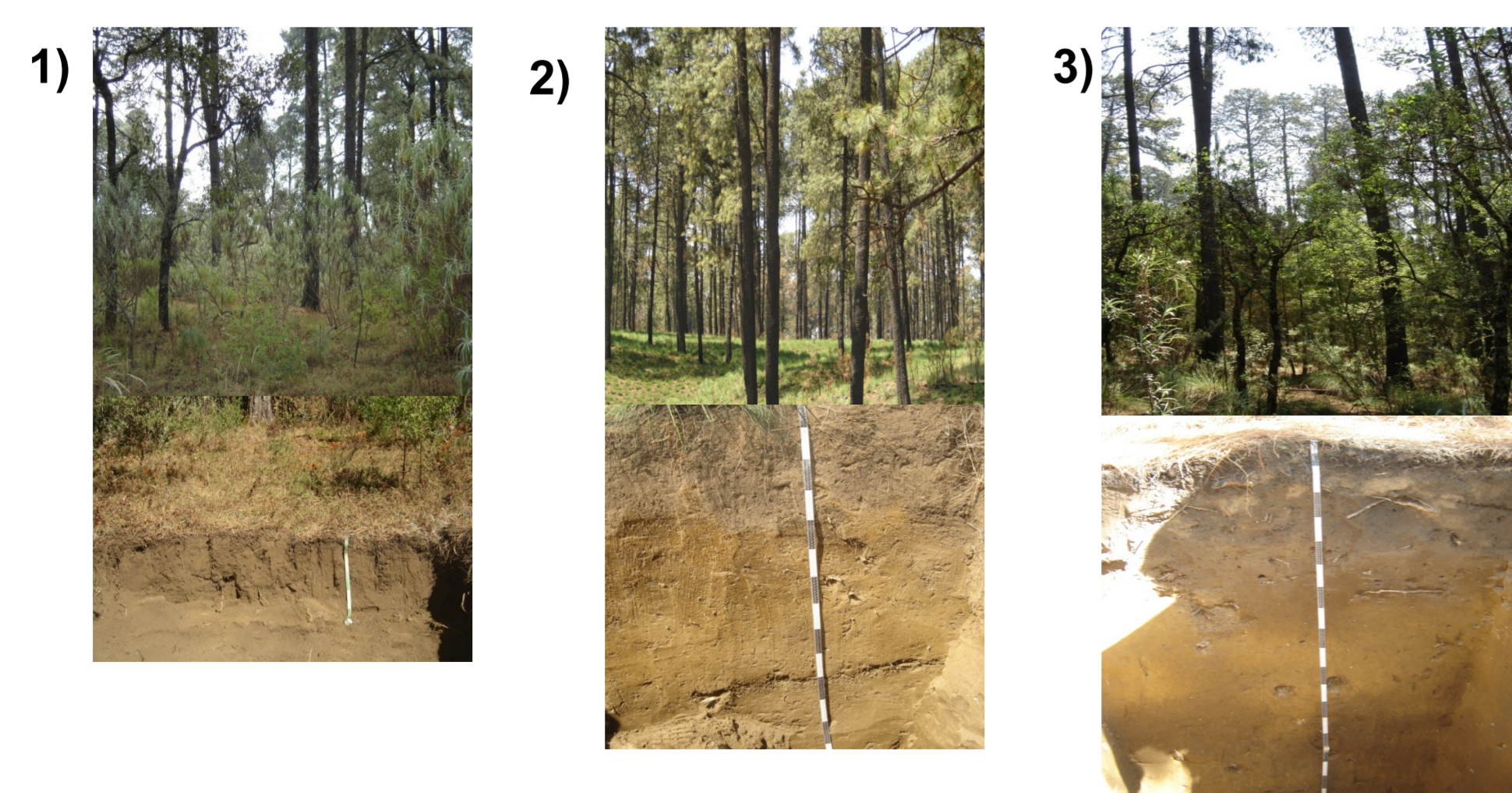**Validation of P fractionation**
The behavior of the P fractions along the chronosequence was compared with the Walker and Syers model (1976). And the sum of fractions was compared with the total P measured by XRF (X-ray fluorescence spectroscopy) to assess the extraction efficiency of the sequential extraction.

Results

Total P and sum of fractions of air dried and burned samples:

- Air dried samples
- Burned samples
- P total

The different P fractions along the soil chronosequence

- P Ca
- P No Occ
- P Occ
- P o

EPMA images from Paricutín tephras (I) showing fluorapatite (a) included in palgioclase (b), Popocatépetl tephras (II) with fluorapatite (c) included in volcanic glass (d), and Guespalapa tephras (III) with fluorapatite (e) included in olivine (f) , and CP spectra of all minerals (a, b, c, d, e, f).

Organic P

- Air dried samples
- Burned samples
- Burned- Air dried*

Air dried samples
y = 2.07x + 0.12
r = 0.68, p = 0.09

Burned samples
y = 0.95x + 2.70
r = 0.81, p = 0.02

Burned -air died *
y = 0.42x + 3.12
r = 0.81, p = 0.02

*Sum P fractions of burned samples - Sum P fractions of Air dried samples

A
B
C

Field moist sample
R² = 0.78, p = 0.019
f(x) = 0.25 ln (x) + 0.65

Air dried samples
R² = 0.88, p = 0.006
f(x) = 0.19 ln (x) + 0.85

Burned samples
R² = 0.93, p = 0.002
f(x) = 0.17 ln (x) + 0.77

P Bray
R² = 0.13, p = 0.485
f(x) = 0.05 ln(x) +1.41

Conclusions

- The fractionation extracted only 39% of total P.
- The dominant P fraction was the one of primary P minerals (P Ca), followed by non-occluded P in Regosols and Andosols, and organic P in Andosols, while occluded P was constant along the chronosequence.
- Apparently the method does not extract exhaustively occluded P, and fails to dissolve P in primary minerals, since in these volcanic ashes the dominant P mineral is fluorapatite included within other primary minerals. Organic P can be estimated by burning the samples.
- P extracted by ion exchange resins is present sufficiently in all soils along the chronosequence and correlates well with foliar P contents.
- The latter indicates that P is not limiting tree growth in young and moderate developed volcanic ash soils (Regosols and Andosols).
- To elucidate the evolution of P fractions during soil development in volcanic soils, the extraction of occluded fractions needs to be improved, as well as the dissolution of primary P minerals.
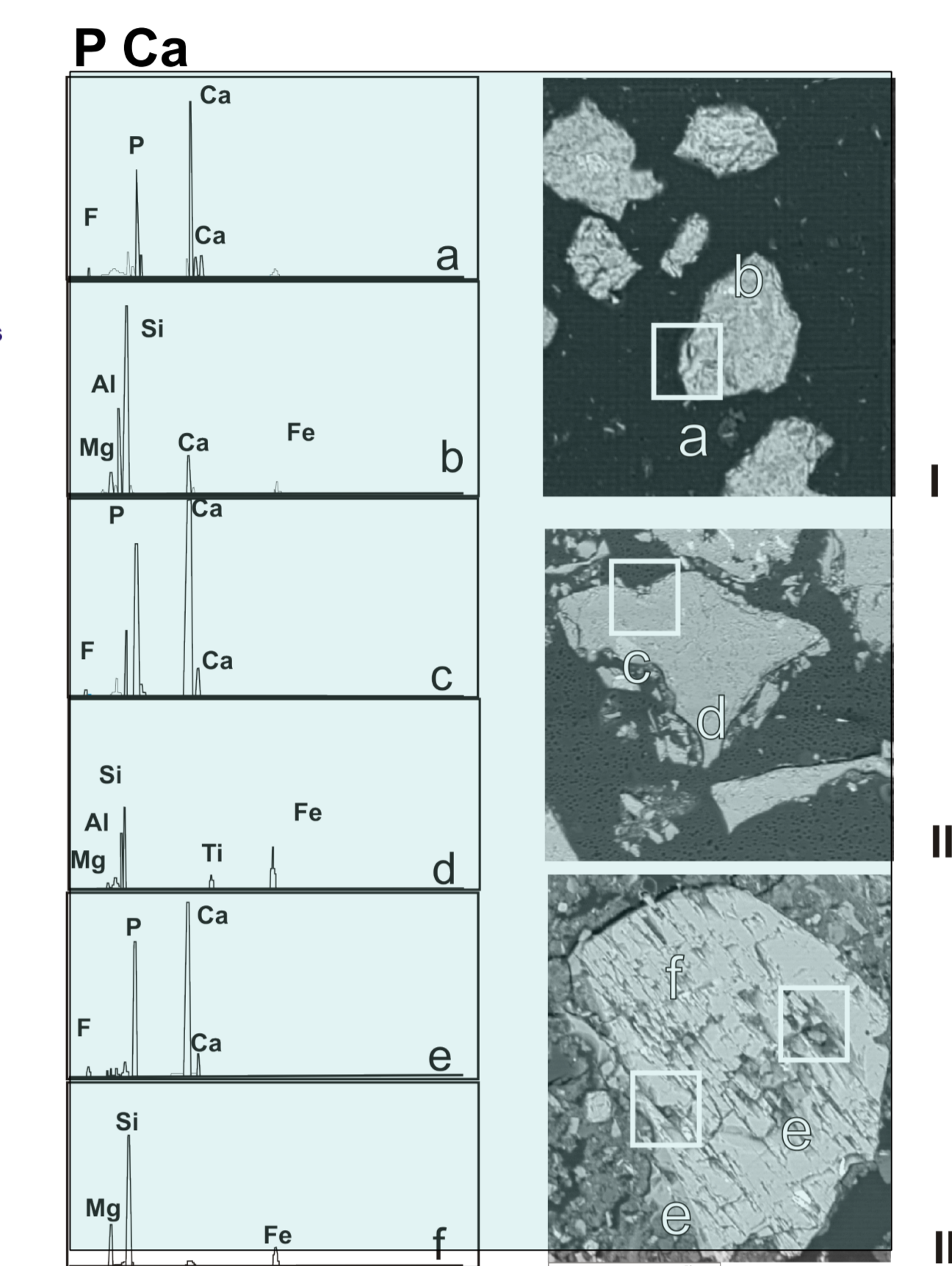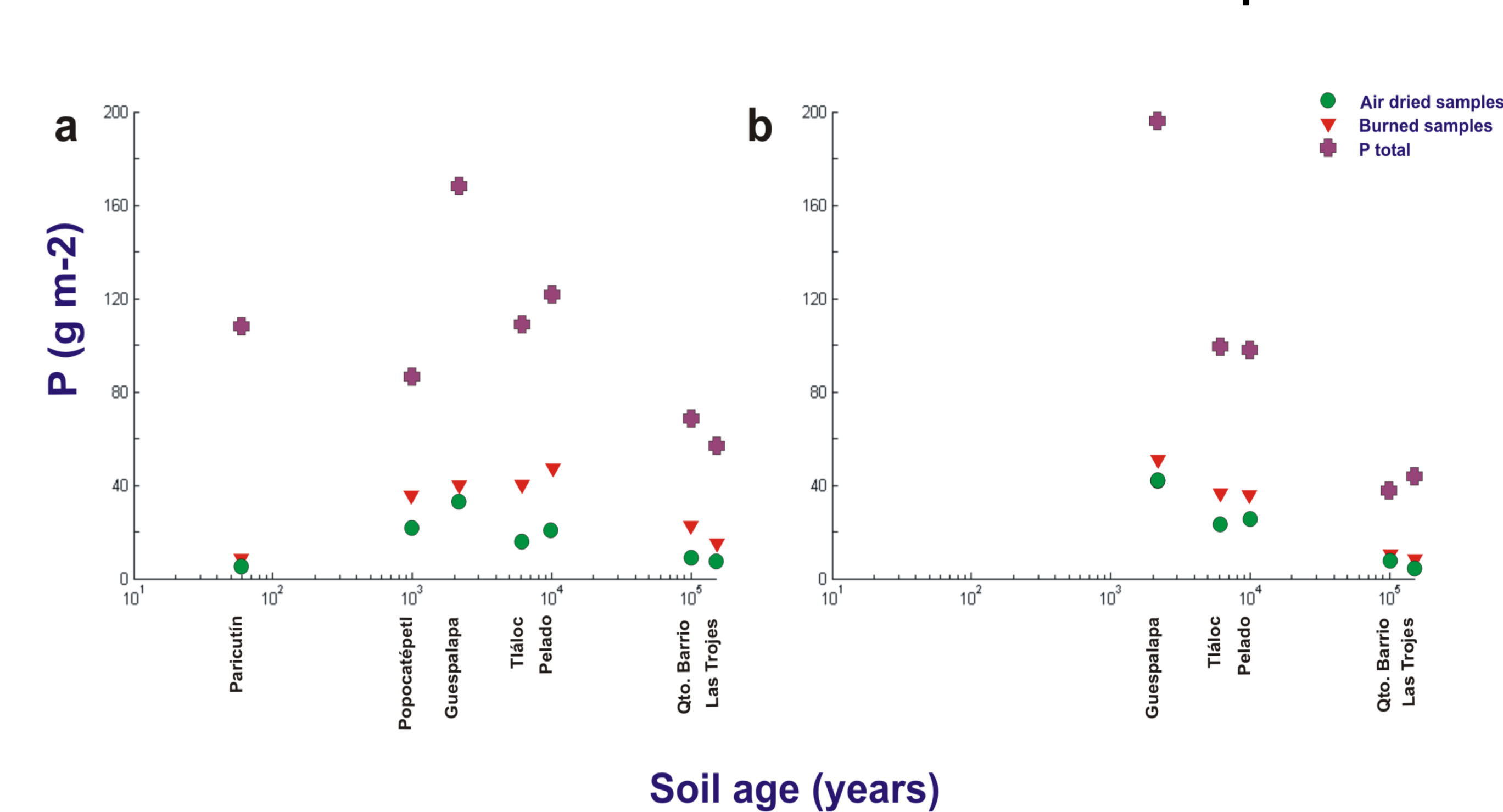
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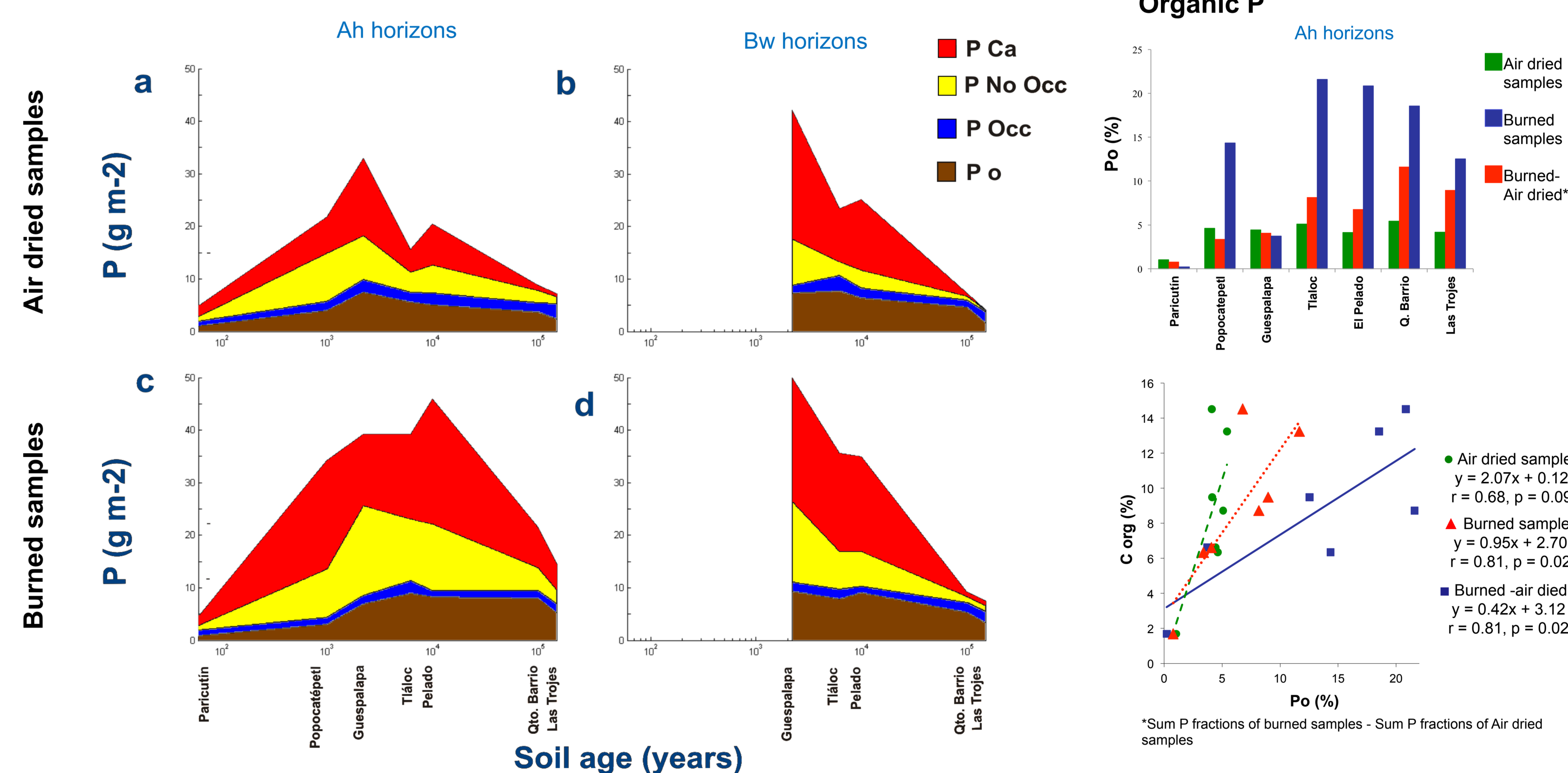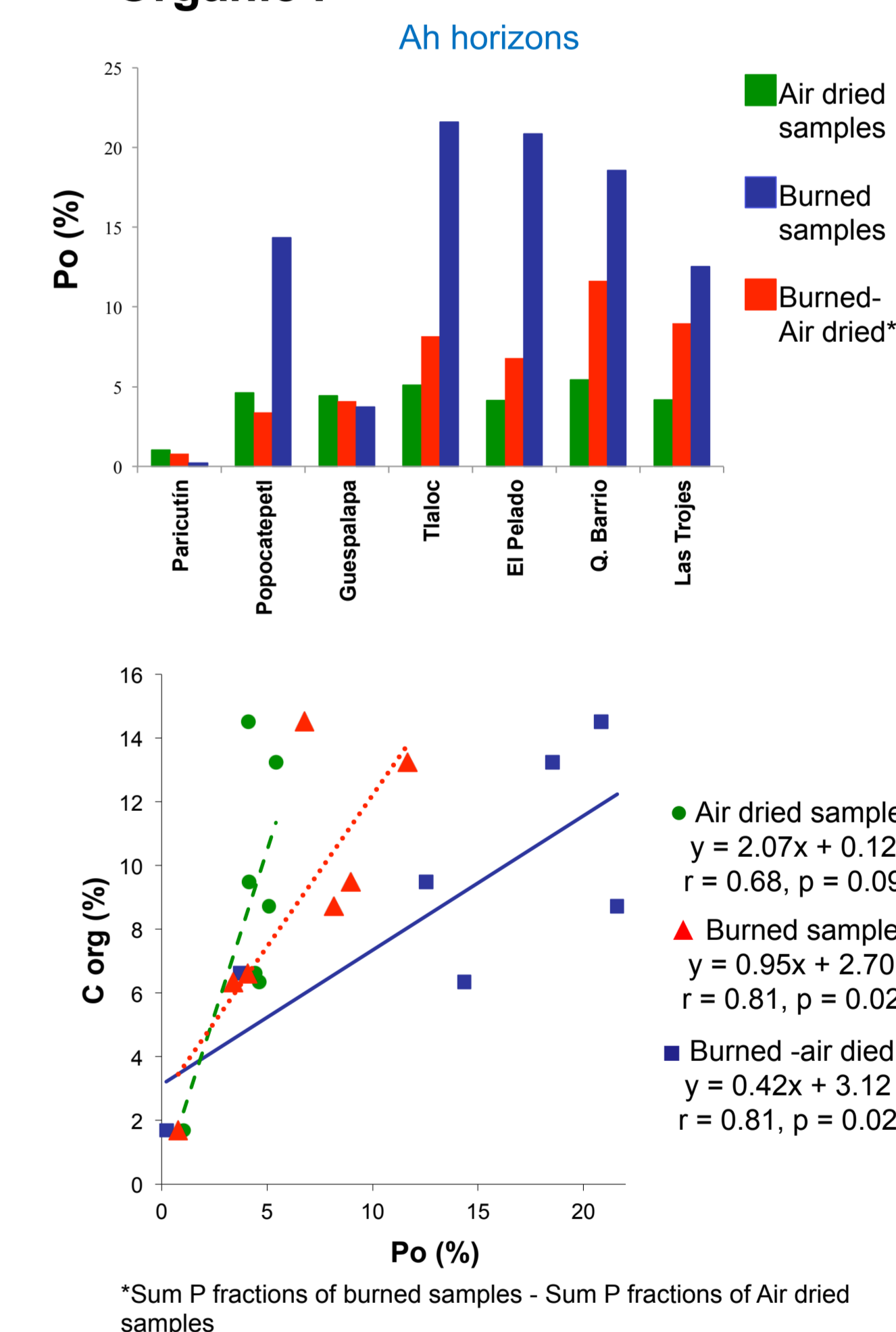•Walker, T. W. and J. K. Syers, 1976. The fate of phosphorus during pedogenesis. Geoderma, 15: 1-19.