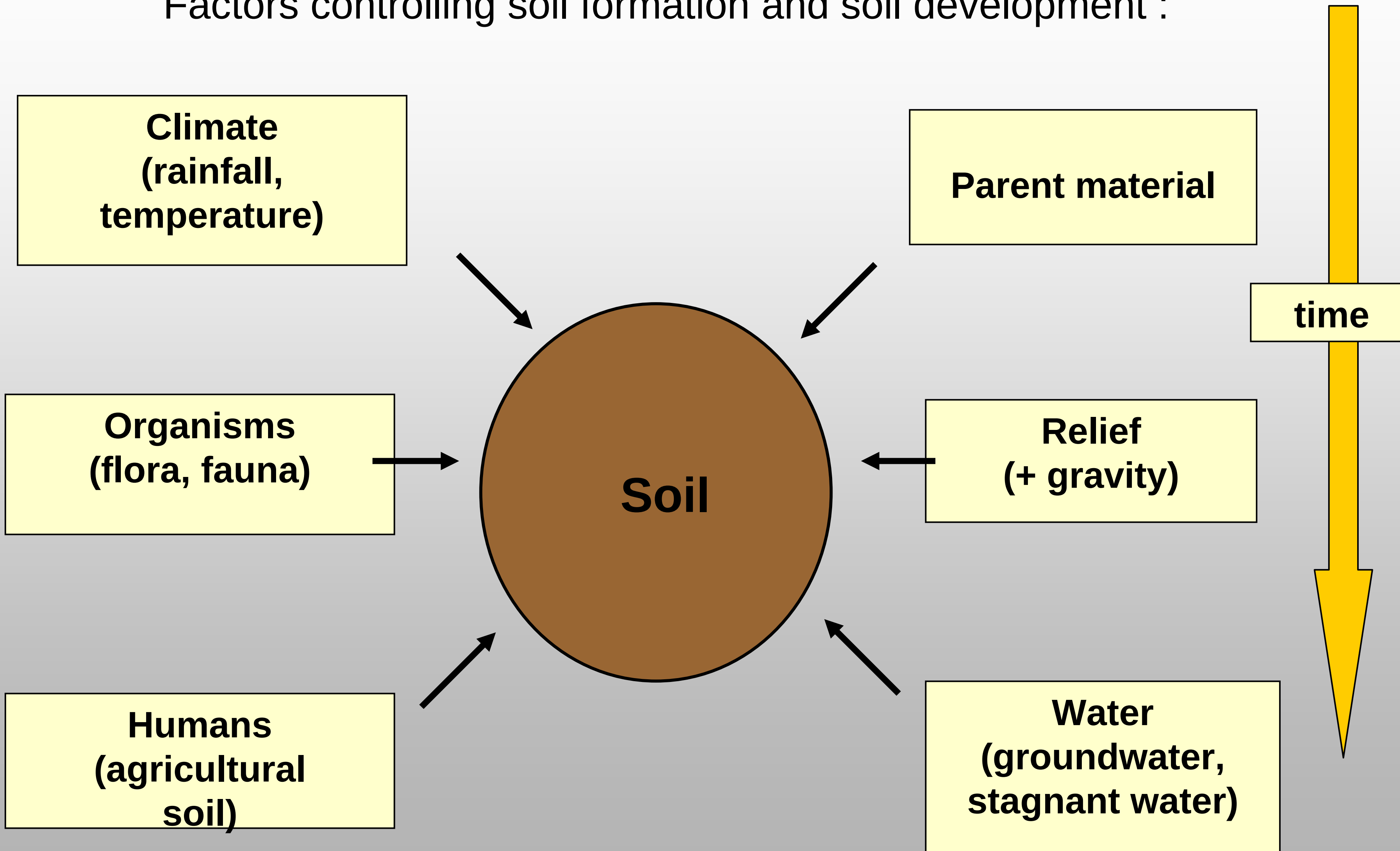
Factors controlling soil formation and soil development :



Soil is a function of the interaction of these factors

Climate

Climate directly influences the soil development by Warmth and Water and indirectly through the vegetation on the soil

Temperature influences the speed and intensity of weathering, decay, mineralization, evaporation and transpiration.

The rainfall percolating through the soil provides a transport and chemical reaction medium in the soil and it influences:

- movement of soil constituents,
- chemical reactions
- upward movement (e.g. capillary rise) of water evaporation
- erosion effect of surface runoff
- stagnant groundwater and pseudo-gley-water

Ramann‘s weathering factor (after Jenny, 1941)

	Average soil Temperature	Relative dissociation of water *	Days Weathering	Weathering factor	
				Absolute	Relative
Arctic	10	1.7	100	170	1
Temperate	18	2.4	200	480	2.8
Tropical	34	4.5	360	1620	9.5

*** index of the rate of chemical activity**

➔ in tropical regions the effectiveness of weathering is almost ten times that in arctic regions and three times that in temperate regions

(Bridges, 1997)

Water as a factor of soil development

Influence of water as

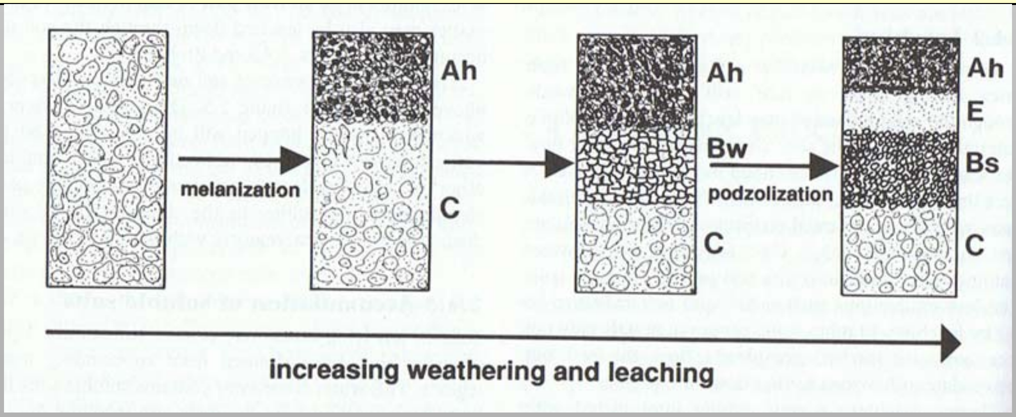
Percolating water	Ascending water (capillary rise)	eroding runoff	Stagnating ground- and pseudo-gley-water
↓	↑	↙	✥
Transport of soluble salts, carbonates, clay, humus, oxides and hydroxides	Enrichment of soluble salt, carbonates	Erosion and colluviation	Redox- and diffusionprocesses, humusaccumulation

Parent material

The parent material provides the mineralogical components and thus determines the physical and chemical properties of the soil like e.g.:

soil texture, soil structure, sorptivity, cation exchange capacity

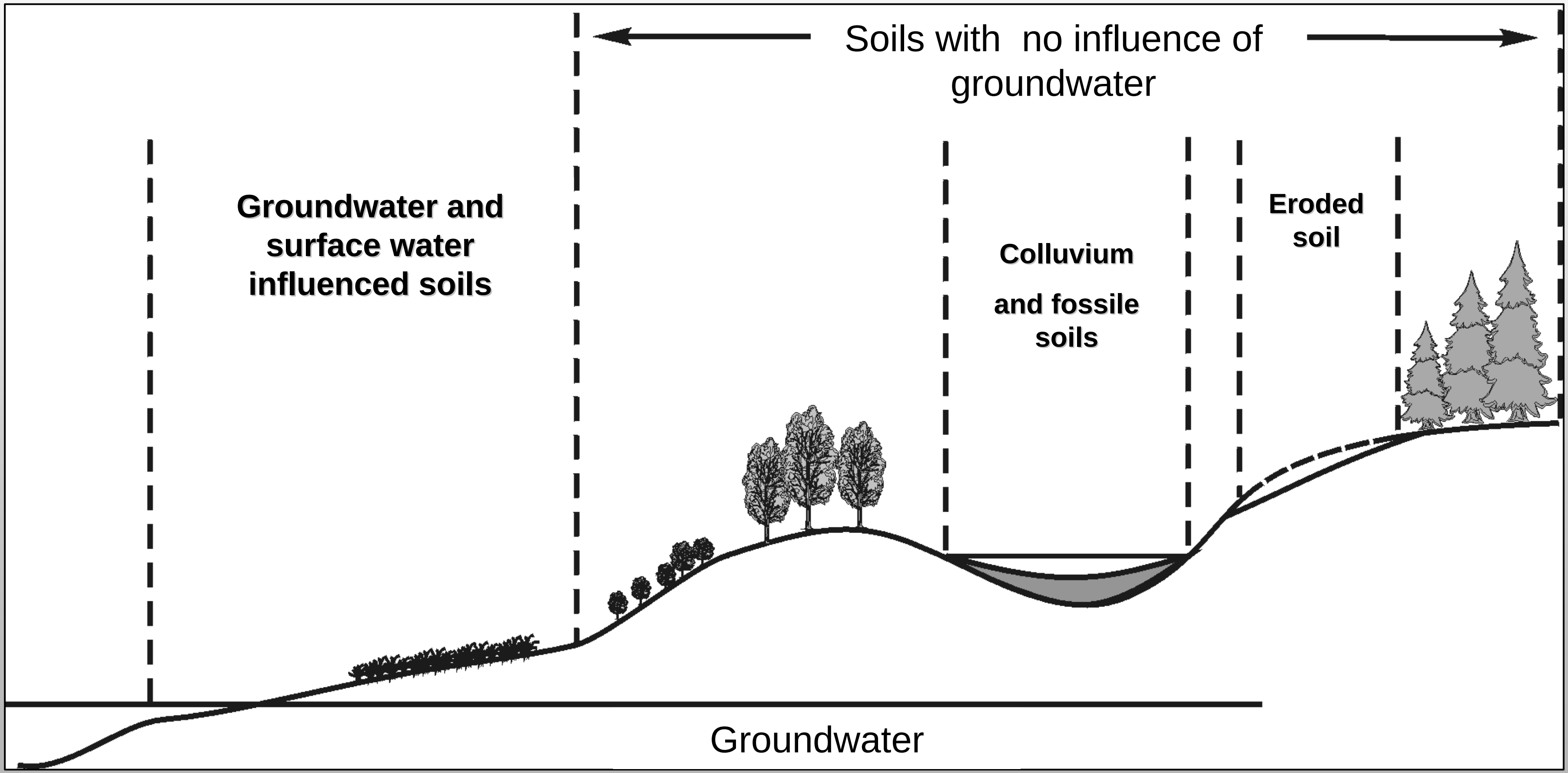
The relation between the properties of the parent material and the actual soil is closer if the soil development period is shorter



General sequence of soil development resulting from weathering and leaching

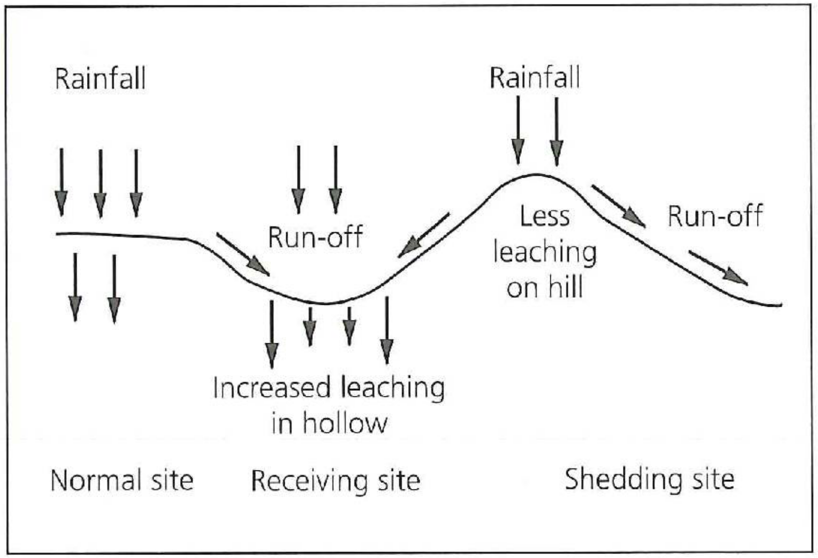
(McLaren&Cameron, 1996)

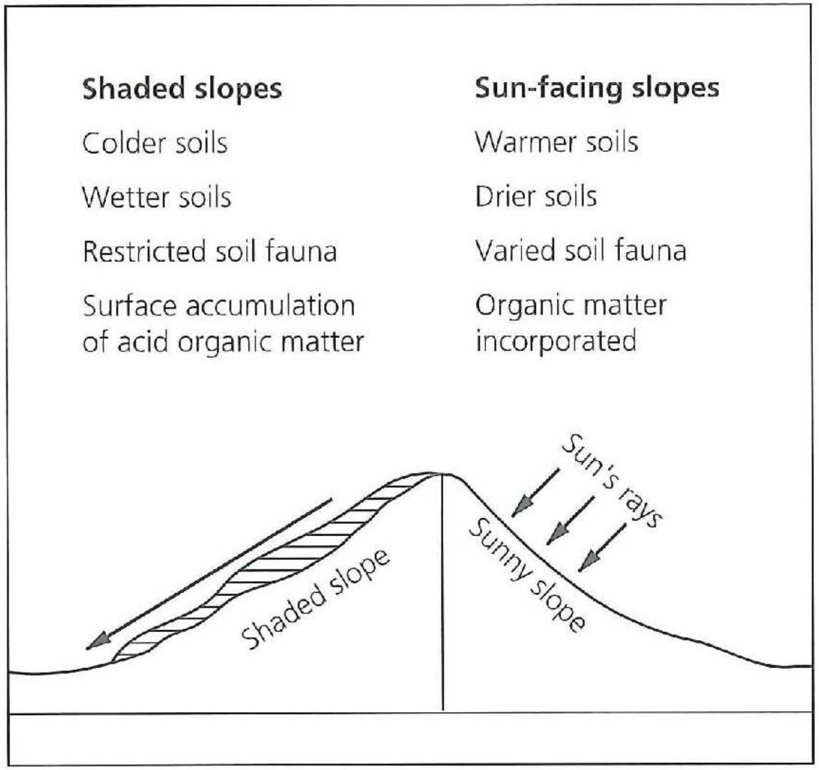
Influence of relief on soil formation



factors of soil formation : relief

- effect of slope and water availability
- effect of aspect, relief and sun radiation:

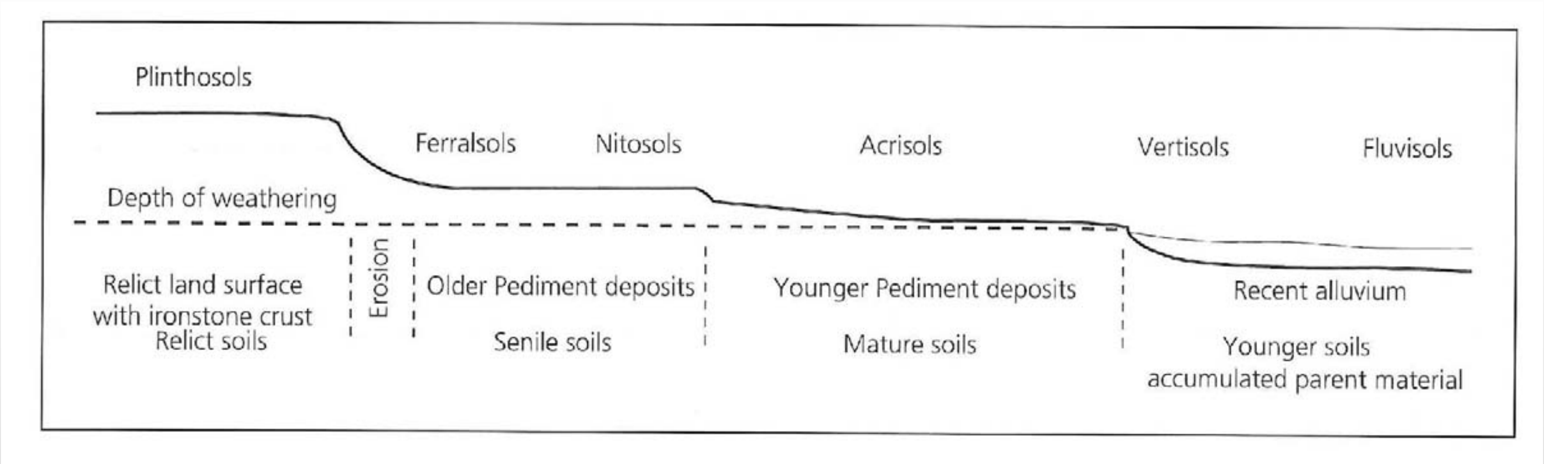




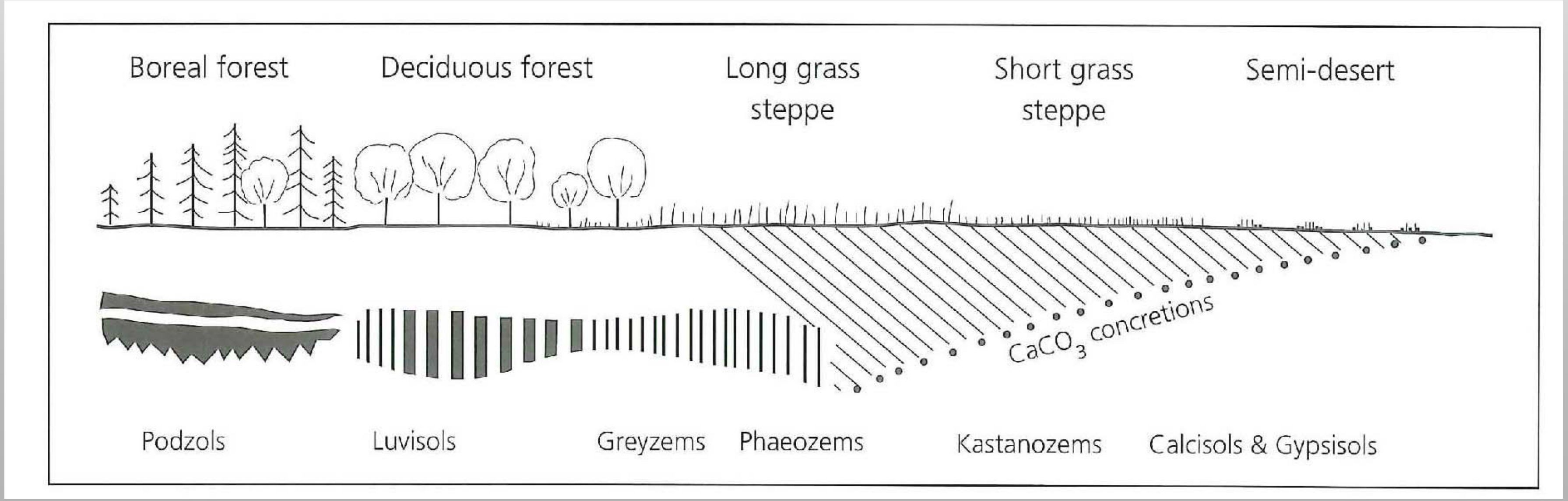
Catena: linked sequence of soils with position on the slope

(Bridges, 1997)

Factors of soil formation: effect of time, rainfall, etc.



2A: time scale and morphology of the landscape in an inter-tropical region: age and position of soils on the landscape. Different geomorphic surfaces give rise to soils of different maturity



2B: correlation of soil characteristics with rainfall : leaching of calcium carbonate from the soil:
higher rainfall ➔ calc. carb. deeper in profile;

(Bridges, 1997)

Fauna and Flora

The soil together with flora and fauna builds one system: the ecosystem

The soil biota is not an independent influencing factor.

Between the biota and the soil there exist very close relationships and interactions; e.g. vegetation depends on climate and soil properties and thus the dead plant material as a source for humus is soil and climate specific

Human activities

Humans directly influence the soils formation and development through agricultural activities e.g.

- Plowing,
- deep tilling ,
- Fertilizing,
- Liming

and indirectly through changing :

- the climate,
- the relief,
- the soil material
- the vegetation

Time

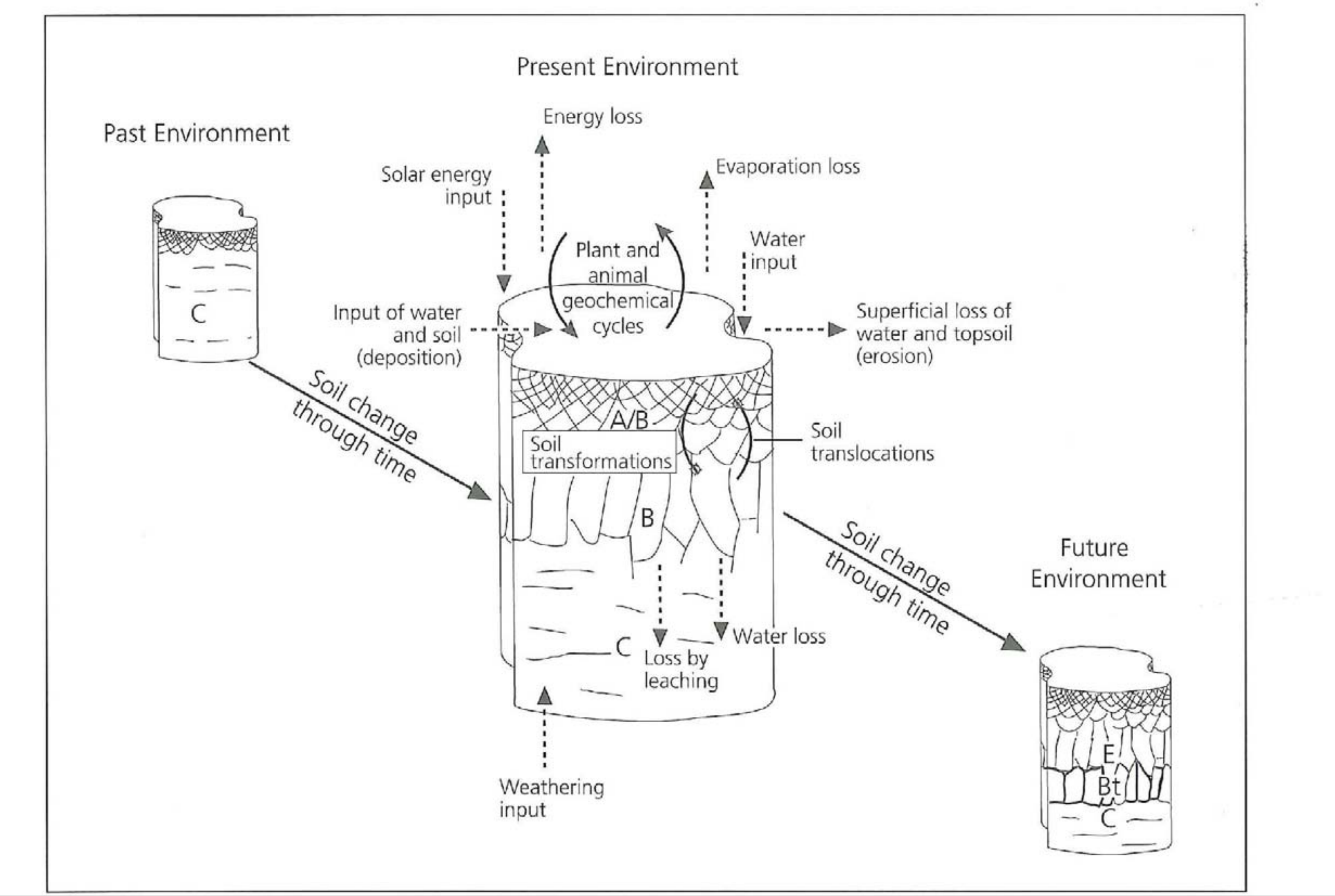
The longer the different soil formation factors

climate,
parent material,
relief,
humans,
vegetation

influence the soil, the more it differs from the original state.

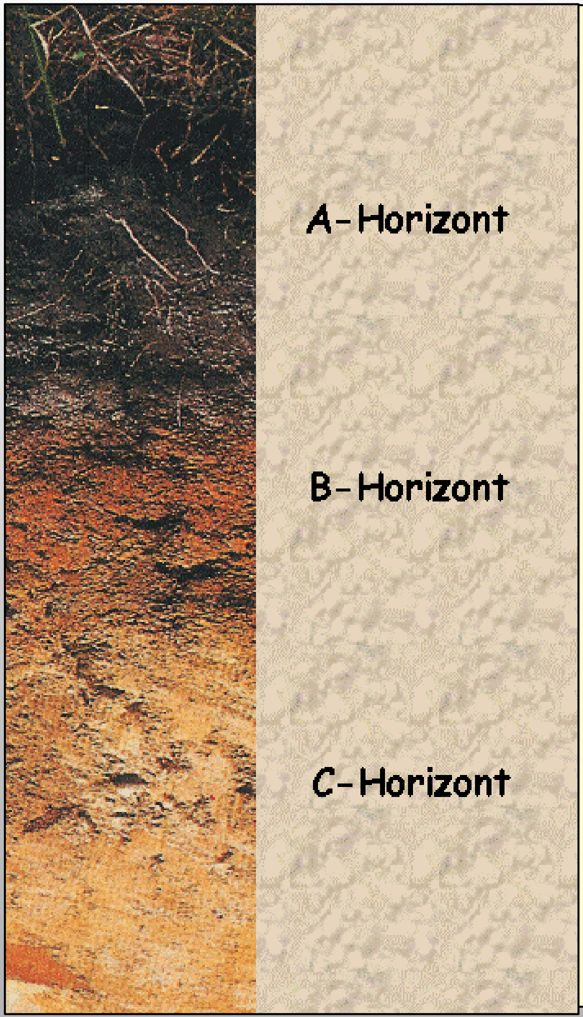
If a soil does not change any more it is in eqilibrium with the environmental conditions and had reached a steady state or climax state (e.g. Podsol in humid areas).

Time



(Bridges, 1997)

Processes of soil formation

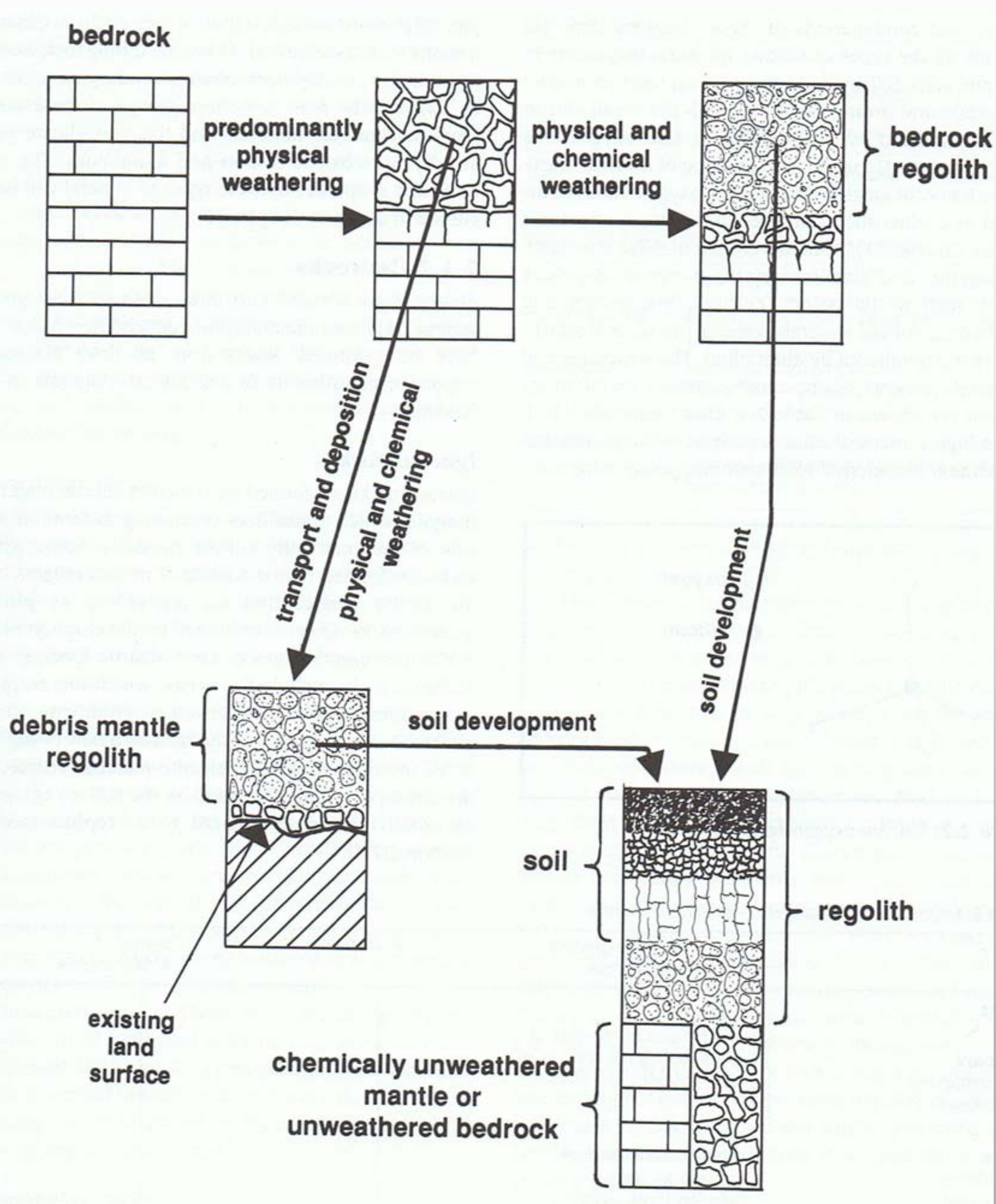


Important soil formation processes are:

1. weathering and mineral composition
2. decomposition and humification
3. structure formation,

4. displacement processes

a) clay eluviation (lessivierung),
b) podsolization,
c) gleying,
d) pseudo-gleying,
e) turbation: (bio-, cryo- and pedoturbation).



Pathways of soil formation showing the relationship between bedrock, regolith and soil

(McLaren and Cameron, 1997)

Notation of soil horizons FAO-system 1/3

O An organic horizon at the soil surface, normally not saturated with water.

H An organic horizon at the soil surface normally saturated with water, characteristic of peaty deposits.

A A mineral horizon formed at or near the surface, characterized by the incorporation of humified organic matter intimately associated with mineral materials. Subdivisions include:

- Ah for an uncultivated horizon; accumulation of humus;
- Ap for a cultivated (ploughed) horizon;
- Ag for a poorly drained surface horizon.

E A mineral horizon, just below the soil surface, which has lost clay, organic matter or iron by downward movement. Subdivisions include:

- Eg for poorly drained horizons.

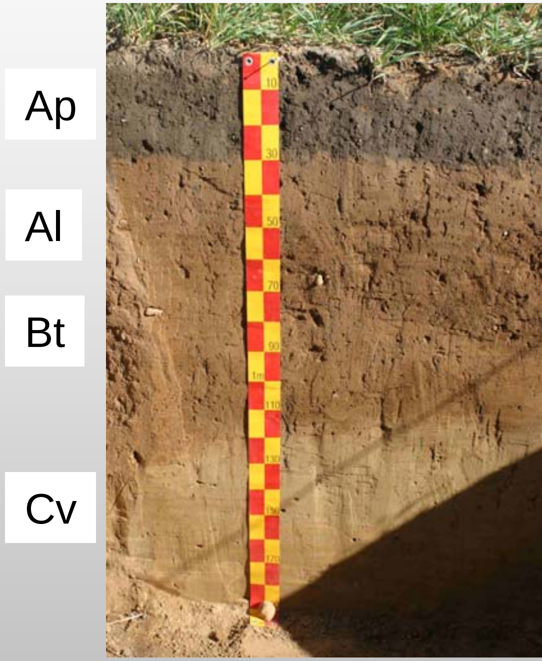
Normal Podzol from Ireland with a pronounced white eluvial horizon and separate illuvial humus and iron B horizons below *(Haplic Podzol)*

(Bridges, 1997)

B A subsurface mineral horizon resulting from the change *in situ* of soil material or the washing in of material from overlying horizons.

Subdivisions include:

- Bg for poorly drained;
- Bh for accumulation of humus;
- Bs for an illuvial accumulation of iron or aluminium sesquioxides;
- Bt for increase of clay;
- Bw for changes of colour or structure;
- Bx for compact brittle horizon known as a fragipan;
- By for accumulation of gypsum;
- Bz for accumulation of salts more soluble than gypsum.



(fluvic) Luvisol (Germany)

Luvisols are soils that have a higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration) leading to an *argic* subsoil horizon.

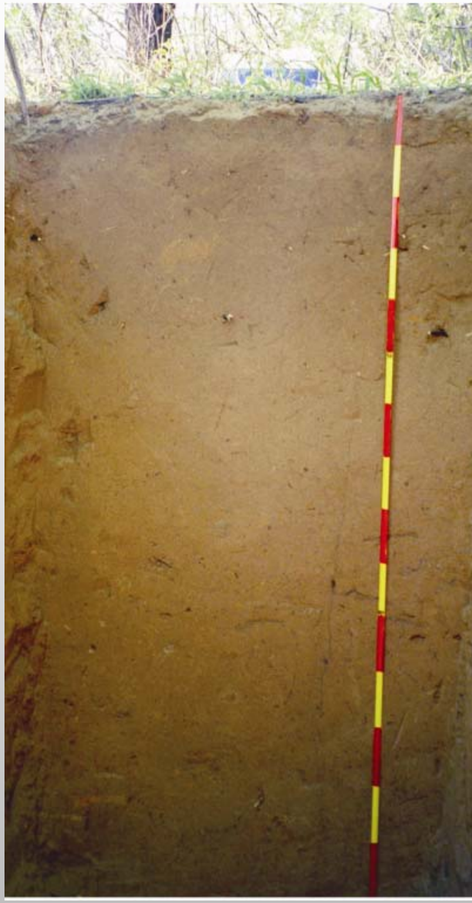
(Bridges, 1997)

C An unconsolidated or weakly consolidated mineral horizon which retains evidence of rock structure and lacks the properties diagnostic of the overlying A, E or B horizons.

Subdivisions include:

- Cg for poorly drained;
- Ck for enrichment with calcium carbonate;
- Cm for cemented material;
- Cx for compact brittle material known as a fragipan;
- Cy for enrichment with gypsum;
- Cz for accumulation of salts more soluble than gypsum.

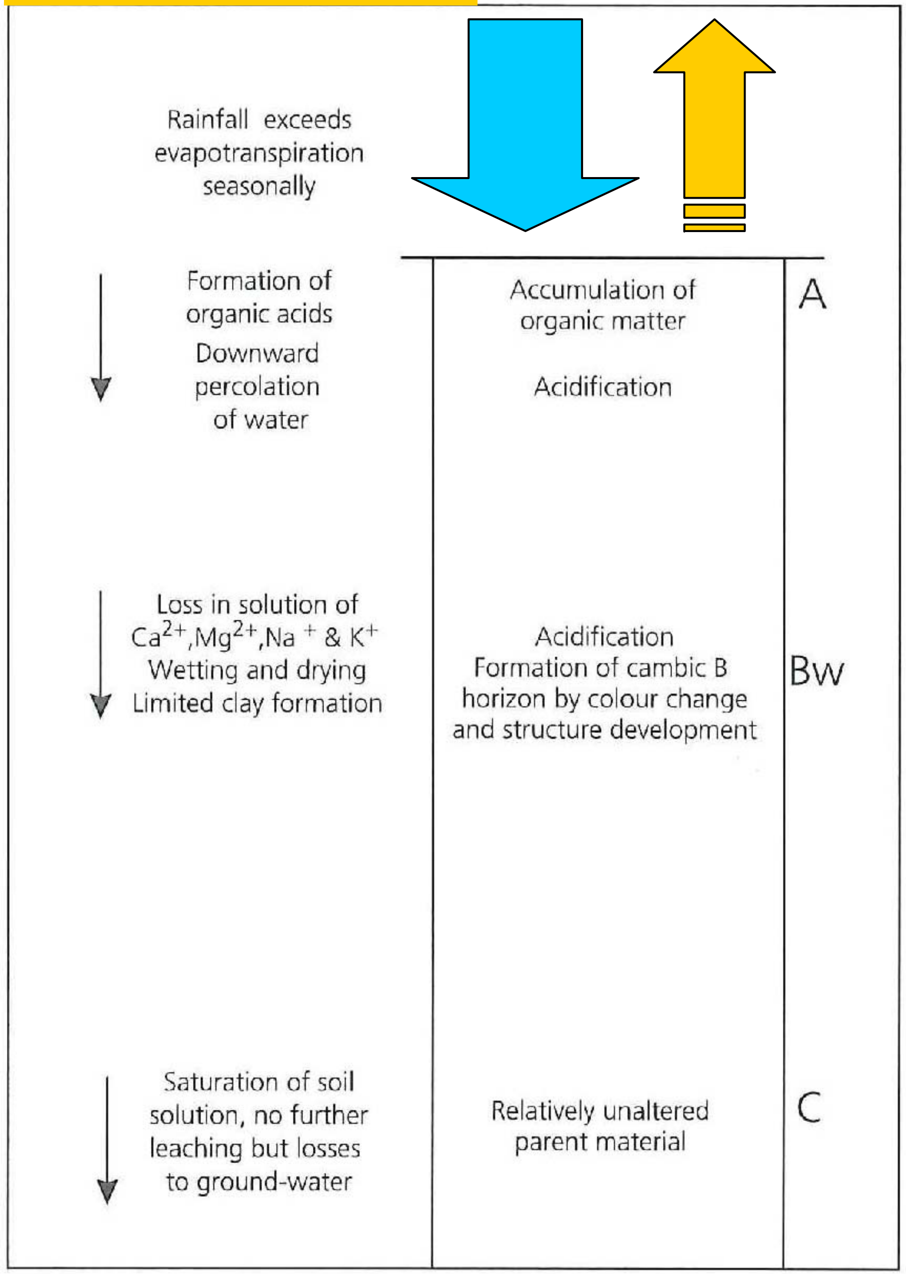
R Continuous hard or very hard bedrock.



Ferralic Arenosol
(Kalahari, Botswana)
A-C profile

(Bridges, 1997)

Process of Leaching

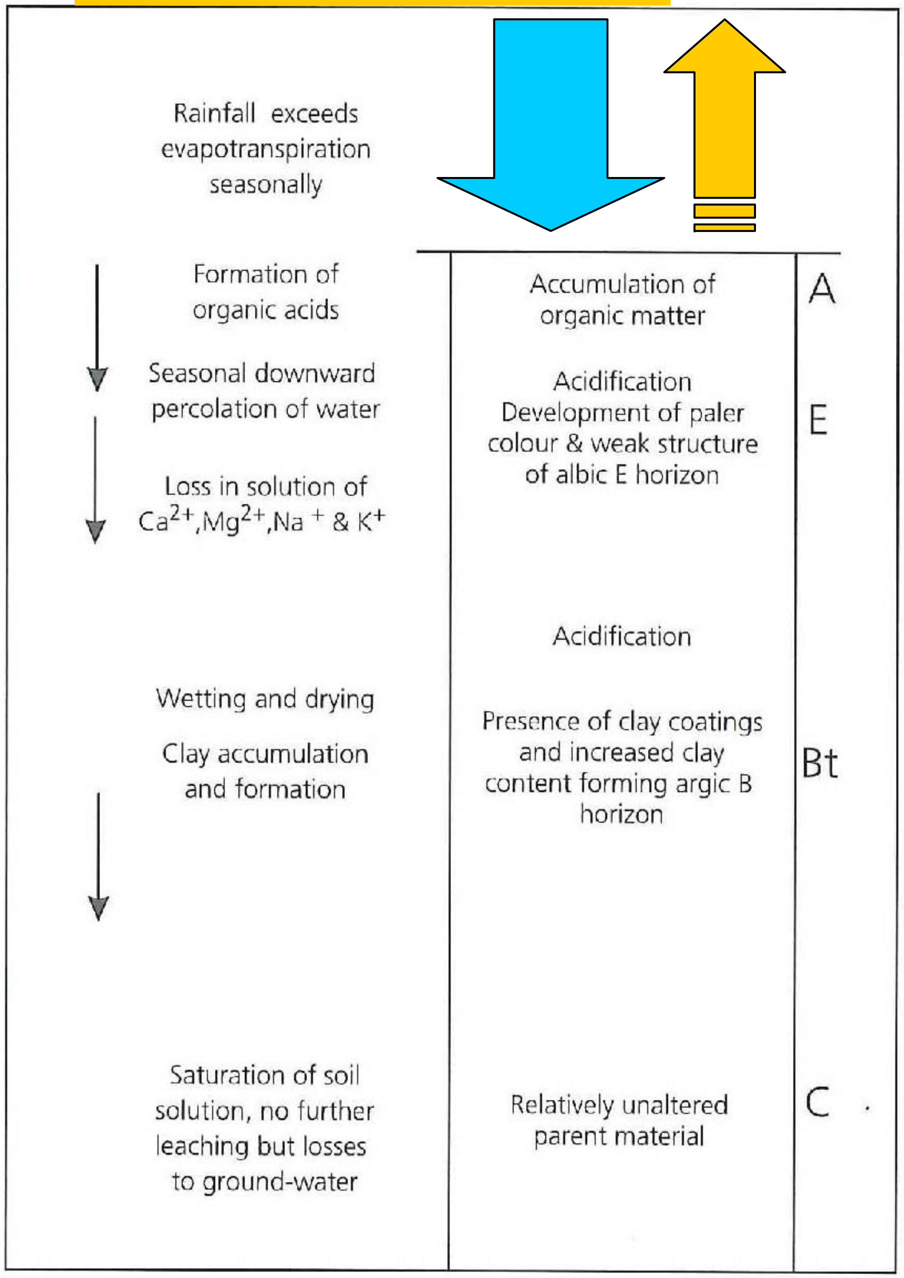


Leaching:
- process by which soluble constituents are removed from the soil
- if rainfall exceeds evaporation,
- readily soluble salts are dissolved by water percolating downwards
- soluble salts, calcium carbonate and even sparingly soluble minerals are dissolved and carried away
- process of proton exchange takes place in which hydrogen ions are exchanged for the cations, gradually acidifying the soil.
- in association with clay formation, leaching is responsible for the development of the cambic B horizon

- liming stops acidification
- plant take up solutes from the subsoil and return them as litter to the sop soil

(Bridges, 1997)

Process of Clay Eluviation



Clay eluviation:

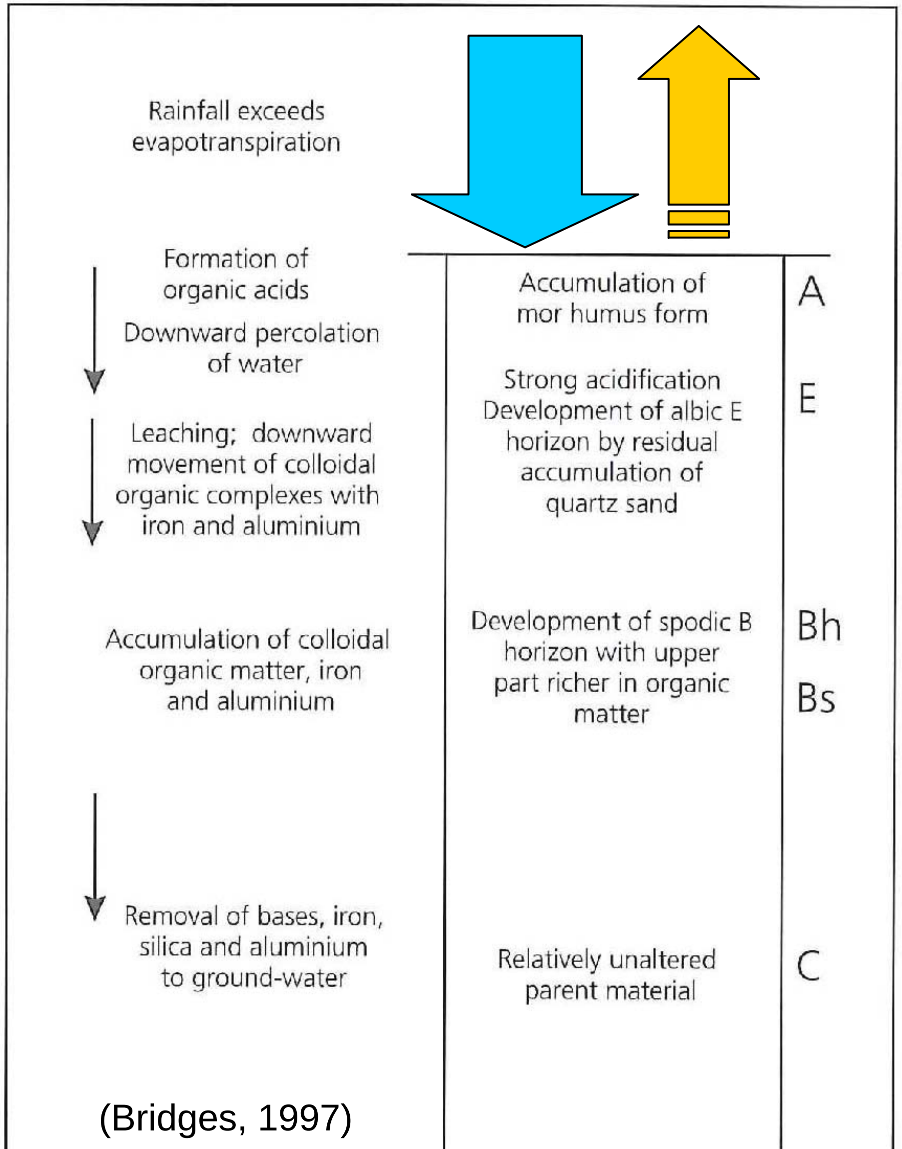
-Eluviation is the loss in suspension of material from a soil horizon.

- finely dispersed humus and clay particles, as well as other weathering products, can move as colloidal suspensions from upper, eluvial horizons to illuvial horizons
- process is encouraged by a climate in which a period of desiccation results in the soil shrinking and cracking
- As the soil dries, the suspended material is deposited from the soil solution on the side of the peds and in the pores
- development of a B horizon enriched in clay, which is referred to as an argic B horizon (also called an argillic horizon, a Bt horizon

(Bridges, 1997)

Clay eluviation

Process of podsolization



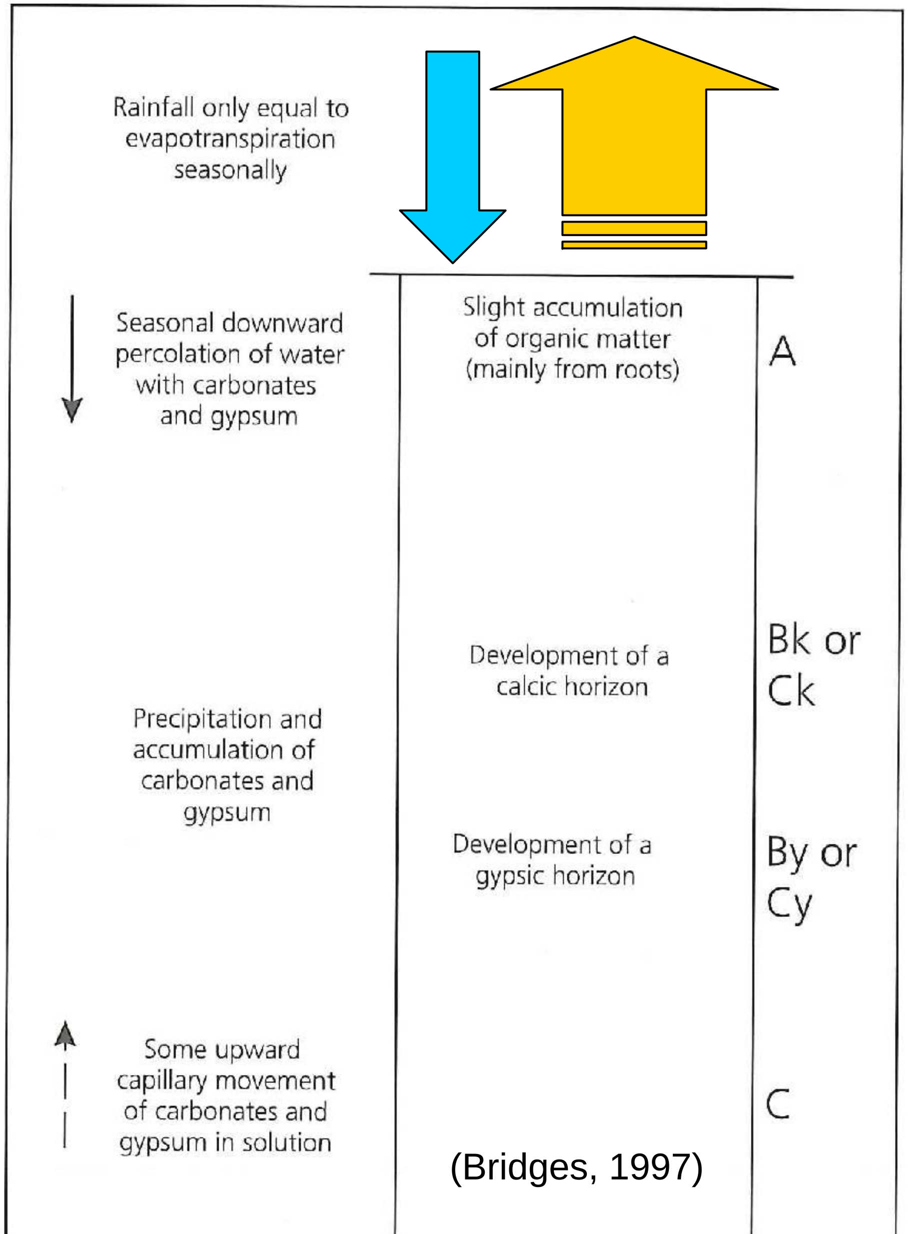
(Bridges, 1997)

<u>Podsolization</u>:

- in soils of the cool humid parts of the world,
- also responsible for the development of extremely deep soils on quartzitic sands in tropical regions
- podzolization involves the development of an extremely acid humus form known as „mor“
- the acidified soil solution is capable of disrupting the structure of the clay minerals, releasing the constituent like silica and alu-minium from clays, iron from iron minerals -
- even the most sparingly soluble elements are eventually removed by this process
- a strongly bleached, grey **albic E horizon,** typical of Podzols, gradually forms
- an A horizon, with its accumulation of organic matter, remains thin in the absence of earthworms to mix the organic and mineral materials
- iron and aluminium oxides and organic matter are deposited in an illuvial B horizon which has been given the name **spodic** B horizon

Podsolization

Process of calcification/gypsification



(Bridges, 1997)

Calcification:

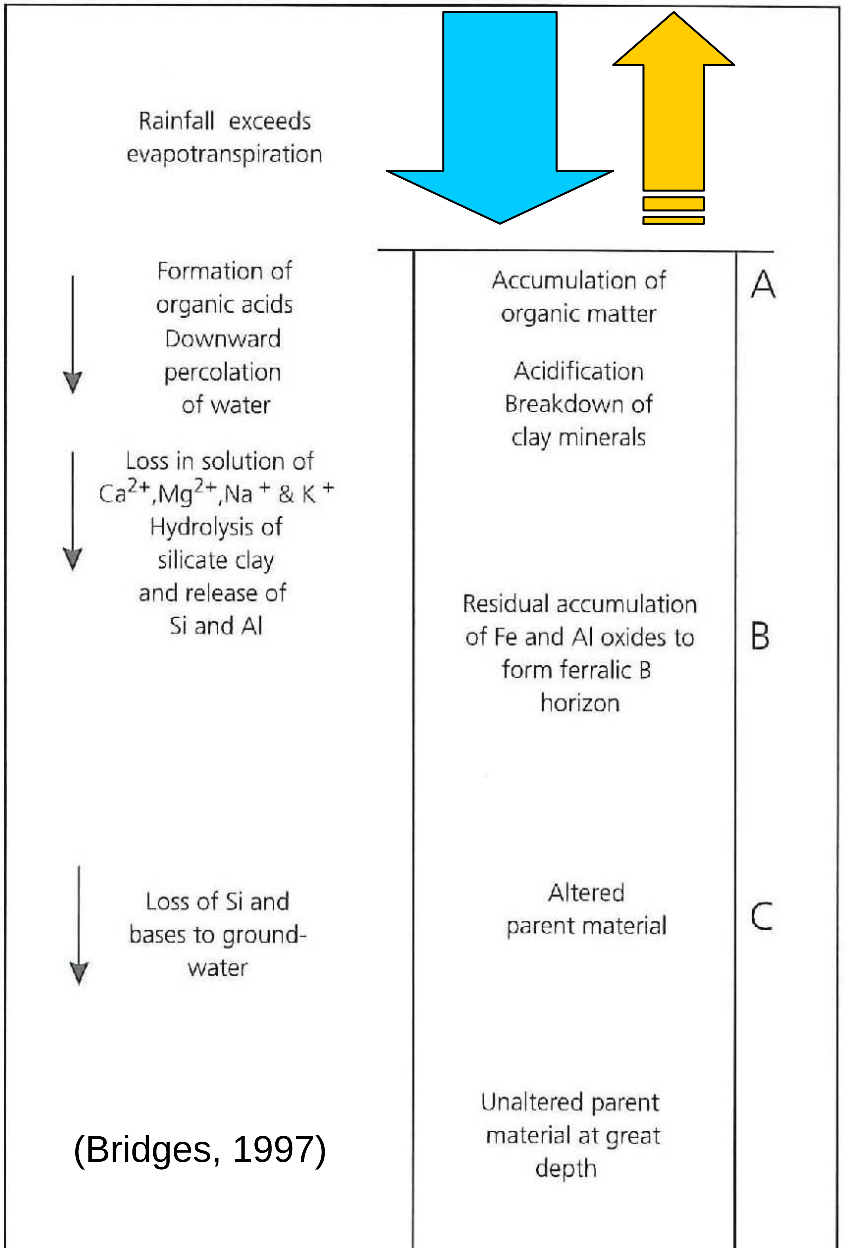
-calcification is characteristic of soils in low-rainfall semi-arid and arid areas

- leaching is slight, but soluble constituents are not removed from the soil profile
- ater seasonal rains these soils are wetted only to a depth of 1 to 1.5 m,and moisture begins to be drawn back to the surface to re-evaporate
- successive wetting and drying cycles in the soil lead to the deposition of calcium carbonate in a **calcic horizon** in the lower B or upper C

-To qualify as a calcic horizon there must be a zone of at least 20 cm where calcium carbonate is accumulating

- calcium carbonate accumulation may be in the form of fine particles, as concretions of soft, powdery lime or as discrete nodules
- in some cases also continuous, strongly cemented layers which may occur at depth or at the surface where erosion has exposed them: named **petrocalcic** horizons
- accumulation of gypsum: a **gypsic** horizon can occur as scattered crystals through the matrix of the as crystallaria ('desert roses') or as a massive petrogypsic horizon

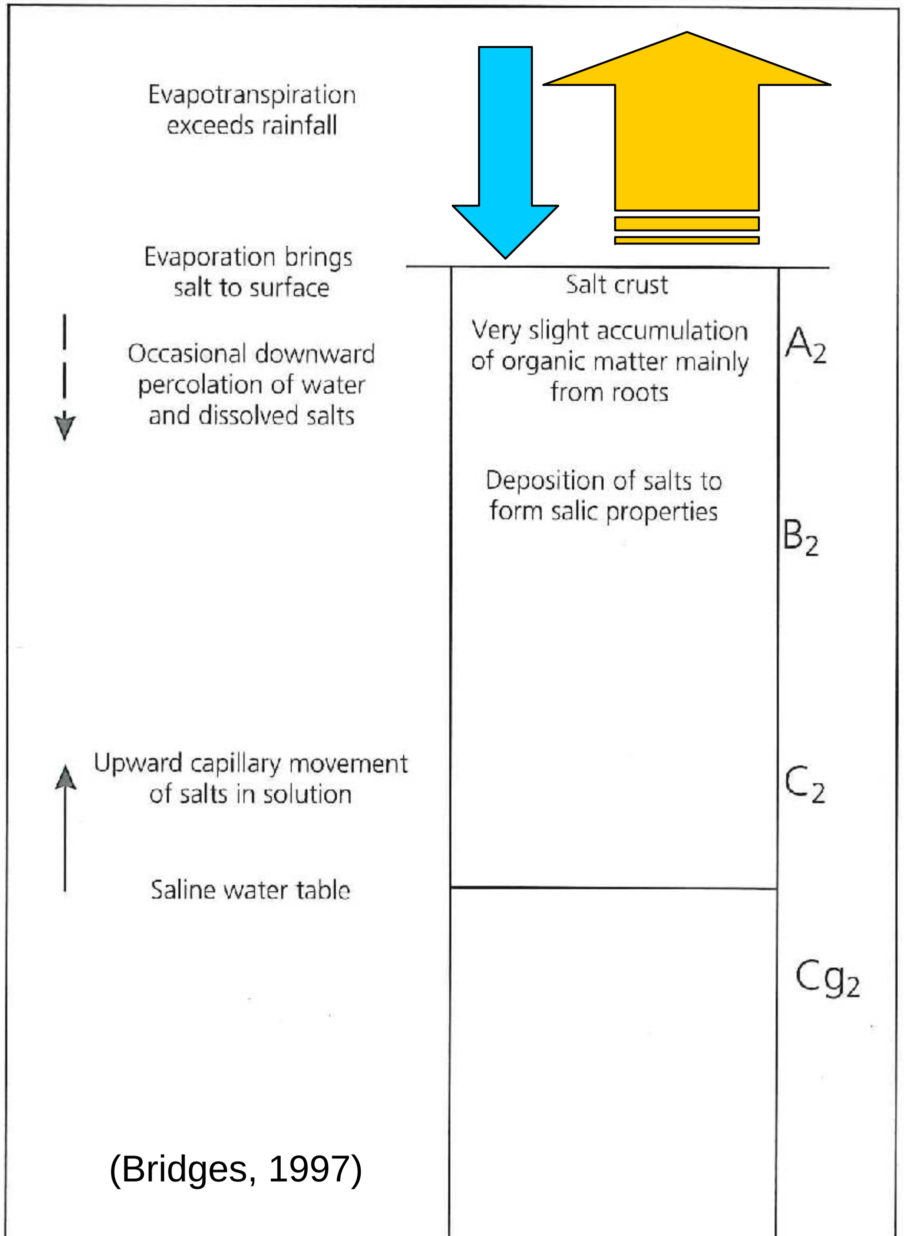
Process of Ferrallitization



(Bridges, 1997)

Ferrallitization:
- characteristic of soil formation in the humid tropical regions (in past: referred to as laterization, latosolization, kaolinization or desilicification)
- involves the net loss of silica, the formation of kaolinite and the relative accumulation of the sesquioxides of iron and aluminum
- accumulation of Fe and Al gave this process of soil formation its name.
- on basic parent rocks the process is fairly rapid, leading to the formation and accumulation of the iron minerals goethite and hematite
- on acid rocks the process is much slower and clay formation is restricted to the kaolinite group of clay minerals.
-In both cases, the clay minerals frequently are coated and cemented with iron oxides.
- ferrallitization is accompanied by strong leaching of the soil, so pH values are low. The rapid decay and recycling of the elements contained in leaf-fall from the forest trees keep the limited amounts of plant nutrients and bases in circulation between plant and soil
- Development of a highly weathered, low base-status **ferralic B horizon**

Process of Salinization



(Bridges, 1997)

Salinization:

-in arid climates the rainfall is irregular and is insufficient to remove soluble salts from soil

- in semi-arid areas salts may be washed from soils of the upland areas, and there is a redistribution of salts into the soils on the lower parts of the landscape
- Regions with a high ground-water level and imperfect or poor natural drainage
- many soils are suffering salinization due to excessive use of irrigation water without adequate drainage
- The soils often develop a surface encrusta-tion of salt and are known as **Solonchak soils** and have **salic properties**

-salt may originate from a salt rich geological substratum, or from windblown salt sea-spray

- primary saline soils: salt in the profile results from natural processes
- secondary saline soils: salt from irrigation

Other soil formation processes

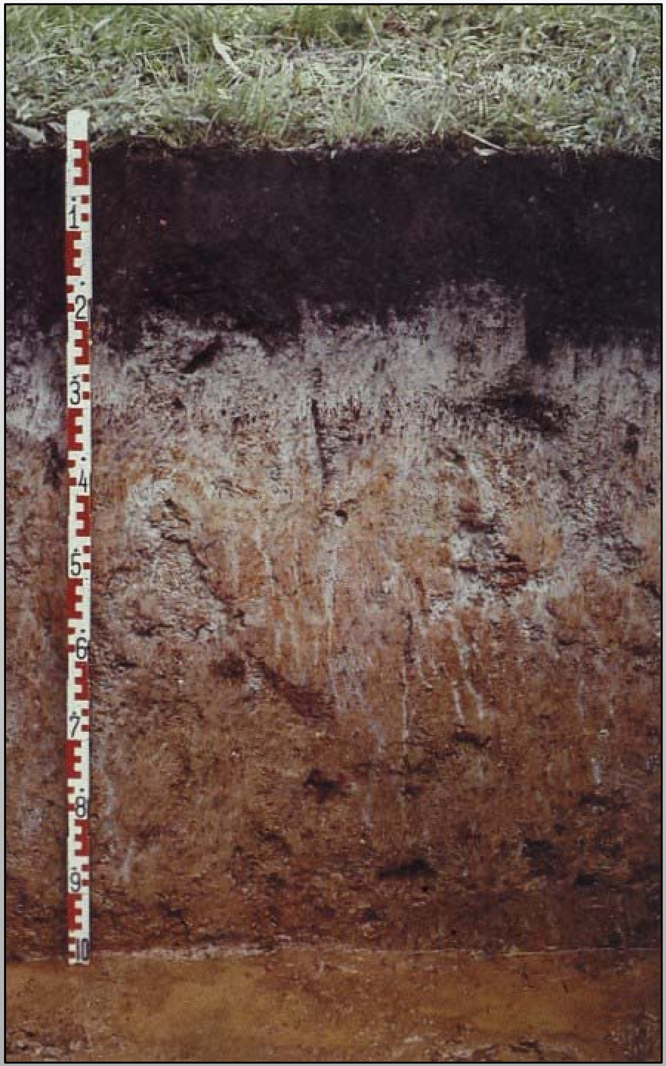
Alkalization: occurs when sodium ions come to dominate the exchange positions of the clay-humus complex of a soil: a **natric B horizon** develops

Rubefaction: soils, formed under cool wet winters and hot dry summers, having a marked red colour caused by an even distribution of iron oxides throughout the profile: a hematite coating on soil particles (red earths in Australia)

Gleying:

- process of gleying involves the reduction of iron compounds and either their complete removal from the profile or their segregation into mottles or concretions due to anaerobic conditions
- a strongly gleyed soil or gleyed horizon is frequently an unrelieved grey or bluish colour, but where some oxygenation takes place there will be mottles of rust-coloured ferric oxide
- two basic types of Gley soil: a **Pseudogley Soil** where water is held upon a slowly permeable layer, with stagnic properties ; a **Ground-water Gley** is produced, with gleyic properties at sites with higher water tables: Fe and Mg-oxides are reduces in the permant waterfilled range of the profile

Pseudo gleying and gleying



Processes: weathering and mineral formation

Weathering of iron containing minerals with the formation of iron oxides as a feature of the degree of profile differentiation is of high importance.

Calcium carbonate leaching and lowering of the pH value below 7

↷

Formation of brown coloured Fe-Oxide, especially Goethite

Brunification: Cv- ➡ Bv -Horizon

It is often coupled with the formation of clay; this process is called **loamification**

Decomposition, humus formation und humus forms

The organic matter that gets on or into the soil is mainly mineralized.

Only a smaller part is turned into humic substances, that will stay unchanged for a longer period

Humic substances together with litter rests build the humus of the soil.

Humus is a complex polyphenolic organic substance with many active chemical funtional groups

Type and amount of humus depends on the annual production of litter and its composition

Humus form, content and amount of soil organic matter in soils in the temperate humid climate region

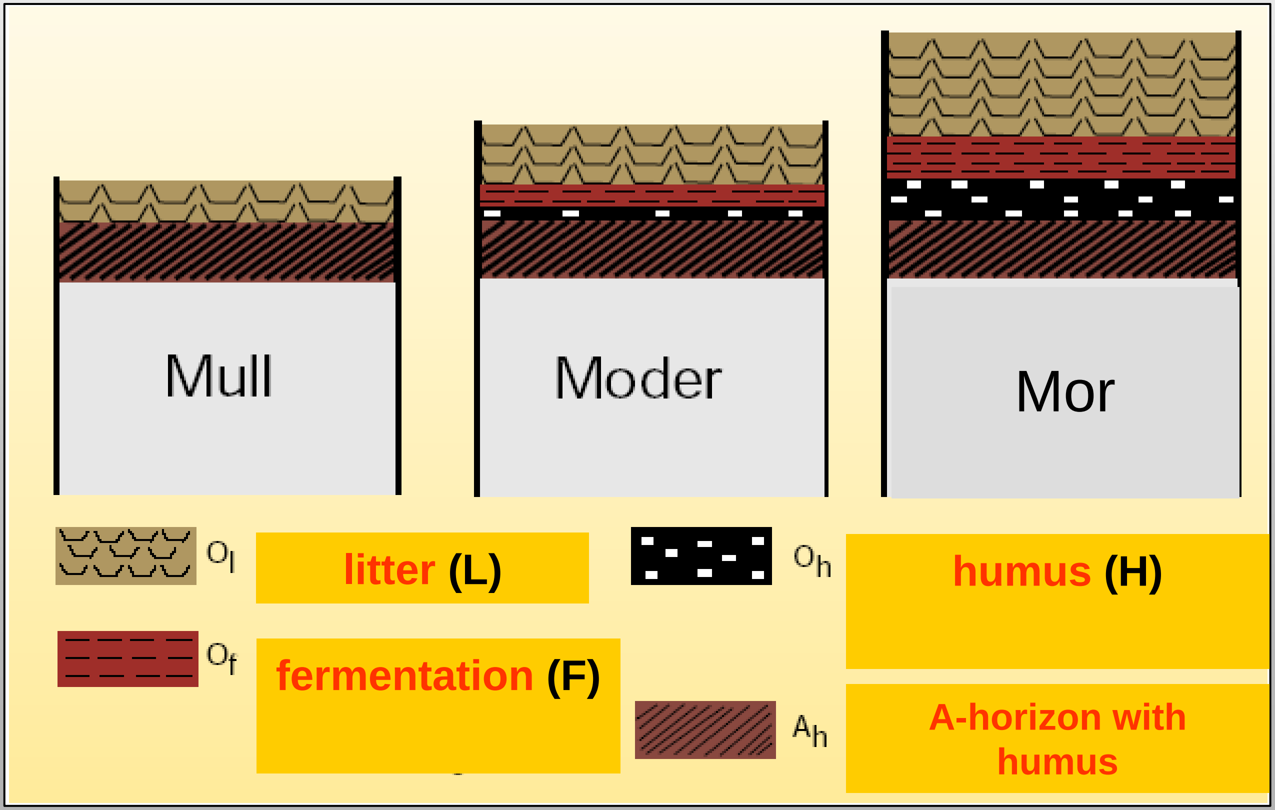
Vegetation bzw. Land use	Humus-form	Content of soil organic matter in the top soil %	Amount of soil organic matter till 1m depth in dt/ha
Decideous forest	Moder	4	2000
Coniferous forest	Mor	6	2400
Grassland	Mull	7	3500
Arable land	Mull	2	1600

Humus forms

Humus forms are combinations of the following humus horizons:

Mor, Moder and Mull

They are named after the dominating humus compound



Organic Horizons

three distinct organic horizons can be identified:

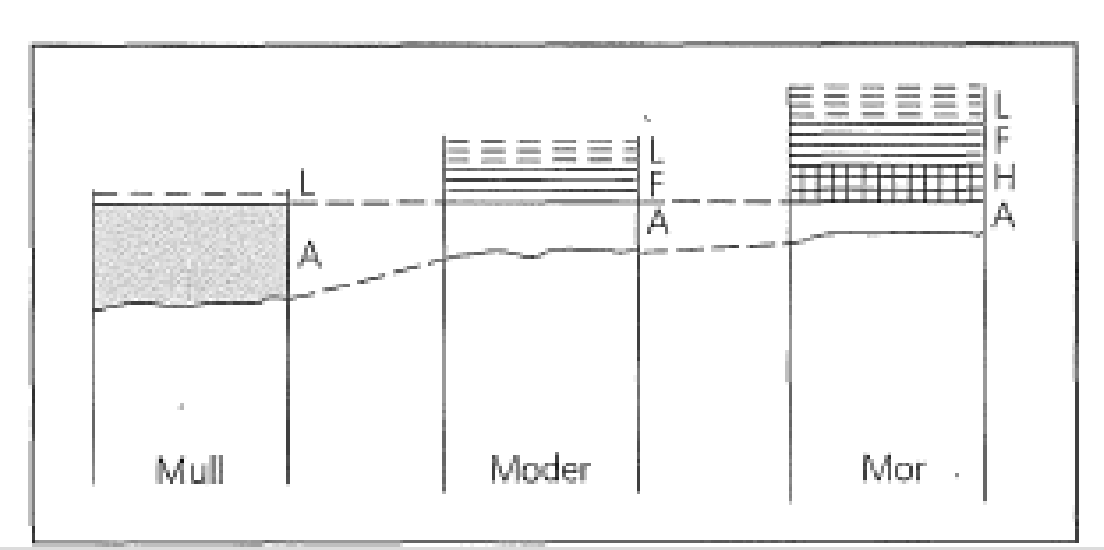
- the litter (L) layer: mainly undecomposed leaves, needles, twigs, etc.

- the fermentation (F) layer: half decomposed leaves, needles etc.

- the humus (H) layer: mainly fine humus and less than 30 % of litter rests with a recognizable plant tissue structure

These layers are included in the O-horizon of the FAO horizon designation system.

Humus forms

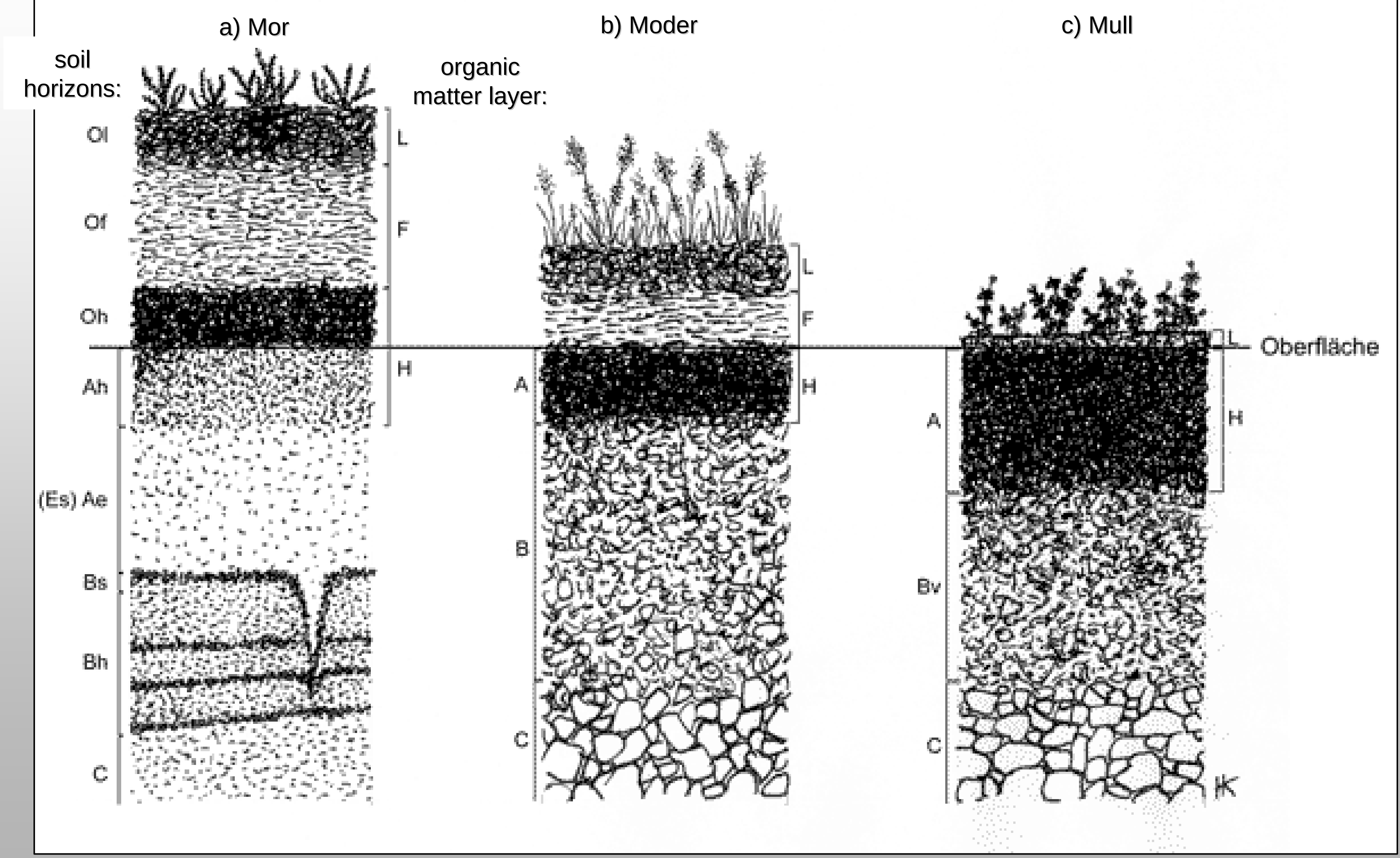


litter (L), fermentation (F) humus (H)

Mor develops beneath a heath or coniferous forest plant community and is associated with strongly acid soils. Organic breakdown in the acid conditions of mor is achieved by fungi; earthworms are usually absent from such soils, so there is little incorporation of the humus.

Mull forms in freely drained, base-rich soils with good aeration. Such conditions are good for plant life as well and so there is a plentiful supply of plant litter, and associated with it a rich soil fauna including earthworms.

Moder is a form of organic matter intermediate between mor and mull. It is often found under woodland conditions in association with Dystric Cambisols, and it is more acid and has a more restricted soil fauna than mull


a) Mor
b) Moder
c) Mull
soil horizons:
organic matter layer:
Ol
Of
Oh
Ah
(Es) Ae
Bs
Bh
C
L
F
H
A
B
C
L
F
H
A
Bv
C
L
H
K
Oberfläche


Mull

Moder

Mor

Structure formation

Soil structure refers to the shape, size and degree of development of the aggregation (if present) of the primary soil particles into naturally or artificially formed structural units (peds, clods and fragments) and this off course also influences the pore system in the soil

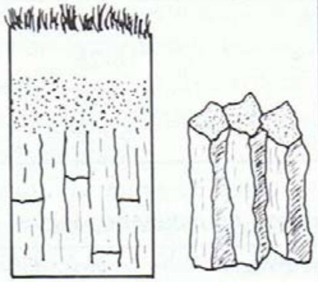
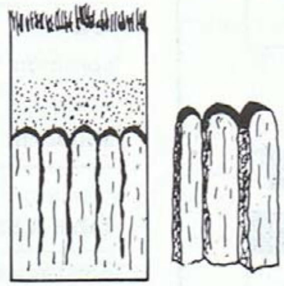
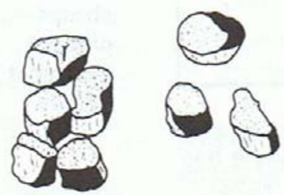
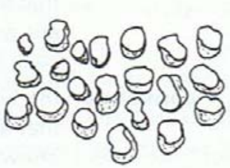
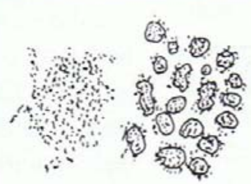
Structure

The coarser the soil structure and denser the individual stucture units the more negative the soil properties will be

Factors influencing soil structure formation

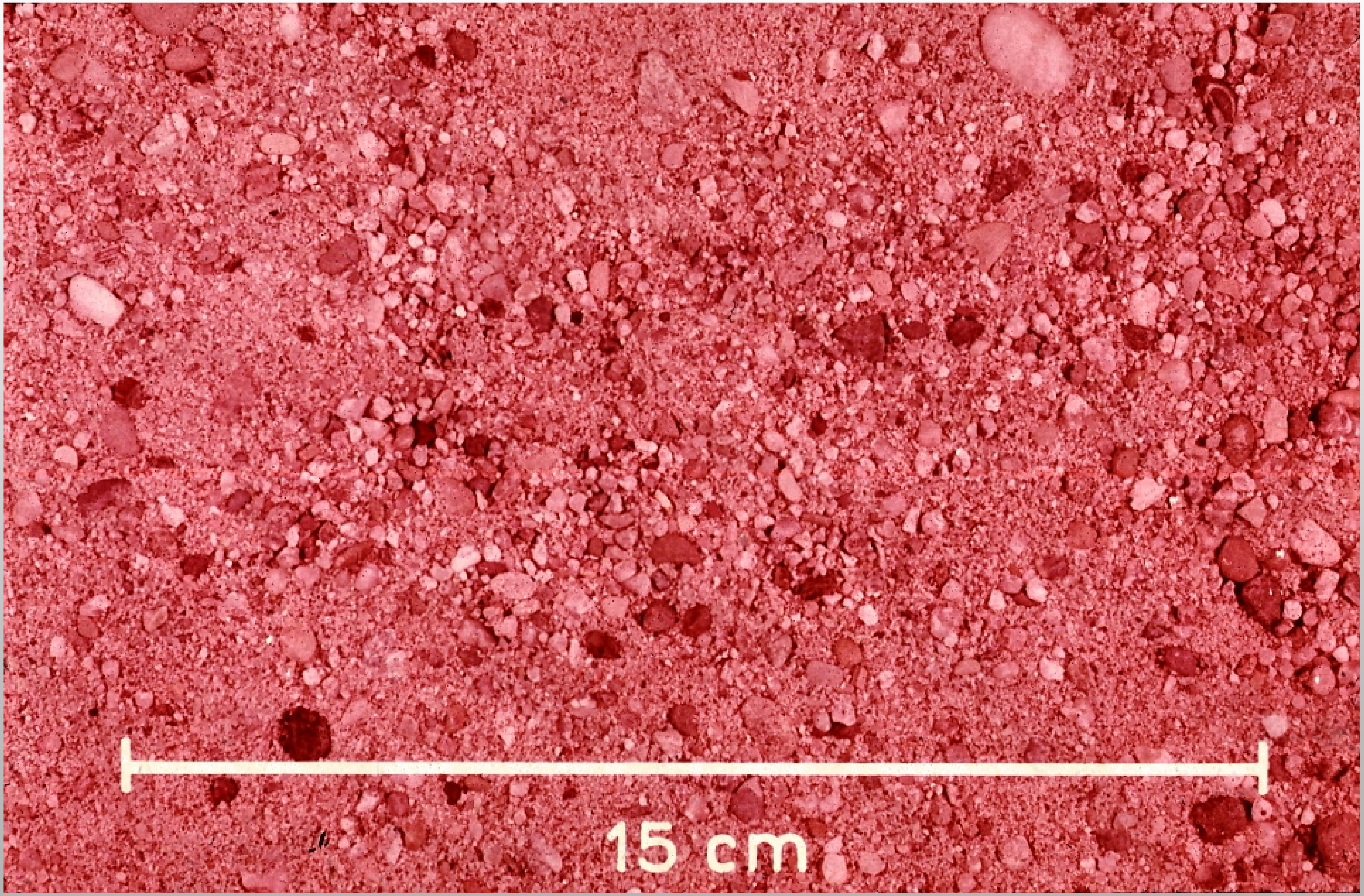
- swelling/shrinking
- freezing/thawing
- texture of the soil
- cultivation and compaction (grazing, trafficability)
- bioturbation and root growth (soil loosening)
- cation at CEC, cementation (org. matter, iron-oxides)

Soil structure types

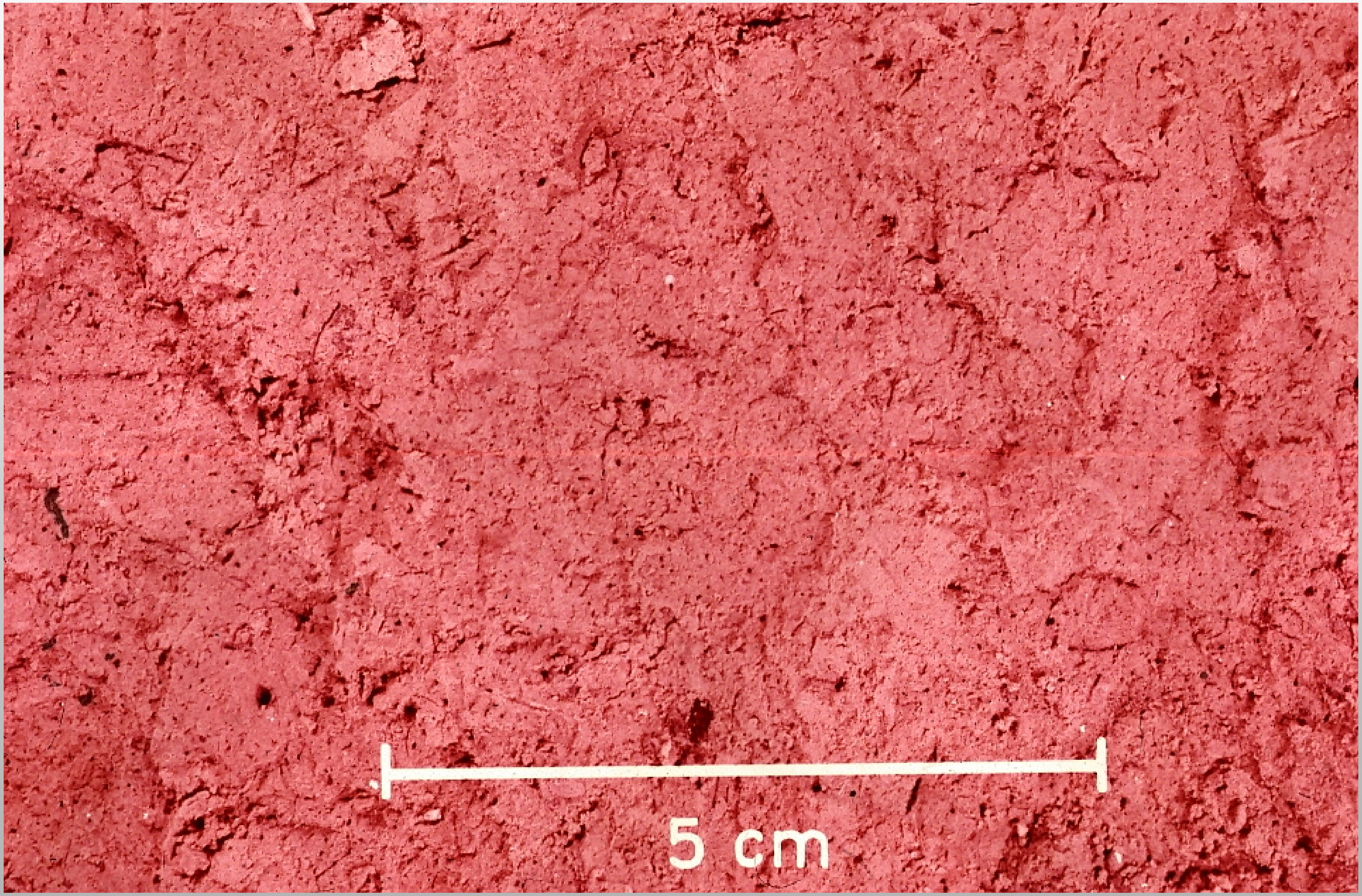
soil structure types			notes
plate-like	 platey		may occur in any part of the profile
prism-like	 prismatic	 columnar	The tops of prismatic aggregates are essentially flat, whereas those of columnar aggregates are rounded. Both types of aggregate are found in subsoils of soils of subhumid to arid regions, however, columnar aggregates are less common than prismatic ones.
block-like (fitting)	 blocky	 subangular blocky (nutty)	Blocky aggregates have flattened faces and most vertices are sharply angular - common in clay to clay loam textured subsoils of humid regions. Subangular blocky aggregates have mixed rounded and flattened faces with many rounded vertices - common in topsoils and subsoils of humid regions
spheroidal (non-fitting)	 granular	 crumb	Characteristic of A horizons - commonly found together under grass in humid and sub-humid regions Crumbs are porous peds similar in appearance to crumbs of bread. Granular aggregates are non-porous.

(McLaren and Cameron, 1997)

granular soil structure



coherent structure



block-like

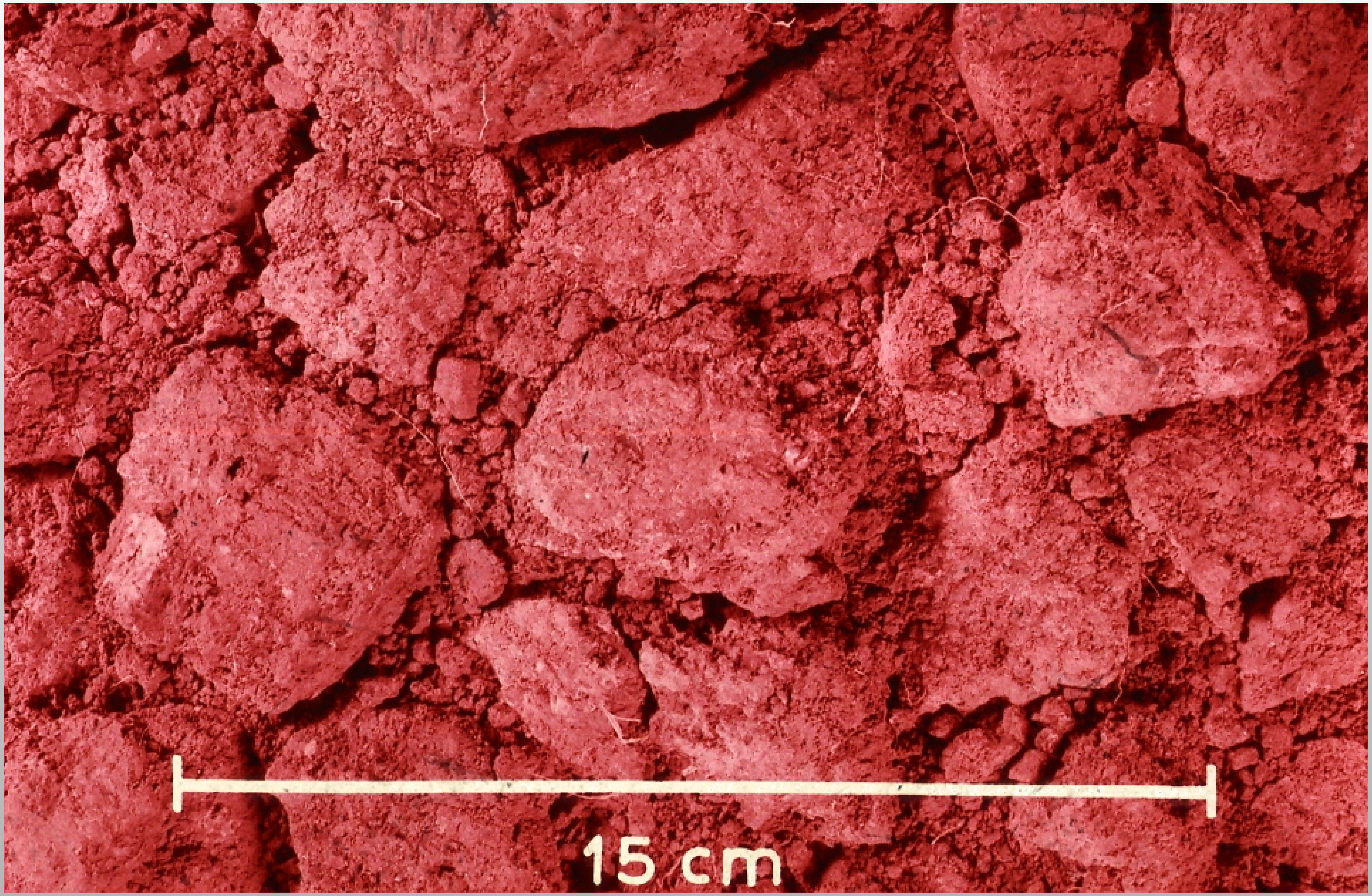
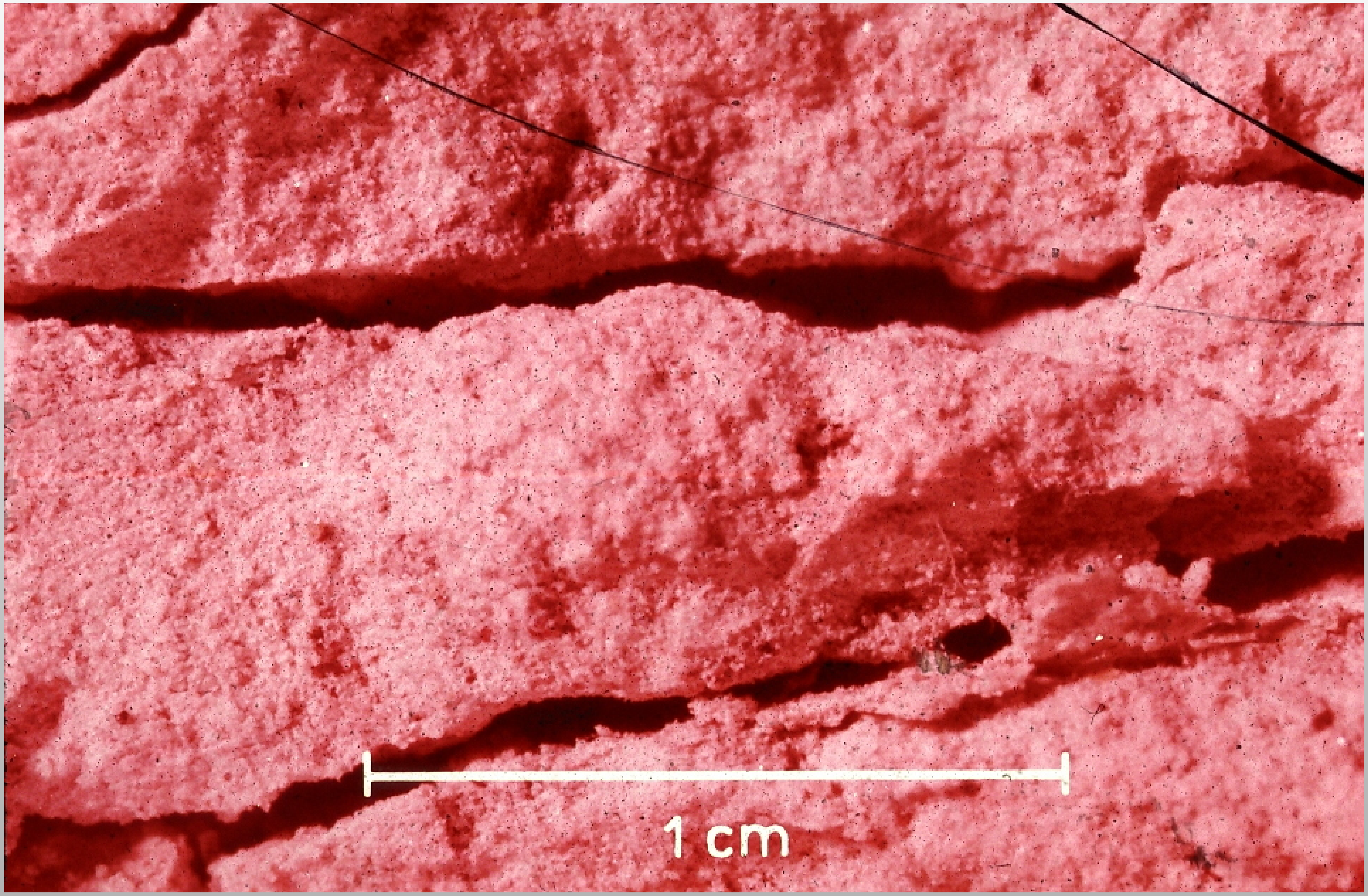


plate-like



Turbation

Pedoturbation (multicoloured claystone)

cryoturbation (Ungarn)

Soil typs / soil classification