

The Lithosphere

Weathering

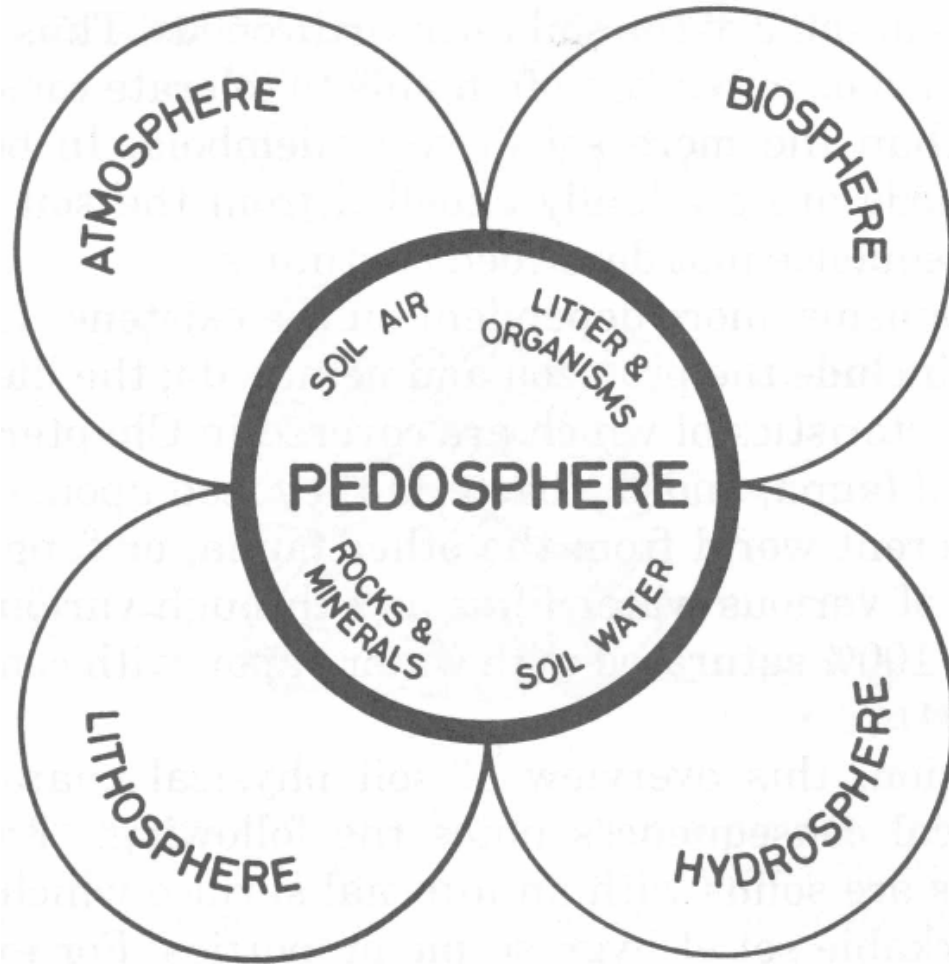
- physical processes
- chemical processes
- biological processes
- weathering rates

Soil development

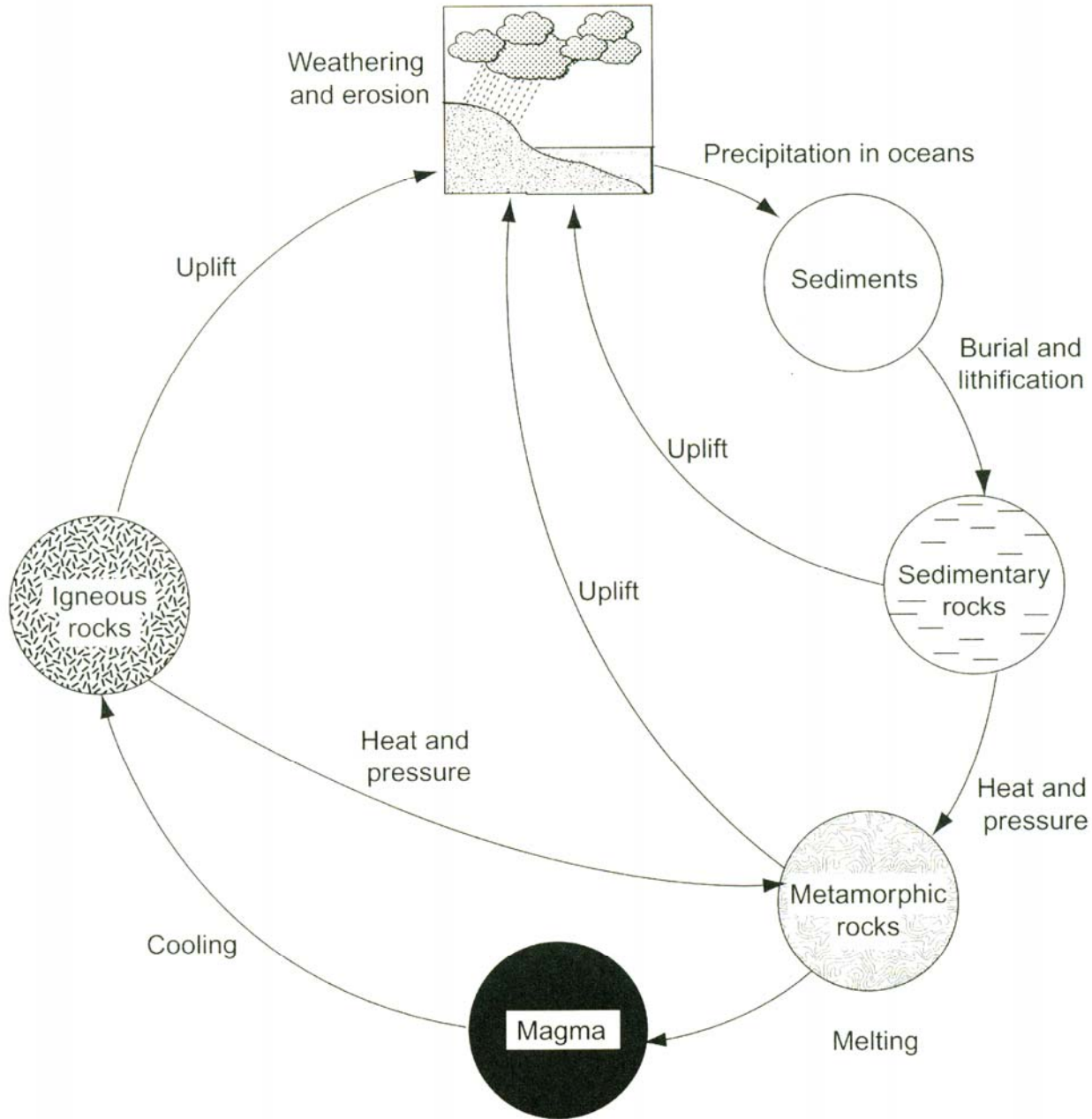
- soil formation processes
- types of soils and vegetation
- soil properties
 - physical
 - chemical
 - biological

Soil's role in biogeochemistry





Igneous rocks + acid volatiles = sedimentary rocks + salty oceans



Physical processes of weathering:

Fragmentation and breakdown of rocks and other particles without any chemical changes.

1. Temperature: mediate the breakdown of rocks and particles;
2. Motion by water, ice and wind;
3. Activities of plant roots and animals.

Note: the rate of physical weathering is often difficult to be determined separately because many other kinds of weathering are intimately coupled with physical weathering.

Chemical processes of weathering:

Weathering from chemical reactions.

1. H_2CO_3 and other acid volatiles
2. Hydration
3. Hydrolysis
4. Dissolution
5. Oxidation-reduction (e.g., S, Fe)

Ferromagnesian Series

Felsic Series

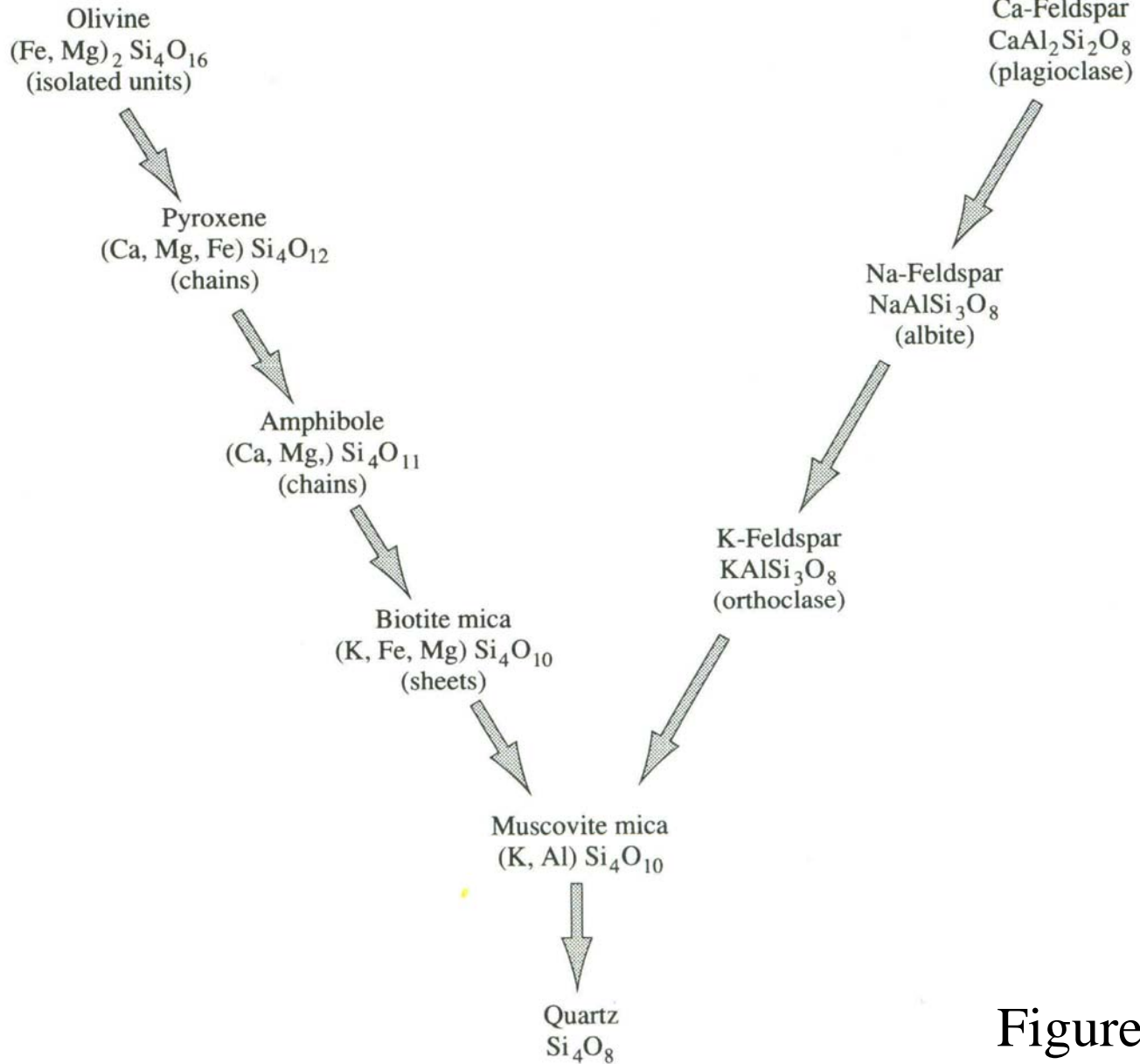


Figure 4.1

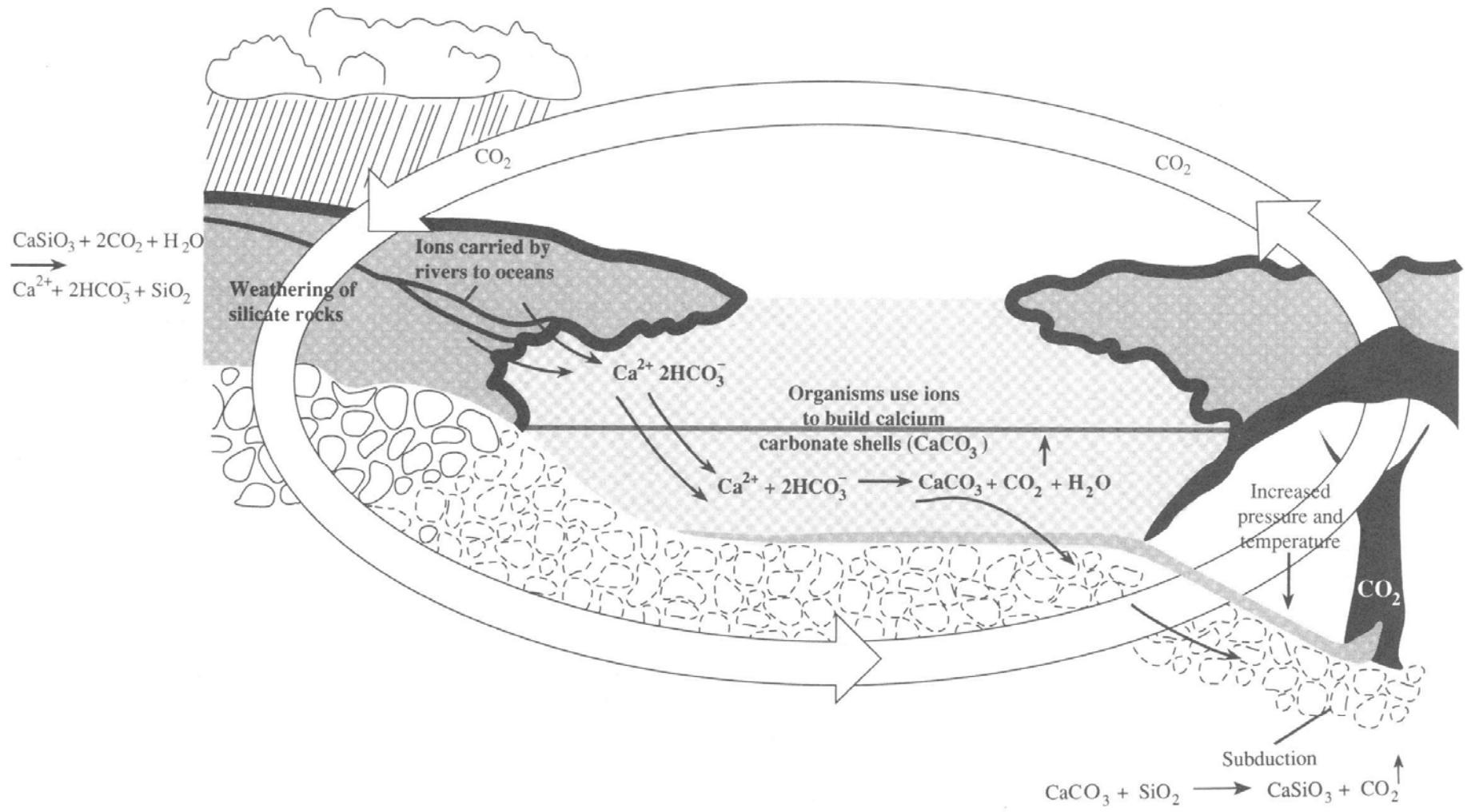


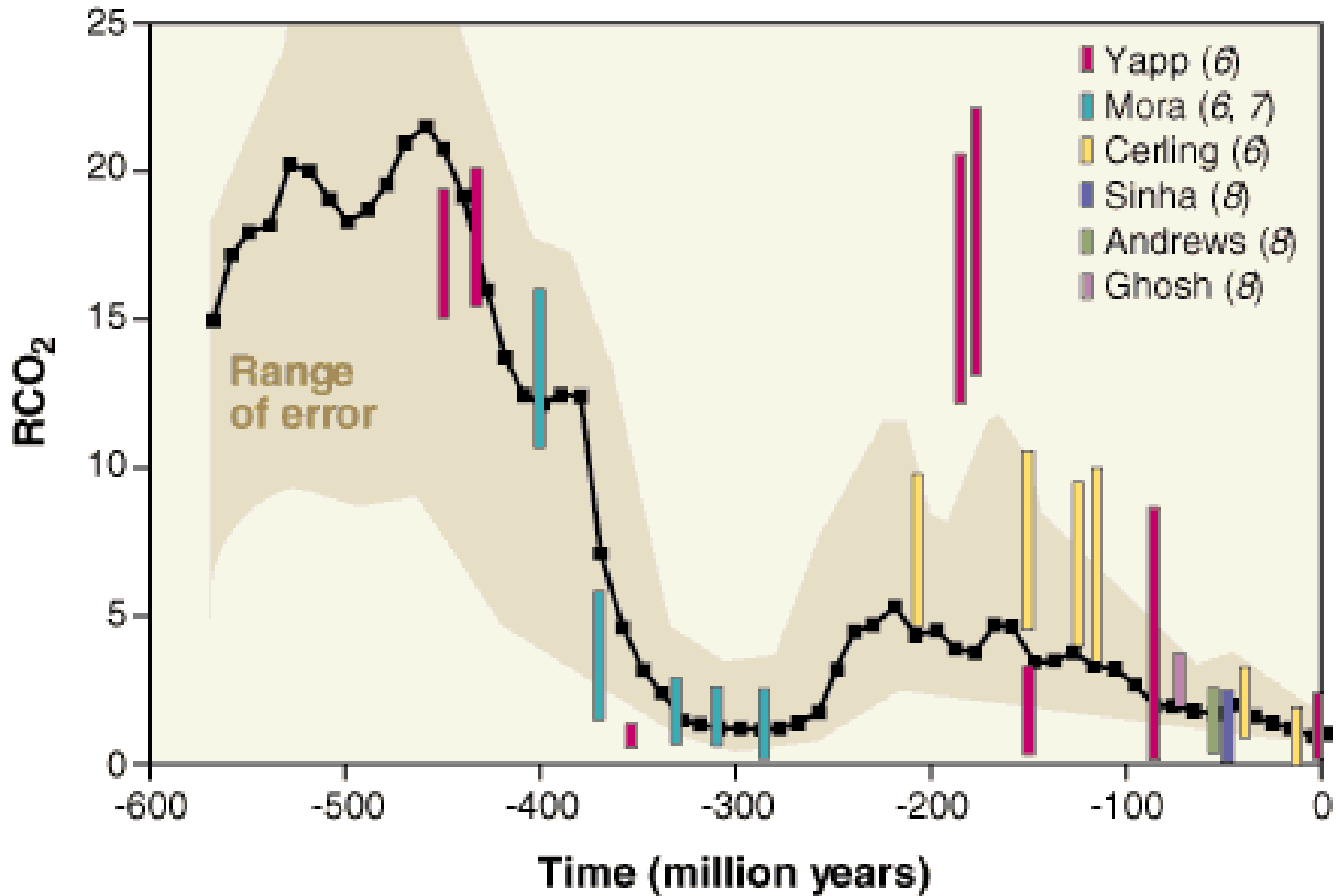
Figure 1.4 The interaction between the carbonate and the silicate cycles at the surface of the Earth. Long-term control of atmospheric CO_2 is achieved by dissolution of CO_2 in surface waters and its participation in the weathering of rocks. This carbon is carried to the sea as bicarbonate (HCO_3^-), and it is eventually buried as part of carbonate sediments in the oceanic crust. CO_2 is released back to the atmosphere when these rocks undergo metamorphism at high temperature and pressures deep in the Earth. Modified from Kasting et al. (1988).

Biological processes of weathering:

Weathering caused by biological activities.

1. Breaking force of root growth
2. CO₂ production
3. Organic acids from roots and litter
4. Activities of soil animals

Atmospheric carbon over geologic time



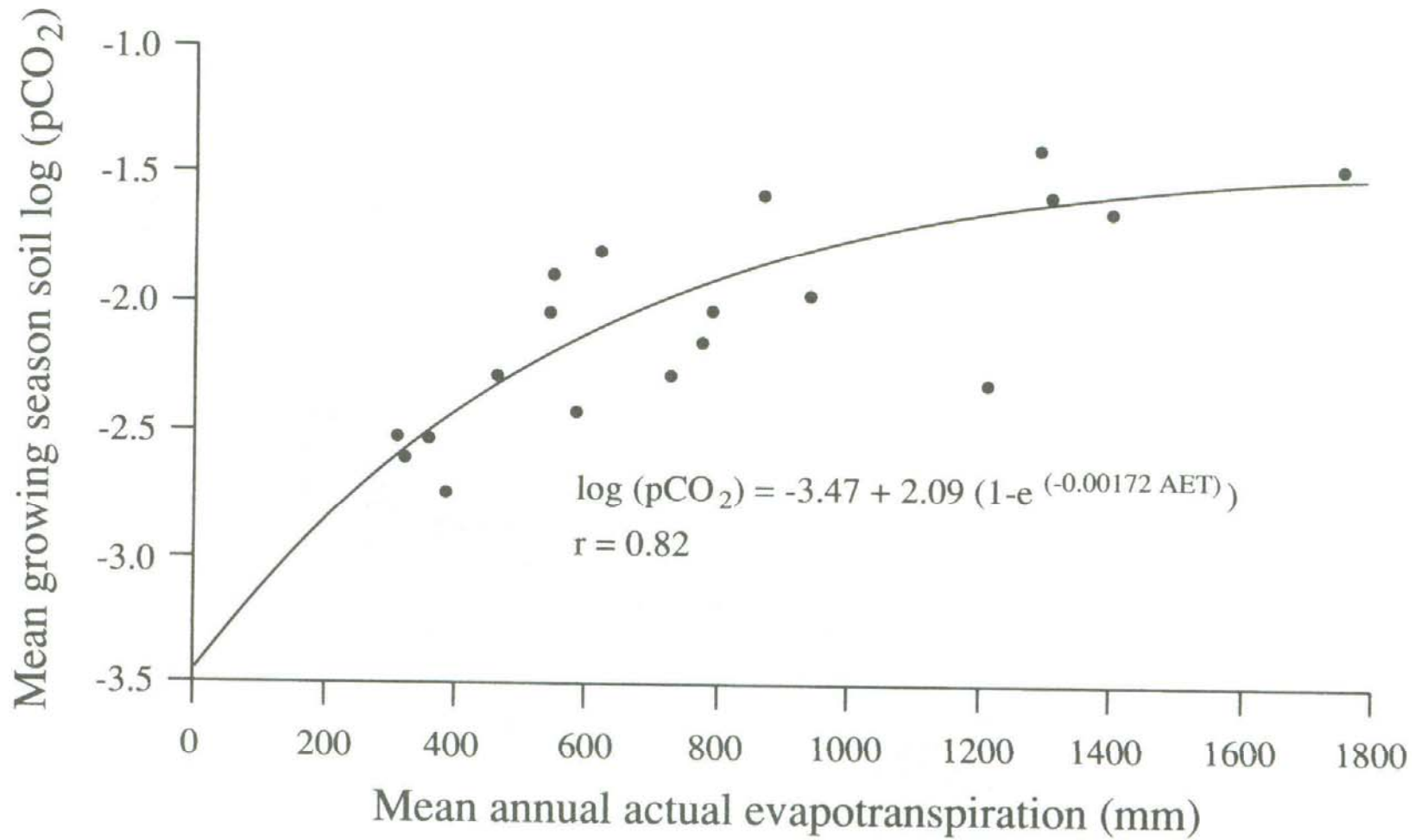


Figure 4.3 The relationship between the mean concentration of CO₂ in the soil pore space and the actual evapotranspiration of the site for various ecosystems of the world. From Brook et al. (1983).

Weathering rates

1. Types of minerals,
2. climate
3. biota,
4. topography
5. time

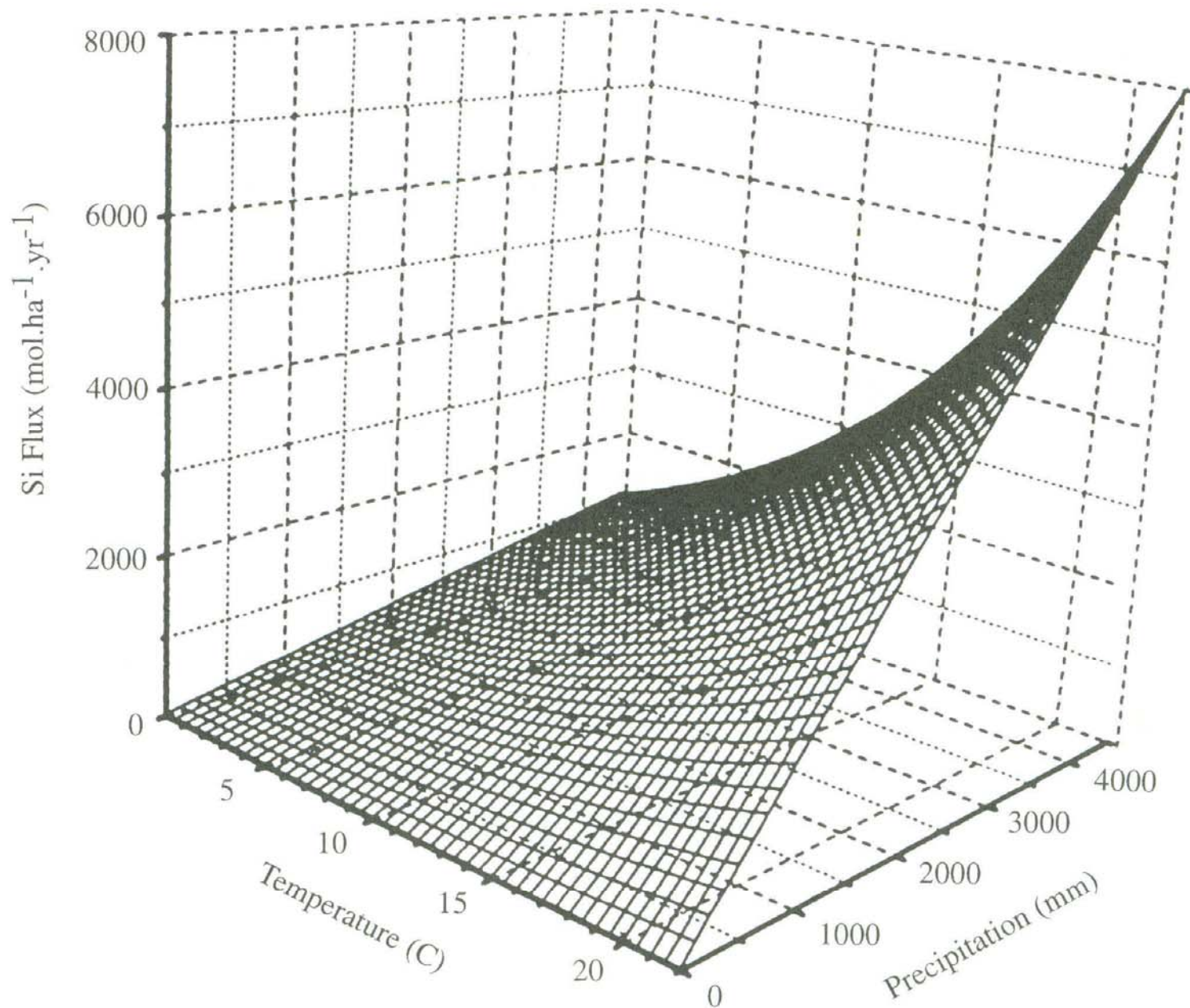


Figure 4.2 Loss of silicon (SiO₂) in runoff as a function of mean annual temperature and precipitation in various areas of the world. Modified from White and Blum (1995).

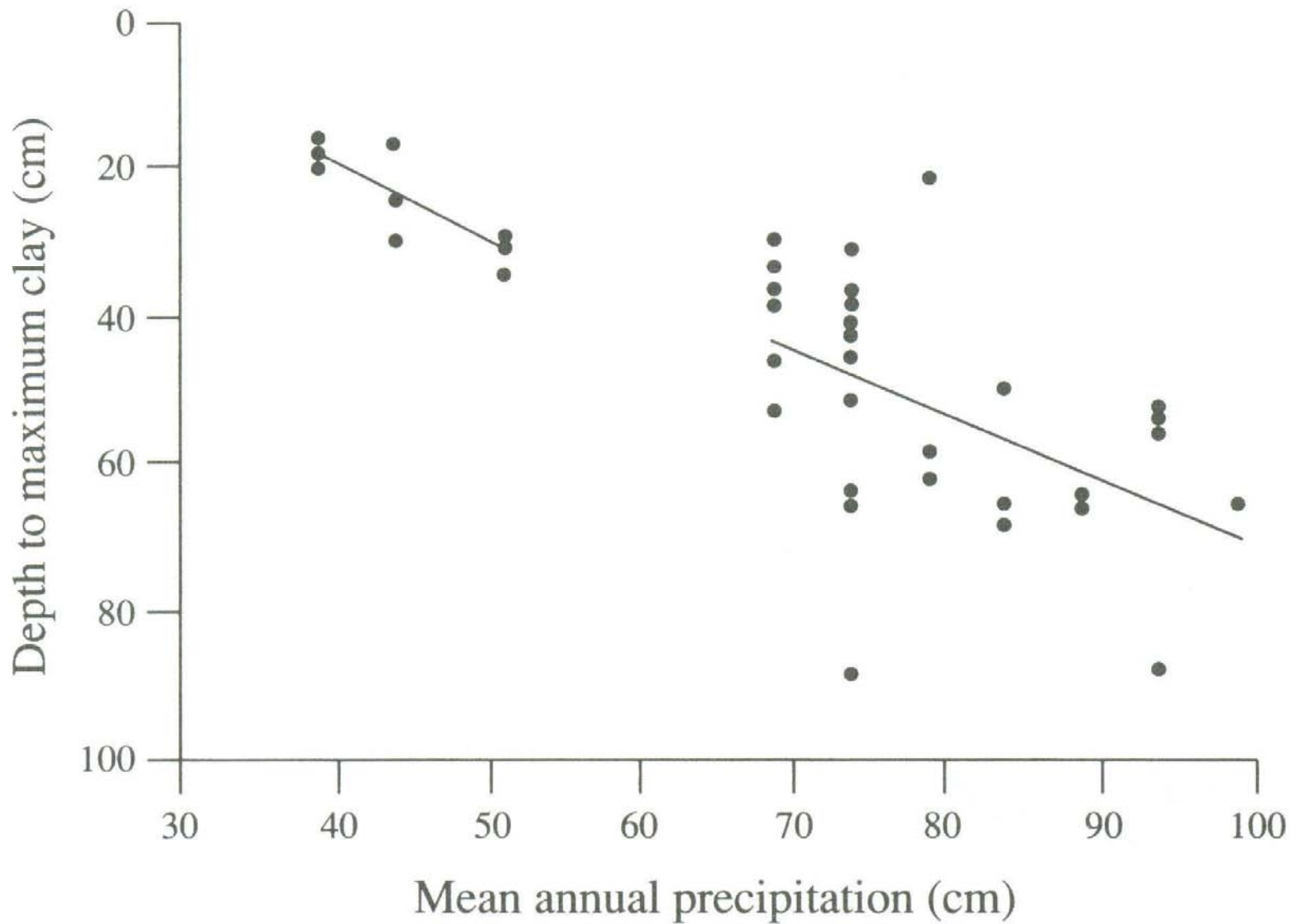


Figure 4.15 The depth to the peak content of clay in the soil profile, an index of weathering and soil development, decreases from east to west across the Great Plains of the United States as a function of the decrease in mean annual precipitation. From Honeycutt et al. (1990).

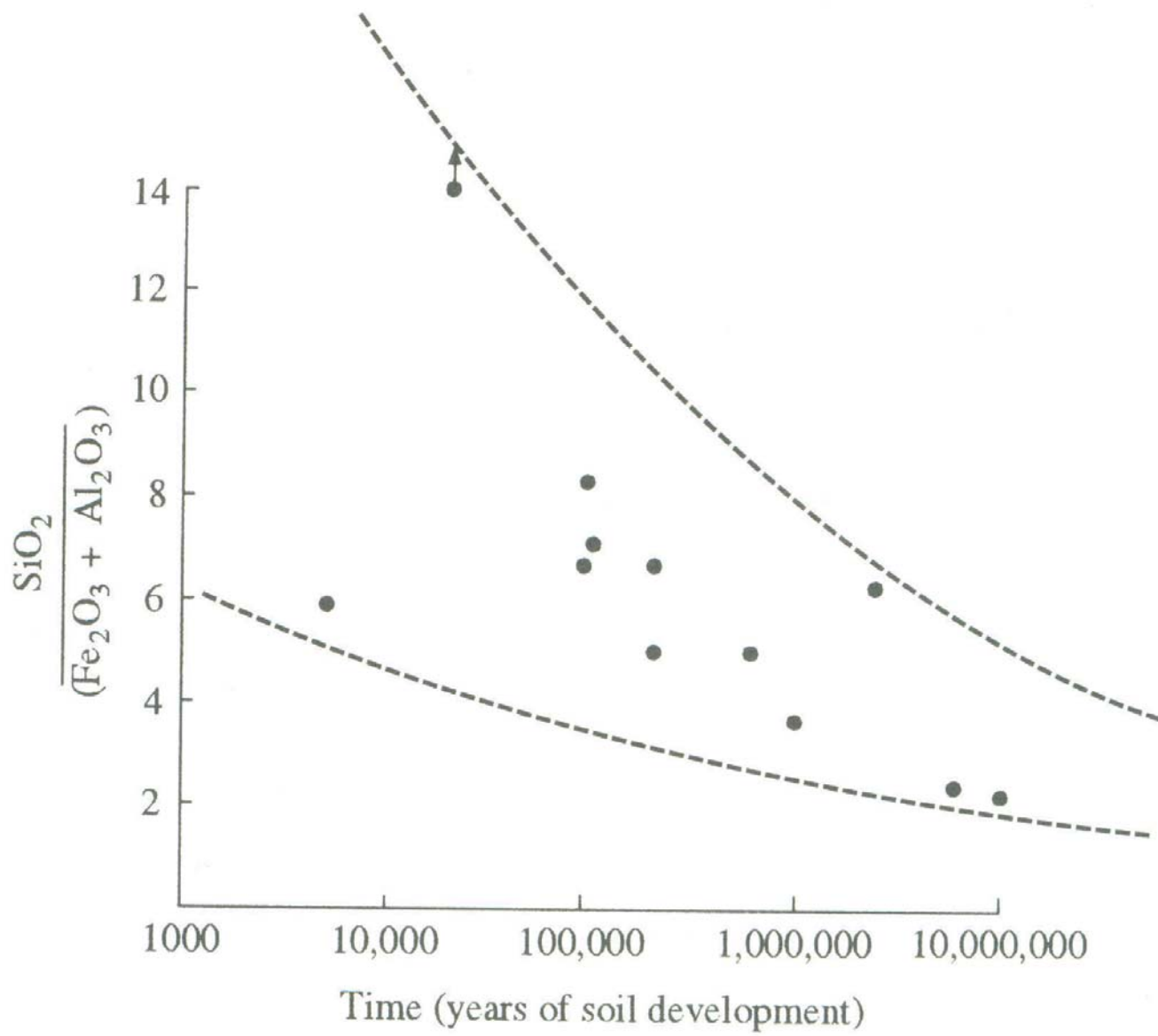


Figure 4.14 Schlesinger 1997

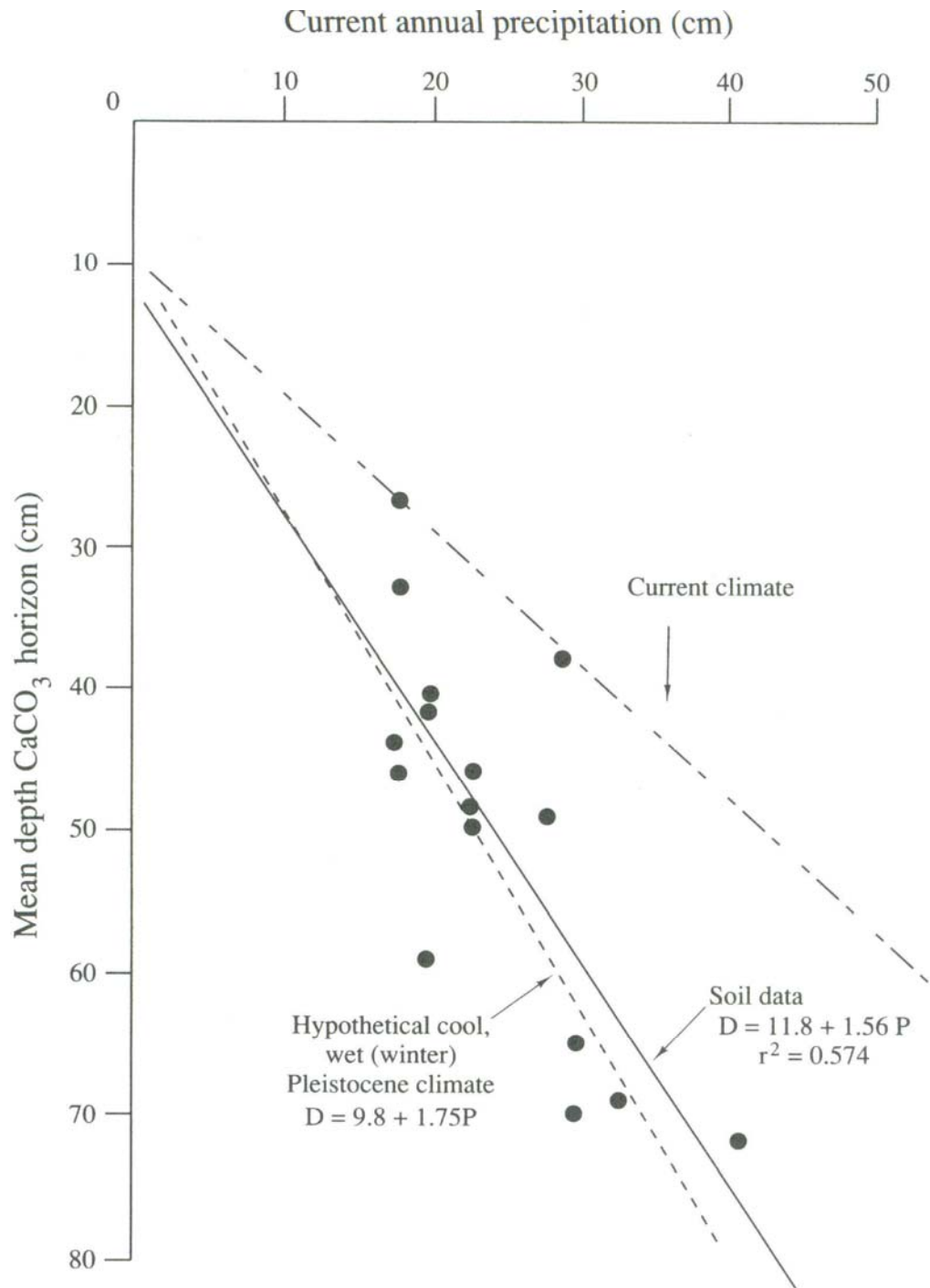


Fig4.16

Table 4.2 Chemical Composition of Precipitation, Soil Solutions, and Groundwater in a 175-yr-old *Abies amabilis* Stand in Northern Washington^a

Solution	pH	Total cations (mEq/liter)	Soluble ions (mg/liter)			Total (mg/liter)	
			Fe	Si	Al	N	P
Precipitation							
Above canopy	5.8	0.03	<0.01	0.09	0.03	0.60	0.01
Below canopy	5.0	0.10	0.02	0.09	0.06	0.40	0.05
Forest floor	4.7	0.14	0.04	3.50	0.79	0.54	0.04
Soil							
15 cm E	4.6	0.12	0.04	3.55	0.50	0.41	0.02
30 cm B _s	5.0	0.08	0.01	3.87	0.27	0.20	0.02
60 cm B ₃	5.6	0.25	0.02	2.90	0.58	0.37	0.03
Groundwater	6.2	0.26	0.01	4.29	0.02	0.14	0.01

^a Data from Ugolini et al. (1977), *Soil Sci.* **124**, 291–302. Copyright (1977) Williams & Wilkins.

Table 4.5 Inputs and Outputs of Elements from the Hubbard Brook Experimental Forest, New Hampshire^a

	Inputs (%)		Output as a percent of input
	Atmosphere	Weathering	
Ca	9	91	59
Mg	15	85	78
K	11	89	24
Fe	0	100	25
P	1	99	1
S	96	4	90
N	100	0	19
Na	22	78	98
Cl	100	0	74

^a Data from Likens et al. (1981).

TABLE 20. Differential Chemical Weathering at Hubbard Brook.

Element	Abundance in bedrock ^a , %	A	B	Differential weathering ratio ^c = (A/B) × 100, %
		Annual release from bedrock by weathering, ^b kg/ha	Amount contained in 1,500 kg of bedrock, kg	
Ca ²⁺	1.4	21.1	21.1	100
Na ⁺	1.6	5.8	24.1	24
Mg ²⁺	1.1	3.5	16.5	21
K ⁺	2.9	7.1	43.6	16
Al ³⁺	8.3	1.9	124.8	2
Si ⁴⁺	30.7	18.1 ^d	461.7	2

^aTaken from Johnson et al. (1968).

^bBased on net output of dissolved substances (Table 11) plus living and dead biomass accumulation, which for Ca²⁺, Na⁺, Mg²⁺, and K⁺ is 9.5, 0.17, 0.9, and 6.1 kg/ha·yr, respectively.

^cNormalized to calcium, i.e., assuming the complete extraction of calcium from 1,500 kg of bedrock.

^dAssuming that dissolved silica is in the form of SiO₂ (Table 11), and 0.1 kg Si per hectare is exported in stream water as organic particulate matter.

Table 4.6 Net Transport (Export Minus Atmospheric Deposition) of Major Ions, Soluble Silica, and Suspended Solids from Various Watersheds of Forested Ecosystems^a

Watershed characteristics	Caura River, Venezuela	Gambia River, W. Africa	Catoctin Mtns., Maryland	Hubbard Brook, New Hampshire
Size (km ²)	47,500	42,000	5.5	2
Precipitation (cm)	450	94	112	130
Vegetation	Tropical forest	Savanna forest	Temperate forest	Temperate forest
Net dissolved transport (kg ha ⁻¹ yr ⁻¹)				
Na	19.4	3.9	7.3	5.9
K	13.6	1.4	14.1	1.5
Ca	14.2	4.0	11.9	11.7
Mg	5.7	2.0	15.6	2.7
HCO ₃ ⁻	124.0	20.3	78.1	7.7
Cl ⁻	- 1.4	0.6	16.6	-1.6
SO ₄ ²⁻	1.5	0.4	21.2	14.8
SiO ₂	195.7	15.0	56.1	37.7
Total transport (kg ha ⁻¹ yr ⁻¹)	372.7	47.6	220.9	80.4

^a Modified from Lewis et al. (1987).

TABLE 4.9 Sources of Major Elements in World River Waters (in percent of actual concentrations)

Element	Atmospheric cyclic salt	Weathering			
		Carbonates	Silicates	Evaporites	Pollution
Ca^{2+}	0.1	65	18	8	9
HCO_3^-	$\ll 1$	61	37	0	2
Na^+	8	0	22	42	28
Cl^-	13	0	0	57	30
SO_4^{2-} ^a	2	0	0	22	43
Mg^{2+}	2	36	54	$\ll 1$	8
K^+	1	0	87	5	7
H_4SiO_4	$\ll 1$	0	99+	0	0

^a SO_4^{2-} is also derived from the weathering of pyrite.

Source: From Berner and Berner (1987). Used with permission of Prentice Hall.

TABLE 4.8 Chemical and Mechanical Denudation of the Continents

Continent	Chemical denudation ^a		Mechanical denudation ^b		Ratio mechanical/ chemical
	Total (10 ¹⁴ g/yr)	Per unit area (kg ha ⁻¹ yr ⁻¹)	Total (10 ¹⁴ g/yr)	Per unit area (kg ha ⁻¹ yr ⁻¹)	
N. America	7.0	330	14.6	840	2.1
S. America	5.5	280	17.9	1000	3.3
Asia	14.9	320	94.3	3040	6.3
Africa	7.1	240	5.3	350	0.7
Europe	4.6	420	2.3	500	0.5
Australia	0.2	20	0.6	280	3.0
Total	39.3	267	135.0	918	3.4

^a Source: From Garrels and MacKenzie (1971).

^b Source: From Milliman and Meade (1982).

Weathering rates

1. Types of minerals,
2. climate
3. biota,
4. topography
5. time

Why are these weathering rates important to be known?

Soil development

Soil formation processes

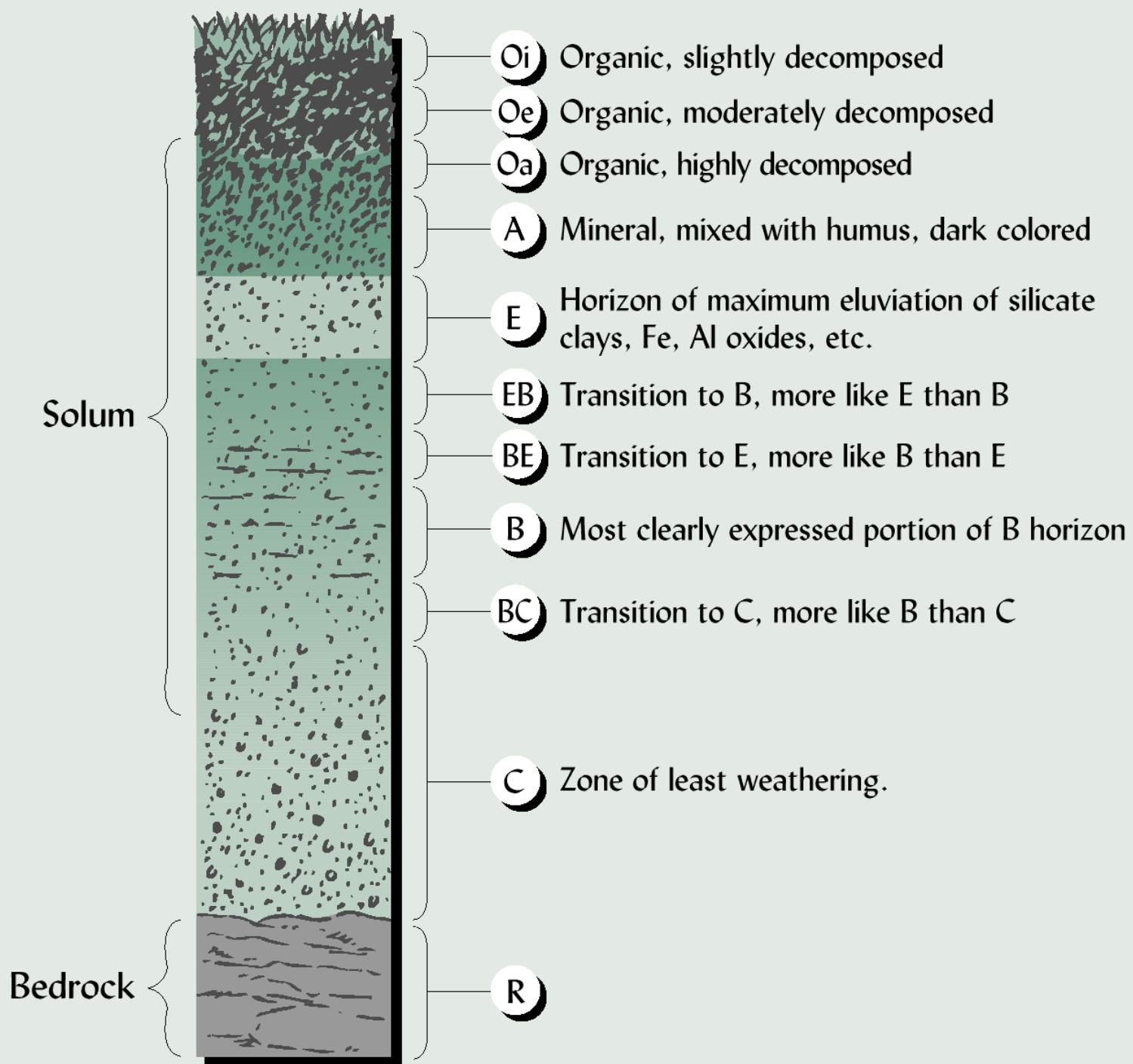
Types of soils and vegetation

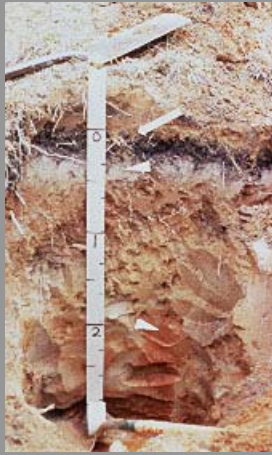
Soil properties

physical

chemical

biological





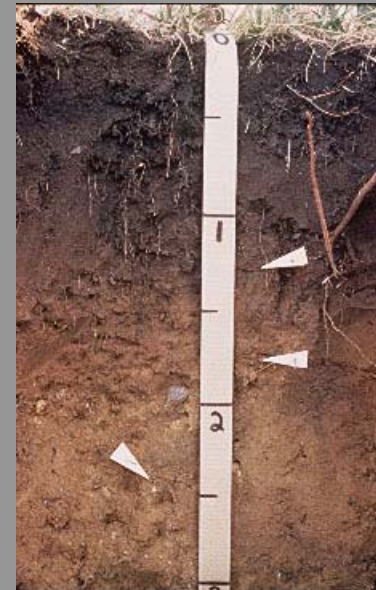
Minnesota Spodosol



Germany Spodosol



Australia Oxisol

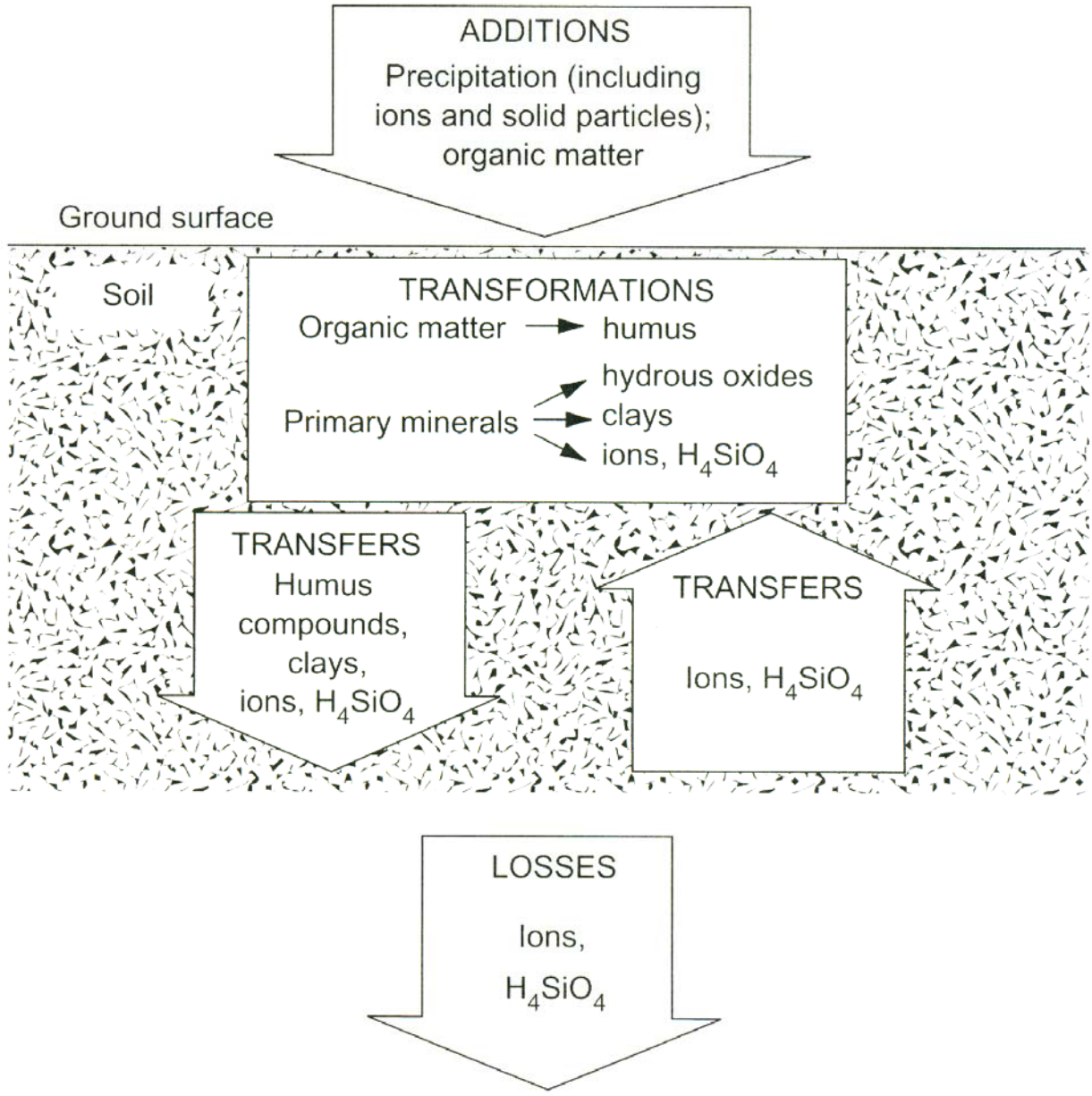


Minnesota Mollisol

Soil formation processes

What is soil formation? Most soils are mineral soils formed by the weathering of solid rock masses into unconsolidated materials, except for organic soils that mostly develop from plant residues.

Soil formation consists of two inter-connected parts: (1) the production and accumulation of unconsolidated materials by **weathering** and subsequent movements; and (2) **horizon development** involving changes within the loose material over time.



Soil forming factors

Parent materials (rocks, loess, glacial till, alluvium, etc)

Climate (precipitation, temperature, wind, etc)

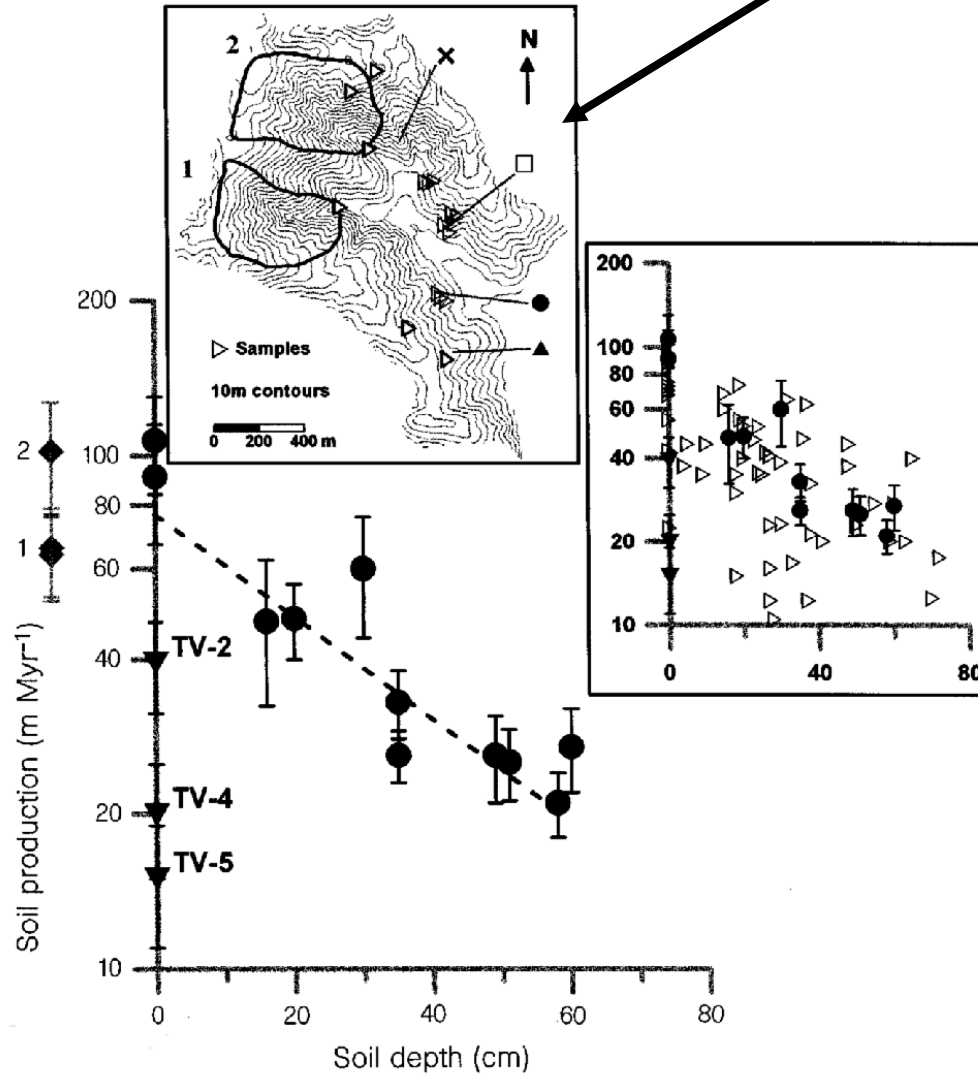
Biota (organic and living)

Topography (or relief, modify water and temperature)

Time (without time, nothing changes)

Interactions of all

Tennessee Valley, Marin county, CA



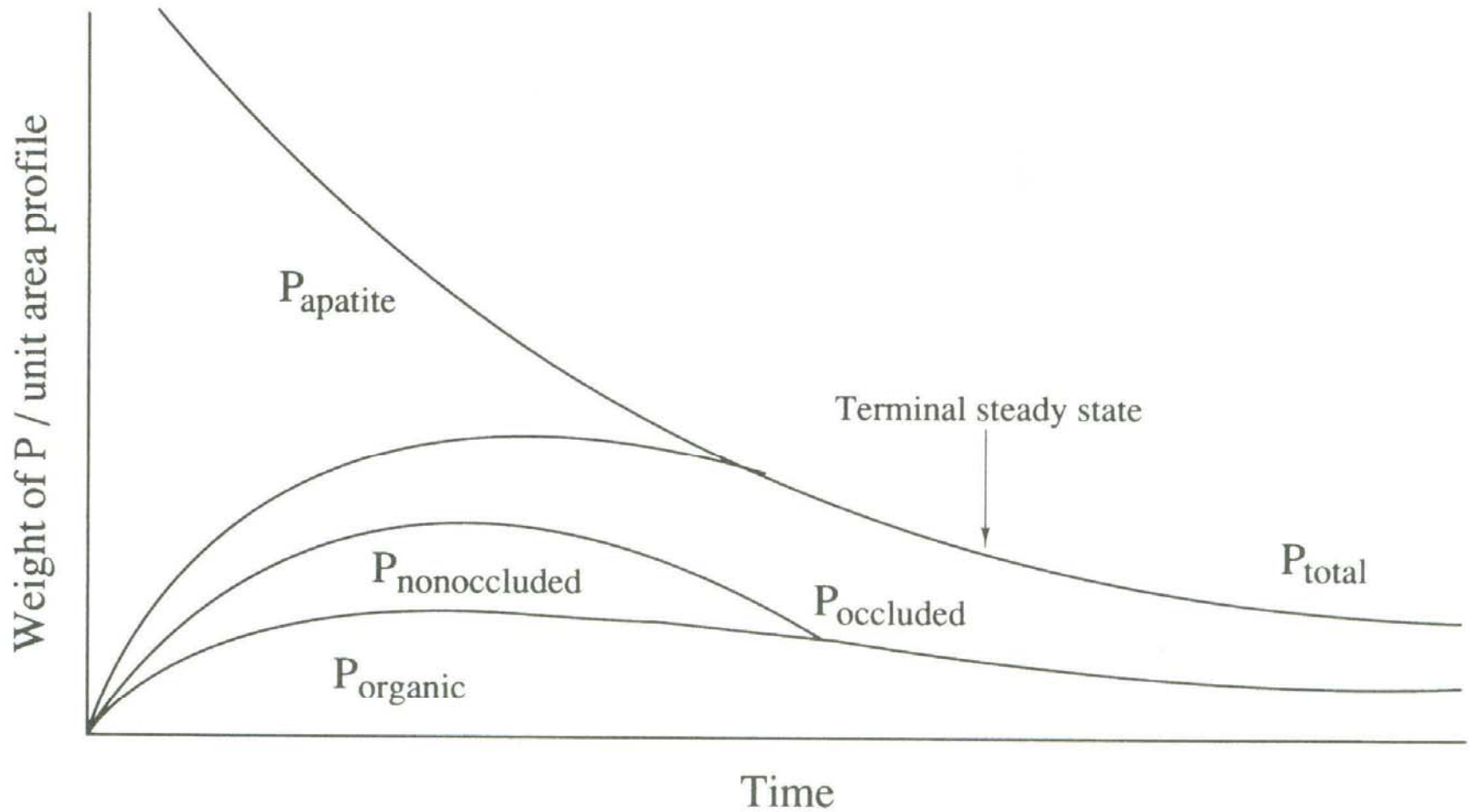


Figure 4.11 Changes in the forms of phosphorus found during soil development on sand dunes in New Zealand. Modified from Walker and Syers (1976).

Types of soils

In general, soils and vegetation are co-evolving through time. They are entangled parts of terrestrial ecosystems often with distinctive features associated with each particular coupling between the two. Understanding and discussion of the relationship between soils and vegetation are inevitably imbedded in their climate and other environmental conditions.



Plate 3: Aridisols

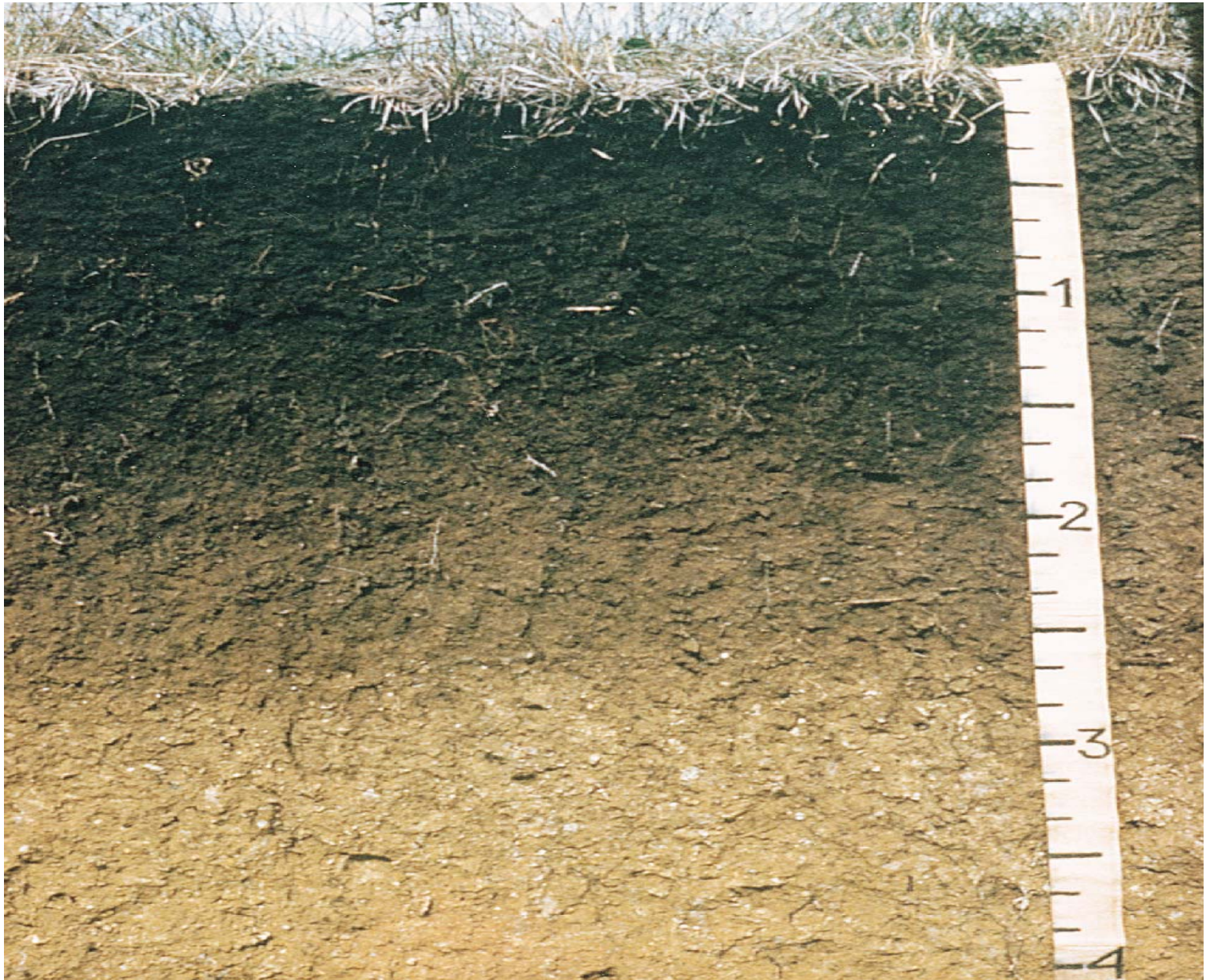


Plate 8: Mollisols



Plate 5: Gelisols



Plate 10: Spodosols



Plate 11: Ultisols



Plate 9: Oxisols

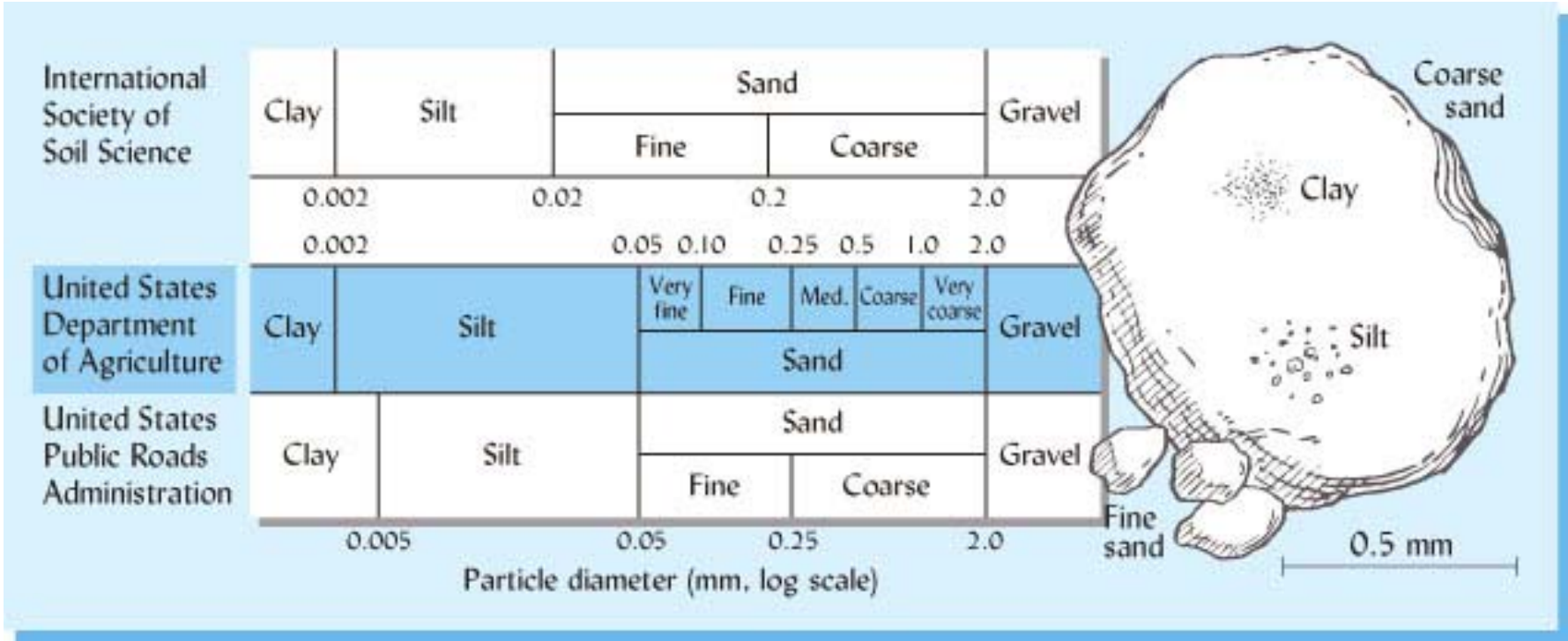
Soil properties:

Physical: e.g., texture, structure and bulk density

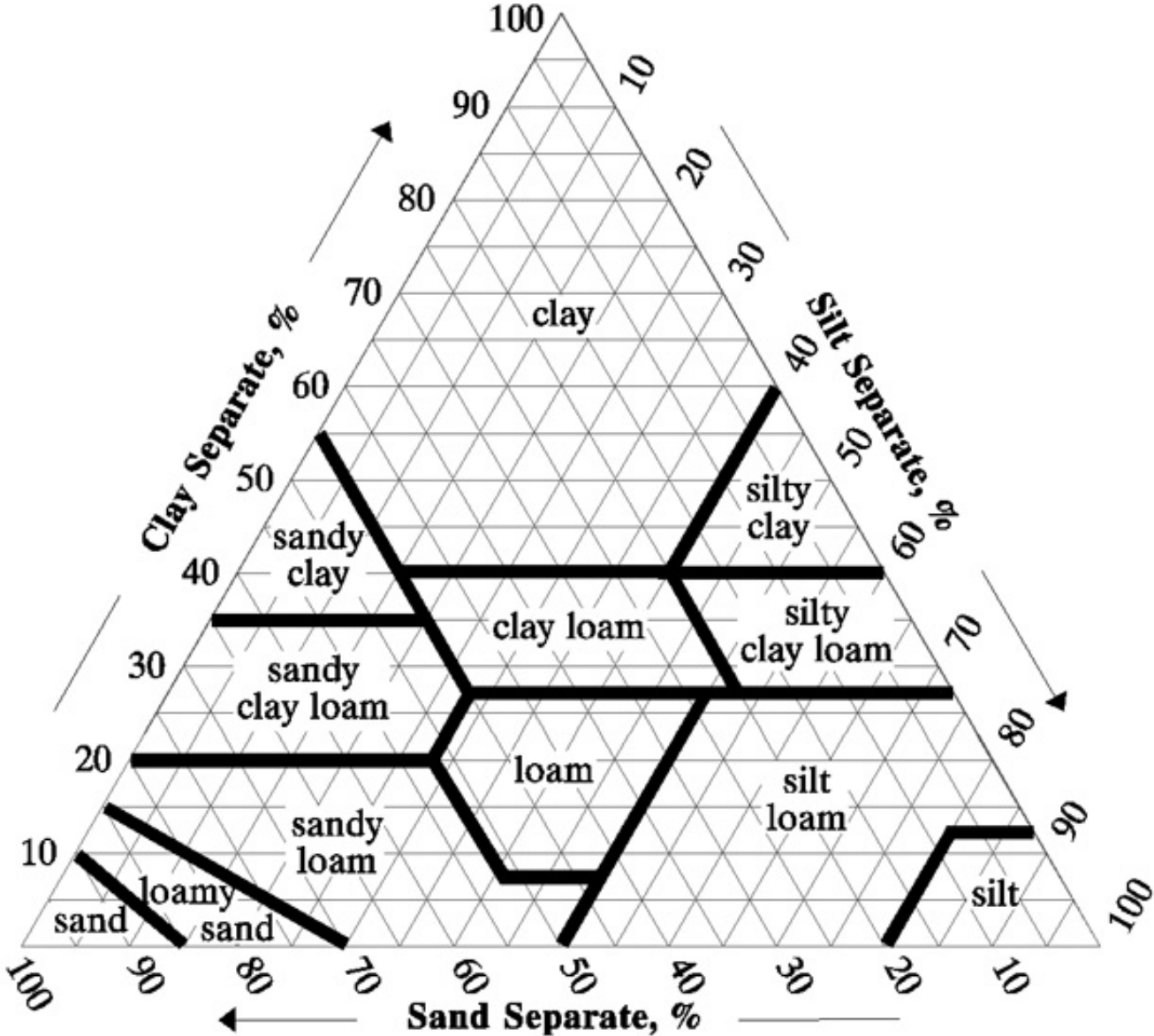
Chemical: e.g., pH, CEC and Redox potential

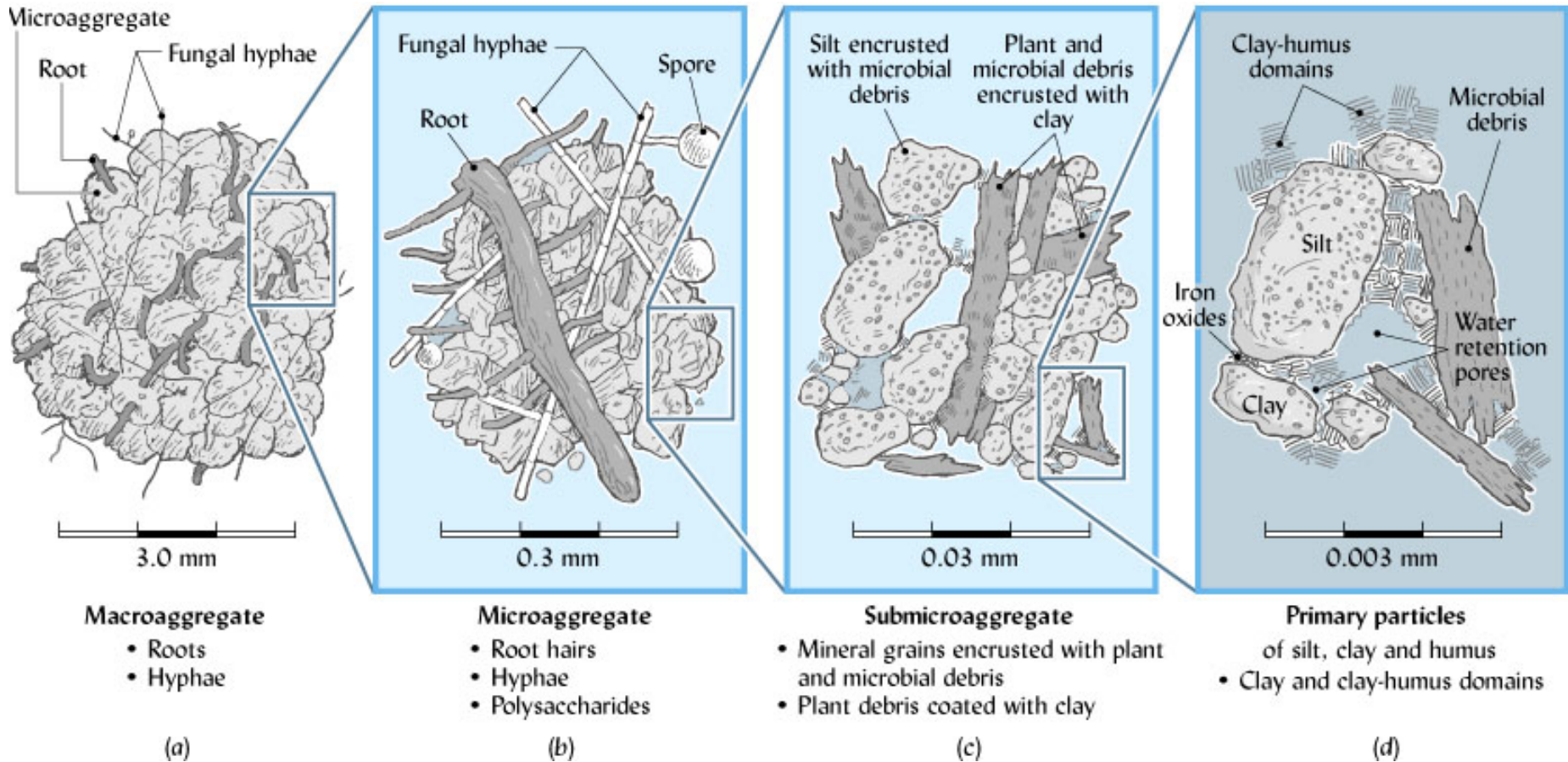
Biological: e.g., respiration, fertility and food webs

Soil particle sizes

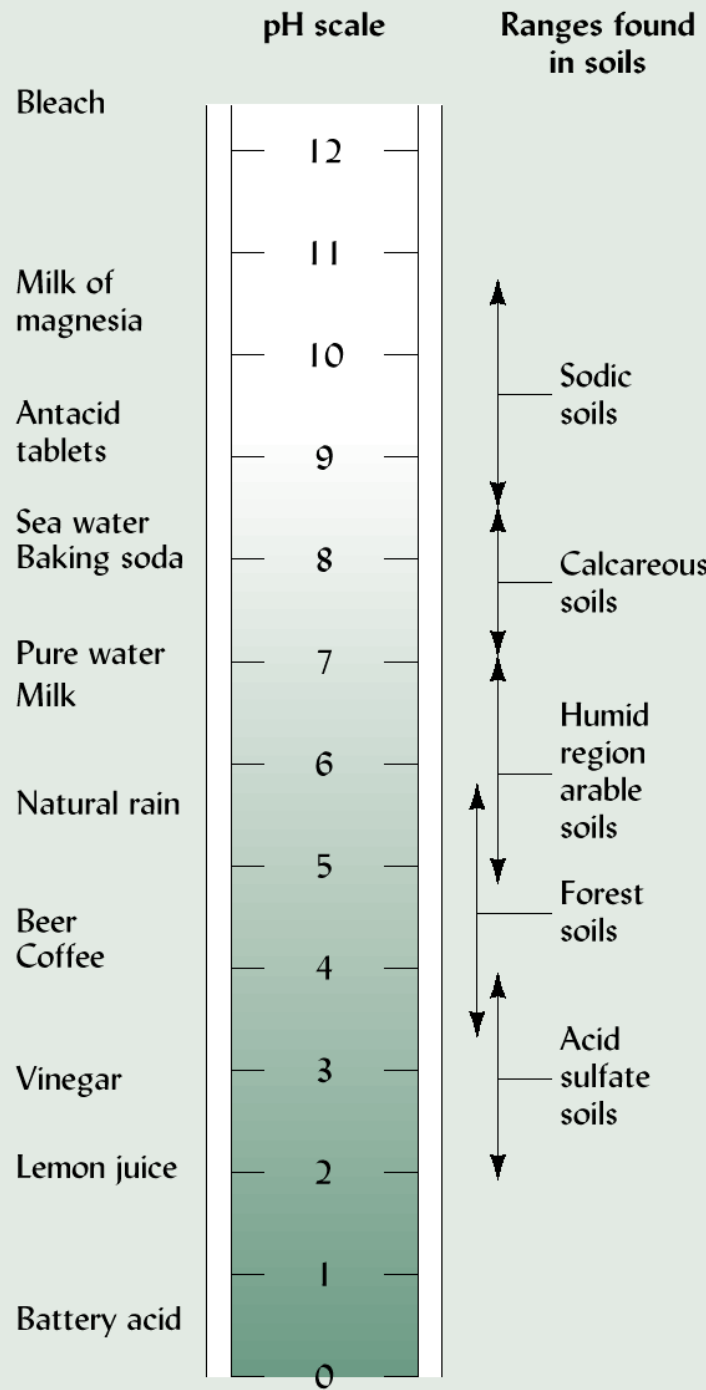


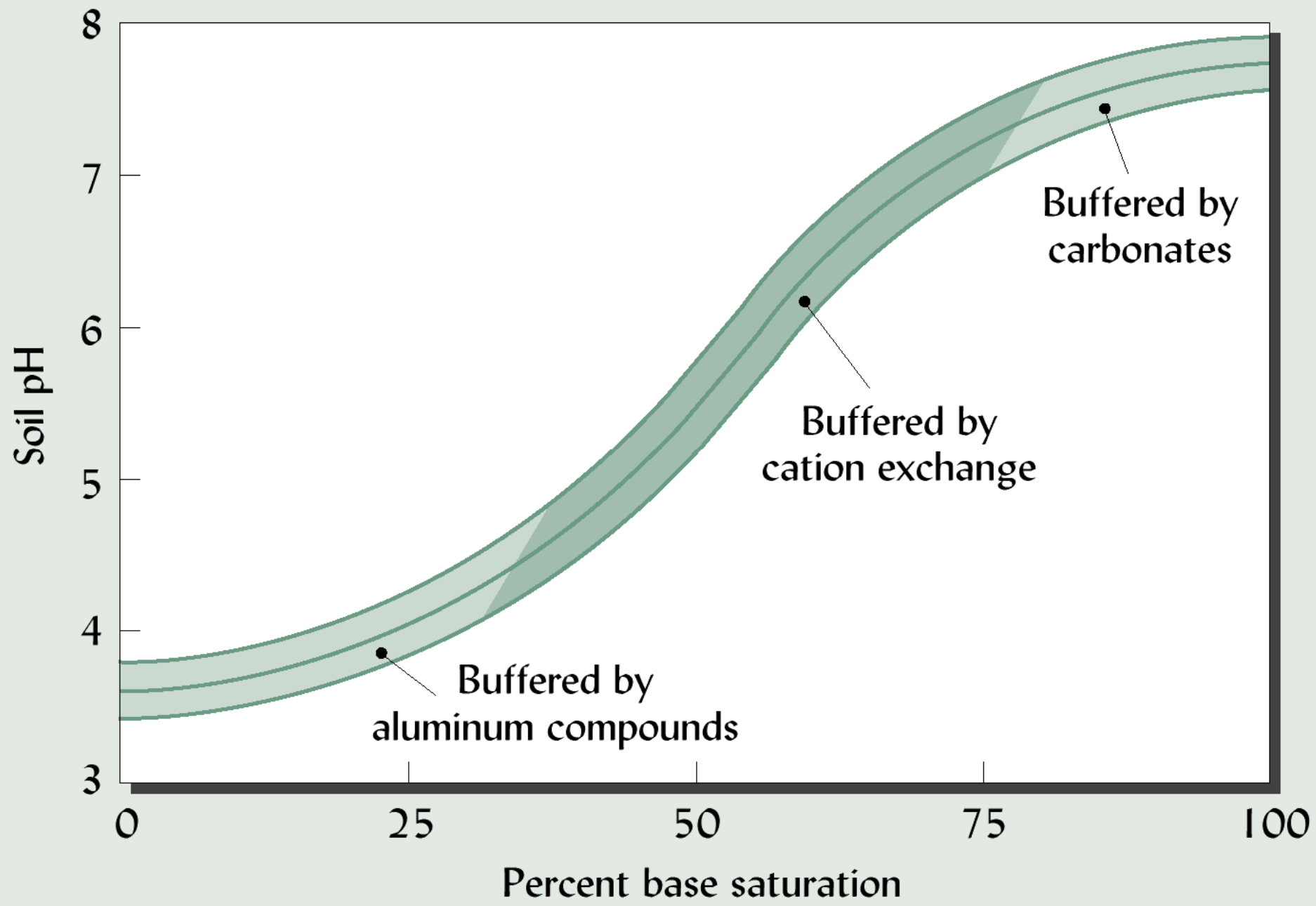
Soil Texture Triangle





Soil Bulk Density is defined as the mass of a unit volume of dry soil with preserved air pore space.





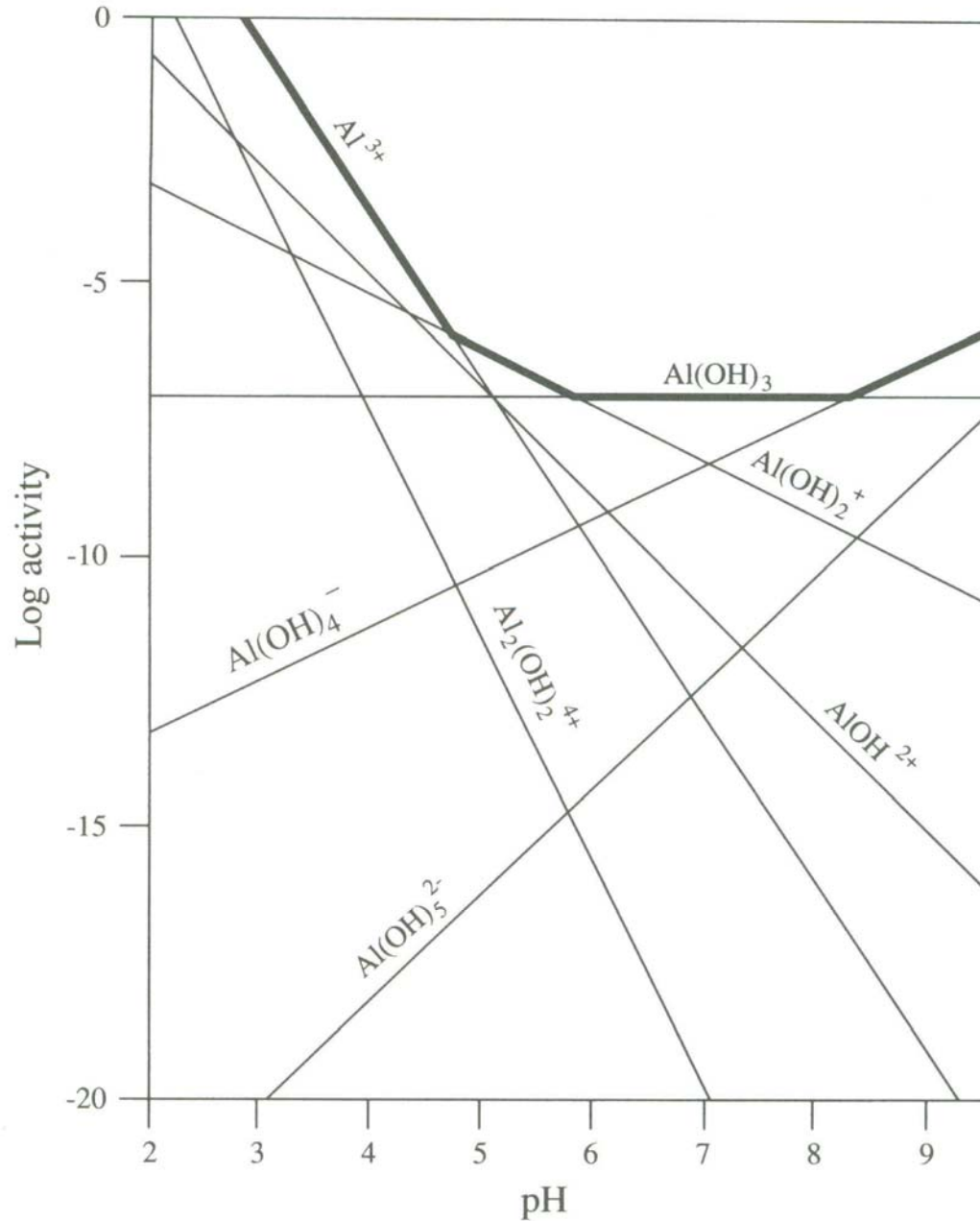


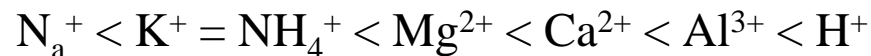
Figure 4.7 The solubility of aluminum as a function of pH. For pH in the neutral range, gibbsite [Al(OH)₃] controls aluminum solubility, and there is little Al³⁺ in solution. Al³⁺ become more soluble at pH < 4.7. From Lindsay (1979).

What is CEC (Cation Exchange Capacity)?

Surfaces of clay minerals and humus usually have negative charges. These charges attract or hold positively charged ions (**CATIONS**) in equilibrium with other cations in solution. The replacement of adsorbed cations by other cations in solution is called **cation exchange**. Cation exchange is controlled by (1) type of cations, and (2) their concentration relative to concentrations of other cations in the solution and on the exchangeable surfaces. All cation exchange processes are **REVERSIBLE** reactions, and take place following the **principle of charge equivalence**.

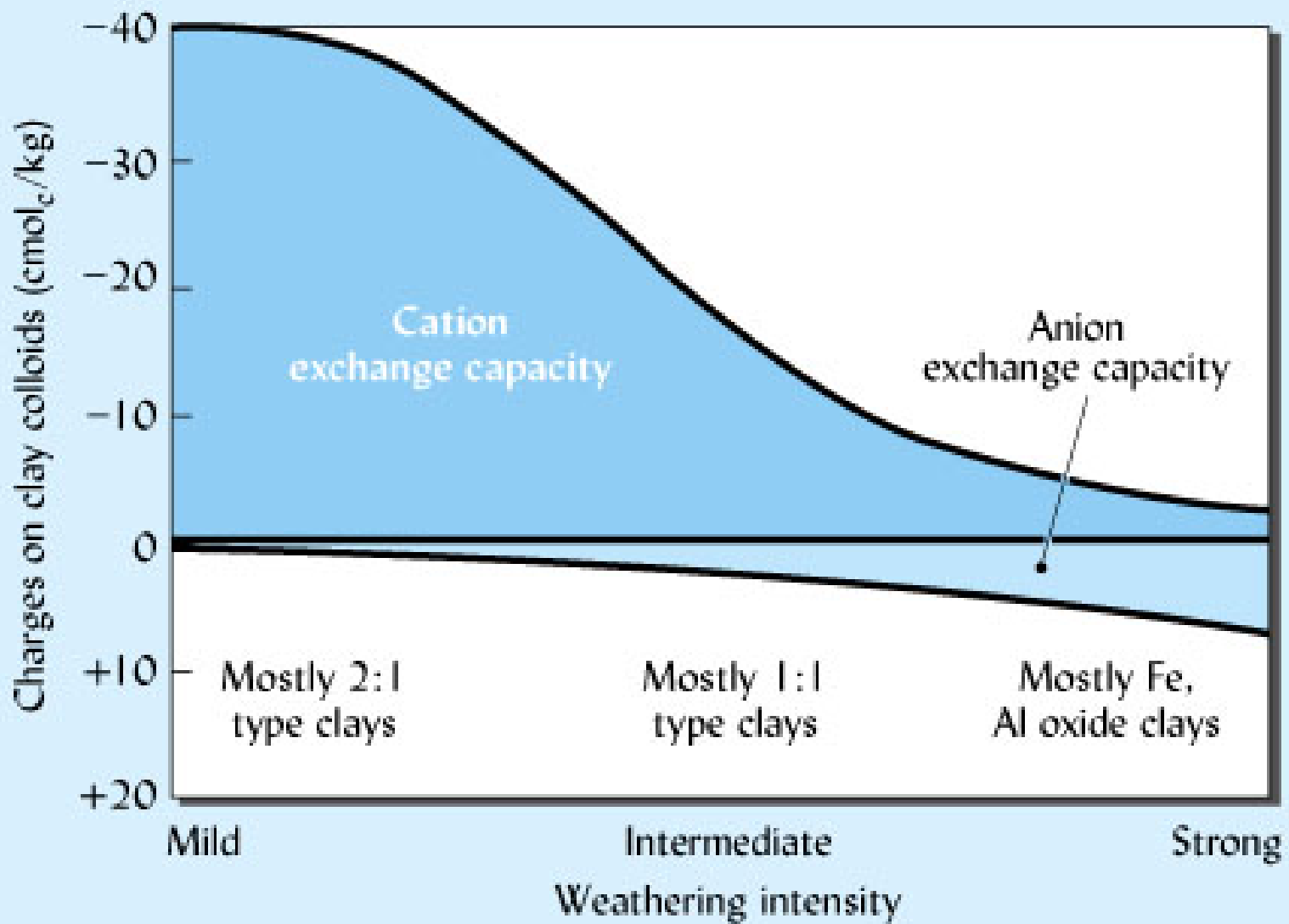
Types of Cations:

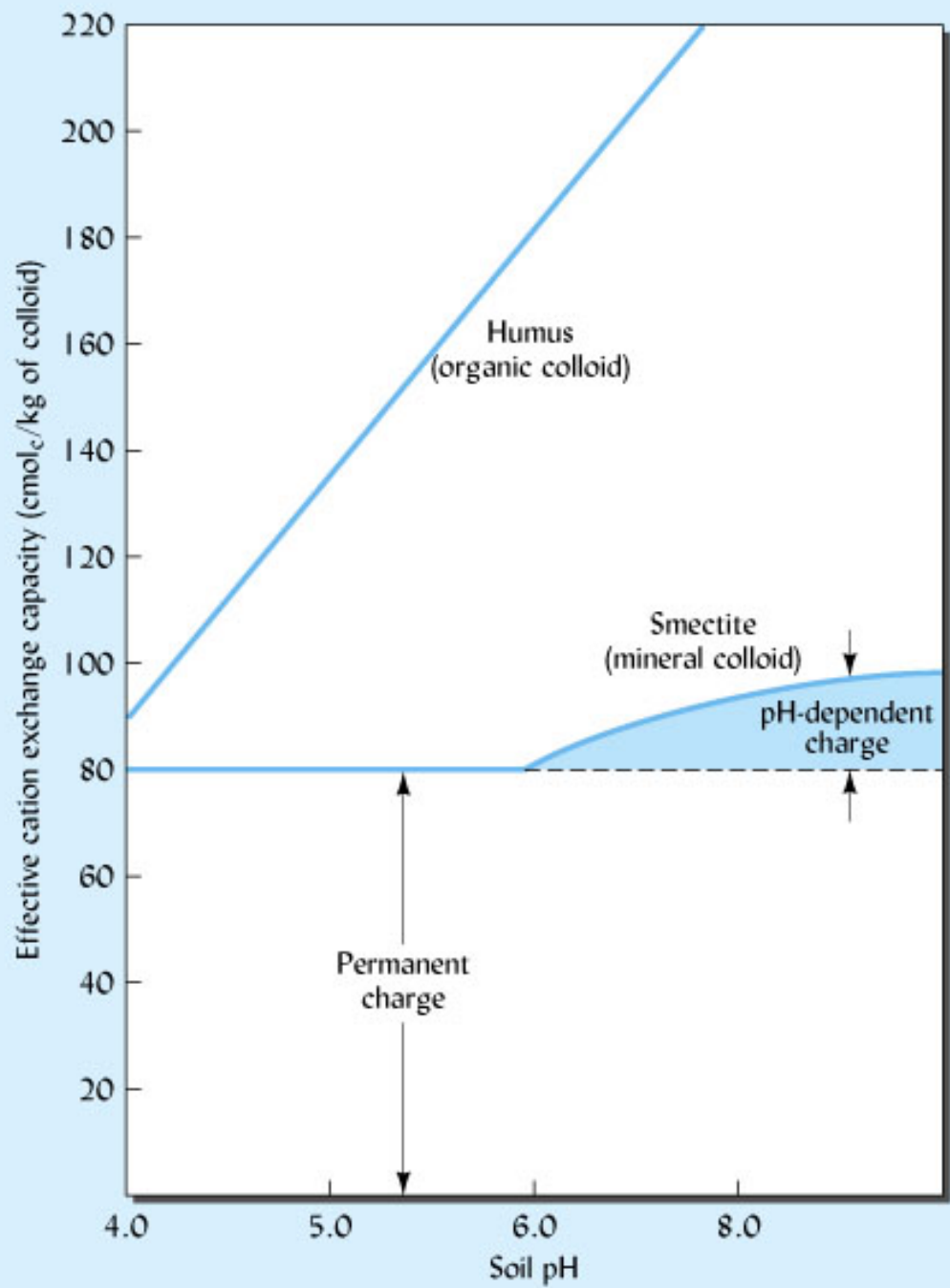
The strength of cation adsorption increases as (1) the charge of the cation increases; and as (2) the radius of the hydrated cation decreases:

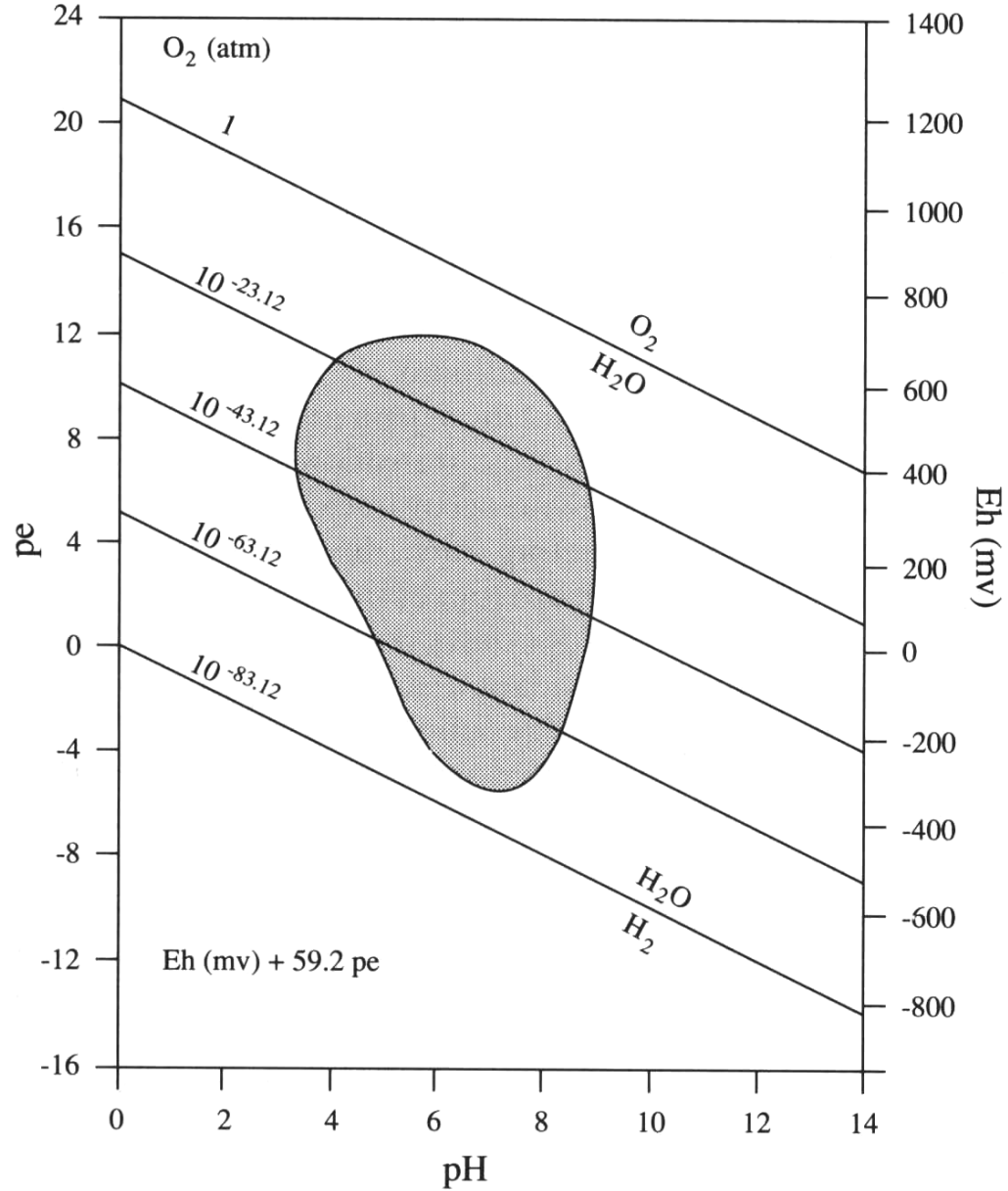


Cation Exchange Capacity (CEC) is the total quantity of exchangeable cation sites (mole of charge) per unit weight of dry soil, often expressed in $cmol_c/kg$.

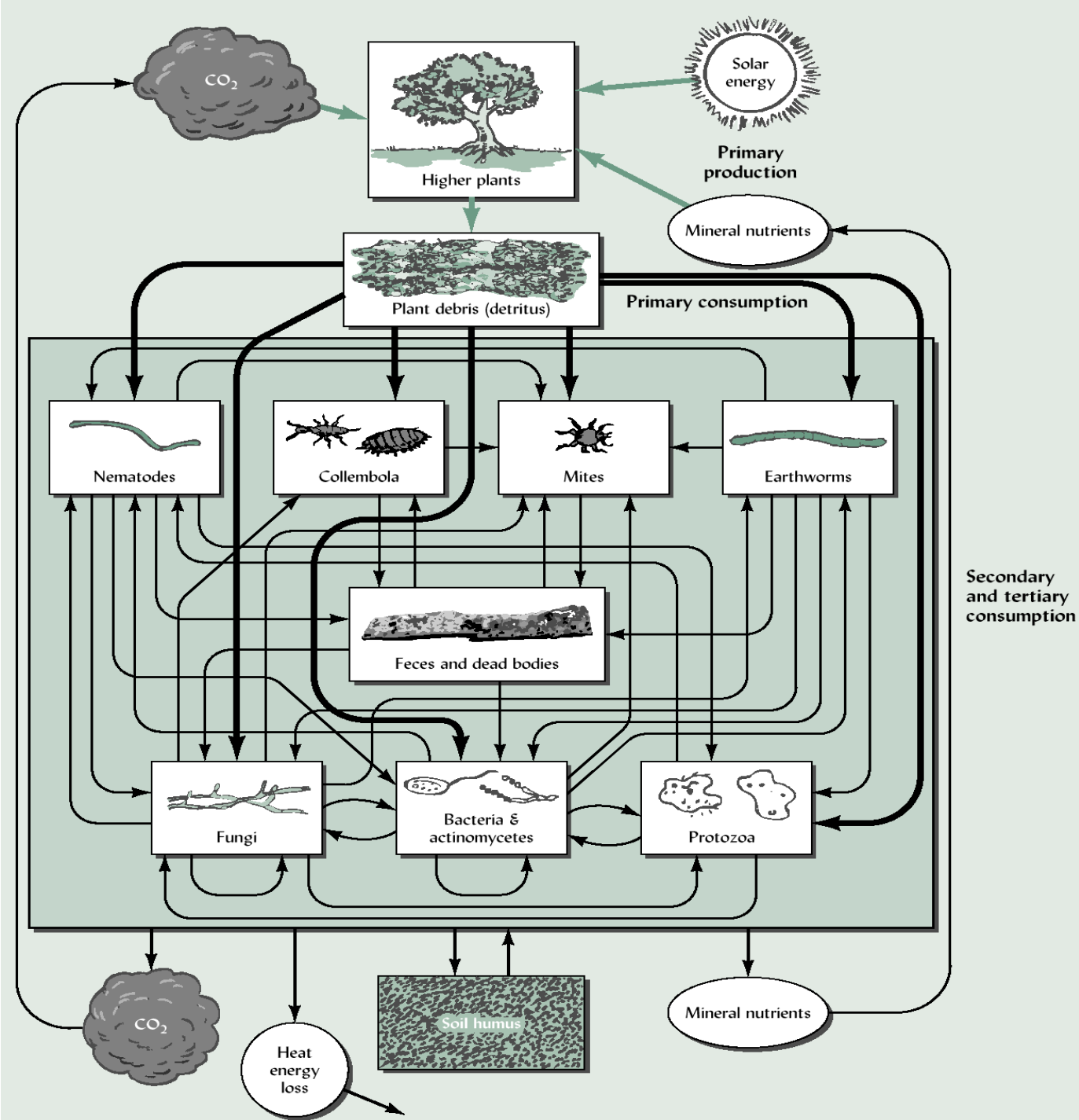
(1 $cmol_c/kg$ = 1 milliequivalent /100g).







Note: "pe" is another way of expressing redox potentials, which is the negative log of the electron activity and expresses the energy of electrons.



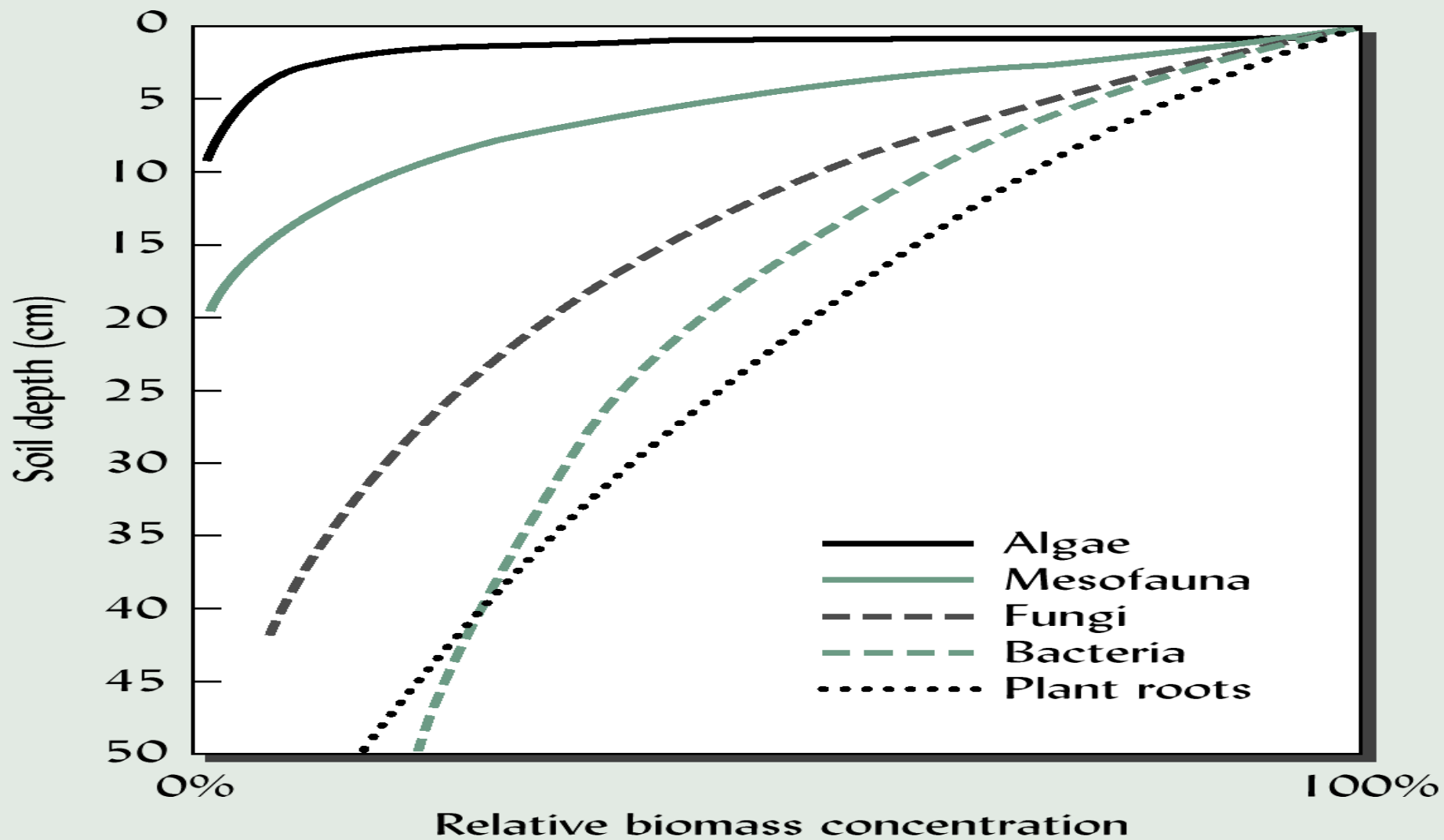


Figure 10.12

Soil's role in Biogeochemistry

1. Vital compartment of biogeochemical processes
2. Vulnerable film of the planet Earth
3. The most important source of nutrients in the Biosphere
4. Soil links the atmosphere, the hydrosphere and the lithosphere.
5. Soil supports 50% of the primary production on Earth
6. More???

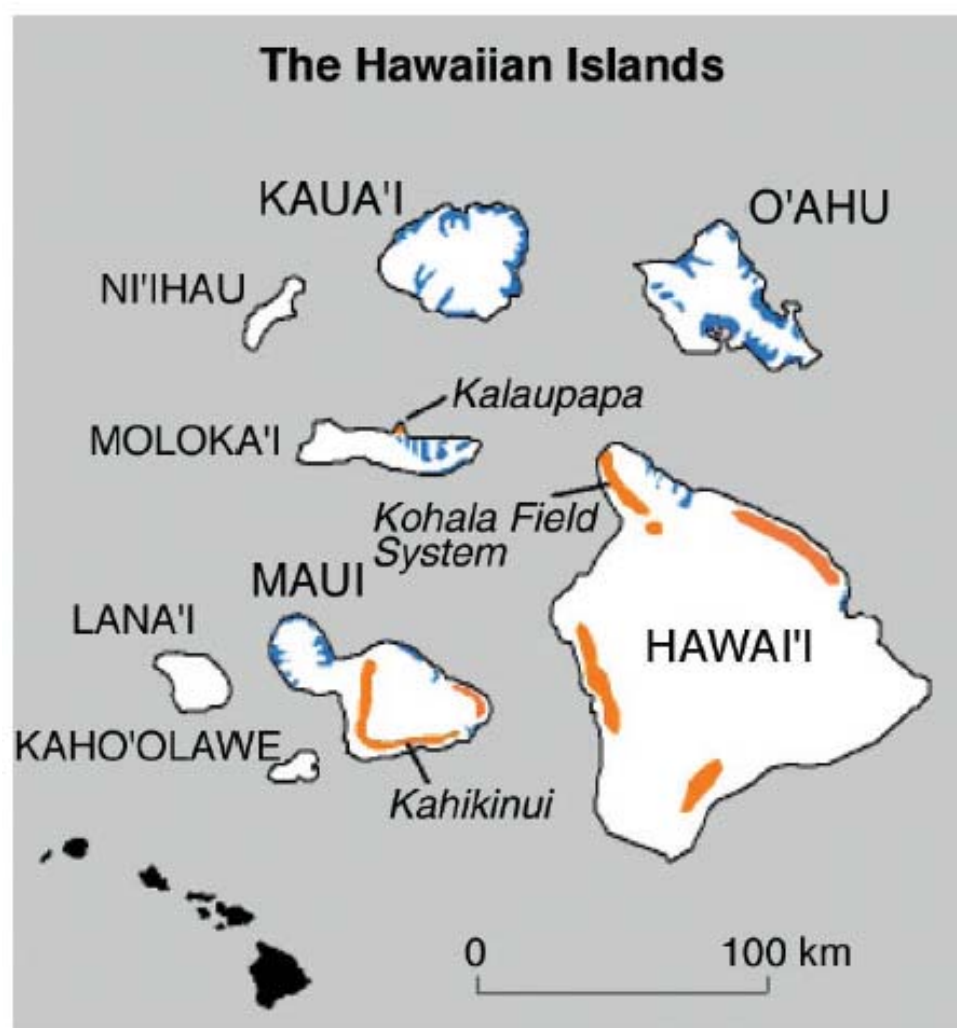
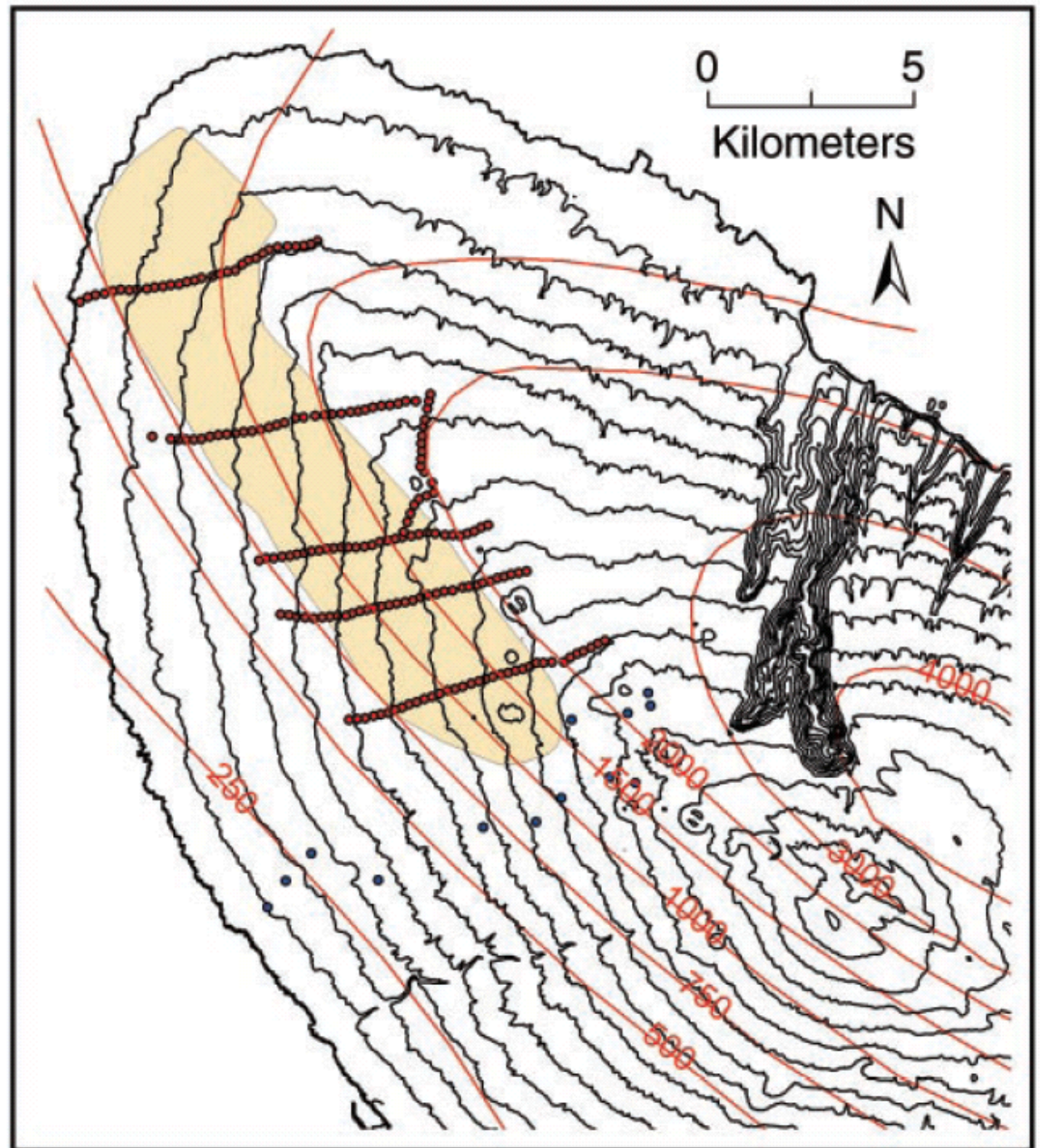


Fig. 1. The distribution of large, intensive, rain-fed dryland agricultural systems (orange shading) and irrigated wetland systems (blue shading) across the Hawaiian archipelago [updated from (10)]. Large dryland systems mostly were confined to the younger volcanoes on the islands of Maui and Hawaii'i.

Fig. 2. Rainfall in leeward Kohala, and the location of the Kohala field system and the Kohala climate transect. Solid black lines represent 100-m elevation contours, and red lines represent rainfall isohyets. The field system (shaded area) reaches uphill from the coast on the north into the rain shadow of Kohala Mountain, with its lower boundary corresponding to a median annual precipitation near 750 mm. The red points represent soil samples collected along multiple transects across the field system, and the blue points represent the Kohala climate transect (29) to the south of the field system.



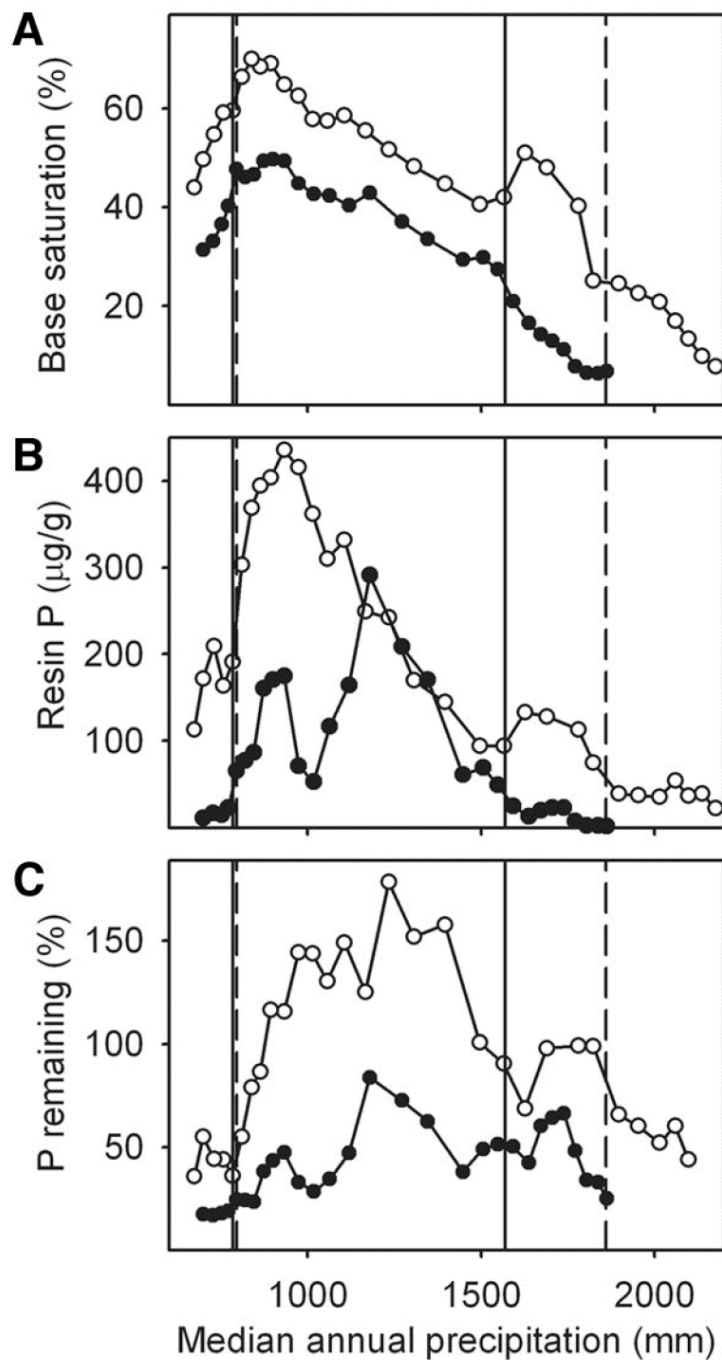


Fig. 3. Soil properties along two transects across the leeward Kohala field system, Hawai'i. One transect lies on 150,000-year-old Hawi substrate (\circ) and the other lies on 400,000-year-old Pololu substrate (\bullet). Dashed and solid vertical lines represent the boundaries of the field system on the Hawi and Pololu substrates, respectively. **(A)** Base saturation. **(B)** Resin-extractable P. **(C)** Total P as a percentage of the P in basaltic parent material, calculated as described in (21). Results from all of the sample points in Fig. 1 are summarized in table S1.

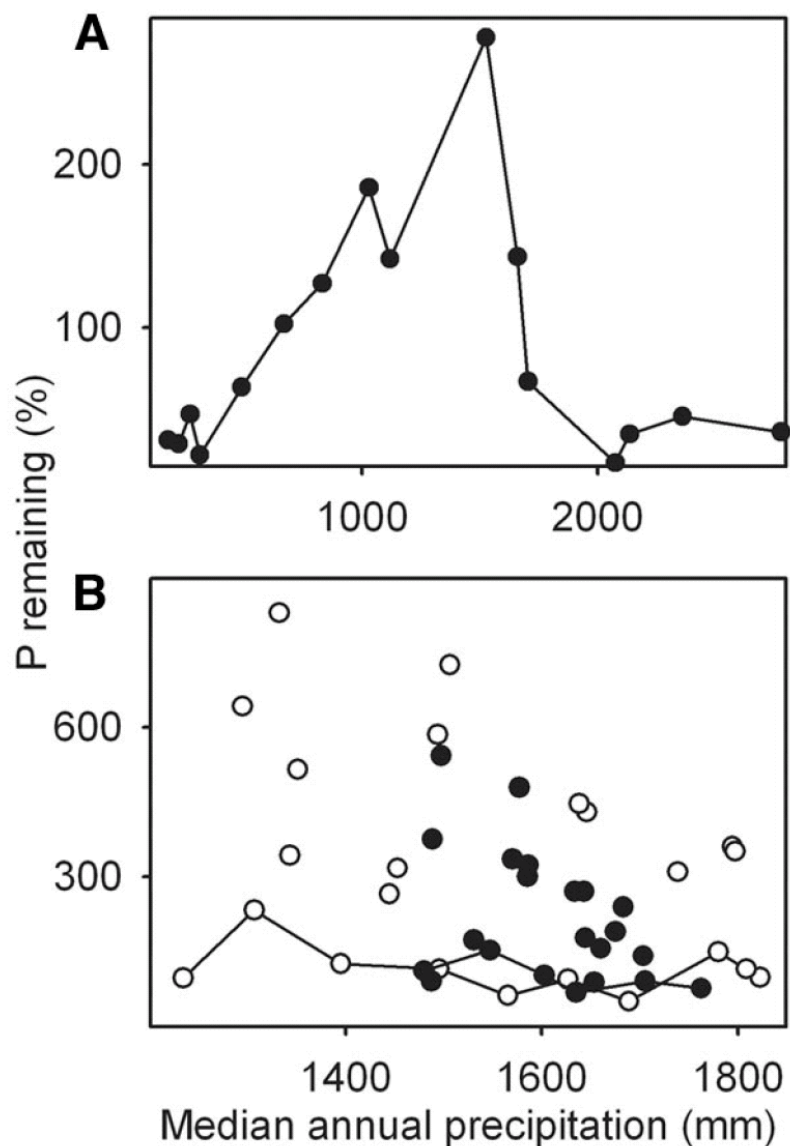


Fig. 4. Causes of P enrichment within the Kohala field system. **(A)** The percentage of P remaining in soils along the Kohala climate transect, outside the agricultural field system to the south (see Fig. 2). **(B)** The percentage of P remaining in surface soils within the agricultural system (lines connecting symbols) versus that in surface soils that were buried below field walls (unconnected symbols), along the upper portions of transects on the younger Hawi substrate (○) and on older Pololu substrate (●).

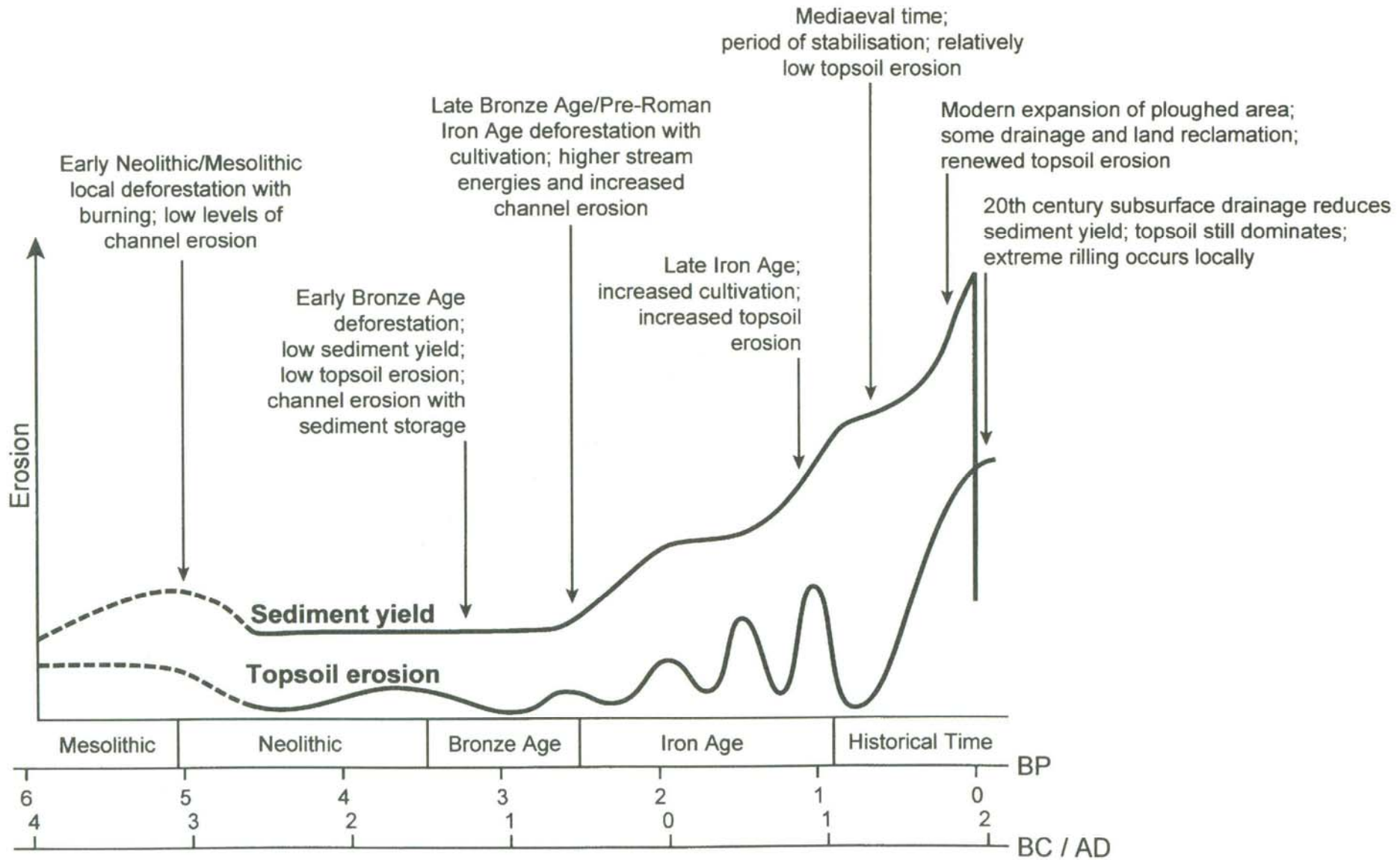


Figure 9.10 Generalised model of erosional intensity and sources since Mesolithic times in southern Scania, Sweden. Redrawn after Dearing (1991).

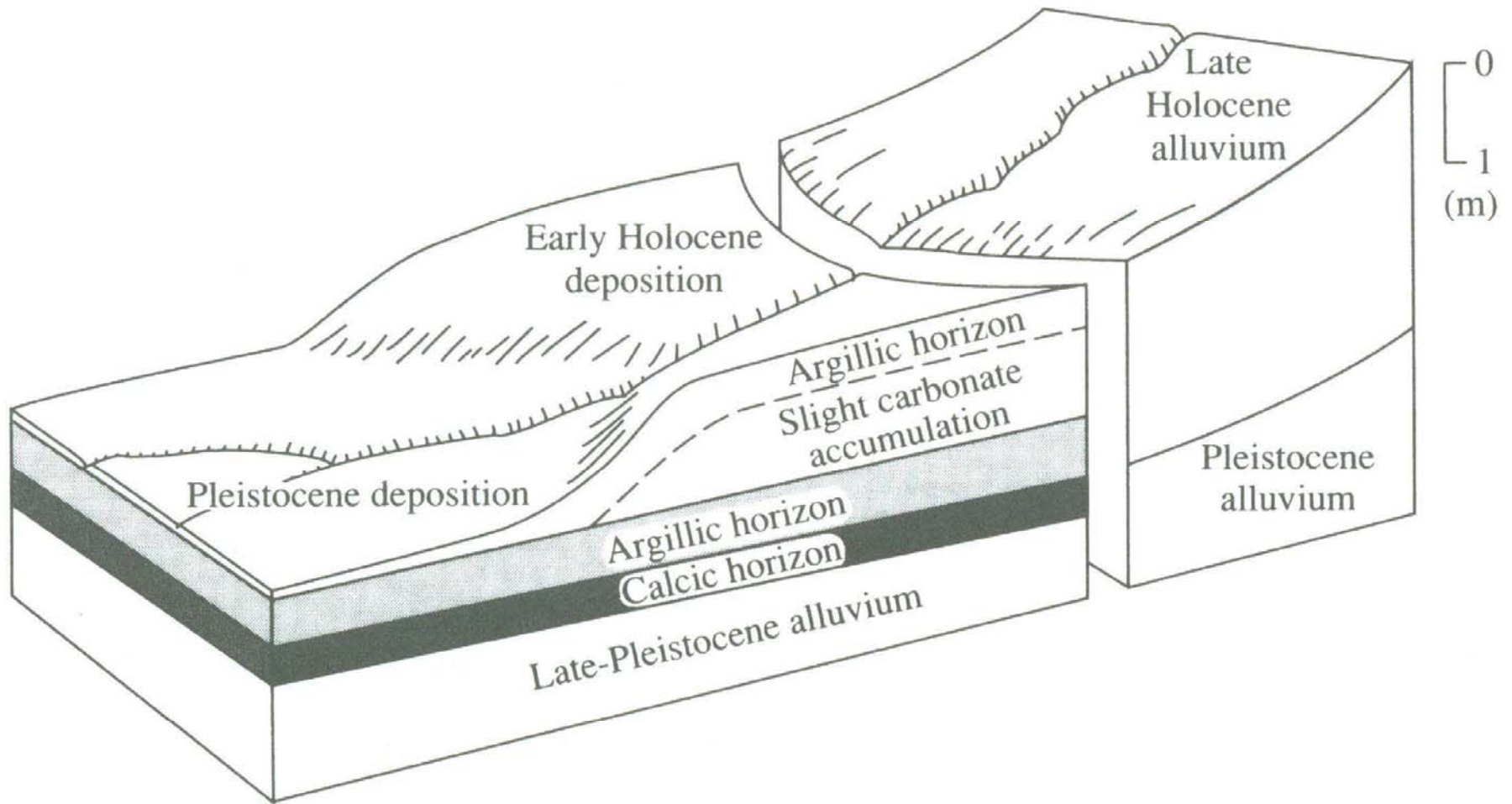


Figure 4.12 Sequence of soil age and formation on alluvial material in the Chihuahuan desert of New Mexico. From Lajtha and Schlesinger (1988).