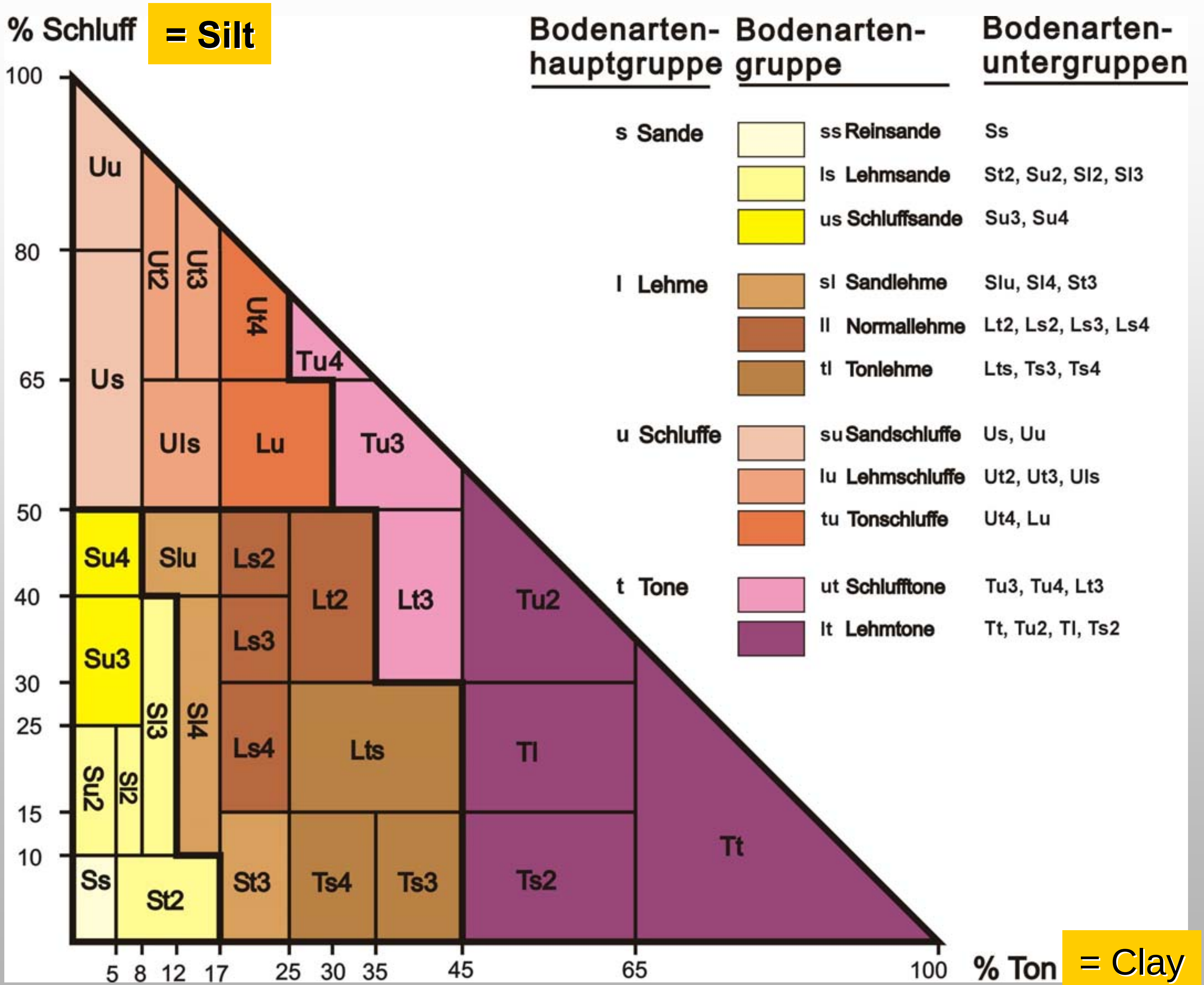
Composition of mineral soils

- Gaseous (Air) ca. 5-30 %
- Liquid (Water) ca. 10-35 %
- Solid
  (Mineral) 45-60 %
  (Organic): <1 up to 10 %

German soil texture classes KA5

Soil components



1. Uu
2. Ut
3. Su
4. Sl
5. St
6. Ls
7. Lts
8. Tu
9. Ts
10. Us
11. Uls
12. Ss
13. Slu
14. Lu
15. Lt
16. Tl
17. Tt

With:

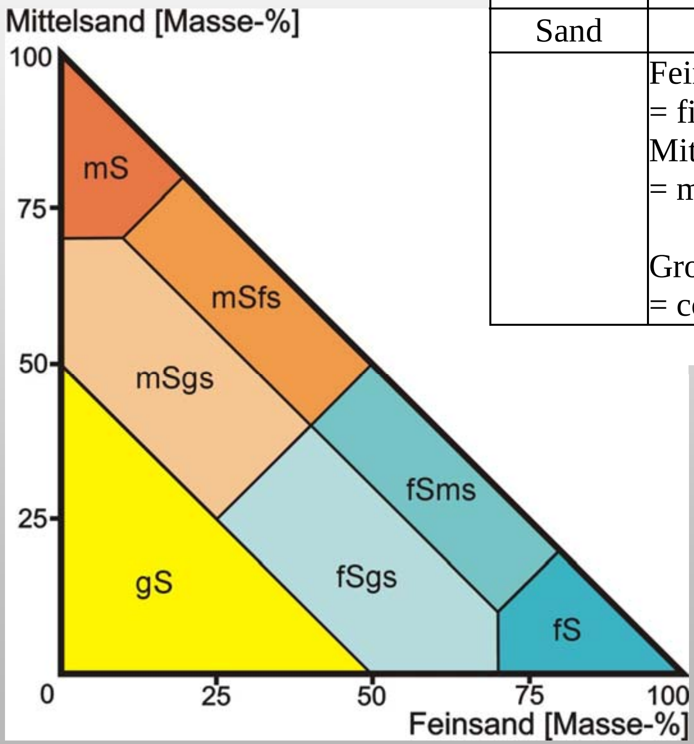
S = Sand
U = Silt
T = Clay
L = Loam

s = sandy
u = silty
l = loamy
t = clayey

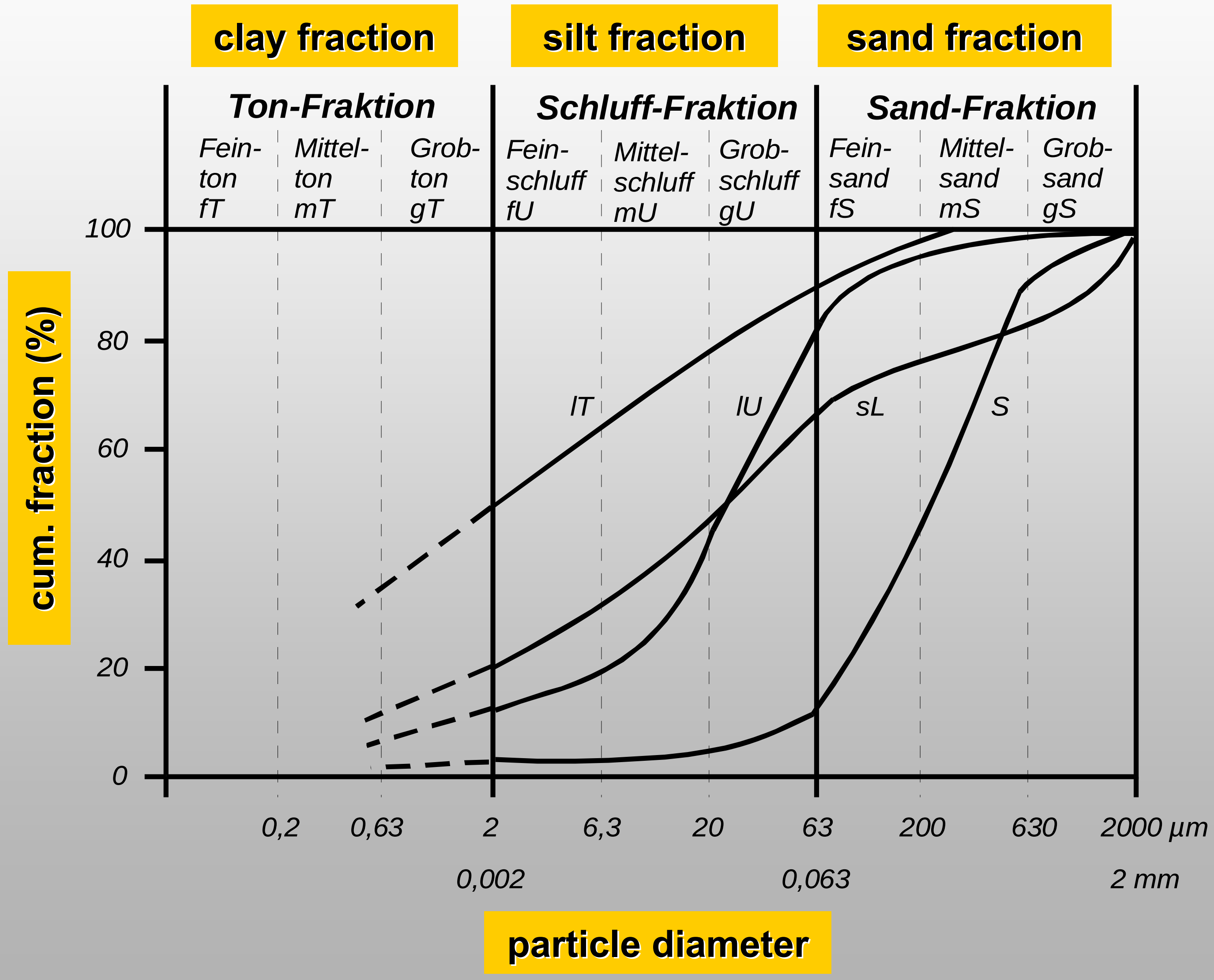
2 = low, weak
3 = medium
4 = high, strong

Sand:

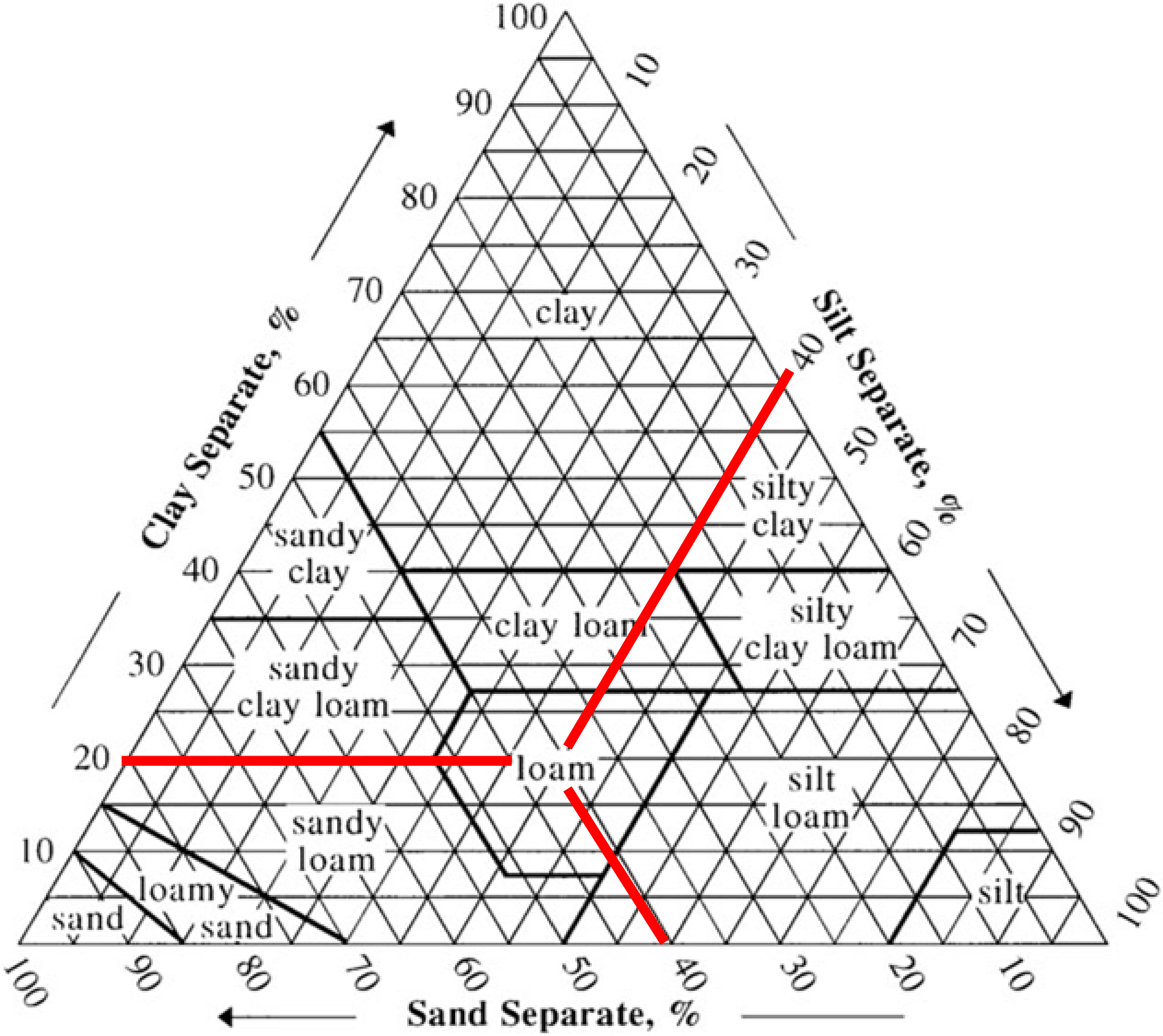
Fraction		Symbol	Equivalent diameter in µm	in mm
Clay		T	< 2,0	< 0,002
Silt		U	2 bis < 63	0,002 bis < 0,063
Sand		S	63 bis < 2000	0,063 bis < 2,0
	Feinsand = fine sand	fS	63 bis < 200	0,063 bis < 0,2
	Mittelsand = medium sand	mS	200 bis < 630	0,2 bis < 0,63
	Grobsand = coarse sand	gS	630 bis < 2000	0,63 bis < 2,0



Particle size distribution curve for a Sand (S), loamy Silt (lU) from Loess, a sandy Loam (sL) and a loamy Clay (lT)



Soil texture triangle, showing the 12 major textural classes, as defined by the USDA.



In the United States, twelve soil texture classifications are defined by the USDA:

- Clay
- Silt
- Sand
- Loam
- Silty clay
- Sandy clay
- Clay loam
- Silt loam
- Sandy Loam
- Loamy sand
- Silty clay loam
- Sandy clay loam

Particle size scales as defined by the USDA.

Soils and Particle Size

particle	diameter
clay	less than 0.002 mm
silt	0.002 mm – 0.05 mm
sand	0.05 mm – 2.00 mm
fine pebbles	2.00 mm – 5.00 mm
medium pebbles	5.00 mm – 20.00 mm
coarse pebbles	20.00 mm – 75.00 mm

Sand fractions (mm):

Very fine sand	0.05–0.10
Fine sand	0.10–0.25
Medium sand	0.25–0.50
Coarse sand	0.50–1.00
Very coarse sand	1.00–2.00

Porperties of soil textures

Soil properties	Soil texture			
	Sand	Silt	Clay	Loam
Soil cultivation	++	+	--	0
Nutrient storage	--	-	++	+
Nutrient supply	-	0	+	++
Water holding capacity	--	++	+/0	++
Water supply	-	++	-	+
Drainage	++	-	--	0
Erosion	0	++	--	-/0

++ very good (very high); + good (high); 0 satisfactory (medium); - bad (low); -- very bad (very low)

Minerals in soils: two groups, based on origin:

➔ **Primary minerals:** are those derived from the parent material
+ The primary minerals have usually been through at least one cycle of weathering, so that only the more resistant ones remain.
+ In the soils of the humid temperate climate zone, the sand fraction is composed largely of quartz grains, but it may also contain some grains of feldspar, mica, and a few of the rarer persistent minerals such as zircon, tourmaline or glauconite. These minerals can sometimes be used to determine the origin of the soil parent material and also to determine quantitatively the path of weathering from rock to soil.
+ Quartz grains often constitute between 90 and 95 per cent of all the sand and silt particles of soils derived from sedimentary rocks.

➔ **Secondary minerals** are the product of chemical weathering and have been formed in the soil itself.
The **clay minerals** are the most important of these mineral constituents of soils;
+ they consist of fine, platy-shaped mineral grains which can be identified only indirectly, or by an electron micro scope.
+ they are characterized by a layered, crystalline structure, and chemically they are hydrous silicates of aluminium. There are three main members of this group: of minerals: kaolinite, smectite and the hydrous micas.

Minerals in the soil:

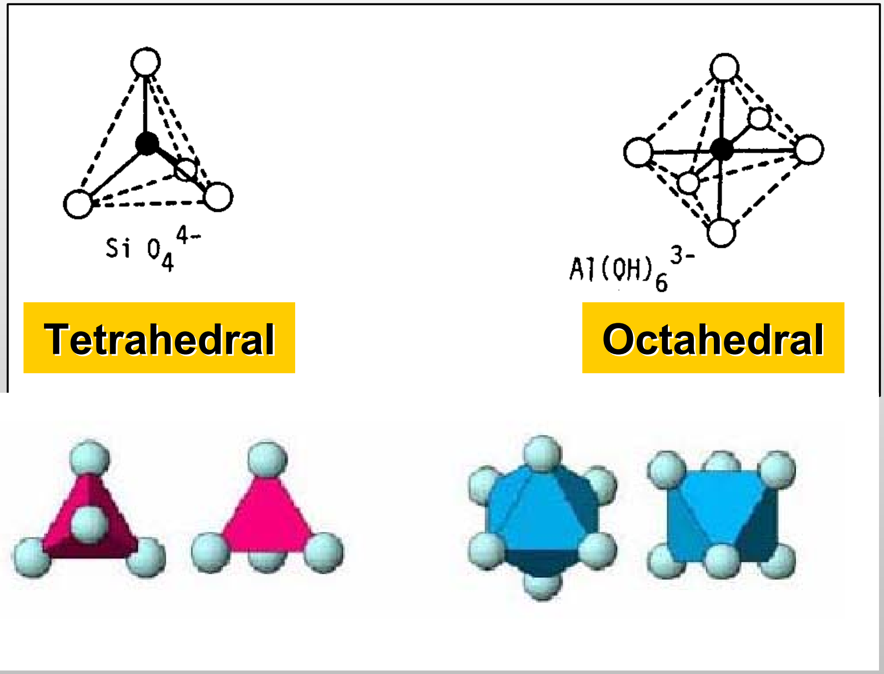
In soils developed in the **humid tropical environment**:
- most weatherable primary minerals such as feldspars and mica are normally absent
- the soil is composed largely of quartz and secondary clay minerals. The clay mineral kaolinite together with iron and aluminium hydroxides constitute the clay fraction.
- The amount of quartz sand is variable but silt-sized material is proportionately low.

-

Formation of clay minerals

- weathering releases elements that pass into the soil solution from which recrystallization takes place to form a completely new mineral.
- kaolinite, $Al_4Si_40_{10}\,(OH)_8$, can be formed in this way from soil solutions rich in aluminium and silicon;
- under base-rich conditions the mineral montmorillonite, $NaMgAl_5Si_{12}O_{1O}(OH)_6$ (smectite group), prevails, may be formed
- clay minerals can also be formed in the soil by simple alteration of primary minerals

Molecular geometry in Silicium and Aluminium minerals



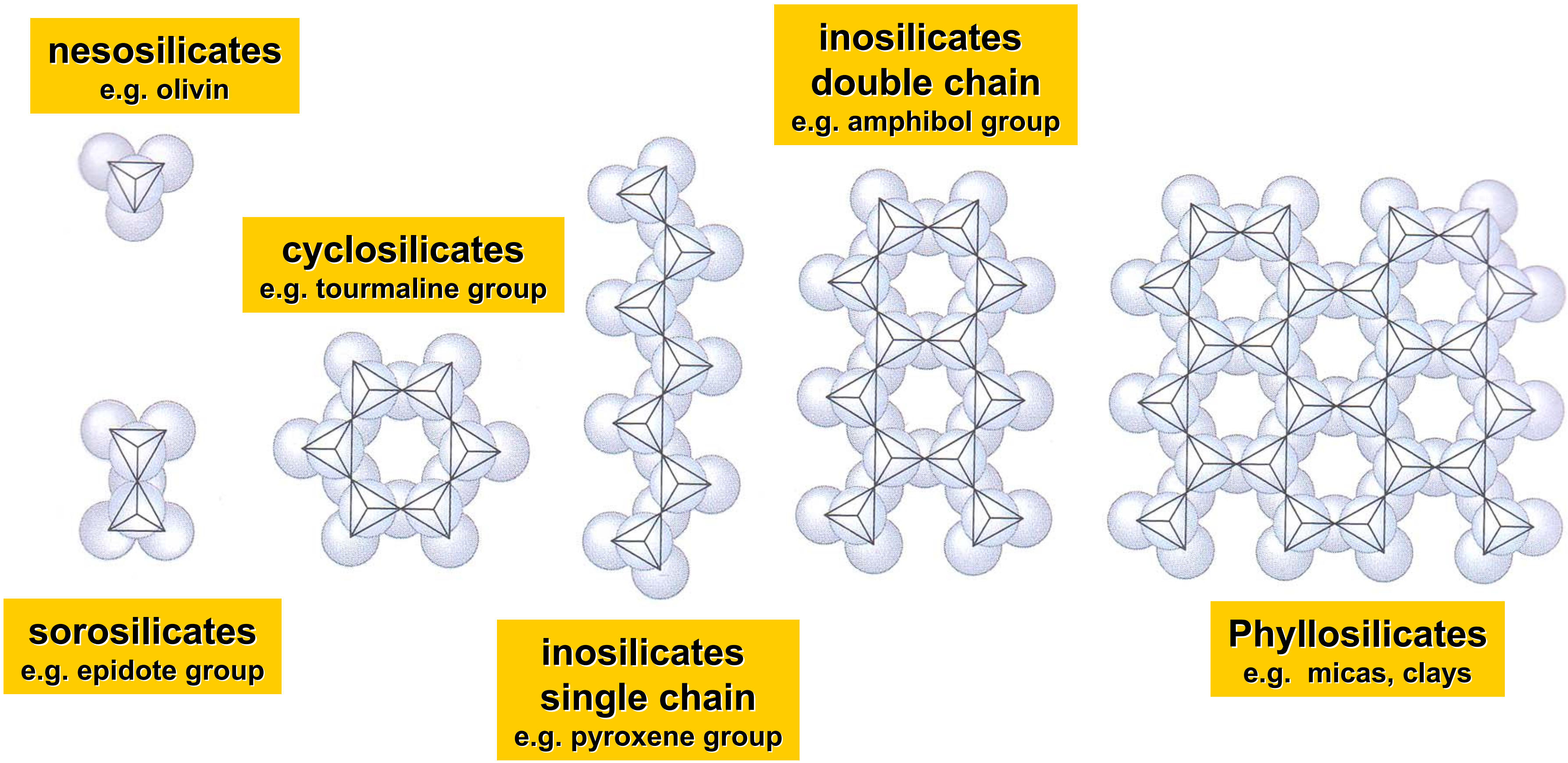
- Clay minerals are constructed from layers of silica and aluminium atoms and their attendant oxygen and hydroxyl groups. The silicon and aluminium layers are held together by shared chemical bonds.

- Kaolinite has one layer of silicon atoms and one layer of aluminium atoms in a 1: 1 structure

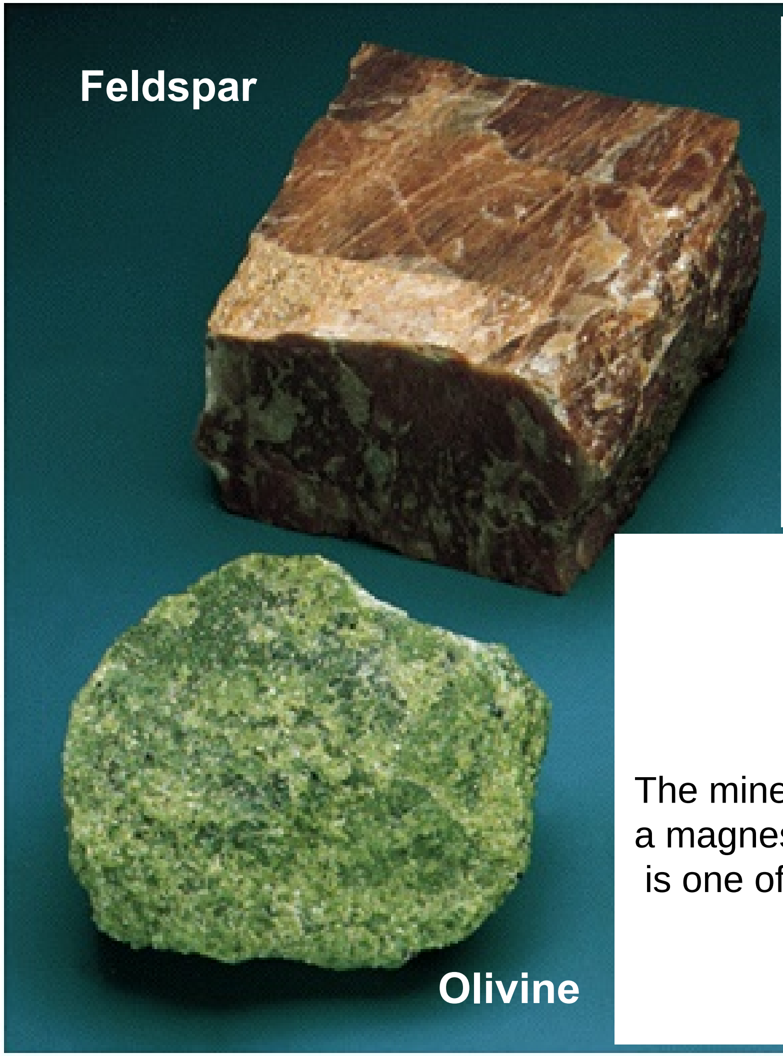
- Smectite minerals have three layers with the aluminium atoms lying between two layers of silicon atoms in a 2:1 structure, sharing the valencies of their oxygen atoms.

Geometry of different silicates

- in igneous rocks the silicates are with 80% the most common minerals
- silicates are the main source for mineral formation by weathering



Silicate minerals



Feldspars ($KAlSi_3O_8$ - $NaAlSi_3O_8$ - $CaAl_2Si_2O_8$) are a group of rock-forming tectosilicate minerals which make up as much as 60% of the Earth's crust

Feldspars crystallize from magma in both intrusive and extrusive igneous rocks, as veins, and are also present in many types of metamorphic rock. Rock formed almost entirely of calcic plagioclase feldspar is known as anorthosite. Feldspars are also found in many types of sedimentary rock.

The mineral **olivine** (when gem-quality also called peridot) is a magnesium iron silicate with the formula $(Mg,Fe)_2SiO_4$. It is one of the most common minerals on Earth.

Silicate minerals

Quartz is the second most abundant mineral in the Earth's continental crust, after feldspar. It is made up of a continuous framework of SiO_4 silicon-oxygen tetrahedra, with each oxygen being shared between two tetrahedra, giving an overall formula SiO_2.
There are many different varieties of quartz, several of which are semi-precious gemstones. Especially in Europe and the Middle East, varieties of quartz have been since antiquity the most commonly used minerals in the making of jewelry and hardstone carvings.

The **pyroxenes** are a group of important rock-forming silicate minerals found in many igneous and metamorphic rocks.

Pyroxenes have the general formula $XY(Si,Al)_2O_6$

-(where X represents calcium, sodium, iron+2 and magnesium and more rarely zinc, manganese and lithium and

-Y represents ions of smaller size, such as chromium, aluminium, iron+3, magnesium, manganese, scandium, titanium, vanadium and even iron+2). Although aluminium substitutes extensively for silicon in silicates such as feldspars and amphiboles, the substitution occurs only to a limited extent in most pyroxenes.

Silicate minerals

The **mica** group of sheet silicate (phyllosilicate) minerals includes several closely related materials having highly perfect basal cleavage. All are monoclinic with a tendency towards pseudo-hexagonal crystals and are similar in chemical composition. The highly perfect cleavage, which is the most prominent characteristic of mica, is explained by the hexagonal sheet-like arrangement of its atoms.

The word "mica" is thought to be derived from the Latin word *micare*, meaning "to glitter", in reference to the brilliant appearance of this mineral (especially when in small scales)

Chemically, micas can be given the general formula $X_2Y_{4-6}Z_8O_{20}(OH,F)_4$

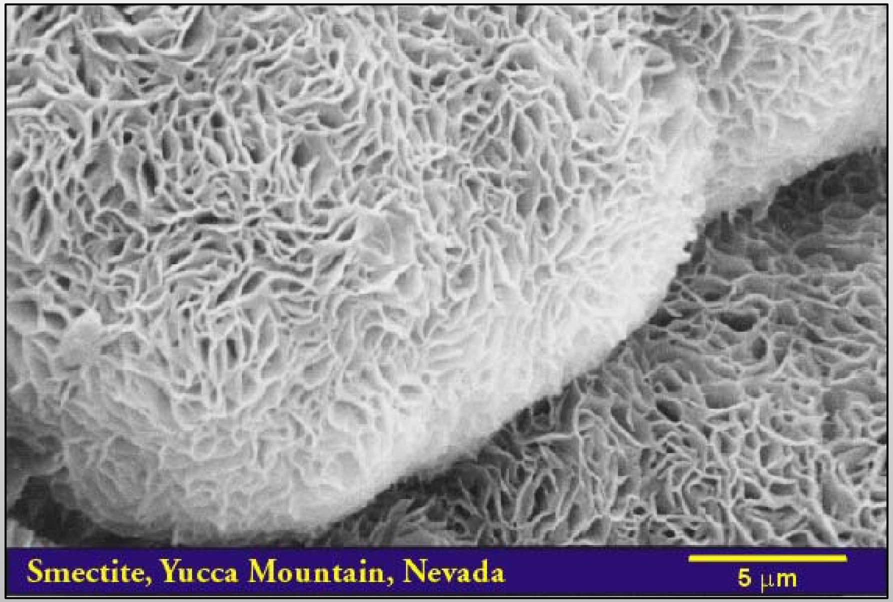
in which *X* is K, Na, or Ca or less commonly Ba, Rb, or Cs;
Y is Al, Mg, or Fe or less commonly Mn, Cr, Ti, Li, etc.;
Z is chiefly Si or Al but also may include Fe3+ or Ti.

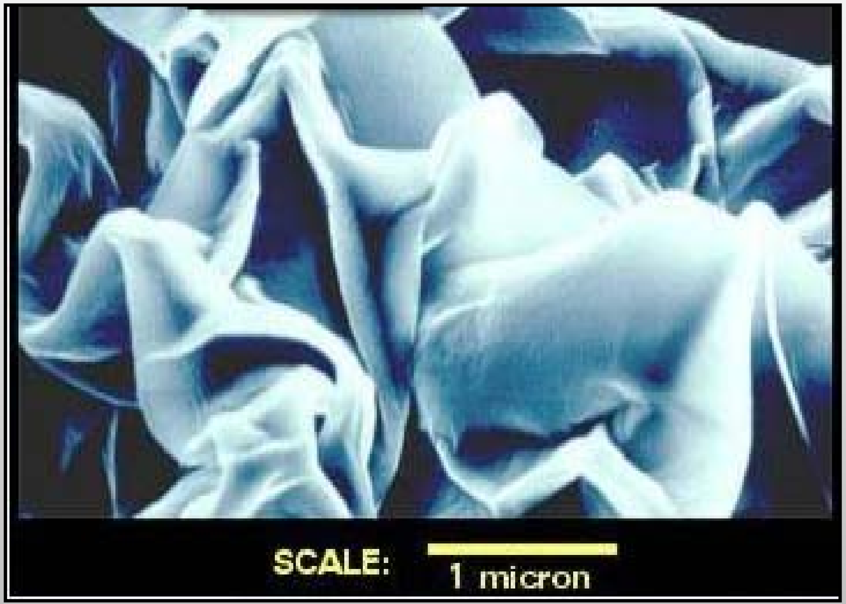
Structurally, micas can be classed as *dioctahedral* (*Y* = 4) and *trioctahedral* (*Y* = 6). If the *X* ion is K or Na the mica is a *common* mica whereas if the *X* ion is Ca the mica is classed as a *brittle mica*.

Common micas: Phlogopite, Biotite, Zinnwaldite, Lepidolite, Muscovite

Clay minerals

Clay minerals are mineral products from phyllosilicates of colloidal size (< 2 μm)





<u>Properties:</u>

- large surface,
- are plastic,
- swelling and shrinking
- ability to absorb ions

Type depends on structure:

- two-layer (e.g. Kaolinit)
- three-layer (e.g. Illit, Vermiculit)
- four-layer – Clay minerals (e.g. Chlorit)

Possibilities of clay formation

Mica —(- K)→ Illite ⇄ (- K / + K) Vermiculite, Smectit ⇄ (+ Al / - Al) sec. Chlorite

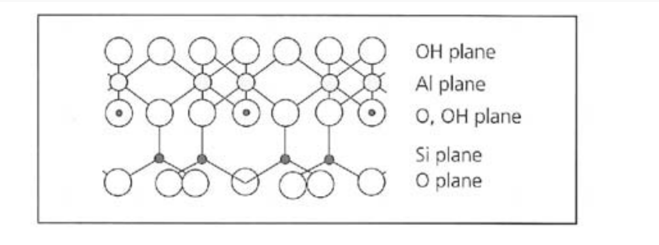
Feldspar, Pyroxene, Olivine a.o. —(- (Ca, Mg, K, Na, Si))→ decomposition products

- decomposition products —(- Si)→ Goethite, hematite, gibbsite
- decomposition products → Allophane, kaolinite, halloysite
- decomposition products —(+K)→ Illite
- decomposition products —(+Mg, Ca)→ Smectite, vermiculite

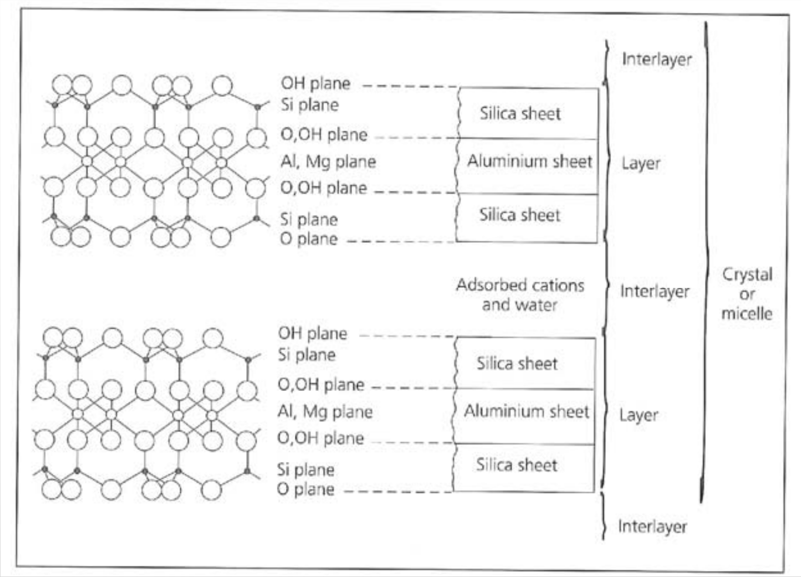
<u>Clay mineral alteration:</u>

Smectite, Vermiculite, Illite —(- (Ca, Mg, K, Na, Si))→ Kaolinite, Halloysite ⇄ (+ Si / - Si) Goethite, hematite, gibbsite

Two- (1:1) and three- (2:1) layered clay minerals



Kaolonite

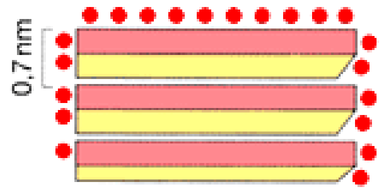


Montmorilonite

isomorphic exchange: Si and Al ➔ e.g Fe Mg

two-layered clay mineral

z.B. Kaolinit (von Kau ling, Berg in China, Fundort von Porzellanerde = Kaolin) Schichtflächenabstand nicht variabel, nicht quellbar, Ionen-Adsorption nur an Außen- und Bruchflächen.

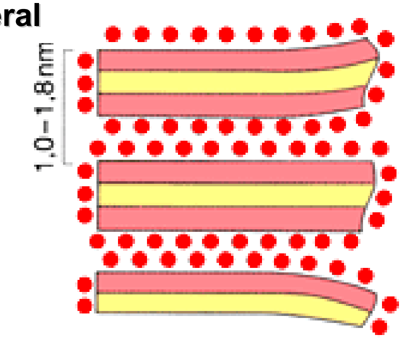


Silica sheet
Alluminium sheet

exchangeable ions

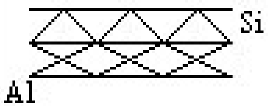
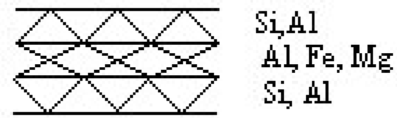
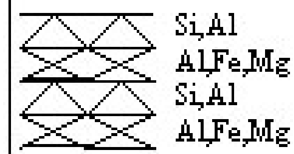
three-layered clay mineral

z.B. Montmorillonit (von Montmorillon, Ort in Frankreich, hier erstmals beschrieben) Schichtflächenabstand variabel, gut quellbar durch Eintritt von Wasser, Ionen-Adsorption vorwiegend an „inneren" Oberflächen sowie an Außen- und Bruchflächen.

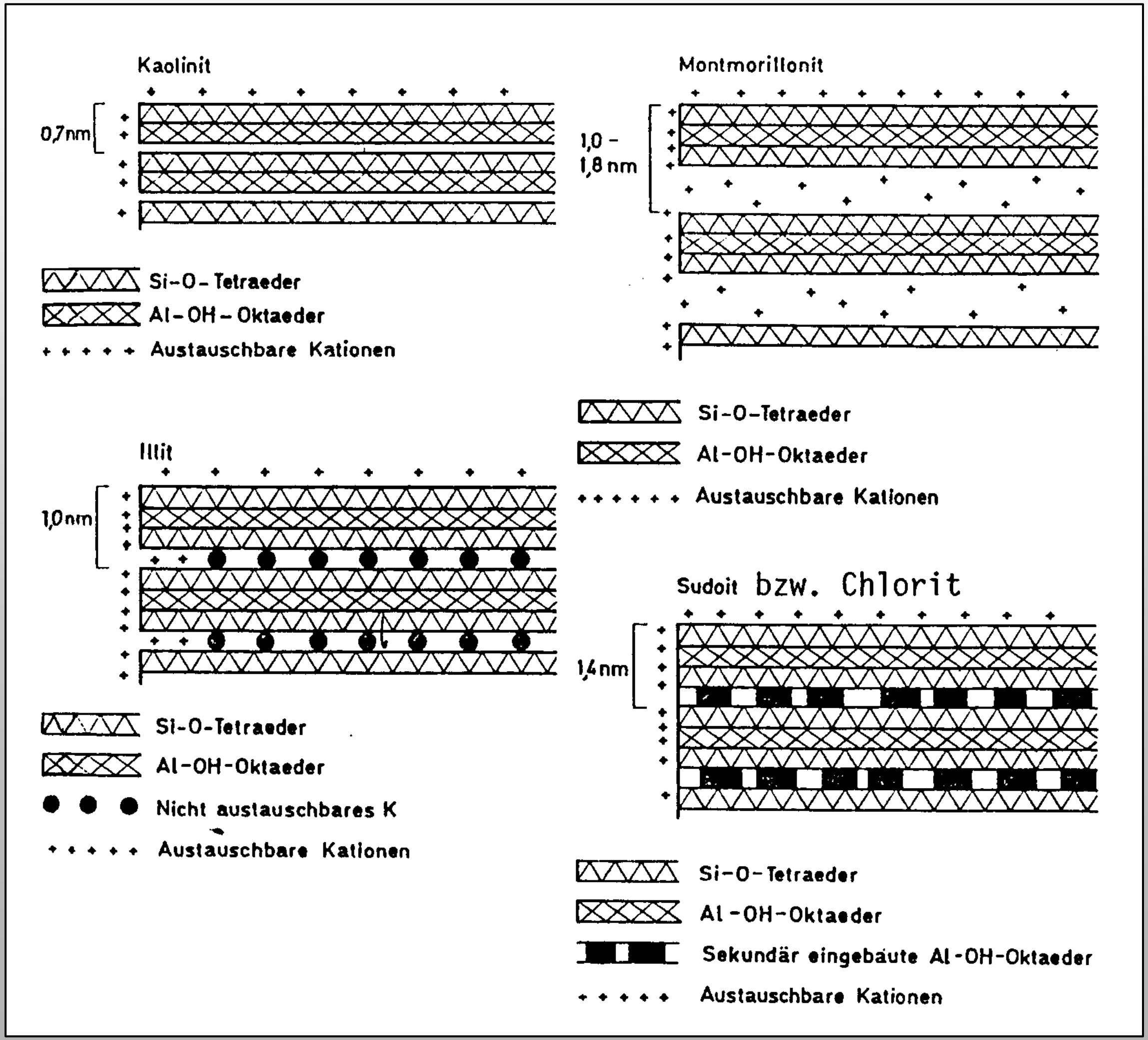


Clay minerals

Structure and properties of clay minerals

	Kaolinit	Illit	Übergangs-minerale	Vermiculit	Montmoril-lonit	Chlorit
lattice type **basic structure**	1:1 	2:1 				2:1:1 
Isomorpher Einsatz	-	vorwiegend in Tetraedern			vorwiegend in Oktaedern	in Tetraedern und Oktaedern
Negativer Ladungs-Überschuß	~0	0,60 – 0,90			0,25-0,60	~0
Aufweitbarkeit	-	-	x	xx	xxx	-
Zugängliche innere Oberfläche	-	x	xx	xxx	xxx	-
Wasserhaltevermögen	x	x	xx	xxx	xxxx	x
Adsorptionsvermö-gen	x	xx	xxx	xxxx	xxx	x
Kontraktilität bei K-Zufuhr	-	-	xxx	xxx	x	-
Plastizität, Kohäsion	x	x	xx	xxx	xxx	x

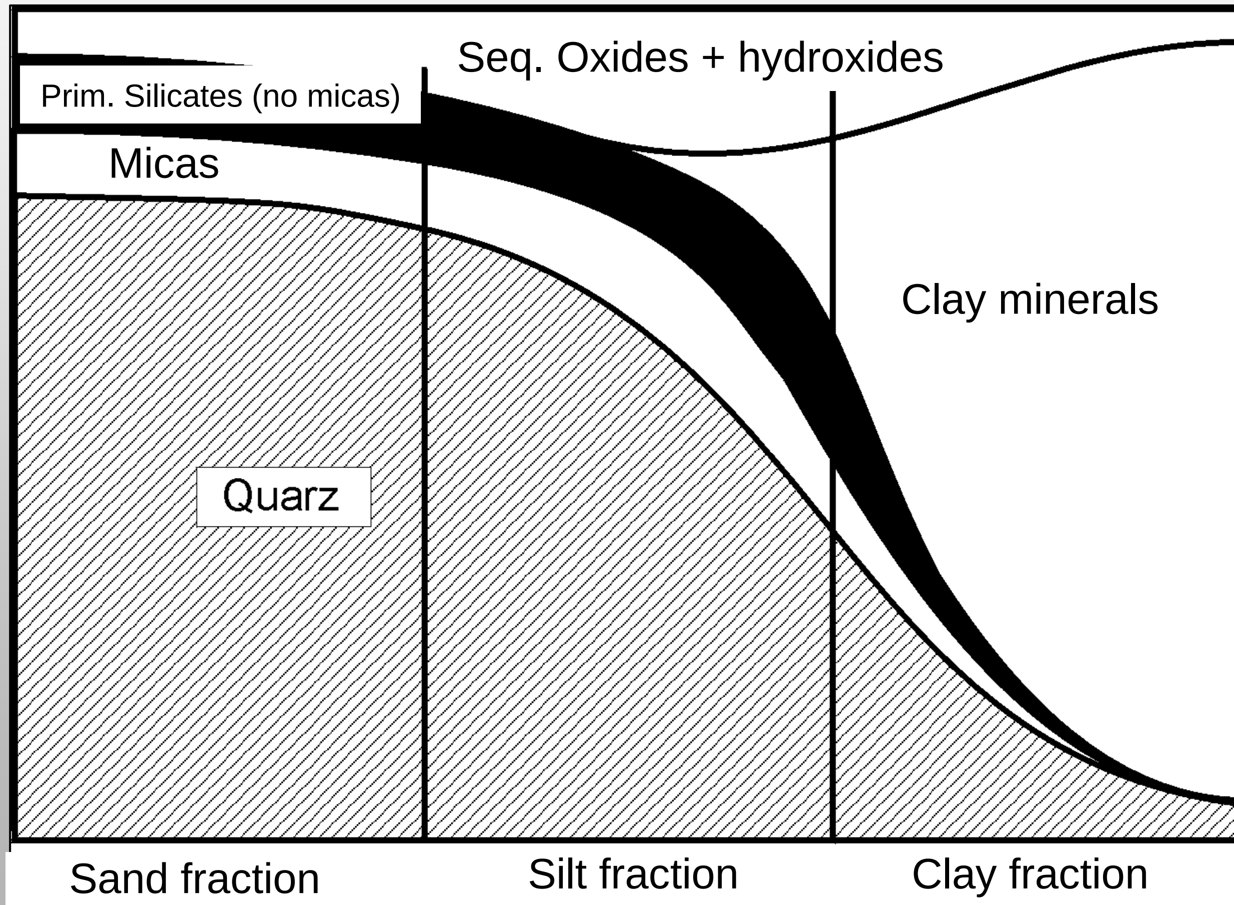
Layer composition and sorption of clay minerals



Important secondary oxides and hydroxides

Element	Name	Chem. Formula	structure	Colour	formation
Si	*Opal*[1)] *Quarz*	$SiO_2 * nH_2O$	amorphous lattice structure	colourless colourless	Weathering of Silicates aging of opal
Al	*Aluminium-Hydroxide* *Gibbsite*	$Al(OH)_3 * nH_2O$ γ- $Al(OH)_3$	amorphous oktaedrisch	colourless colourless	Ausfällung bei schwach saurer bis neutraler Reaktion vorwiegend durch Alterung von Al-Hydroxid
Fe	*Iron(III)-Hydroxide*[)] *Goethite (Nadeleisenerz)* *Lepidokrokit (Rubinglimmer* *Hematite*	$Fe(OH)_3 * nH_2O$ α-FeOOH γ-FeOOH α-Fe_2O_3	amorphous to parakristallin nadelförmig bis faserig blattförmig sechseckige Prismen	auburn auburn Brown to orangered red	Ausfällung bei schwach saurer bis alkalischer Reaktion vorwiegend durch Alterung von Fe^{III}-Hydroxid vorwiegend durch Oxidation von Fe^{III}-Verbindungen Alterung von Fe^{III}-Hydroxid bei hoher Temperatur
Mn	*Mangan(III)-Hydroxide* *Manganite* *Pyrolusite*	$Mn(OH)_3 * nH_2O$ γ-MnOOH MnO_2	amorphous christalline christalline	Black-brown Black-brown Black-brown	Ausfällung bei schwach saurer bis alkalischer Reaktion Alterung von Mn^{III}-Hydroxid Alterung von Mn-Hydroxiden

General tendency of the mineral distribution of different grain fractions



Silt: 0.002 – 0.064 mm (German)
0.002 - 0.050 mm (US)

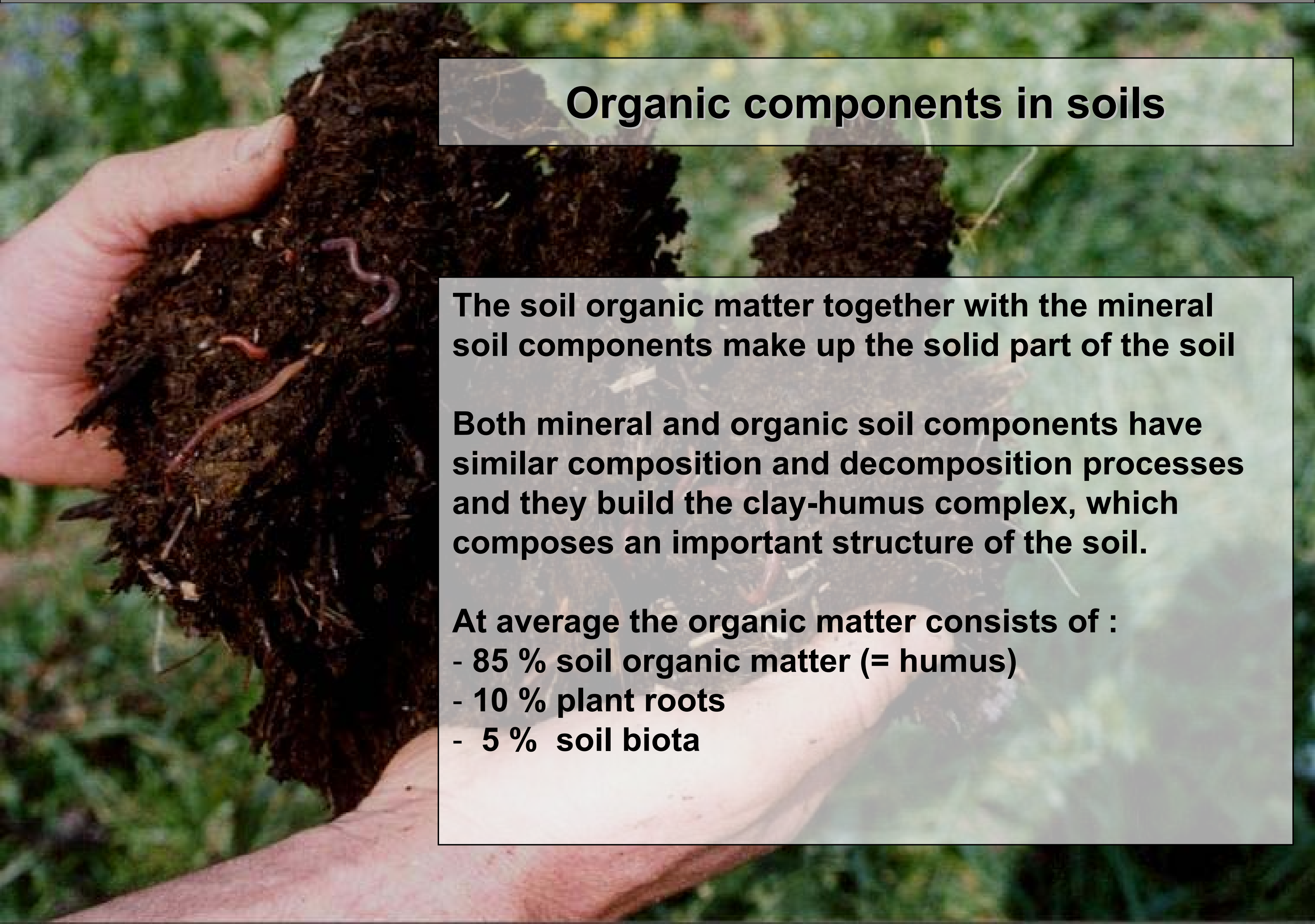
1. Silt is created by a variety of physical processes capable of splitting the generally sand-sized quartz crystals of primary rocks by exploiting deficiencies in their lattice. These involve chemical weathering of rock and regolith, and a number of physical weathering processes such as frost shattering.

2. The main process is abrasion through transport, including fluvial comminution, aeolian attrition and glacial grinding. It is in semi-arid environments that substantial quantities of silt are produced.

3. Silt is sometimes known as 'rock flour' or 'stone dust', especially when produced by glacial action.

4. Mineralogically, silt is composed mainly of quartz and feldspar.

5. Sedimentary rock composed mainly of silt is known as siltstone.



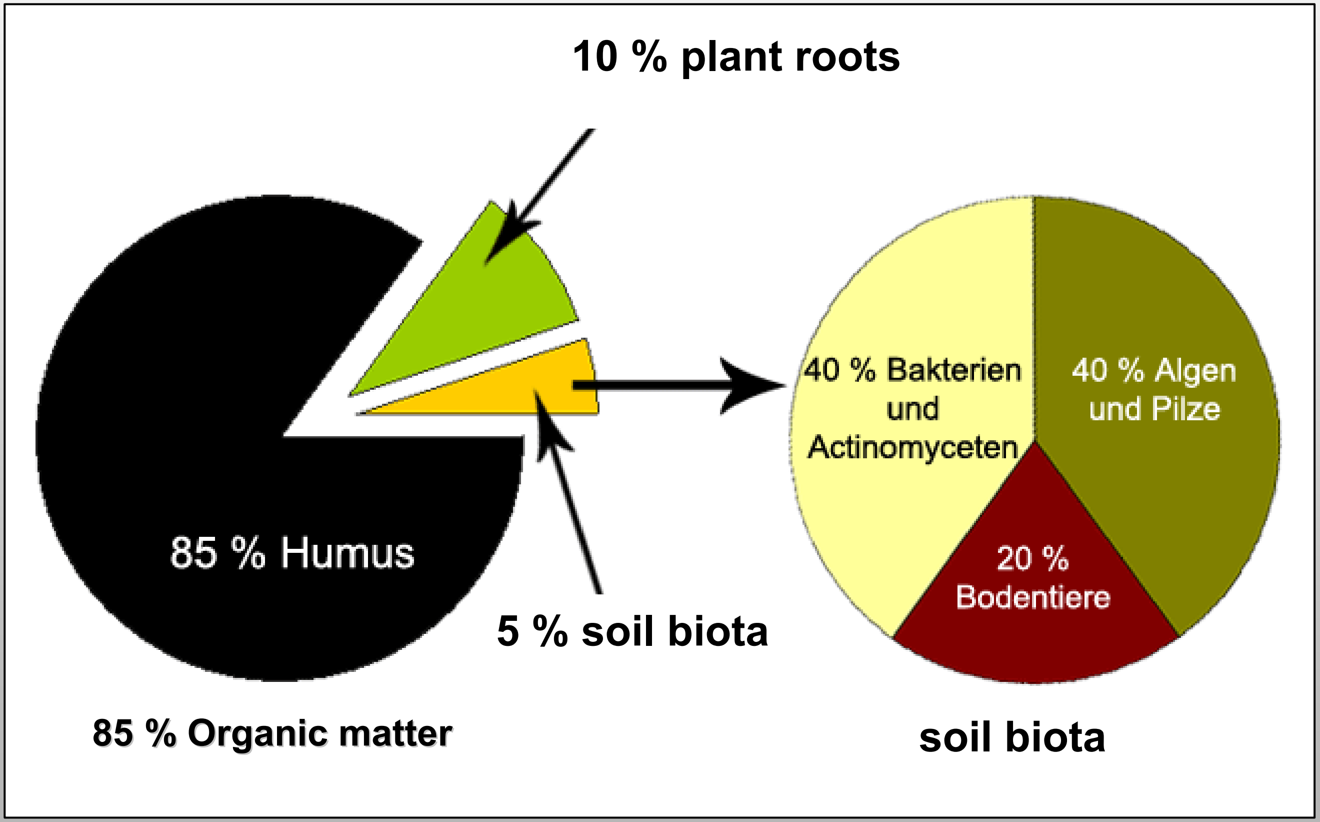
Organic components in soils

The soil organic matter together with the mineral soil components make up the solid part of the soil

Both mineral and organic soil components have similar composition and decomposition processes and they build the clay-humus complex, which composes an important structure of the soil.

At average the organic matter consists of :
- **85 % soil organic matter (= humus)**
- **10 % plant roots**
- **5 % soil biota**

Composition of organic matter in soils



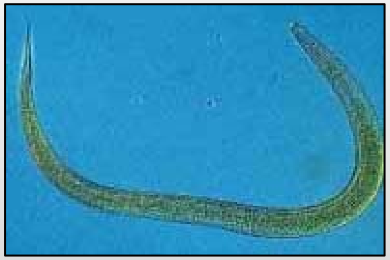
Soil organisms

Soil Biota

Soil biota is subdivided according to the size of the organisms into Micro-, Meso-, Macrofauna of the soil:

Microfauna: size:< 100 µm

e.g. yeasts, bacteria (commonly actinobacteria), fungi, protozoa, roundworms, and rotifers



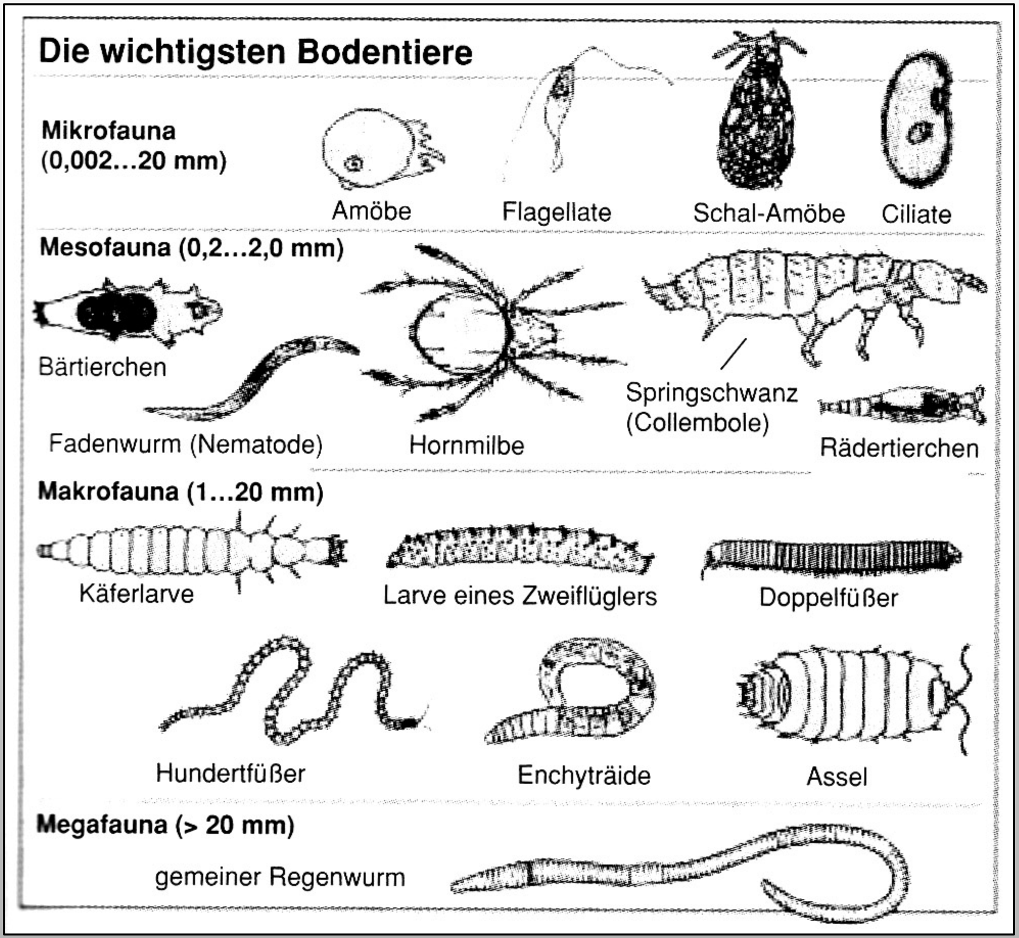
Mesofauna: size: 100 µm – 1 cm

e.g. tardigrades, mites and springtails

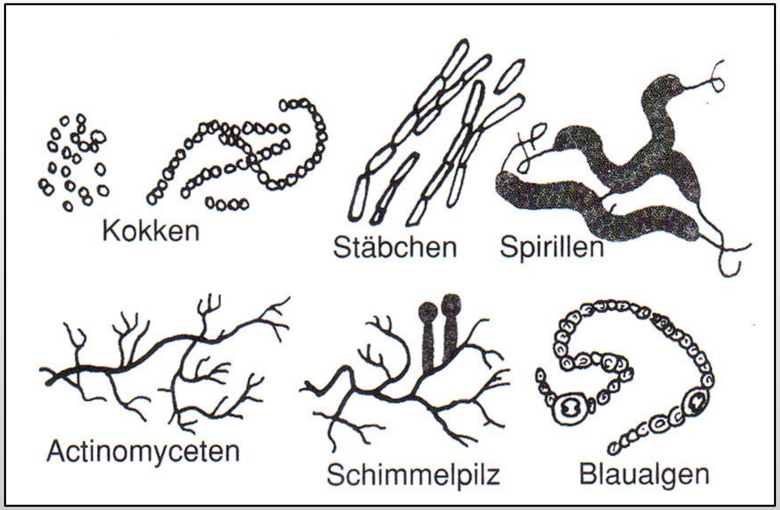
Macrofauna: size: > 1cm

e.g. woodlice, earthworms, beetles, centipedes, slugs, snails, ants, and harvestmen

Soil organisms



Soil biota



soil microflora

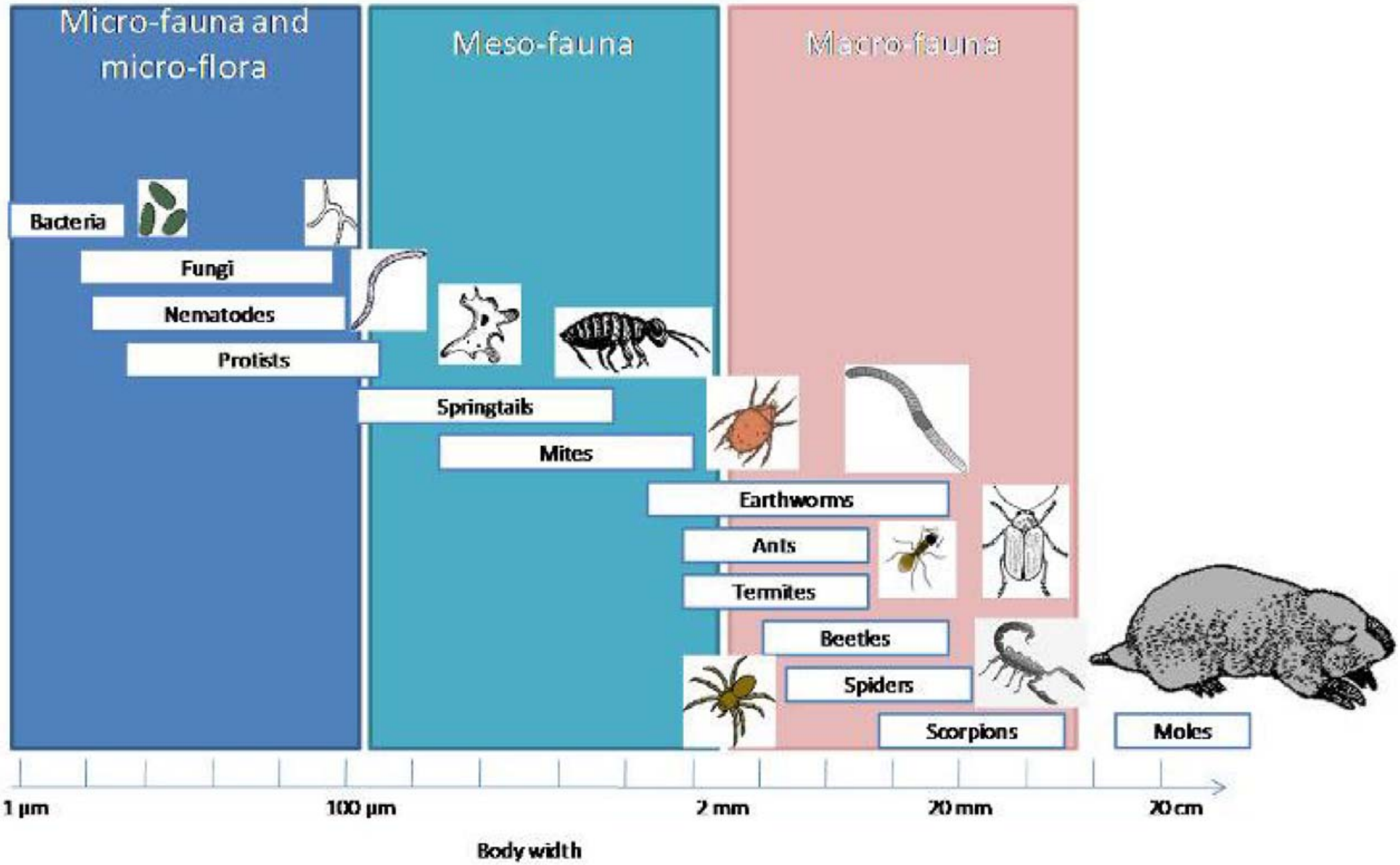


Figure 1-1: Main soil inhabitants, by size

Soil organism

Mean number and weights of important soil organims

	Number per m²	Weight g/m² (Dry Matter)
Bacteria	10^{14}	100
Actinomycets	10^{13}	100
Fungi	10^{11}	100
Algae	10^{8}	20
Microfauna	10^{8}	5
Threadworms	10^{6}	5
Small bristle worms	3×10^{4}	5
Earthworms	100	30

≈ 4 t/ha DM

≈ 25 t/ha wet

The effect of the soil biota on soil genetic and soil ecological processes

- Soil mixing and deepening of the A - Horizon
- build up of the clay-humus complex
- mechanical decomposition of organic matter

Excrements of earthworms

Decomposition of leafs

Number and fresh weights of earthworms in different soils

Area	Land use	Number per m^2	Fresh weight (g/m^2)
Russia	Taiga	3 - 23	1,0 - 8,4
Europe	Deciduous forest	10 - 140	10 - 100
	Meadows	100 - 650	60 - 200
	Grassland	20 - 200	8 - 60
	Arable land	5 - 100	0,5 - 20
New Sealand	Meadows	210 - 2000	60 - 300
Tropical Afrika*	Rain forest	30 - 130	1 - 10
	Mountain forest	2 - 110	0,2 - 3

* no Lumbicides, mainly smaller earthworms

Base material for organic substances

- plant roots
- leafs, needles and twigs of bushes and trees
- vegetation residues of herbs and grasses,
- body substances of soil organisms,
- yield residues like grain stubs, sugar beet leafs and potatoe leafs etc.
- fresh or decomposed organic substances due to activities of people like stall manure, pig slurry , green manure compost, peat

The amount of produced organic substances differs extremely depending on vegetation and productivity of the specific site :

Natural residues in forests > yield residues of arable land and grassland;

Deciduous forest > coniferous forest >; forage crops > cereals > root crops (sugar beets, potatoes)

Composition of different organism(-parts) in %

	Cellu-lose	Lig-nin	Hemi-cellulose	Sugar Starch[1]	Proteins 2	Fats wax resins[3]	Ash	C/N
Coniferous trees								
Wood	44	30	15	1.1	1.3	7.7	0.3	100-400
Growth[4]	44	18	9	16	4.0	5.8	4.2	40-80
Decideous trees								
Wood	47	20	24	0.8	2.5	1.8	0.3	100-400
Growth[4]	37	12	14	23	6.4	2.8	4.2	30-50
Rootwood[5]	33	22	18		1.6	1.3	1.3	190
fine roots[5]	19	33	10	>3	5.4	3.1	3.4	55
Grassland								
Leaves		31		50	8.7	2.7	7.6	10-40
Roots	28	18	27		7.5	8.5		10-40
Cereals								
Straw	39	24	25		2.0	(2)	5.0	50-100
Lakes								
Phytoplankton		18		50	17	1.5	14	5-12
Konsumenten		Chitin[6]						
Isopoden		9		19	63	3	6	
Insekten		6		23	65	3	3	
Zooplankton		9		16	50	10	15	
soil Biota								
Eathworms			17		58	6	19	4-6
Fungus		10		32	25	10	6	10-15

[1] and other non structural carbohydrates

[2] and other n-containing compounds

[3] and other with solvents extractable parts, e.g. Chlorophyll

[4] mainly needles and leaves

[5] of beech, after Bornkamm

[6] and similar builder

Mean values of the annual amount of organic dry matter (DM)

Organic DM	Forest dt/ha	Grassland dt/ha	Arable land dt/ha
Rootmass (hair/fine roots)	30 - >100	30 - 80	5 - 30
Litter	20 - 45	10 - 30	3 - 20
Organic fertilizer	-	-	10 - 20

Plant biomass, net primary production, decay of fresh organic matter and amount of soil organic matter of ecosystems in different climates

ecosystem	Biomass (kg DM/m^2)	annual Net growth (kg DM/m^2)	Decay in first year (%)	SOM in soil (kg/m^2)
Tundren	0,1-3	0,004-0,4	10-20	3-50
Full deserts	0-0,2	0-0,01	50	0-1
Half deserts	0,1-4	0,01-0,25	50	0,1-10
Temperate Steppe	0,2-5	0,2-1,5	120	13-26
Tropical Savanna	0,2-15	0,2-2	120	0,3-9
Boreal und temperate coniferous forests	6-40	0,4-2	11-58	5-32
Temperate decideous forests	6-60	0,6-2,5	37-85	7-24
rain green monsoon forests	6-60	1-2,5		
Tropical rain forests	6-80	1-3,5	100-400	4-21
Arable land	0,4-12	0,1-3,5		

C_{org}-content of the plow layer of longterm field experiments depending on fertilizer application

Site	Halle	Askow		Lauch-städt	Bonn
Experiment period (years)	80	50	50	52	52
Clay (%)	13	4	9	26	17
pH (KCl)	6,4	5,9	7,2	7,0	7,0
Stable manure (dt/ha/Jahr) if applied	120	95	95	100	108
C-content (%):					
- Non fertilized	1,14	0,79	1,30	1,49	1,12
- PK-fertilizer	-	-	-	1,48	-
- NPK-fertilizer	1,26	0,96	1,43	1,61	1,18
- Stall manure	1,69	1,09	1,52	1,77	1,21
- NPK + manure	-	-	-	1,86	1,29

Processes of Transformation

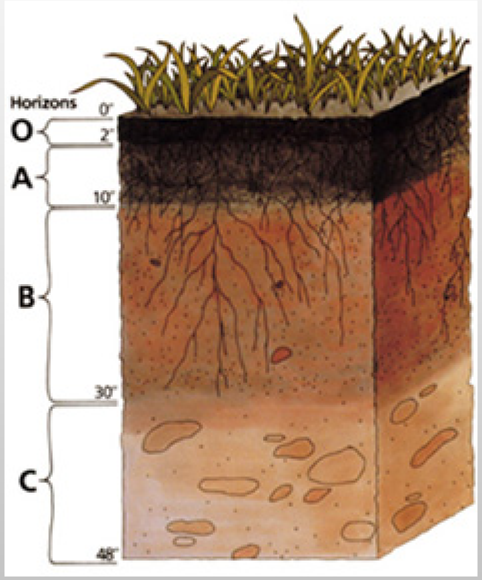
1. **Decay**

- Biochemical initial phase
- Mechanical decomposition
- Microbial decay

2. **Humification** – production of humins

Humins:

- persistent decomposable
- dark coloured
- influence physical and chemical properties of soils



Phases of decomposition

Biochemical initial phase

In the first phase internal substances decompose the newly died organic material produced

Mechanical disintegration

In the second phase the macro- and mesofauna disintegrates and consumes the dead organic material und incorporates it into the soil

Microbial decay

In the third phase microorganisms decay the „preconditioned“ material eventually up to the basic components

Microbial Decay

Microbial decay is in fact biotic oxidation (respiration)
In several interstages the decomposition of $C0_2$ und H-containing organic substances into $C0_2$ und H_20 with the generation of energy for the build-up of the microorganism

At the same time plant nutrients are produced:

Nitrogen as NH_3 (can be nitrified into nitrate), P as Phosphate, S as sulfide and sulfate, K, Ca, Mg and trace elements as free or fixed ions (e.g. Mg^{2+}).

The production of organically bound elements and the transformation into inorganic compounds is called **mineralisation**

Decomposition intensity

The decomposition intensity depends on site factors (temperature, water) as well as on the type and amount of the organic material

Easily decomposable are sugars and starch; followed by proteins and pectines as well as celllulose.

Difficult decomposable are lignines, resins, waxes, tannins.

Stability of organic materials:

Leguminosen < Grasses, herbs< decideous litter < coniferous litter < dwarf shrubs (e.g. heather).

The following factors determine decomposition:
- the amount of difficult decomposable material (e.g. lignine)
- the amount of resins and waxes
- the base content: (decideous litter = calcium richer as coniferous litter)

Environmental conditions influencing the decay of organic matter on and in soils

- Type and amount of the organic matter
- Temperature
- Water
- Aeration
- pH
- anthropogenic influences like litter use

Humification

For the production of humins there exist two ways:

Transformation of plant parts that already have a cyclic base structure (especially lignine, also some proteins, pigments and waxes);

Production from decomposition products of linear carbohydrates and proteins with cyclisation and polymerisation.

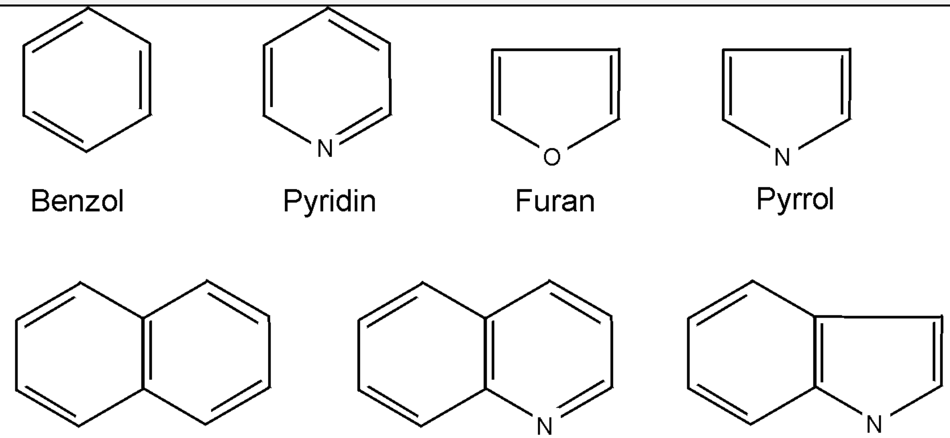
The formation process can take place by:

Chemical reaction between components

Biotic formation in the process of metabolism and autolyse (digestive tract of soil anmimals).

The most important structural components of humins

Kerne (K)



Benzol, Pyridin, Furan, Pyrrol

Naphtalin, Chinolin, Indol

Brücken (B)	-O-	-NH-	-N=	$-CH_2-$	=C-C=
Seitengruppen (R):	-COOH Carboxyl-	-OH Hydroxyl-	$-OCH_3$ Methoxyl-	=C=O Carbonyl-	$-NH_2$ Amino-Gruppe

Characteristics of humins

	Huminstoffe		
	Fulvosäuren Fulvate	**Huminsäuren** Humate	**Humine**
		Sphärokolloide	
Polymerisationsgrad	niedrig →	→	→ hoch
Farbe	gelb- bis rotbraun	braun bis schwarz	schwarz
C (%)	45 →	→	→ >60
N (%)	0,5 – 2 →	→ 3 – 8	n.b.
Säurecharakter	stark ←	←	← schwach
Wasserhalte- und Adsorptionsvermögen	gering →	→ hoch ←	← gering
Mobilität im Boden	stark ←	←	← schwach
Entstehung	vorw. chemisch	vorw. biotisch	durch Alterung von Fulvaten u. Humaten
Vorkommen	vorw. in sauren, nährstoffarmen Böden mit geringer biotischer Aktivität	vorw. in schwach sauren bis neutralen, nährstoffreichen Böden mit hoher biotischer Aktivität	in allen Böden