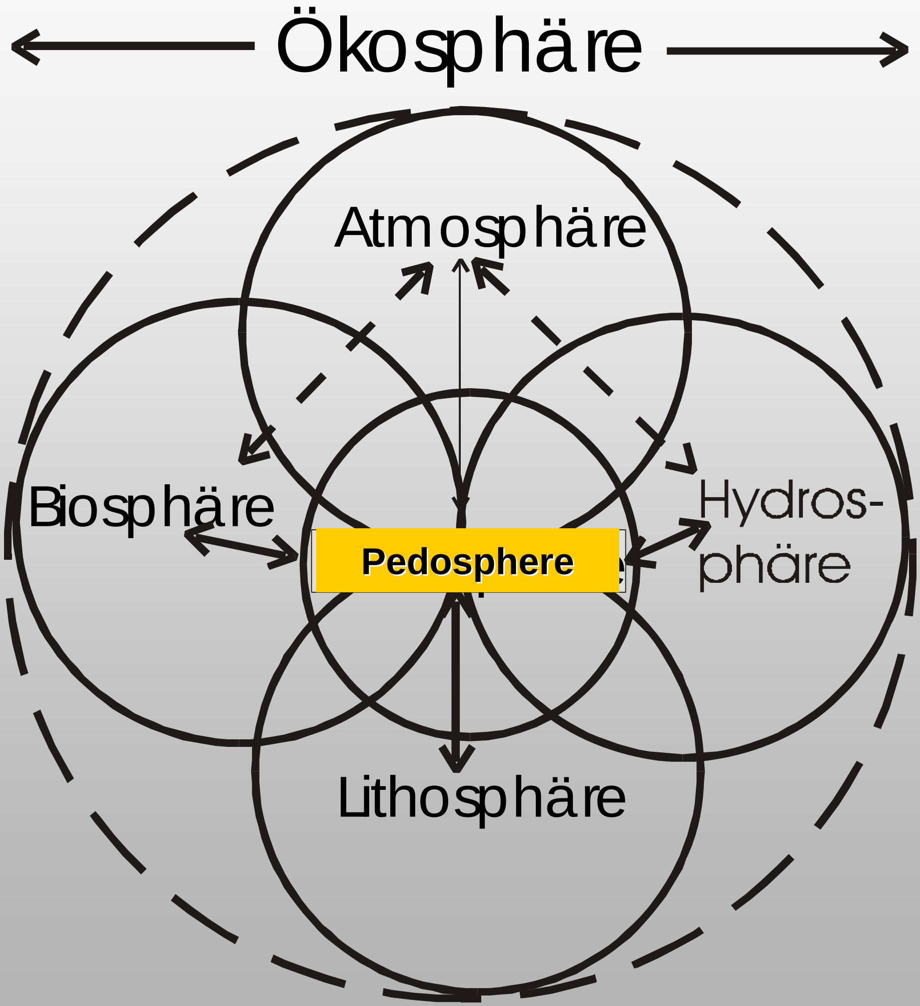
What is Soil
and how did it get there where it is?

Critical Zone: Pedosphere



Functions of soils

1. natural functions

a) as a basis for life and a habitat for people, animals, plants and soil organisms,

b) as part of natural systems, especially by means of its water and nutrient cycles,

c) as a medium for decomposition, balance and restoration as a result of its filtering, buffering and substance-converting properties, and especially groundwater protection,

2. functions as an archive of natural and cultural history and

3. functions useful to man as

a) a medium that holds deposits of raw materials,

b) land for settlement and recreation,

c) land for agricultural and silvicultural use,

d) land for other economic and public uses, for transport, and for supply, provision and disposal.

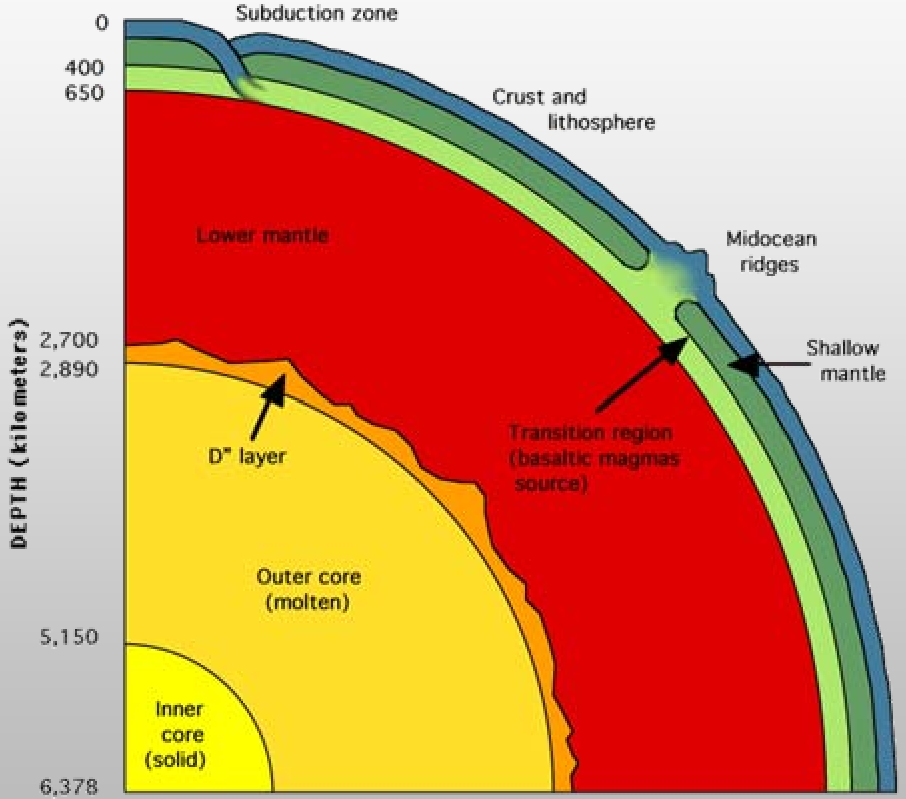
Main threats to soils in Germany

- erosion by wind and water
- decline of SOM and biodiversity
- contamination incl. acidification
- landslides/floods
- soil sealing
- compaction

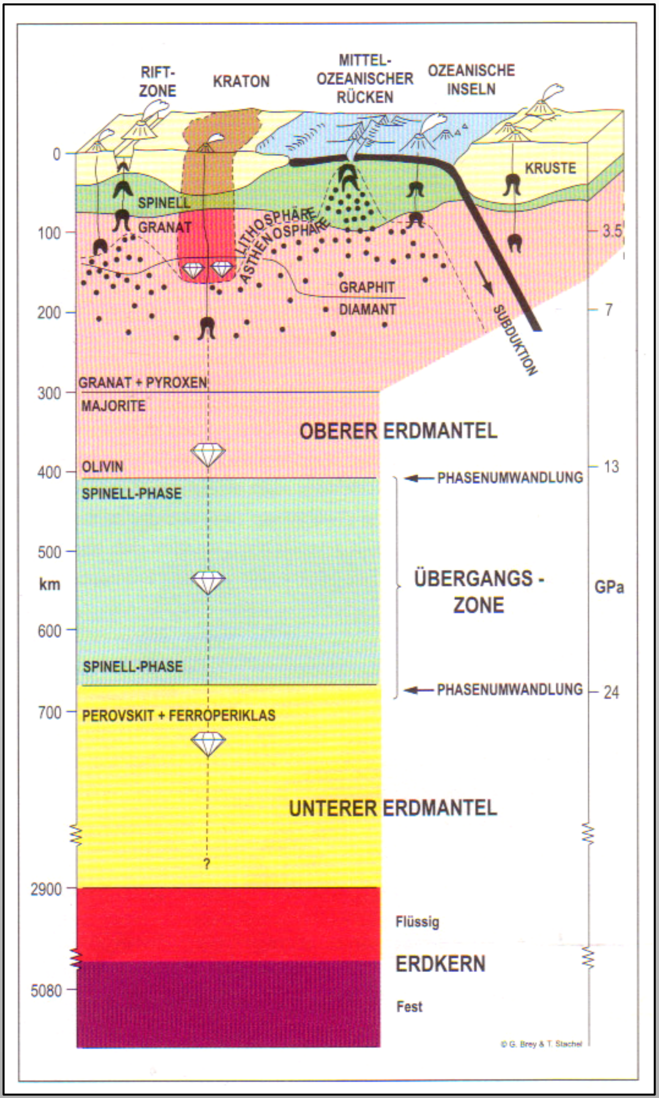
Worldwide:

- Salinisation
- Desertification
- Soil erosion

The earth: structure and composition

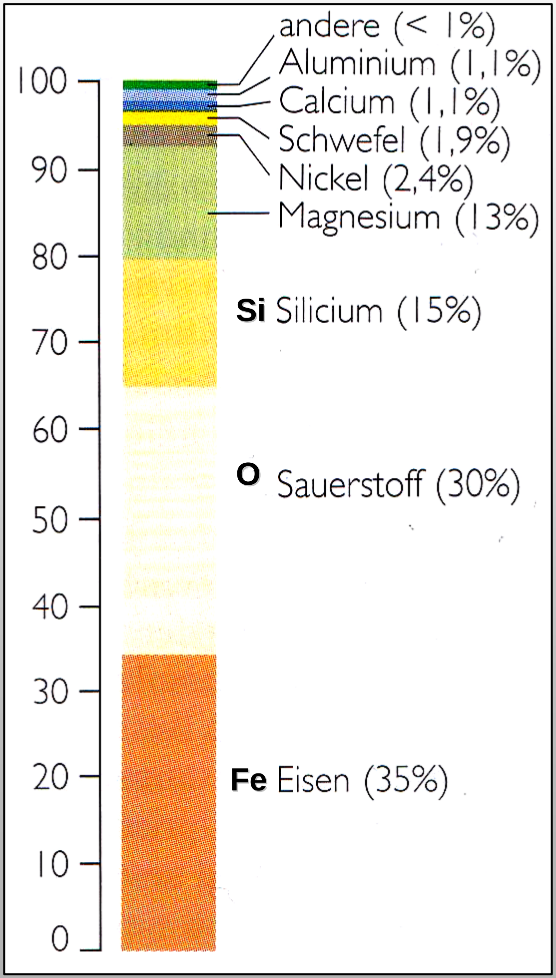


Layered structure of the earth

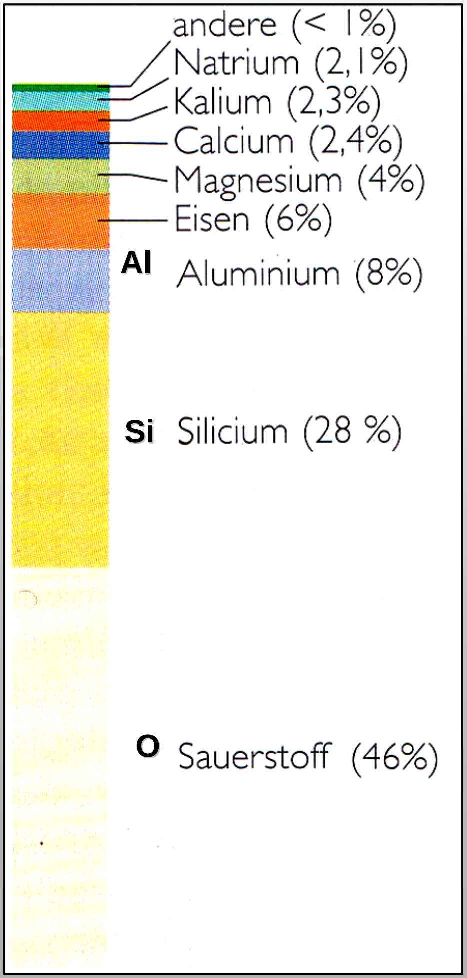


Composition of the earth and the earth mantle

Earth



Earth mantle



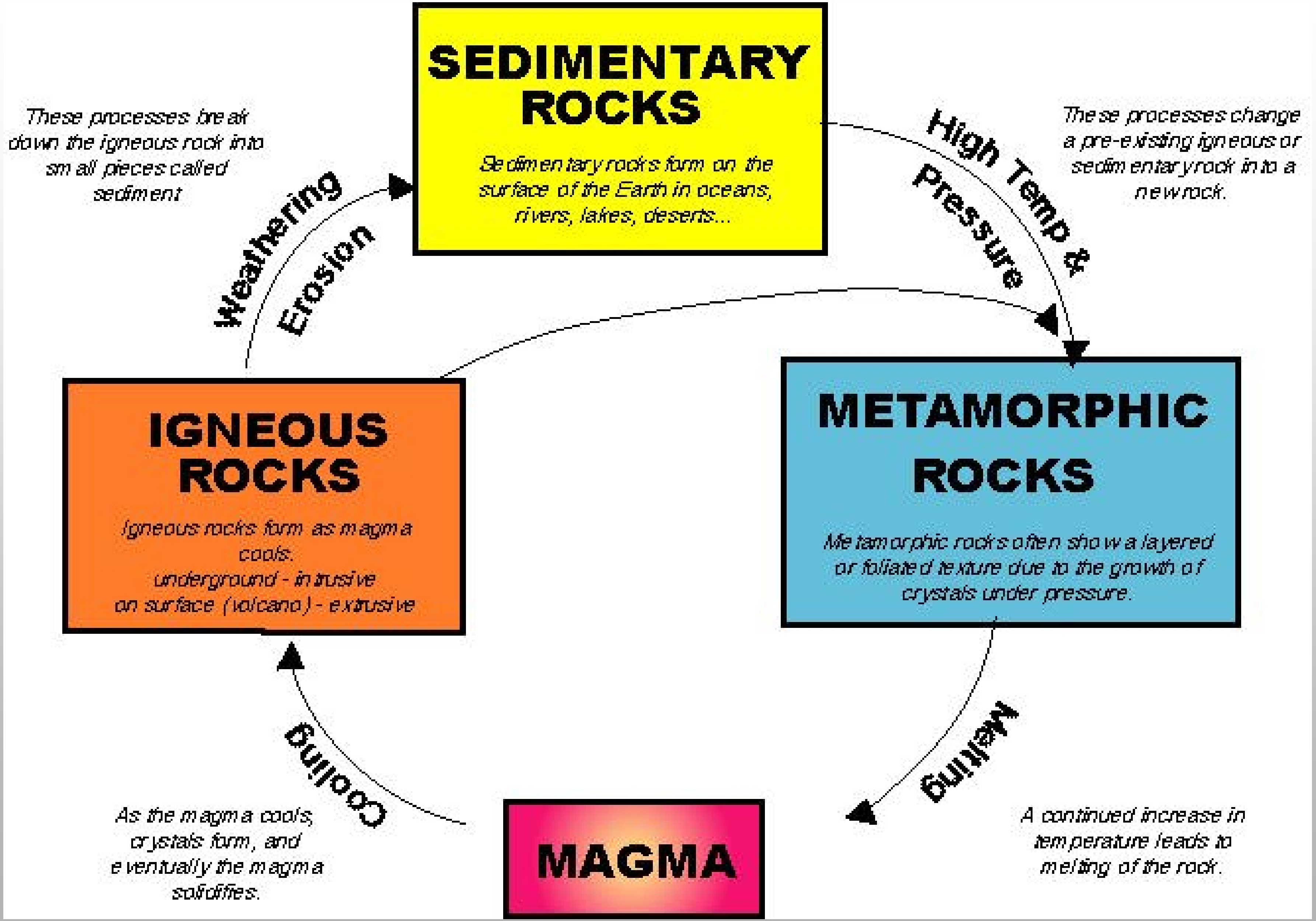
The main rock types

The classification of rocks depends on:

- formation
- mineral composition
- chemical composition
- structure

Main types

- **Igneous Rocks:** Igneous rocks are crystalline solids which form directly from the cooling of magma.
- **Sedimentary rocks:** rock which is made as layers of this debris compacted and cemented together
- **Metamorphic Rocks:** Any rock can become a metamorphic rock. All that is required is for the rock to be moved into an environment in which the minerals which make up the rock become unstable and out of equilibrium with the new environmental conditions.



Sedimentary rocks form on the surface of the Earth in oceans, rivers, lakes, deserts...

Igneous rocks form as magma cools.
underground - intrusive
on surface (volcano) - extrusive

Metamorphic rocks often show a layered or foliated texture due to the growth of crystals under pressure.

These processes break down the igneous rock into small pieces called sediment

These processes change a pre-existing igneous or sedimentary rock into a new rock.

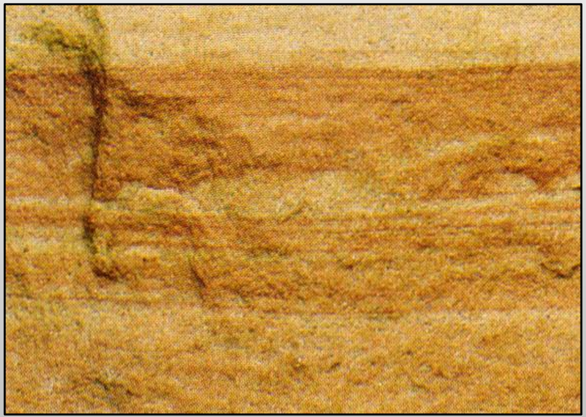
A continued increase in temperature leads to melting of the rock.

As the magma cools, crystals form, and eventually the magma solidifies.

Basic rock types

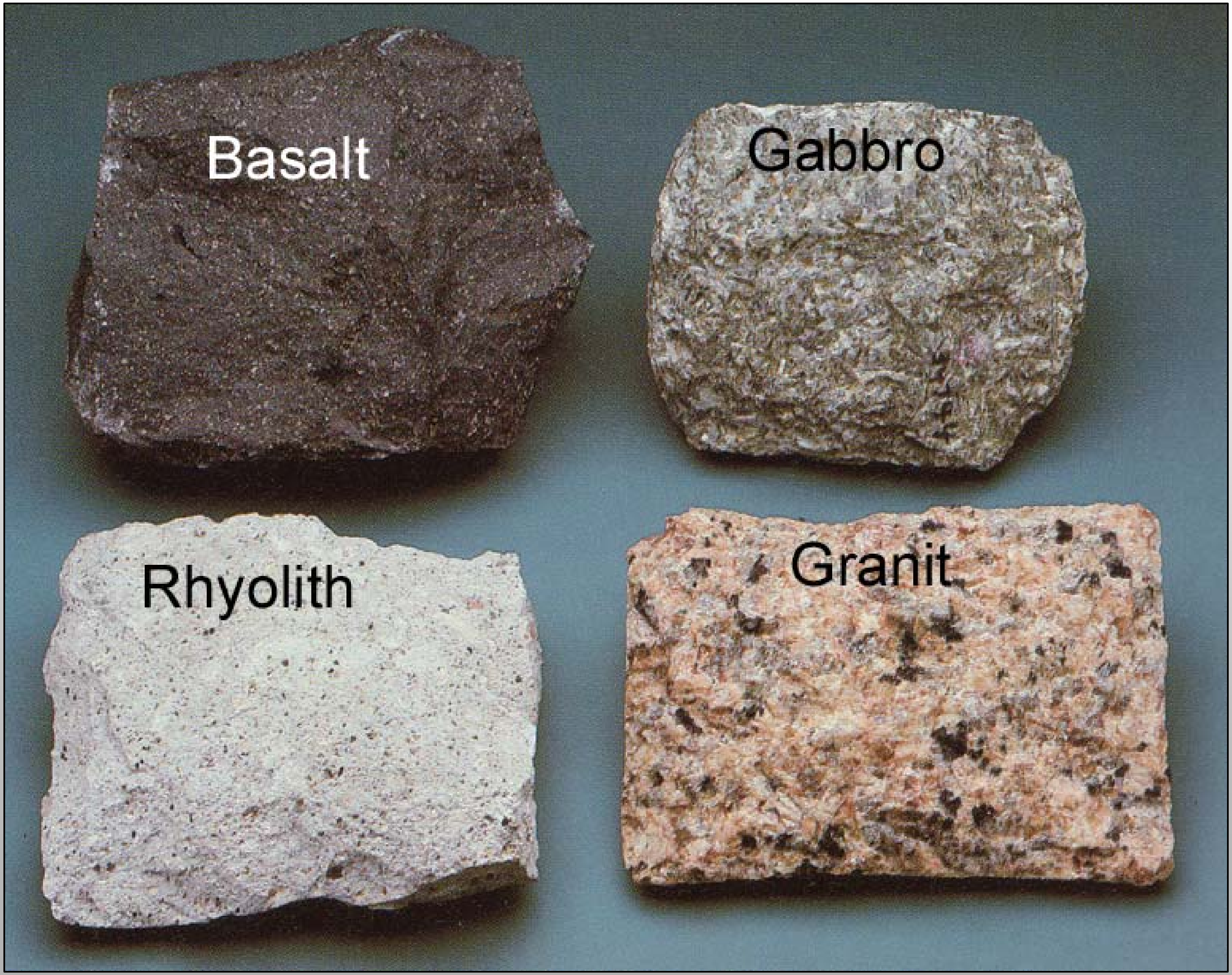
Igneous Rocks

Sedimentary rocks



Metamorphic Rocks

Igneous Rocks



mean chemical composition of important Igneous Rocks

	Oxide in Gew. %								
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O
Granit	70	0,4	15	1,5	1,8	1,0	2,0	3,5	4,0
Syenit	60	0,7	16	3,0	3,3	2,5	4,3	4,0	4,5
Diorit	57	0,8	17	3,2	4,4	4,2	6,7	3,5	2,0
Gabbro	48	1,0	18	3,2	6,0	7,5	11,0	2,5	1,0
Peridotit	41	-	2	3,0	5,5	46,0	0,7	-	-

Sedimentary rocks

Can be classified into:

- clastic sediments: fragments of rock and minerals that are transported and drop out in the process of sedimentation e.g. sandstone, siltstone, claystone

- chemical sediments: material dissolved in water chemically precipitates from the water e.g. halite, gypsum

- biogenic sediments: living organism extract ions dissolved in water and make shells and bones and eventually sedimentation follows, e.g. limestone

- (organogenic sediments: sedimentation of plant material like in marschlands)

Chemical composition of sediments (%-weight)

Sediment	Sand	Loess	Schists	Boulder Clay	Sand stone	Gray-wacke	Carbonatic rock
SiO_2	96,8	72,8	58,9	64,2	70	66,7	8,2
Al_2O_3	1,3	8,6	16,7	6,3	8,2	13,5	2,2
Fe_2O_3	0,2	2,4	2,8	-	2,5	1,6	1,0
FeO	-	-	3,7	3,2	1,5	3,5	0,68
MgO	0,1	n.b.	2,6	1,0	0,06	2,1	7,7
CaO	0,1	5,1	2,2	9,7	4,3	2,5	40,5
Na_2O	n.b.	n.b.	1,6	0,7	0,58	2,9	n.b.
K_2O	1,1	2,6	3,6	2,1	2,1	2,0	n.b.
CO_2	-	3,4	1,3	7,7	3,9	1,2	35,5
Org. Subst. and H_2O	0,5	1,3	8,0	2,4	1,7	2,3	0,4

Limestone
CaCO3
dolomite
CaMg(CO3)2

Metamorphic rocks

are generated from igneous or sedimentary rocks for instance if due to tectonics the earth mantle sinks into greater depth

Example

Dolomite

Marble

Further exemples

Granite

Ortho gneis

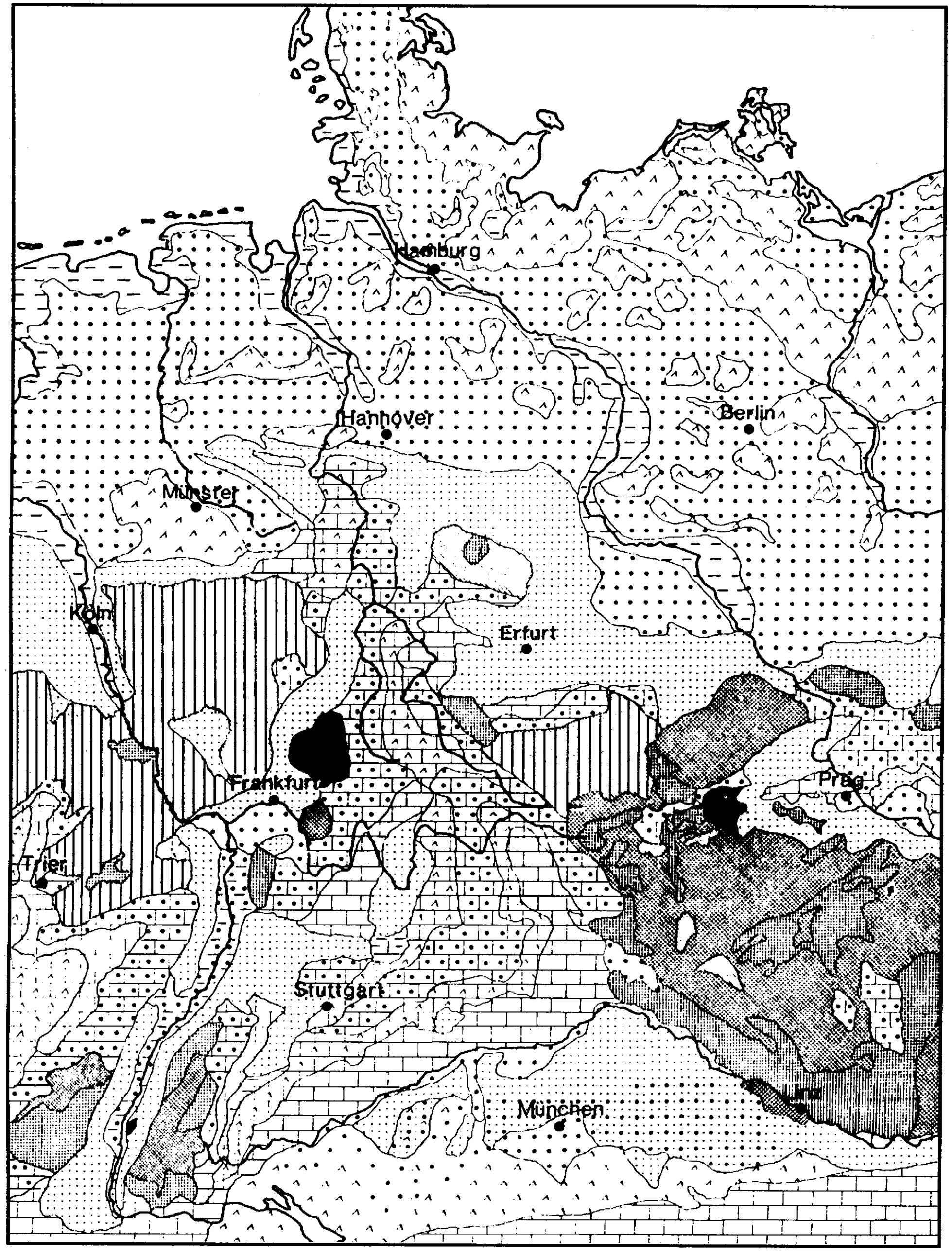
Gabbro

Gray shale

Sandstone

Quartzite

Parent material for soil formation in Middle Europe



Sediments

Unconsolidated		Consolidated	
Clay	– –	Shale clay	▤
Sand+ gravel	⁙	Sandstone	▦
Glacial till	^ ^	Chalk- + claystone	▥
Loess	⋯	Limestone	▭

Igneous Rocks		Metamorphic Rocks	
Granit u. ä.	▒	Gneis u. ä.	▒
Basalt u. ä.	■	Schichts a.o.	|||||

Endogenic and exogenic Processes

Endogenic Processes :

refers to internal processes and phenomena that occur beneath the Earth's surface :

- Volcanoes
- Earthquakes
- Plate tectonics

Exogenic Processes:

refers to external processes and phenomena that occur on or above the Earth's surface, e.g. :

- Weathering
- Erosion
- Transport and sedimentation

Weathering

- Weathering causes disintegration and solution of rocks
- It is the basis for soil building displacement processes.
- The velocity depends on the most stable mineral in the rock

Weathering stability of minerals depends on :

- Structure
- Ratio of stabile Si-O-bonds to instabile Na-O-, K-O-, Mg-O-, Ca-O-bonds
- Amount of oxidizable S^o, S^{2+}, Fe^{2+}, Mn^{2+}

There are different types of weathering that break rocks apart:

- By **chemical weathering,** the minerals in rocks are dissolved into rainwater or changed from one type of mineral into another. Chemical weathering happens quickly in warm, moist environments because water is needed for the chemical changes and warmth speeds up the process. Not all minerals are susceptible to chemical weathering. For instance, feldspar and quartz, the most common minerals in the igneous rock granite, have very different levels of resistance to chemical weathering. Quartz doesn’t weather very easily, but feldspar does. Over a long time, it chemically changes into clay minerals.

- By **physical weathering,** rocks are broken apart into smaller pieces. There are many ways that rocks are physically weathered. Water flowing in rivers and streams can break rock apart, as can ocean waves on a rocky coastline. Tree and plant roots often push rocks apart, especially when they grow in areas with little topsoil. If water freezes into cracks in a rock it will expand as it freezes, opening the crack even more. Large amounts of ice were responsible for physical weathering of rocks during the last Ice Age. They scraped the surface of vast areas of the land, removing bits of the rocks they moved across. Smaller glaciers continue this process in some areas of the Earth today.

- By **biological weathering**: Weathering is enhanced by plants and animals

Weathered rock fragments are either moved away by water or wind, or they become a part of the soil. Soil is formed as rocks are weathered at the surface and combined with plant and animal remains. There are many different types of soil depending on rock weathering and the amount of plants and animals in the environment.

Stability and weathering

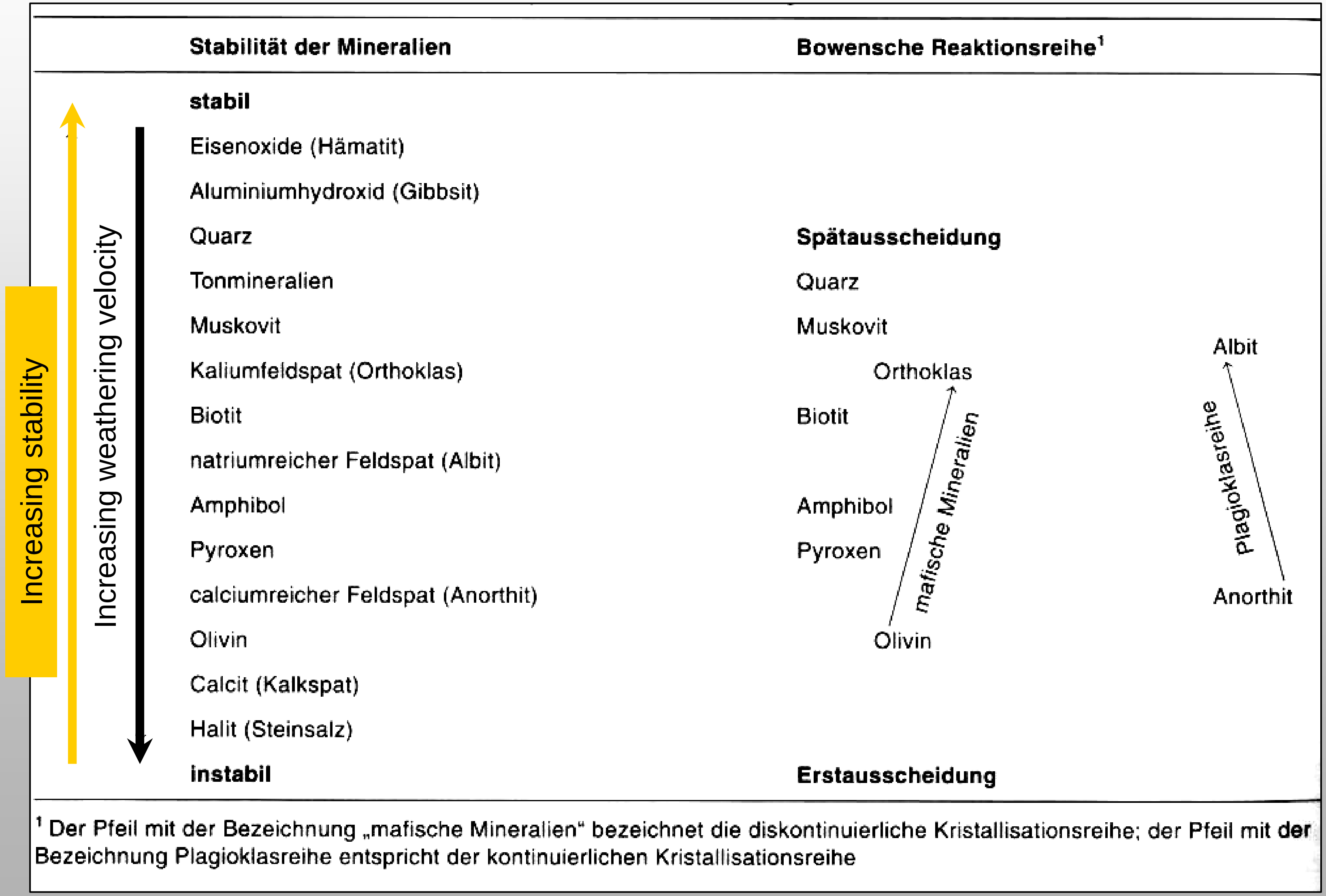
Stability of rocks depends on:

- the type of rock (compacted/loose)
- the mineral composition
- the structure
- the joints
- the layering
- the schistosity
- the type of cementation material

Weathering index

$$\text{Quarz/Feldspar-Index} = \frac{\text{Sum of Quarz in weight-\%}}{\text{Sum of Feldspar in weight-\% \%}}$$

Stability of minerals



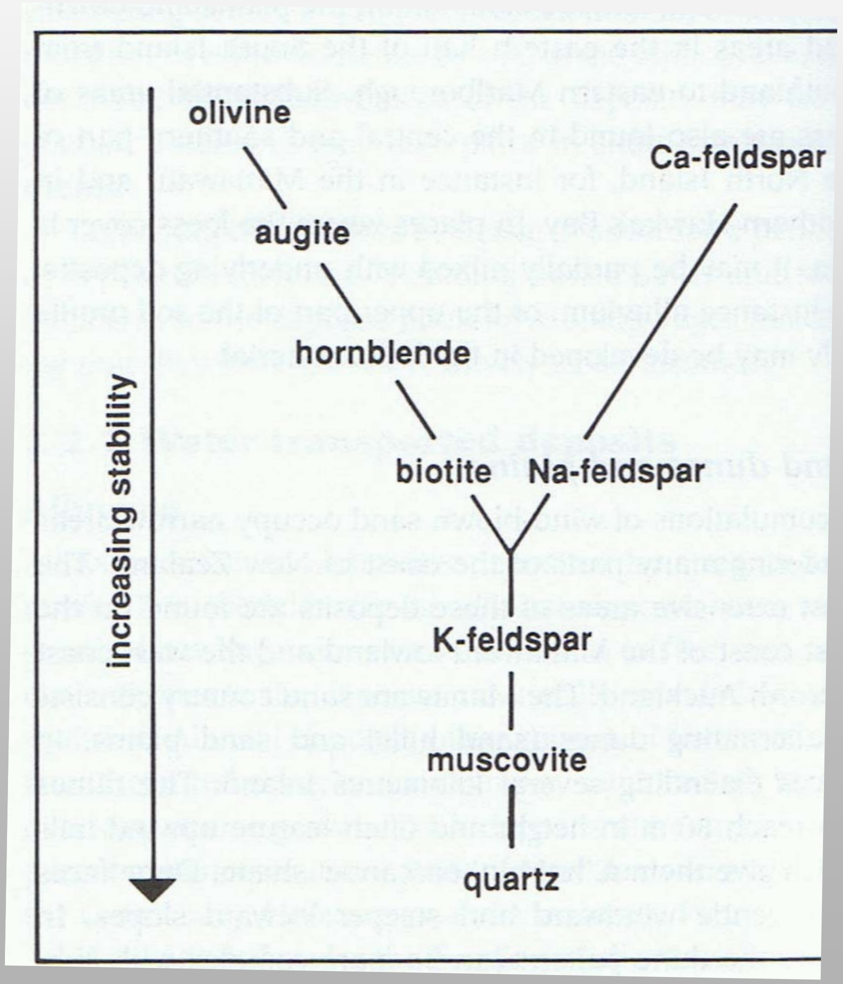
Stabilität der Mineralien	Bowensche Reaktionsreihe[1]
stabil	
Eisenoxide (Hämatit)	
Aluminiumhydroxid (Gibbsit)	
Quarz	**Spätausscheidung**
Tonmineralien	Quarz
Muskovit	Muskovit
Kaliumfeldspat (Orthoklas)	Albit Orthoklas
Biotit	Biotit
natriumreicher Feldspat (Albit)	
Amphibol	Amphibol
Pyroxen	Pyroxen
calciumreicher Feldspat (Anorthit)	Anorthit
Olivin	Olivin
Calcit (Kalkspat)	
Halit (Steinsalz)	
instabil	**Erstausscheidung**

[1] Der Pfeil mit der Bezeichnung „mafische Mineralien“ bezeichnet die diskontinuierliche Kristallisationsreihe; der Pfeil mit der Bezeichnung Plagioklasreihe entspricht der kontinuierlichen Kristallisationsreihe

inverse Bowen's reaction series; more shared Si-O bonds means more resistance to weathering

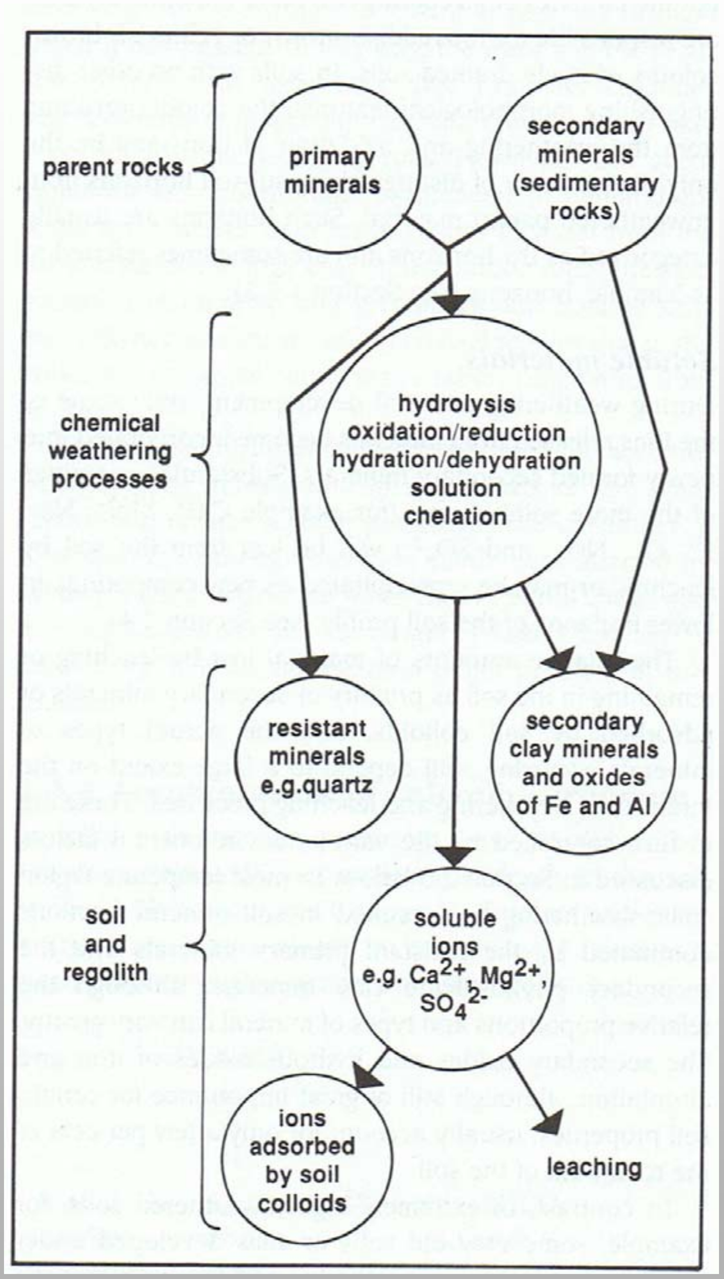
geological and mineralogical basics

Stability of minerals to dissolution and weathering



(Mclaren & Cameron, 1996)

Pathways and products of weathering



geological and mineralogical basics

Biotite Mica
insulation, electronics, filler in plasterboard, cement, paint
peels in thin sheets

Muscovite Mica
insulation, electronics, filler in plasterboard, cement, paint
peels in thin sheets

Calcite
the matrix in cement ($CaCO_3$), optical equipment – double image (#3 on Moh's scale of hardness)

Quartz
glass, crystal, radios, watches, computers, electronics, optical equipment, jewelry (onyx, agate, & amethyst) – hexagonal crystals (#7 on Moh's scale), common in igneous rocks

Sulfur
matches, fireworks, medicine (sulfa drugs), sulfuric acid, vulcanization of rubber – yellow color, flammable, smells acrid

Graphite
pencil "lead", dry lubricant, batteries – (hardness of #2)

Gypsum
drywall, plaster of Paris (#2 on Moh's scale)

Plagioclase Feldspar
abrasives, filler in paint and plastics – most common minerals in igneous rocks

Orthoclase Feldspar
abrasives, filler in paint and plastics – most common minerals in igneous rocks

Hematite
iron ore, cabochon jewelry (when polished)

Halite
table salt, manufacture of soap, paper, petroleum & glass – tastes salty

Galena
lead ore for pipes, x-ray shielding, fishing weights
very dense

geological and mineralogical basics

Magnetite
iron ore – magnetic

Talc
talcum powder, paints, ceramics, paper coatings
softest mineral
(#1 on Moh's scale)

Olivine
source of peridotite for jewelry – green color

Pyrite
sulfuric acid production
known as "fool's gold"

Limonite
iron ore, yellow pigment for paint – adds color to soil

Barite
barium ore for gastrointestinal x-rays, white pigment for paint

Dolomite
lime for neutralizing acidic soil, road aggregate, building stone

Bauxite
aluminum ore for soft drink cans, softball bats, alloy wheels, lawn furniture

Hornblende
common mineral in igneous rocks

Copper
coins, pipes, wire, cooking utensils, jewelry – ductile, malleable and conductive

Kaolinite
ceramics, china, pottery, filler in paper

Chalcedony
arrowheads, driveway gravel, ornamental stone, cabochon jewelry

physical weathering

Cause, transformation forces and impact/responce of physical weathering

Cause	Transformation forces	Impact/Responce
Removal of Overlaying rocks	Pressure reduction	Expansion und thus crack formation in solid rock
Temperature changes	Pressure increase or/and reduction	Strain in rocks causing fractures
ice formation	pressure increase (at - 22°C max. pressure of 2100 kg/cm^2)	Fragmentation by frost, widening of cracks and fissures
salt explosion	pressure increase	widening of cracks and fractures due to crystallization pressure
Water supply and water withdrawal	Shrinking and swelling	Mechanical strain on clay rich material
Flow gradient	movement forces	Abrasion and rounding of rock fragments

Specific surface of the particle fraction

The specific surface O is a function of the particle diameter and can be calculated with:

$$O\ [\ cm^2 / cm^3\ ] = \frac{60}{\text{Particle diameter [mm]}}$$

Particle fraction	**Mean diameter [mm]**	**aprox. specific surface [cm²/cm³]**	**Aprox. number of particles [pcs/l]**
Cobble	100	0,6	10^0
Coarse gravel	10	6	10^3
Coarse sand	1	60	10^6
Fine sand	0,1	600	10^9
Medium silt	0,01	6 000	10^{12}
Clay	0,001	60 000	10^{15}

Chemical Weathering

- **Chemical weathering leads to change of type of minerals or dissolution.**
- **Acting are : dissolving, oxidation, hydrolysis, acids.**
- **speeds up with increasing water availability, temperature and H^+- Ion-concentration as well as higher specific surface**

The main reaction components are: :

- **Water (H_2O)**
- **Oxygen (O_2)**
- **Carbon dioxid (CO_2)**
- **Hydrogen ions (H^+)**

Chemical Weathering

Dissolution weathering:

- acts with soluble salts (e.g. $NaCl$, $CaSO_4$, $CaSO_4 \times 2H_2O$)

- Due to the adsorption of water molecules on cations and anions of the crystal lattice ions are dissolved from the lattice; ions are extracted from crystal lattice and eventually the mineral falls apart

- these processes play an important role with the leaching of salts from sediments/rocks , with the desalinisation of salinized soils and the weathering of gypsum soils.

Chemical Weathering

Hydrolytic Weathering :

- Hydrolysis is one of the most common chemical weathering processes

- Hydrolysis involves the interaction and and replacement of structural cations with H^+ ions dissociated from H_2O. The exchange has a disrupting effect on the crystal surface because of the high charge to ion size ratio of H^+ and weakens the rigidity of the mineral structure

- Hydrolysis is the main mechanism of weathering of feldspars and other aluminosilicates.

Example: Potassium Feldspar (Orthoclase)

$$KAlSi_3O_8 + H_2O \leftrightarrow KOH + HAlSi_3O_8$$

Ongoing weathering produces:

$$HAlSi_3O_8 + 4\ H_2O \leftrightarrow Al(O_4)_3 + 3H_2SiO_3$$

Chemical Weathering

Acid impact (*H*$^+$-Ions):

Acid solutions work much more intense as hydrolysis in pure water.
H^+-Ions (Protons) originate mainly from the weak acid carbonic acid. Carbonic acid action involves combination of carbon dioxide and water. Though present in pure water, carbon dioxide dissolved in water provides ions that produces free hydrogen. Carbon dioxide in the atmosphere combines with rain water to form carbonic acid (H_2CO_3):

$$CO_2 + H_2O \ = \ H_2CO_3 \ \rightarrow \ H^+ + HCO^-_3$$

H^+-Ions can also come from organic acids.

Example of the H^+- impact on Calciumcarbonate $CaCO_3$:

$$CaCO_3 + H_2CO_3 \ = \ Ca(HCO_3)_2 \rightarrow Ca^{+2} + 2HCO_3^-$$

Chemical Weathering

Oxidation:

Oxidation takes place when oxygen reacts with earth materials. Oxygen dissolved in water combines with atoms of metallic elements abundant in silicate minerals. Attacking metals in the soil (Fe^{II}, S^{II} Mn^{II}) , oxidation causes them to rust leaving the soil a brownish red to red color. When oxygen combines with iron, the reddish iron oxide hematite (Fe_2O_3) is formed:

The intensity of the colouring is a rough index of the degree of weathering

Example: Oxidation of Augite (combined with Hydrolysis und H^+- impact):

$$4\ CaFeSi_2O_6 + O_2 + 4\ H_2CO_3 + 6\ HOH \rightarrow 4\ CaCO_3 + 4\ FeOOH + 8\ H_2SiO_3$$

Example: Oxidation of Pyrit (FeS_2) with the production of a strong inorganic acid:

$$4\ FeS_2 + 15\ O_2 + 10\ HOH \rightarrow 4\ FeOOH + 8\ H_2SO_4$$

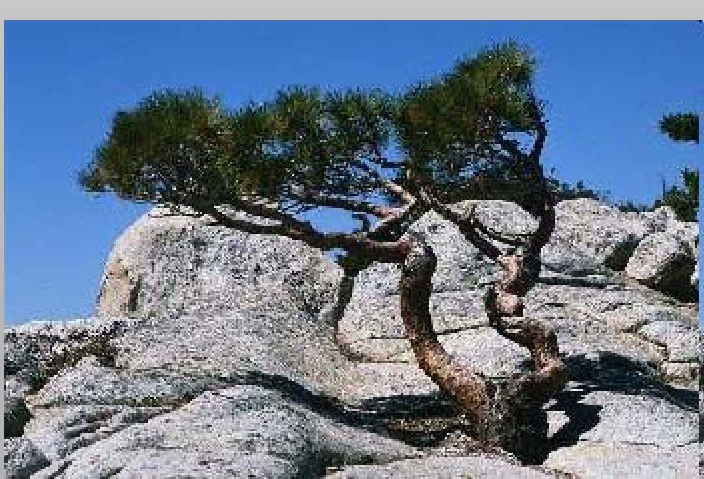
Biological Weathering

Weathering is enhanced by plants and animals

Resulting in:

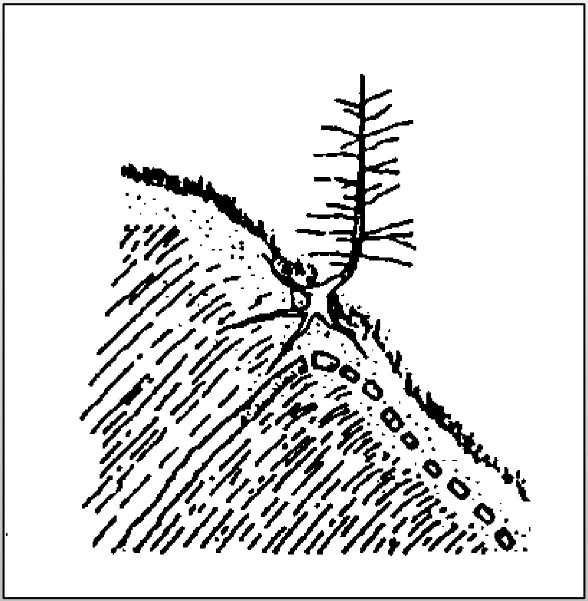
- **CO_2-increase in soil due to root respiration and microbial decay**
- **Increase of mineral surfaces: micro fracking of minerals by microorganism ; Polysaccharide production by bacteria and funghi, root growth**
- **Enhancement of chemical weathering: active acid production by roots, bacteria and lichen**

Biological weathering processes are in principle mainly similar to chemical weathering processes



Erosion, Transport and Sedimentation

Impact of gravity



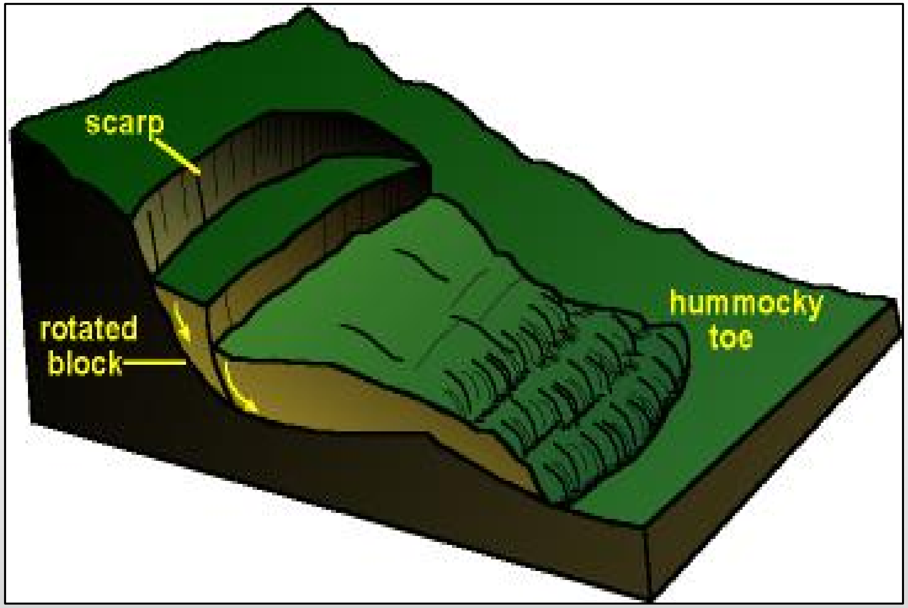
Soil creeping:

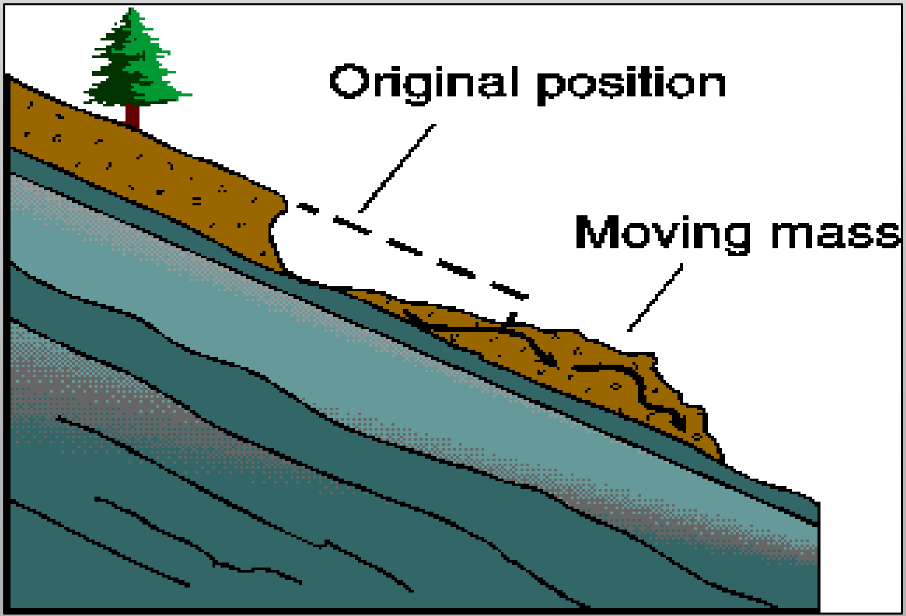
The slow, steady downhill movement of soil and loose rock on a slope. Also known as surficial creep

Solifluction:

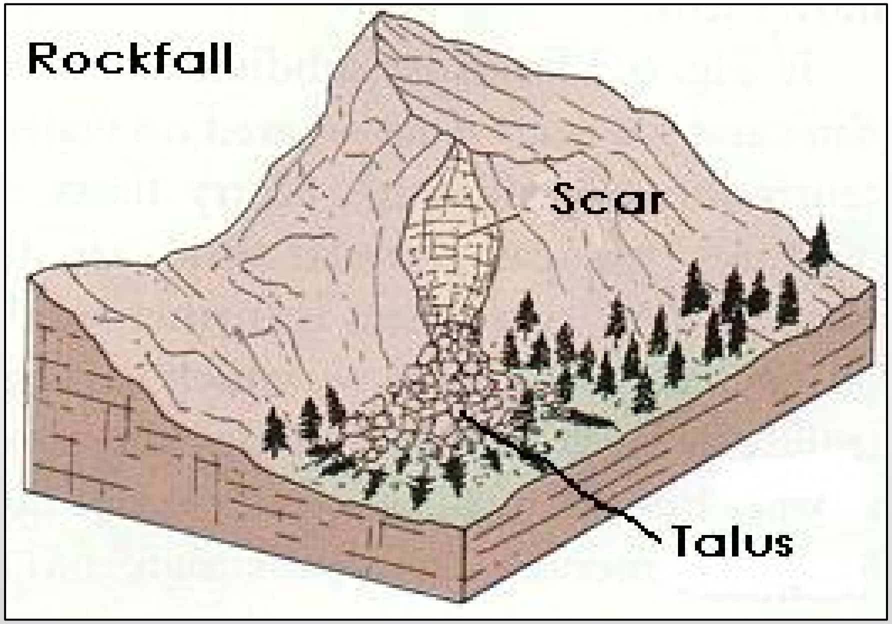
the slow downslope movement of water saturated debris in periglacial regions or areas with cold climates

Landslide (slump)





Rockfall



The effect of surface runnoff

Runnoff develops due to:

Water saturation of the soil, especially due to sealing of the top soil caused by loss of structure

↓

Infiltration rate of the soil less than the rainfall rate

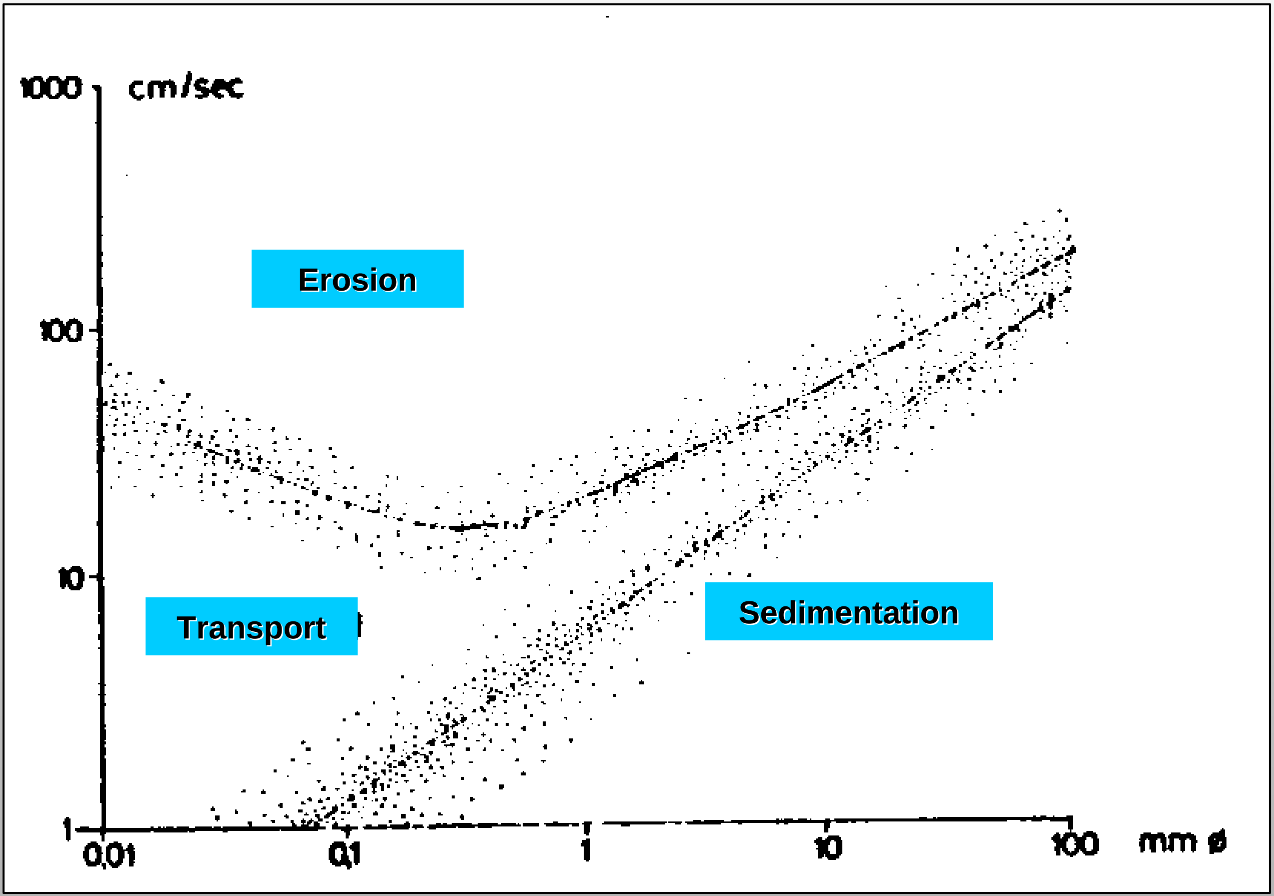
↓

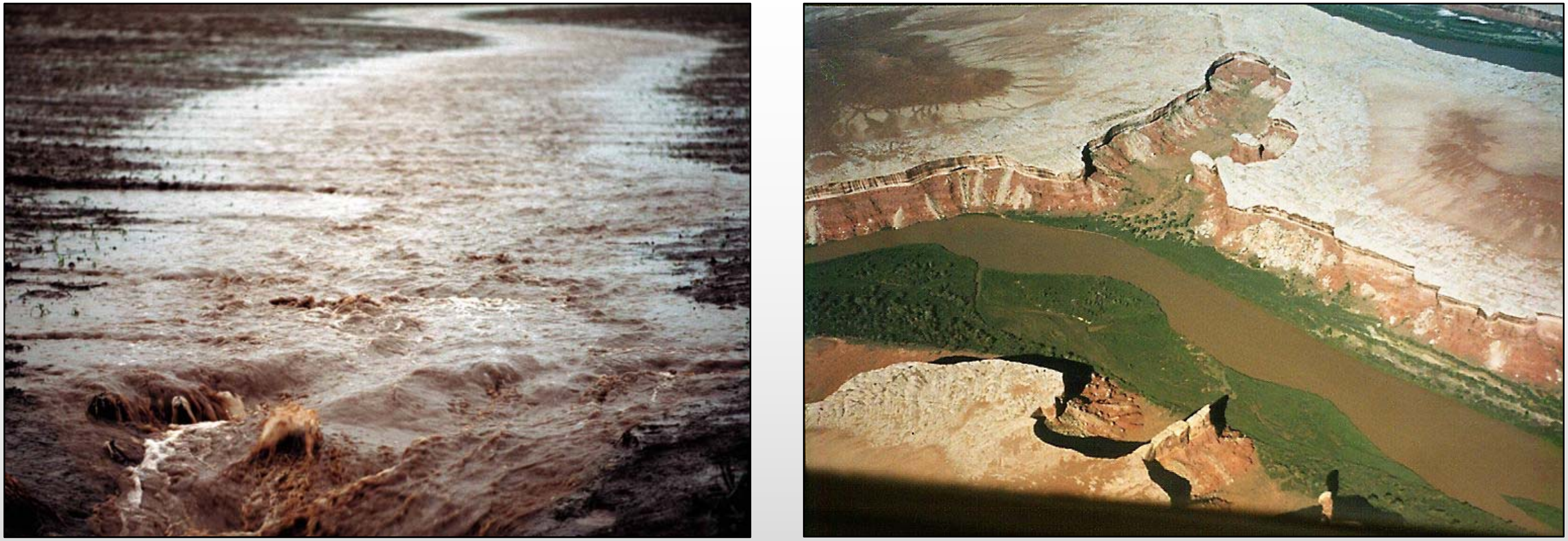
Flowing water can erode, transport and sedimentate soil material

The impact of surface runoff depends upon the following factors:

- Surface relief
- Cohesion and particle size distribution of the soil
- Flow velocity
- Size of the catchment area
- type and density of the vegetation (soil use and soil preparation)

Flow velocity of the water and its transport capacity depending on particle sizes





Water erosion

Impact of Wind

Next to water an important factor for exogene transport and deposition processes

depends on

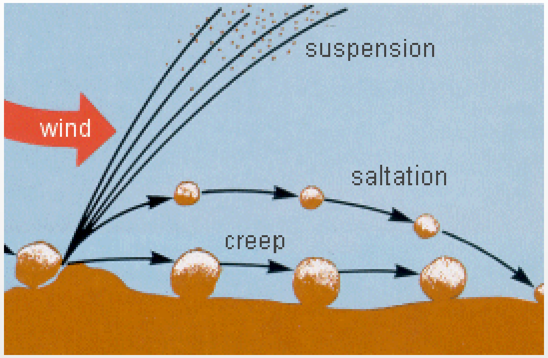
Erosion → Turbulence and windspeed and the actual soil condition

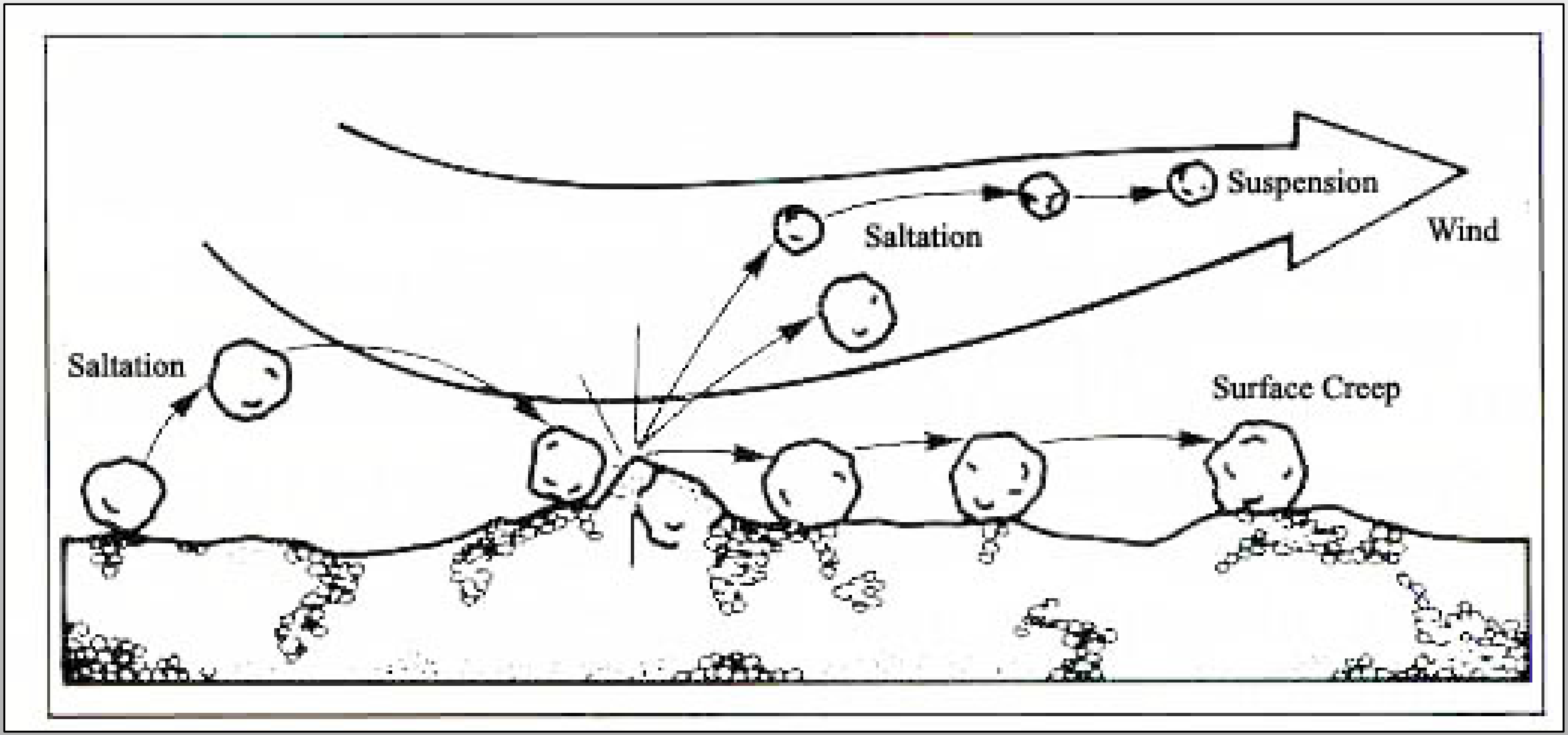
starts → with loose dry sediment particles at the soil surface without vegetation cover

Wind turbulence → Picks up the particles from the soil surface

Wind speed → Determines the type of movement: rolling, jumping or flying

Creep, Saltation, Suspension





Wind speed and moving soil particles

Wind speed after Beaufort			Moved material	
scale	**Wind type**	**m/sec**	**Diameter /mm**	**Particle size**
0	Light air	bis 0,3	0,002 - 0,063	silt (dust, loess)
1	Light air	- 1,5	- 0,1	Very fine sand
2-3	Light to gentle breeze	- 4	- 0,25	fine sand
3-4	Gentle to moderate breeze	- 7	- 0,63	Middle sand
6-7	Strong breeze, high wind	- 15	- 1,0	Coarse sand
8-9	Strong gale to storm	- 25	- 10,0	gravel

Wind erosion

Ice ages and glacial periods

The morphology of Northern Germany is strongly influenced by different ice ages and glacial periods

Ice age map of northern central Europe (from young to older):

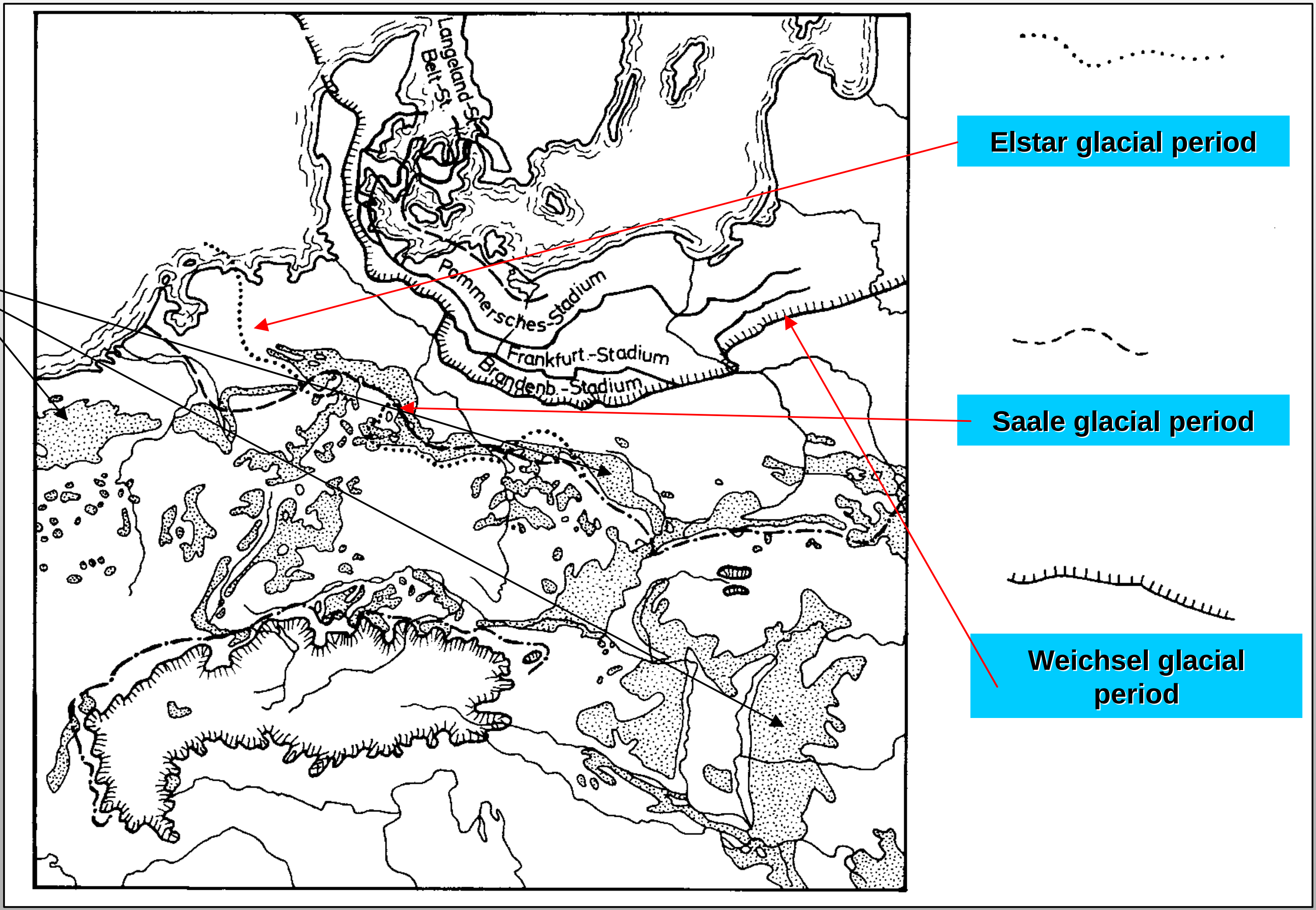
Red: maximum limit of Weichselian ice age;

Yellow: Saale ice age at maximum (Drenthe stage);

Blue: Elster ice age maximum glaciation.

Glacial ages

Ice boundaries and loess deposits (dotted) in Middle Europe



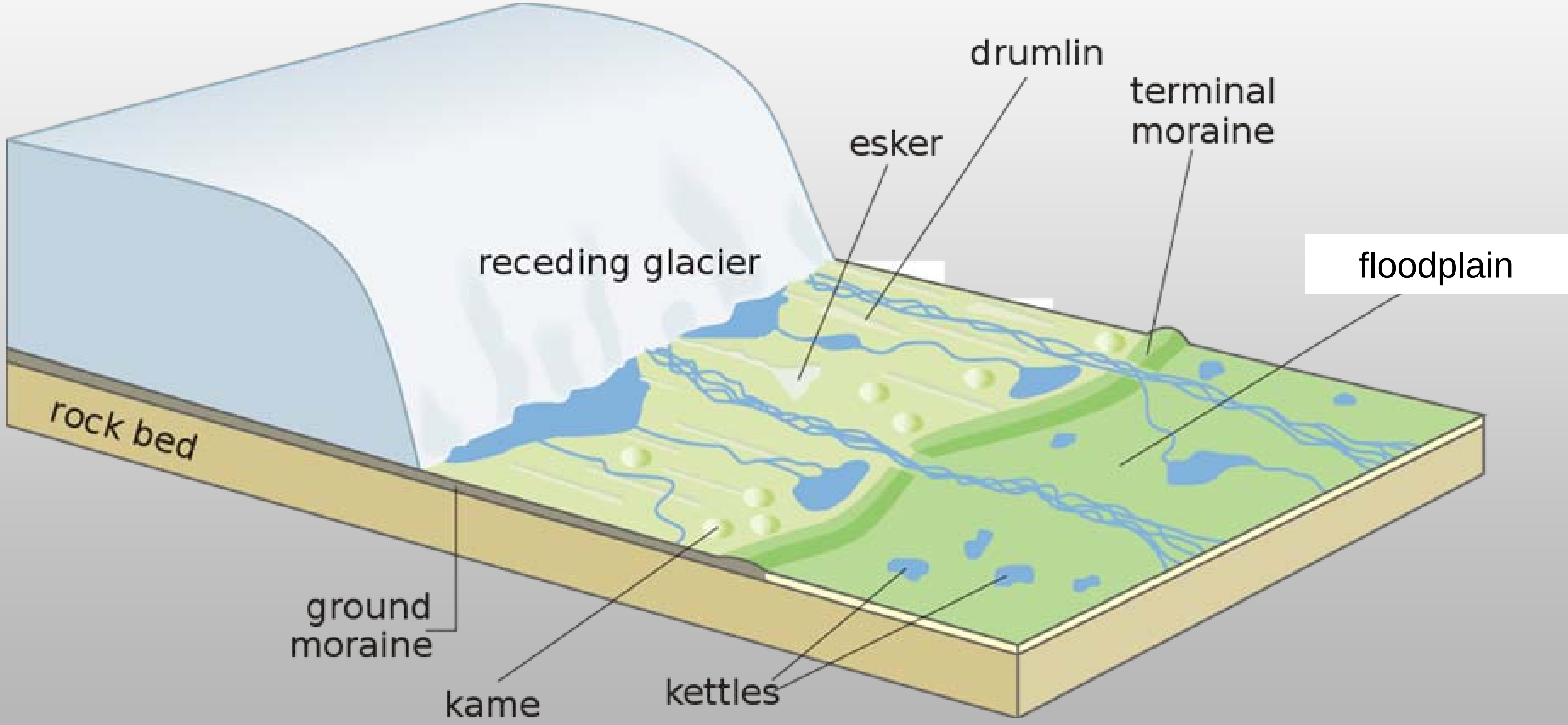
loess

Elstar glacial period

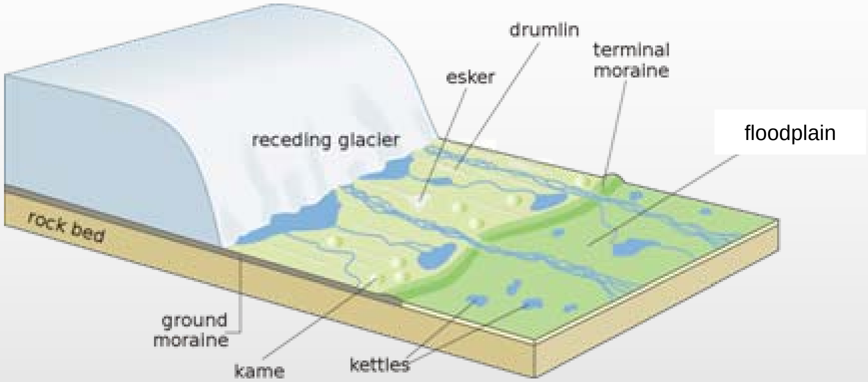
Saale glacial period

Weichsel glacial period

The formation of the lowlands by inland ice during ice ages



geological and mineralogical basics



A **drumlin** (derived from the Gaelic word druim (“rounded hill,” or “mound”) first recorded use in 1833) is an elongated whale-shaped hill formed by glacialaction. Its long axis is parallel with the movement of the ice, with the blunter end facing into the glacial movement. Drumlins may be more than 45 m (150 ft) high and more than 0.8 km (½ mile) long, and are often in drumlin fields of similarly shaped, sized and oriented hills. Drumlins usually have layers indicating that the material was repeatedly added to a core, which may be of rock or glacial till.

An **esker** is a long winding ridge of stratified sand and gravel, examples of which occur in glaciated and formerly glaciated regions of Europe and North America. Eskers are frequently several miles long and, because of their peculiar uniform shape, are somewhat like railroad embankments.

A **kettle** (kettle hole) is a shallow, sediment-filled body of water formed by retreating glaciers or draining floodwaters.

A **kame** is a geological feature, an irregularly shaped hill or mound composed of sand, gravel and till that accumulates in a depression on a retreating glacier, and is then deposited on the land surface with further melting of the glacier. Kames are often associated with kettles, and this is referred to as kame and kettle topography.

Ground moraine

End moraine landscape near Falkenberg

Drumlin

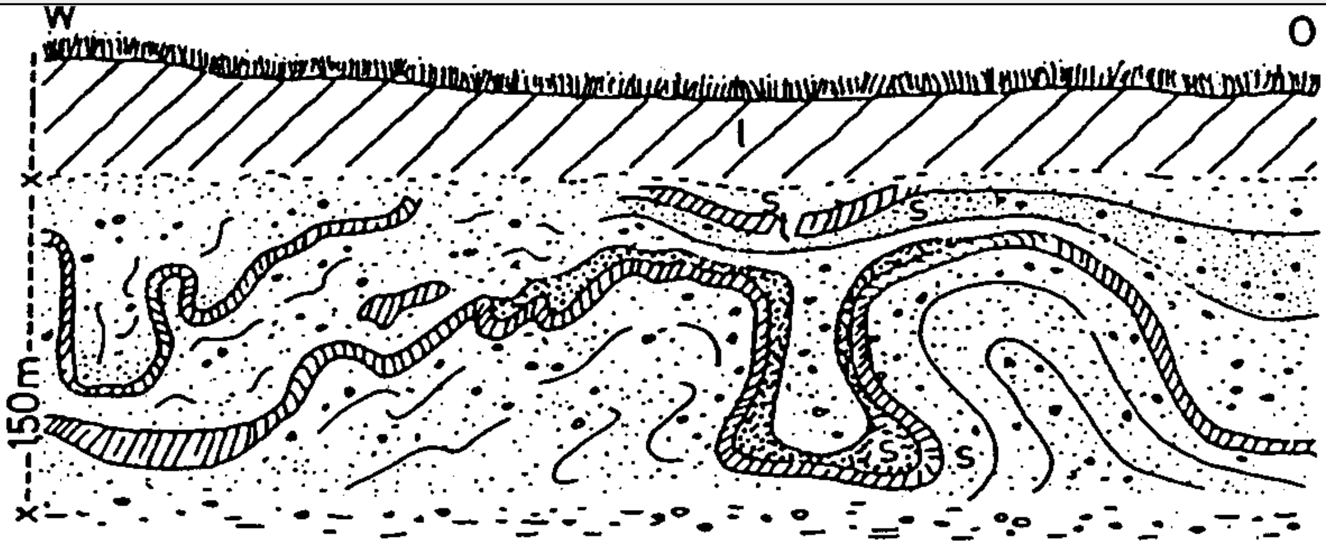
Dead ice hole

The soils of the glacial deposits

deposition	Surface shape	Soil texture	Stone content	landuse
young Groundmoraine	plane and soft undulating	Loamy sand upon sand upon boulder clay or glacial till	moderate (blocks)	wheat, oats, rye, sugar beets, alfalfa
Old ground moraine	plane	Low loamy sand over loam; sand upon sand; loam	moderate (blocks)	Oats, rye, winter barley, potatoes
Silty terminal moraine	kuppig	Depending on age similar as the ground morene of the same age. Due to the dome like surface shape more soil ersosion and thus more soil differences form		
Fluvio glacial sands, almost not transported	plane and soft undulating	Loamy silicat rich sand upon sand; often upon glacial till or boulder clay	low	Rye, oats, potatoes, seradella, lupine, partly also alfalfa, forest
Sandur	Plane and almost plane	Loamy sand over sand	often low	Forest, lupine, rye, potatoes
Oser, Kames, Eisrandterrasse, sandy terminal moraine	Undulating hilly or dome like	Poor loamy sand upon loamy sand upon sand, often gravelly	often low	Rye, potatoes, lupine, forest
Talsand mit tiefem Grundwasser	plain	Silicate poor sand	none	forest
Valley sand with high groundwater table	plain	Silicate poor sand but water in the profile	none	Rye, potaoes, oats, lupine, forest
Terminal moraine	Ridge and dome like	often sandy-gravelly often also loamy change over short distances	High (much blocks)	Strongly variable: depending on slope content and soil texture, but mainly forest

Cryoturbate deformation due to frost (Taschenboden)

In gravel deposits of the Rhine middle terrace near Neuß



Cryoturbation: (frost churning) refers to the mixing of materials from various horizons of the soil right down to the bedrock due to repeated freezing and thawing

- formation of ice lenses and wedges

Cryoturbation (Ungary)

Cryoturbation (Westsibiria)

Soil parent material as a basis for the development of soils - 1

Soils in the hill and mountain regions are often formed in regolith derived directly from the underlying bedrock (igneous rock) or in material moved relatively small distances downslope under the influence of gravity (colluvium).

Colluvium:
Colluvium refers to deposits that accumulate on and at the base of slopes as a result of movement by gravity. Such deposits result from a build-up of unconsolidated material which eventually becomes unstable and moves downslope.

Alluvium:
refers to sediments deposited by streams and rivers. The particle size of alluvial deposits can vary greatly from large stones and boulders to fine silts and clays. Stones in the deposits are usually rounded or subrounded. Alluvial deposits often consist of layers. of different textured material, for example, sand and silt layers overlying coarse gravels. Also glacial meltwater deposits are alluvium: fluvio-glacial deposits.

Soil parent material as a basis for the development of soils 2

Ice transported material:
Glacial till:
refers to compacted deposits of poorly sorted material, consisting usually of large stones in a silty to gravelly sand matrix. These deposits occur in areas which were formerly overridden by a valley or piedmont glacier.

Wind transported material:
Loess:
Glacial loess is derived from the floodplains of glacial braided rivers that carried large volumes of glacial meltwater and sediments from the annual melting of continental icesheets and mountain icecaps during the summer. **Non-glacial:** Non-glacial loess can originate from deserts,dune fields playa alkes and volcanic ash

Sand dunes and plains:
Accumulations of wind-blown sand occupy areas bordering many parts of the coastal areas and river valleys as well as large areas of deserts (Sahara 28 %, Australia 31%)

Volcanic deposits
Andosols: the strong influence of pyroclastic parent material determines that these soils occur in all parts of the world where there is active vulcanicity