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TAURINENSIS

Dipartimento di Scienze Agrarie, Forestali e Alimentari

Linking soil properties and their varibility to water quality

Eleonora Bonifacio
University of Torino – DISAFA
Eleonora.bonifacio@unito.it

Mountain Partnership

IPROMO
12-23 July 2013 – Ormea (Italy)

Understanding Upland Watershed Management

1) Linking soil properties and their variability to water quality
    - Basic soil properties
    - Soil variability
    - Soil maps

2) Soils and watershed management in mountain areas
    - Soil erosion

Main Objectives

Provide bases for understanding the links between soil properties and water quality to implement indicators for watershed management

Develop the ability of understanding land and soil properties from scarce available information

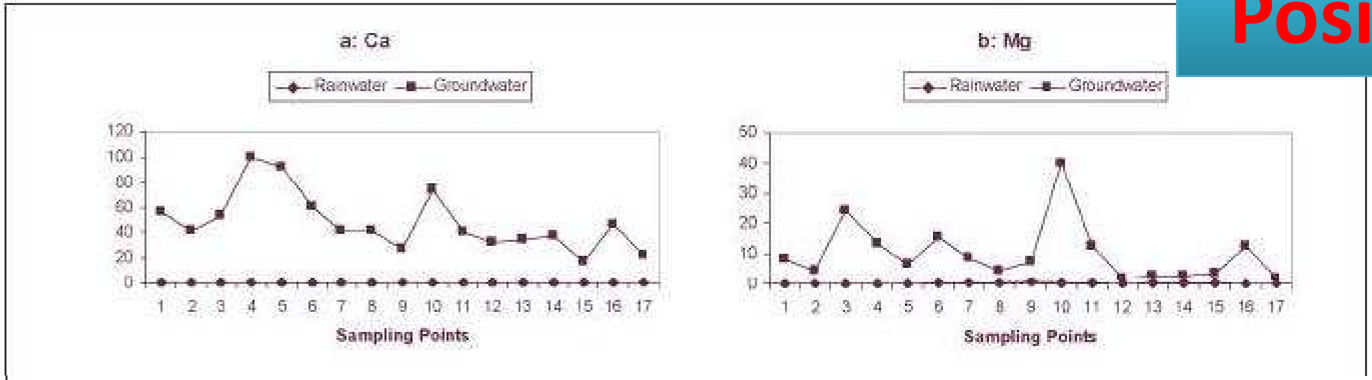
Acquire the ability to predict the consequences of the use/misuse of resources at the watershed level

Forests play a crucial role in the hydrological cycle. They influence the amount of water available and regulate surface and groundwater flows while maintaining high water quality (Forests and Water-International momentum and action, FAO.org)

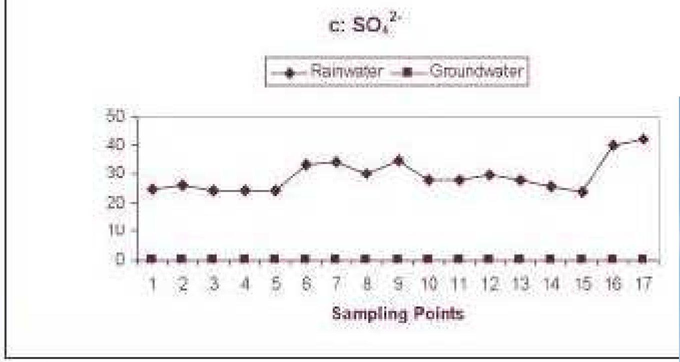
…and what about soils? Do they have a specific role in the water cycle or do they simply support forests?

Soils act as a filter between chemicals (fertilizers, contaminants etc..) and human health (surface and groundwater).
They protect, but they also need to be protected, otherwise they will lose their function

Positive effect

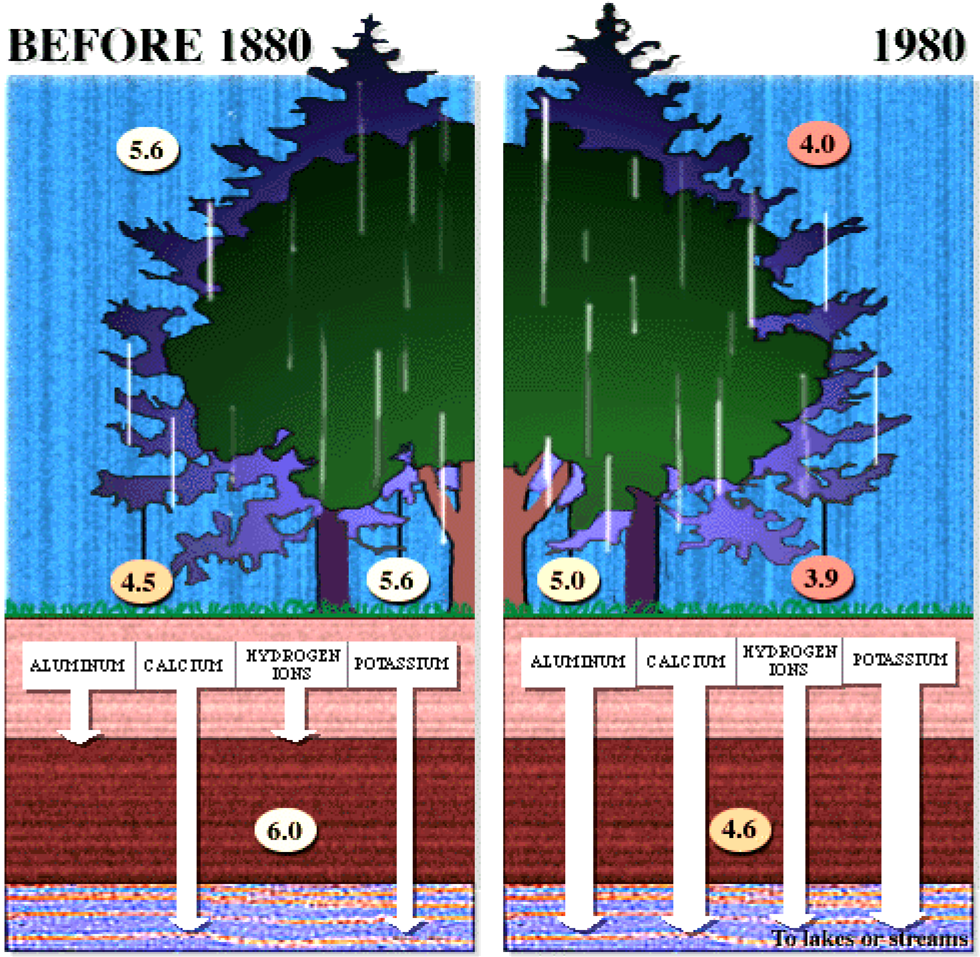


Olobaniyi and Efe (2007)



Acid rain-affected areas: decrease in sulphate and increase in Mg and Ca from rainfall to groundwater

Forest decine due to acid rain in the Krkonose National Park (CZ)



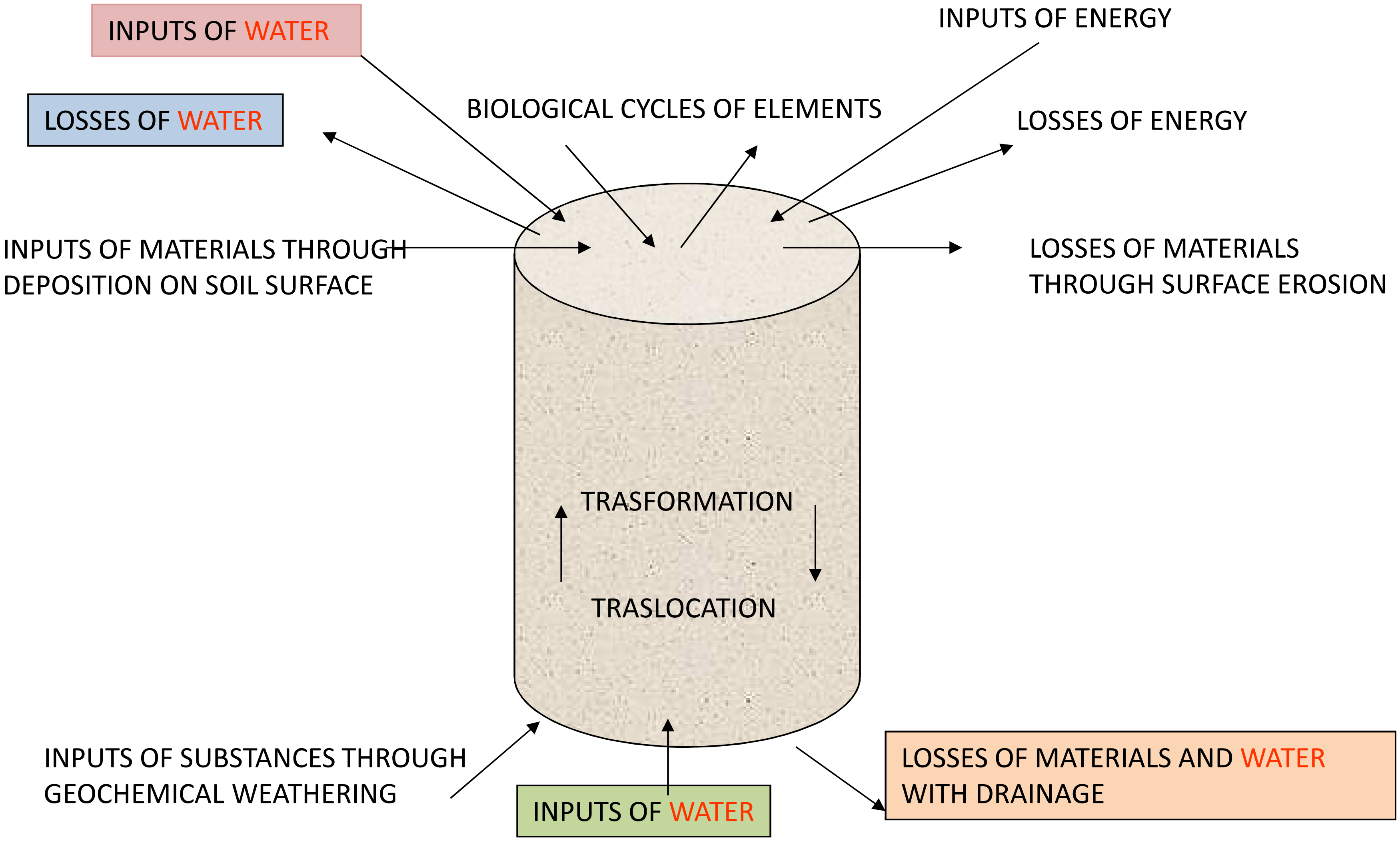
www.globalchange.umich.edu

The positive effect does not last forever!

Negative effect

Inland Acid Sulphate Soil in South Australia

Soil is an open system: it is affected by inputs of energy and materials from other environmental systems, but it also affects them through fluxes of materials.



INPUTS OF WATER

LOSSES OF WATER

BIOLOGICAL CYCLES OF ELEMENTS

INPUTS OF ENERGY

LOSSES OF ENERGY

INPUTS OF MATERIALS THROUGH DEPOSITION ON SOIL SURFACE

LOSSES OF MATERIALS THROUGH SURFACE EROSION

TRASFORMATION

TRASLOCATION

INPUTS OF SUBSTANCES THROUGH GEOCHEMICAL WEATHERING

INPUTS OF WATER

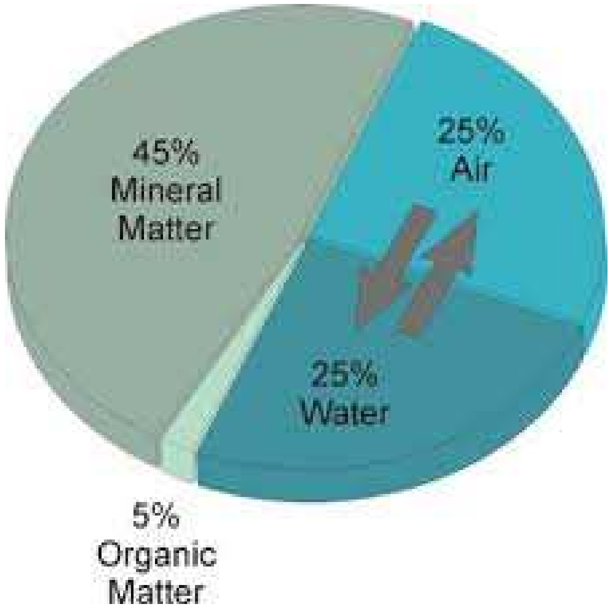
LOSSES OF MATERIALS AND WATER WITH DRAINAGE

Water entering the soil is different from water leaving the soil

1. its pH is different
2. it has a different chemical composition

Soil is a very active buffering system and filters water, often enhancing its quality

Importance of the composition of the solid phase



Soil is made of solids (minerals + organic matter) and voids (pores) which may be filled by water and/or by air.

The reactions occurring between soil water and soil solids change soil water composition.

The amount of water that can ENTER, BE STORED and LEAVE the soil depends on:

- **soil texture (distribution of soil particles in size classes)**
- **soil structure (aggregation of particles)**

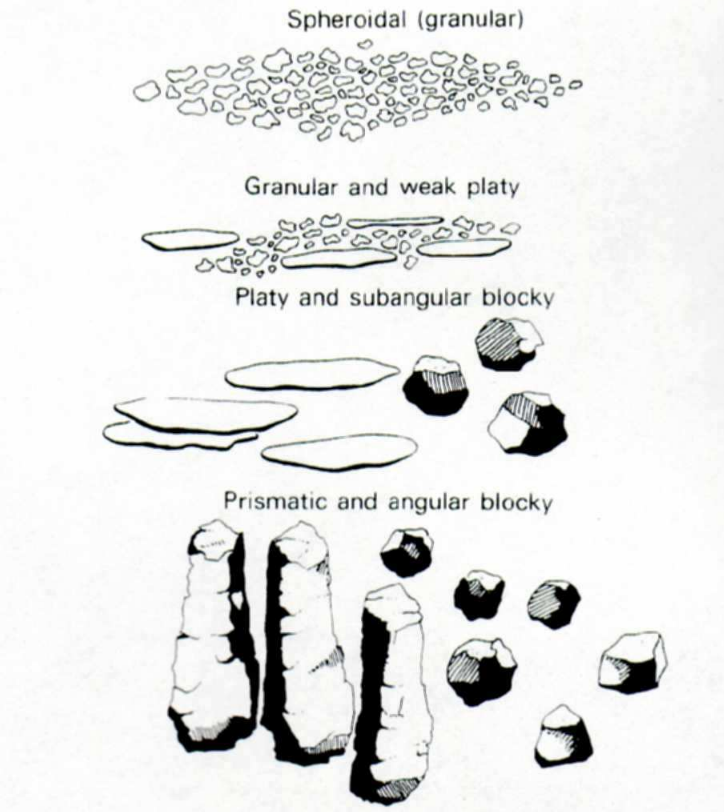
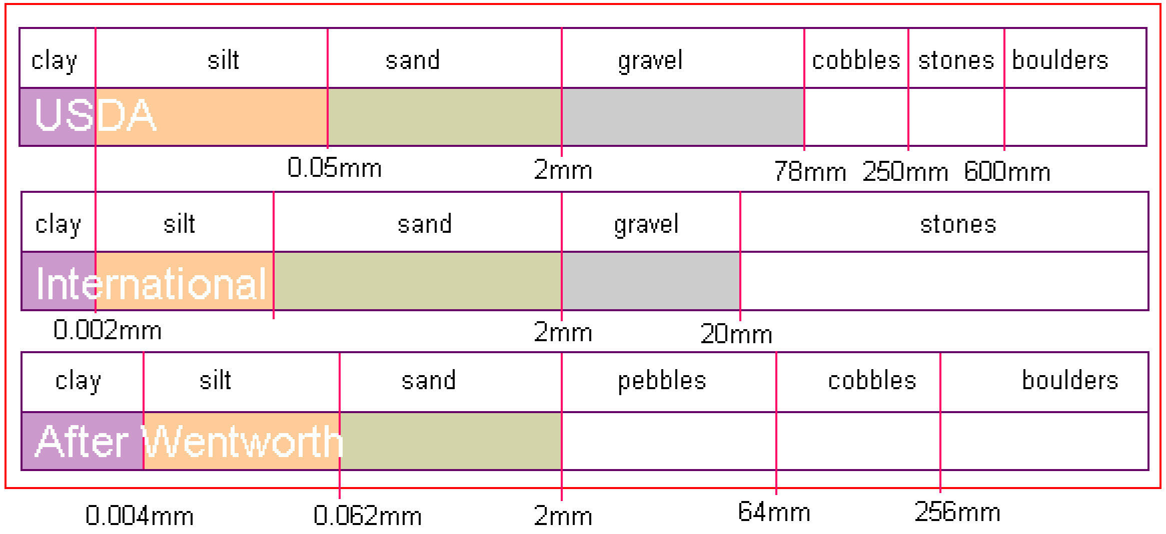
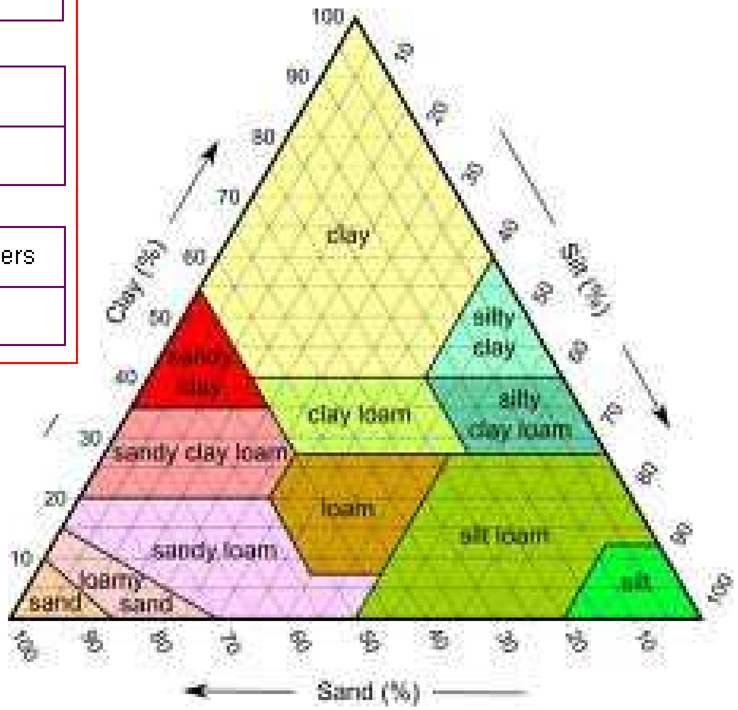


Figure 4.2. Examples of common ped types (after Strutt, 1970).

Soil structure is the 3D arrangement of soil solids.
It varies in shape, size and resistence
The evaluation of soil structure is done in the field





Soil solids are made of particles of different size.

Clay is the smallest fraction.

From Particle Size Distribution soil texture is evaluated

Soil texture can be estimated in the field by standardised tests (e.g. http://soils.usda.gov/education/resources/lessons/texture/)

Solids are mineral and organic components

- they contribute to soil mass (Kg or g) and to soil volume
- voids only contribute to soil volume (m^3 or cm^3)

$$\frac{Volume \quad of \quad soil \quad voids}{Total \quad soil \quad volume} = \quad Soil \quad porosity\,(\%)$$

$$\frac{Weight \quad of \quad soil \quad solids}{Volume \quad of \quad soil \quad solids} = \quad real(particle) \quad density \quad (g/cm^3)$$

~ 2.65 g/cm$_3$

$$\frac{Weight \quad of \quad soil \quad solids}{Total \quad soil \quad volume} = \quad Soil \quad bulk \quad density\,(g/cm^3)$$

$$100 - \frac{bulk \quad density}{real \quad density} \times 100 = \quad soil \quad porosity$$

Although relatively easy to evaluate in principle, practically Bulk Density is often estimated from PEDOTRANSFER FUNCTIONS (PTFs: relations between an unknown property and measured independent variables)

Several PTFs have been developed to estimate BD

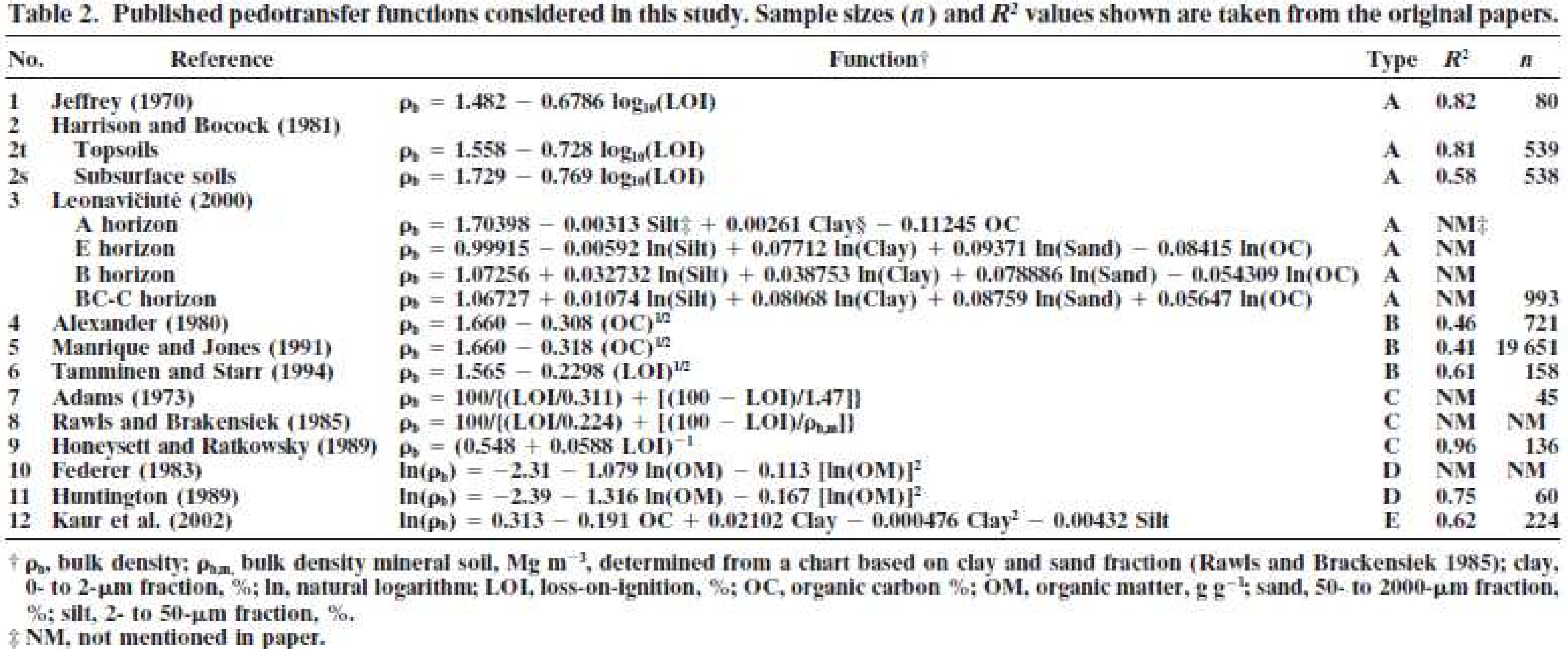


Table 2. Published pedotransfer functions considered in this study. Sample sizes (n) and R^2 values shown are taken from the original papers.

No.	Reference	Function†	Type	R^2	n
1	Jeffrey (1970)	$\rho_b = 1.482 - 0.6786 \log_{10}(\mathrm{LOI})$	A	0.82	80
2	Harrison and Bocock (1981)				
2t	Topsoils	$\rho_b = 1.558 - 0.728 \log_{10}(\mathrm{LOI})$	A	0.81	539
2s	Subsurface soils	$\rho_b = 1.729 - 0.769 \log_{10}(\mathrm{LOI})$	A	0.58	538
3	Leonavičiutė (2000)				
	A horizon	$\rho_b = 1.70398 - 0.00313\ \mathrm{Silt}‡ + 0.00261\ \mathrm{Clay}§ - 0.11245\ \mathrm{OC}$	A	NM‡	
	E horizon	$\rho_b = 0.99915 - 0.00592 \ln(\mathrm{Silt}) + 0.07712 \ln(\mathrm{Clay}) + 0.09371 \ln(\mathrm{Sand}) - 0.08415 \ln(\mathrm{OC})$	A	NM	
	B horizon	$\rho_b = 1.07256 + 0.032732 \ln(\mathrm{Silt}) + 0.038753 \ln(\mathrm{Clay}) + 0.078886 \ln(\mathrm{Sand}) - 0.054309 \ln(\mathrm{OC})$	A	NM	
	BC-C horizon	$\rho_b = 1.06727 + 0.01074 \ln(\mathrm{Silt}) + 0.08068 \ln(\mathrm{Clay}) + 0.08759 \ln(\mathrm{Sand}) + 0.05647 \ln(\mathrm{OC})$	A	NM	993
4	Alexander (1980)	$\rho_b = 1.660 - 0.308\ (\mathrm{OC})^{1/2}$	B	0.46	721
5	Manrique and Jones (1991)	$\rho_b = 1.660 - 0.318\ (\mathrm{OC})^{1/2}$	B	0.41	19 651
6	Tamminen and Starr (1994)	$\rho_b = 1.565 - 0.2298\ (\mathrm{LOI})^{1/2}$	B	0.61	158
7	Adams (1973)	$\rho_b = 100/[(\mathrm{LOI}/0.311) + [(100 - \mathrm{LOI})/1.47]]$	C	NM	45
8	Rawls and Brakensiek (1985)	$\rho_b = 100/[(\mathrm{LOI}/0.224) + [(100 - \mathrm{LOI})/\rho_{b,m}]]$	C	NM	NM
9	Honeysett and Ratkowsky (1989)	$\rho_b = (0.548 + 0.0588\ \mathrm{LOI})^{-1}$	C	0.96	136
10	Federer (1983)	$\ln(\rho_b) = -2.31 - 1.079 \ln(\mathrm{OM}) - 0.113 [\ln(\mathrm{OM})]^2$	D	NM	NM
11	Huntington (1989)	$\ln(\rho_b) = -2.39 - 1.316 \ln(\mathrm{OM}) - 0.167 [\ln(\mathrm{OM})]^2$	D	0.75	60
12	Kaur et al. (2002)	$\ln(\rho_b) = 0.313 - 0.191\ \mathrm{OC} + 0.02102\ \mathrm{Clay} - 0.000476\ \mathrm{Clay}^2 - 0.00432\ \mathrm{Silt}$	E	0.62	224

† ρ_b, bulk density; $\rho_{b,m,}$ bulk density mineral soil, Mg m^{-3}, determined from a chart based on clay and sand fraction (Rawls and Brackensiek 1985); clay, 0- to 2-µm fraction, %; ln, natural logarithm; LOI, loss-on-ignition, %; OC, organic carbon %; OM, organic matter, g g^{-1}; sand, 50- to 2000-µm fraction, %; silt, 2- to 50-µm fraction, %.

‡ NM, not mentioned in paper.

De Vos et al. (2005)

They do not always perform well outside the original environment

One of the most widely used is still Jeffrey's one (1970)

$$BD = 1.482 - 0.6786 \log_{10} LOI$$

BD in T m^{-3},
LOI ~ Soil organic matter in %

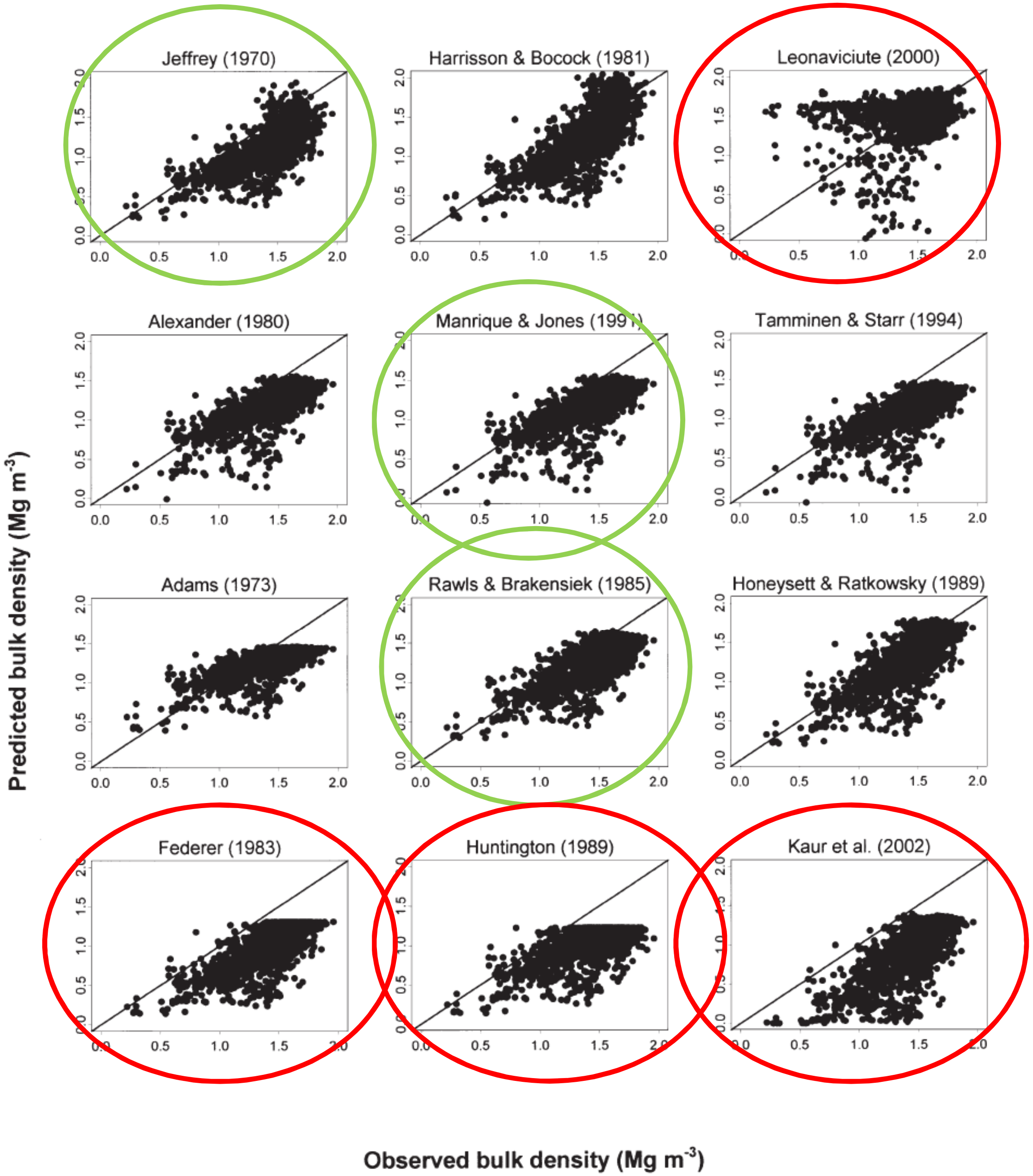


Fig. 1. Performance of published pedotransfer functions for the total dataset: predicted vs. observed bulk densities (Mg m^{-3}) with reference to the 1:1 line. Similar model types are arranged in the same row.

De Vos et al. (2005)

The size of elemental particles influences porosity:

- clayey soils approximate porosity 58%
- loamy soils 52%
- sandy soils 39 %

BUT

The amount of water in soils and water flow does not only depend on total porosity, but is influenced by pore size

Pore class	*size description*	*Size range (µm)*	*Hydrological function*
Biopores	very large	5000-500	rapid infiltration of water and inflow of air
Macropores	large	500-75	infiltration of water, inflow of air, softening of soil
Mesopores	medium	73-30	drainage of water, flow of water and nutrients to roots
Micropores	small	30-0.5	storage of plant-available water
Residual	very small	<0.5	hold soil particles together and make soil hard

From Cass, 1999

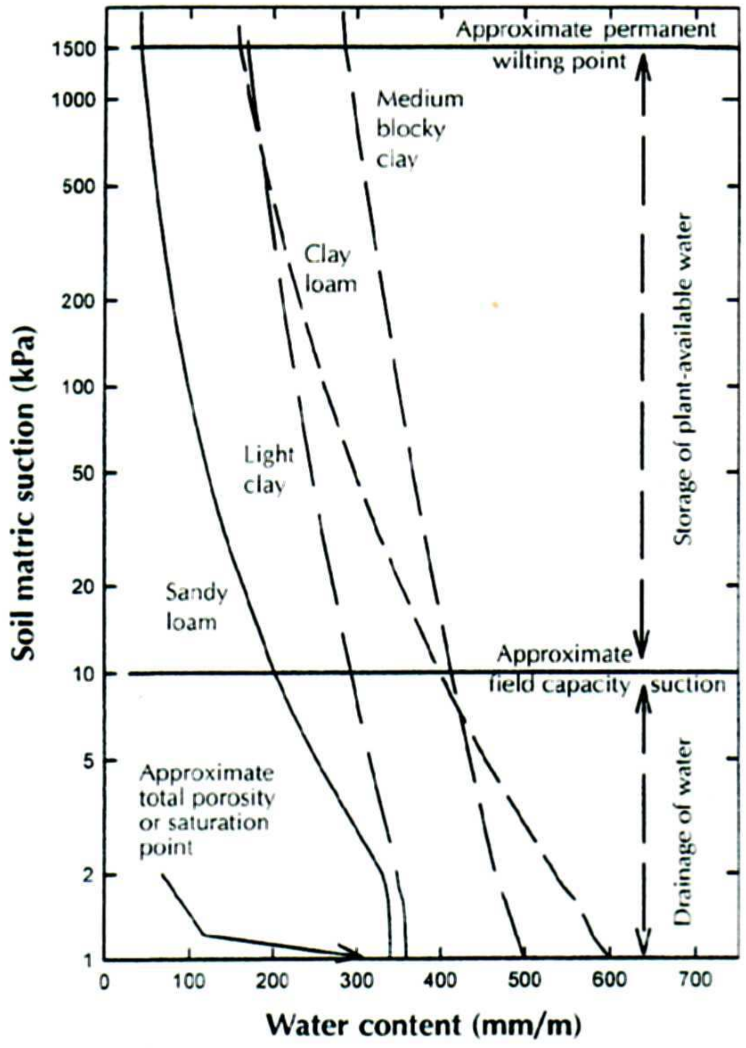


Figure 6.1 Water retention curves for four soil texture classes and approximate field capacity (FC) and wilting point (WP) matric suction values and the saturation or total porosity (TP) point. Total plant-available water (PAW) and air-filled porosity (AFP) are determined from these limits (adapted from Williams *et al.* 1989).

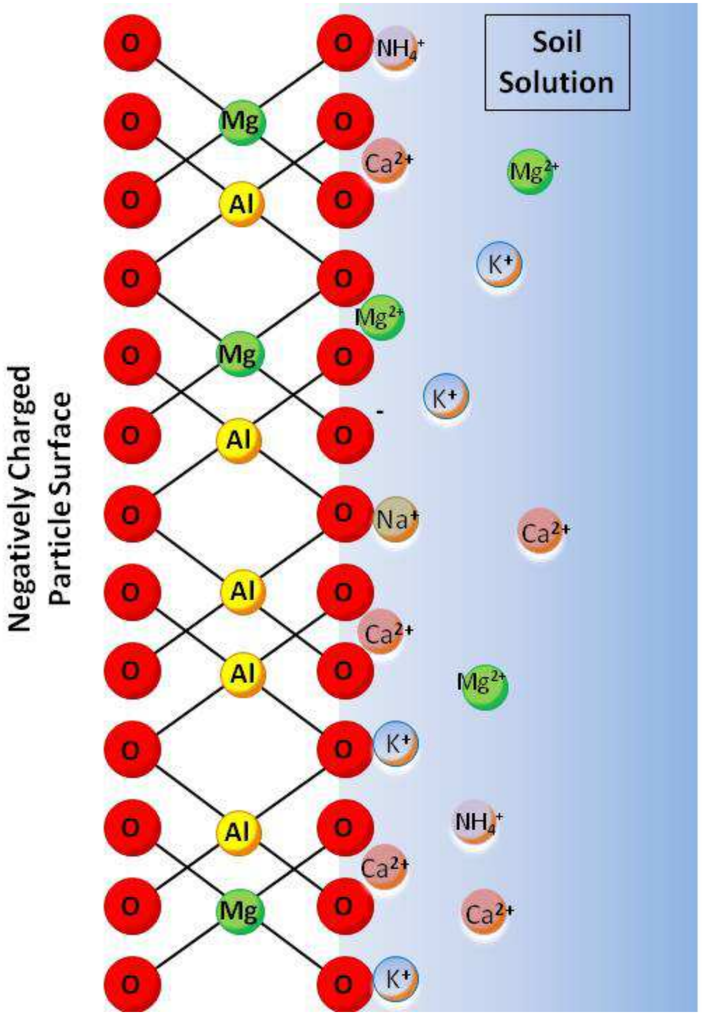
Permanent wilting point

Longer contact time between water and soil components

Field capacity

Rapid drainage

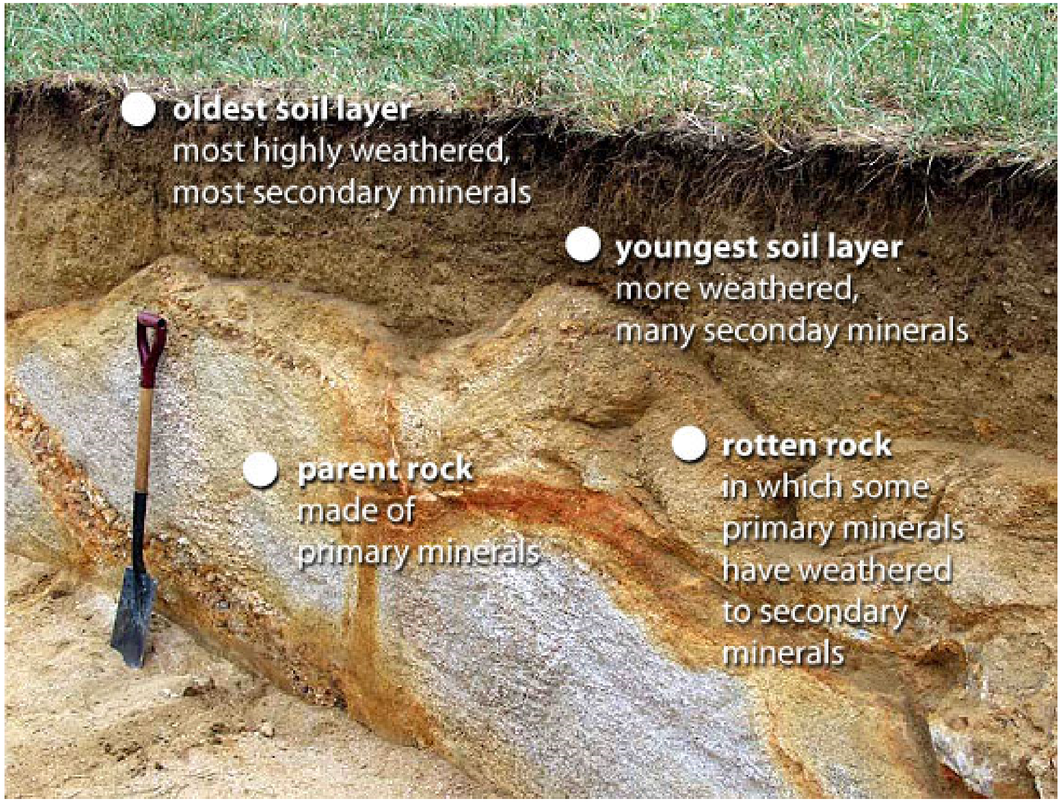
Total porosity

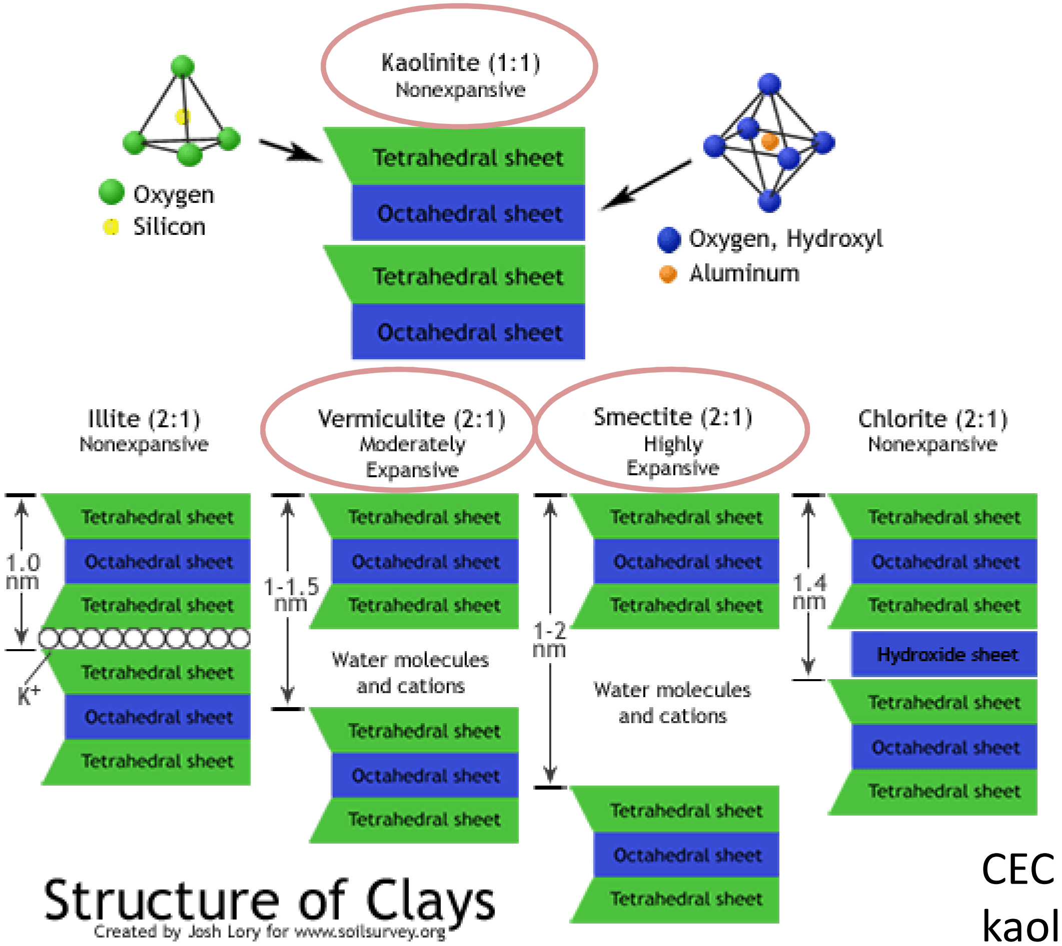


Soil minerals (LAYER SILICATES) have charged surfaces that can retain ions from the soil solution and release them upon changes in solution composition.

Rock minerals do not have.

This property is called **Cation** Exchange Capacity, can be determined in the lab**, is typical of clay** minerals, but varies dependending on the type of mineral.





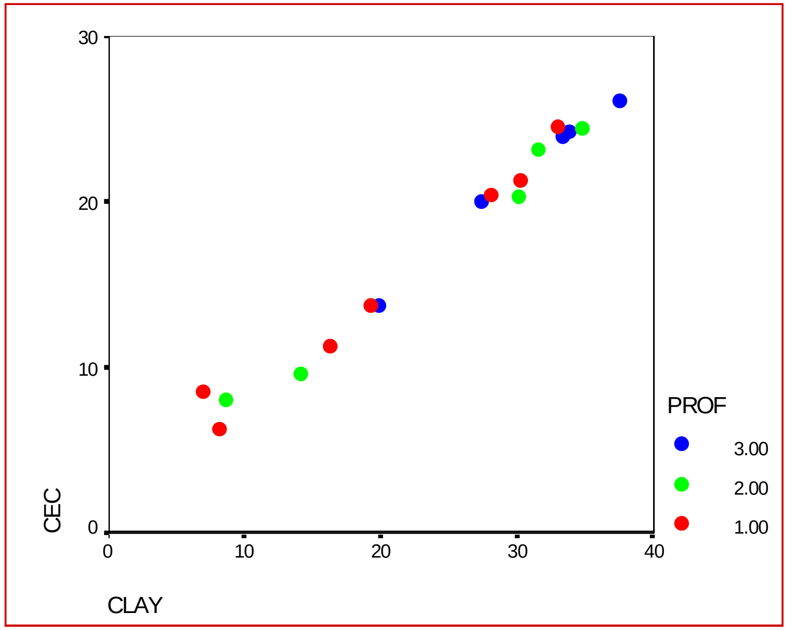
Structure of Clays

Created by Josh Lory for www.soilsurvey.org

Layer silicate	Approx. CEC cmol(+) Kg^{-1}
Kaolinite	10
Chlorite	40
Illite	40
Smectite	100
Vermiculite	150

CEC varies from ~ 10 $cmol_c$ Kg^{-1} clay in kaolinite to more than 100 in smectite and vermiculite

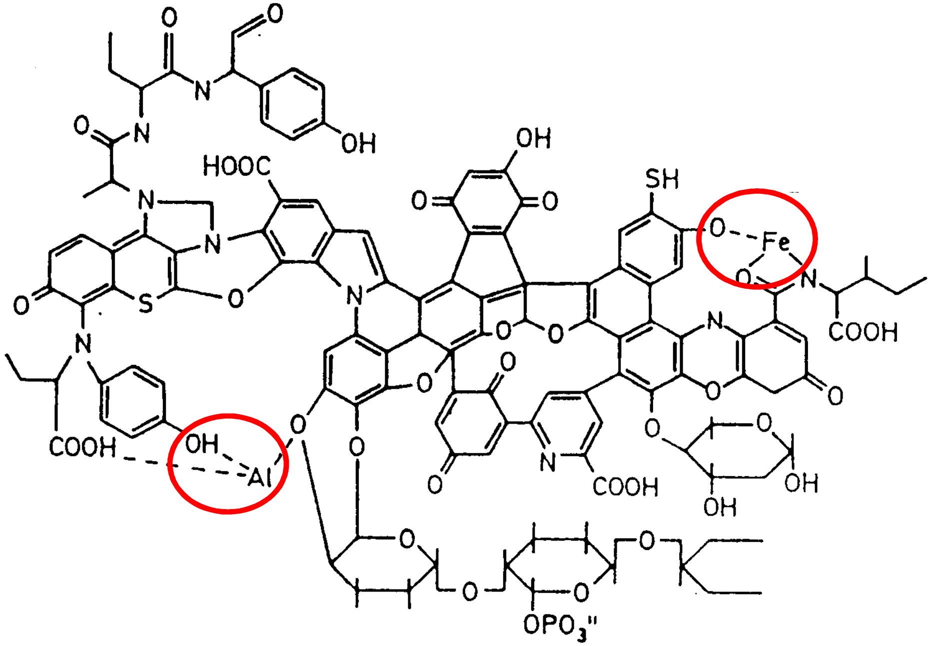
Kaolinite is typical of tropical environments, illite, chlorite and vermiculite of temperate climates



In similar soils, taken form the same climatic environment
The amounts of clay is a good estimate of CEC, the type of mineral is less important

Organic matter is present in the soil at different stages of decomposition

Highly transformed organic compounds and root exudates react with minerals and contribute to aggregate formation

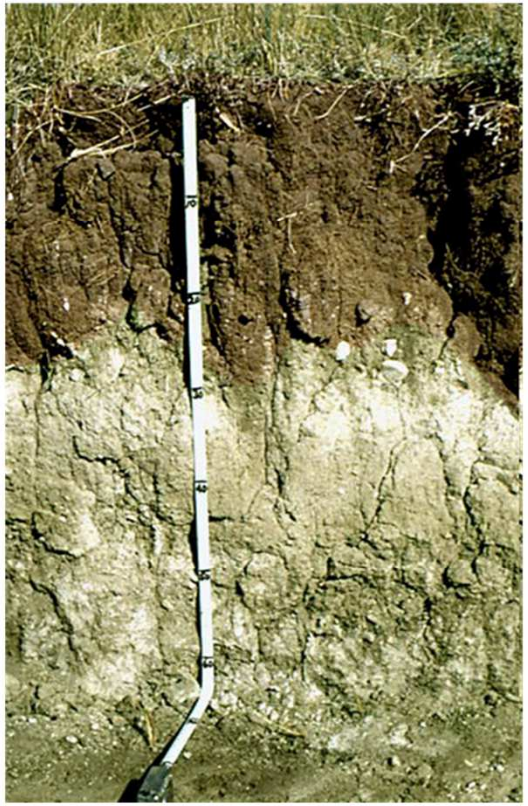


Transformed organic compounds may have both positive and negative charges depending on soil pH

PHAEOZEM

CHERNOZEM

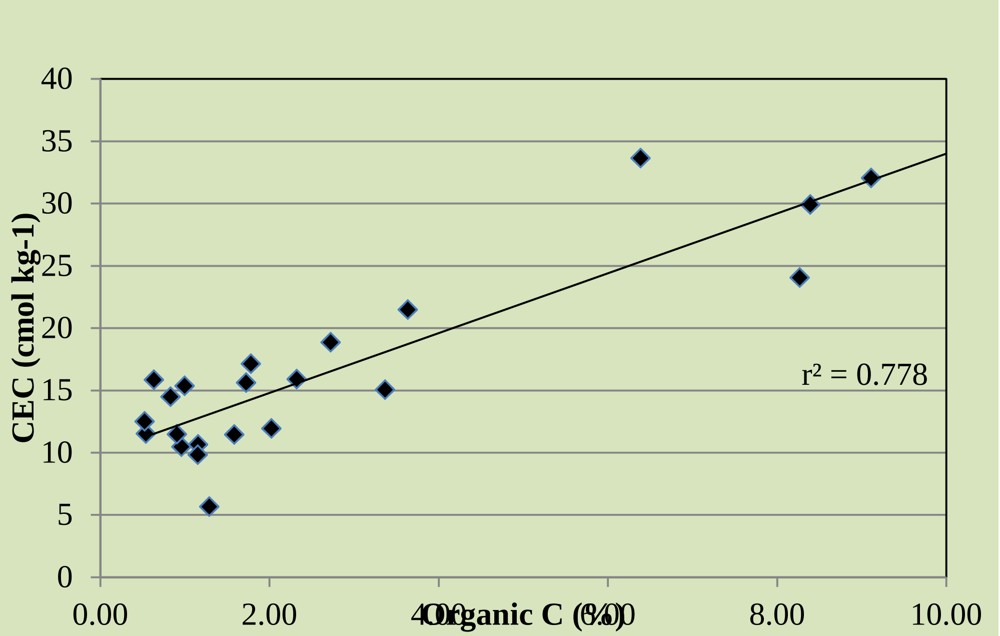
KASTANOZEM

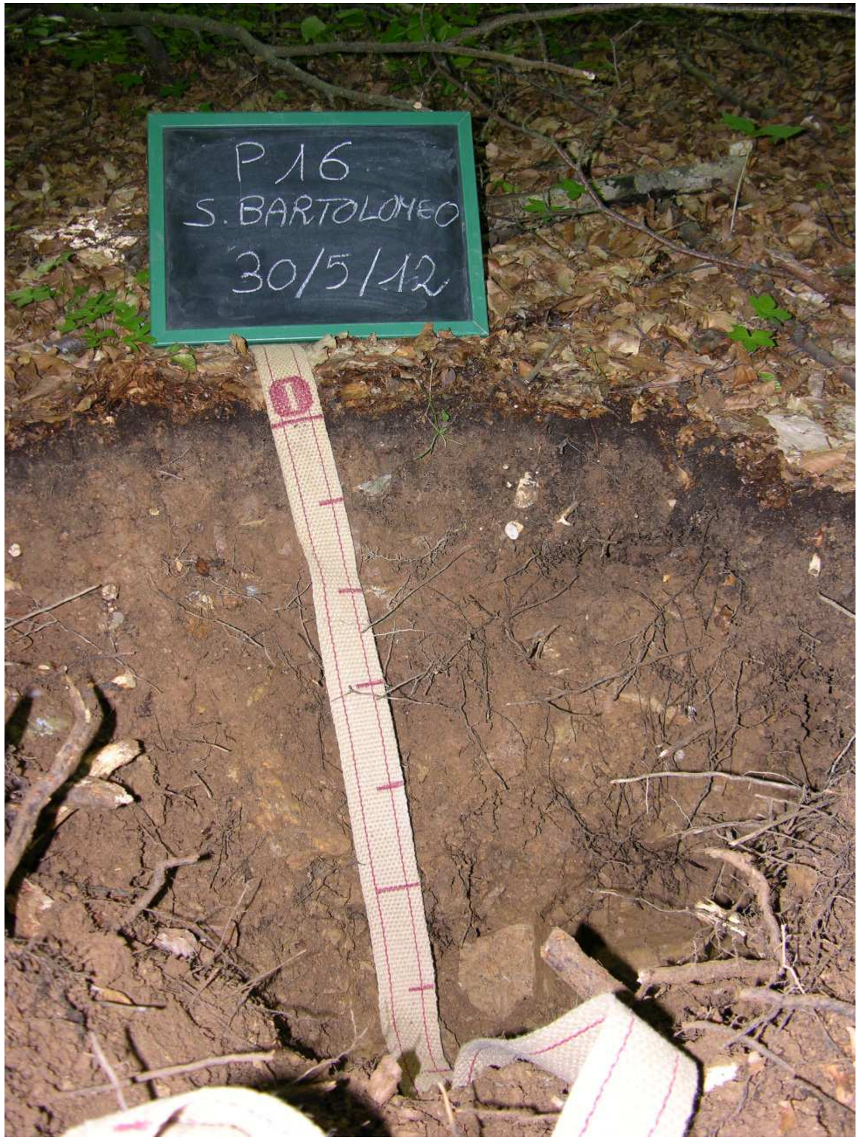


N

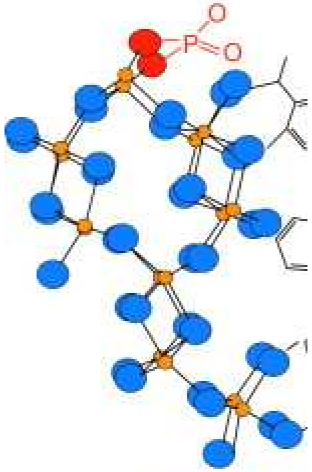
S

OC stocks kg m^{-2}	0-50 cm	
	Mean	CV
Phaeozems	**10.5**	48
Chernozems	**8.6**	56
Kastanozems	**7.5**	55





In sandy or otherwise poorly developed forest soils, CEC depends mainly on SOM

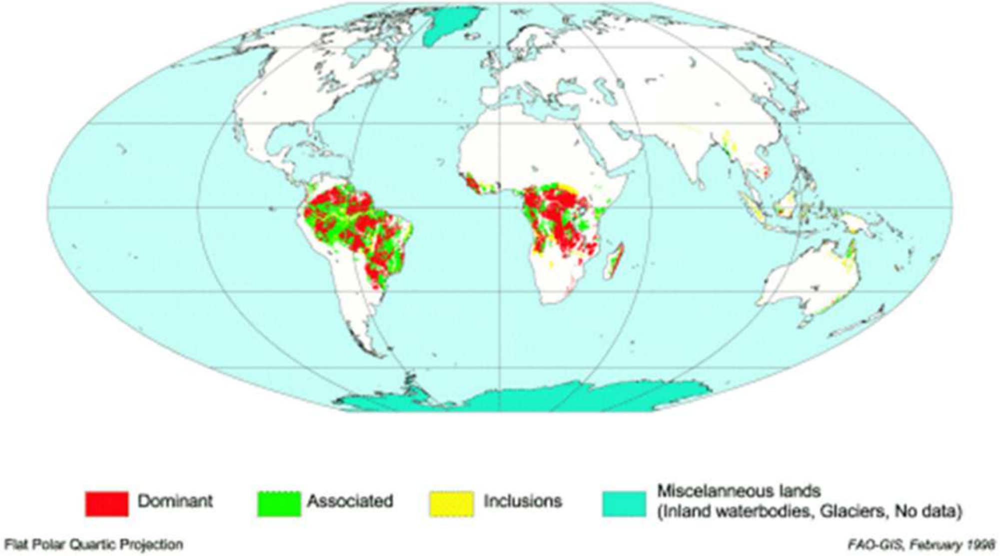


Iron oxide

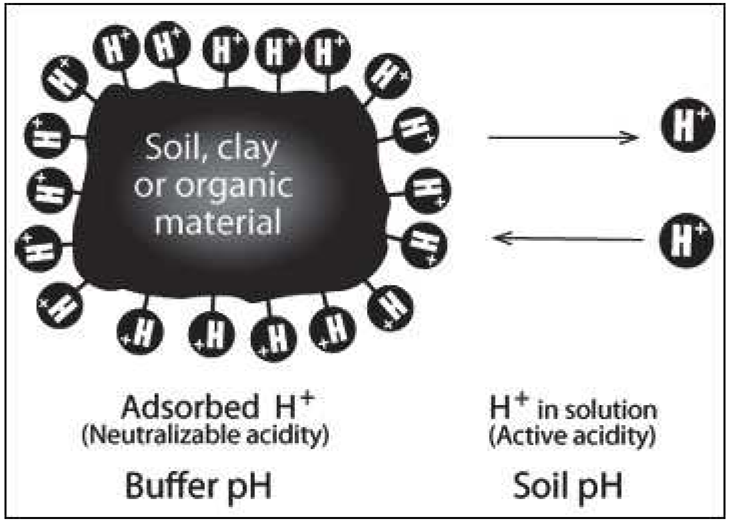
Other minerals, such as Fe and Al oxides, are positively charged, they attract and bind negatively charged ions from the soil solution. Oxides are present in every soil but they are sometimes very abundant.

Some anions are retained, others are not. This deeply influences the quality of ground and surface waters.

Ferralsols

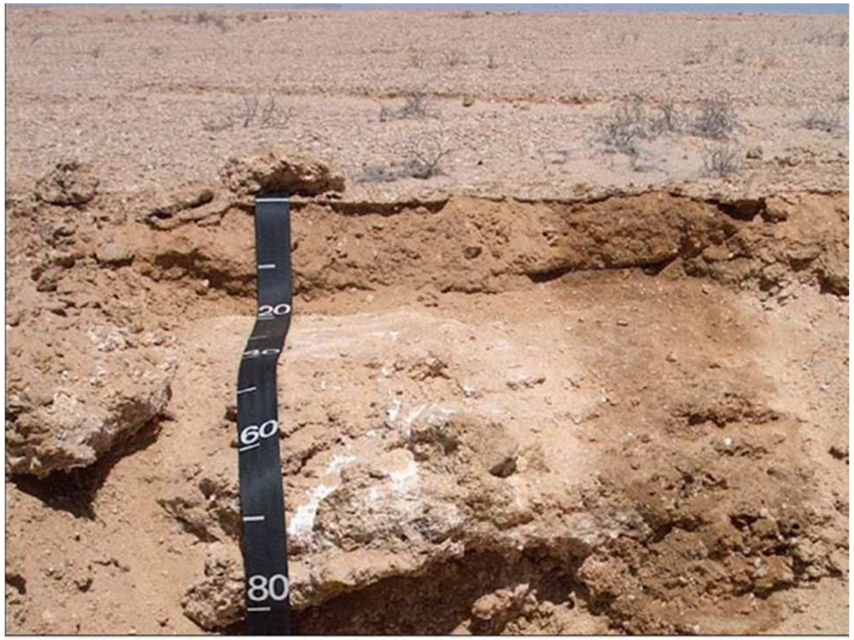


Acidity is related to the presence of H^+, soil can buffer water acidity thanks to CEC



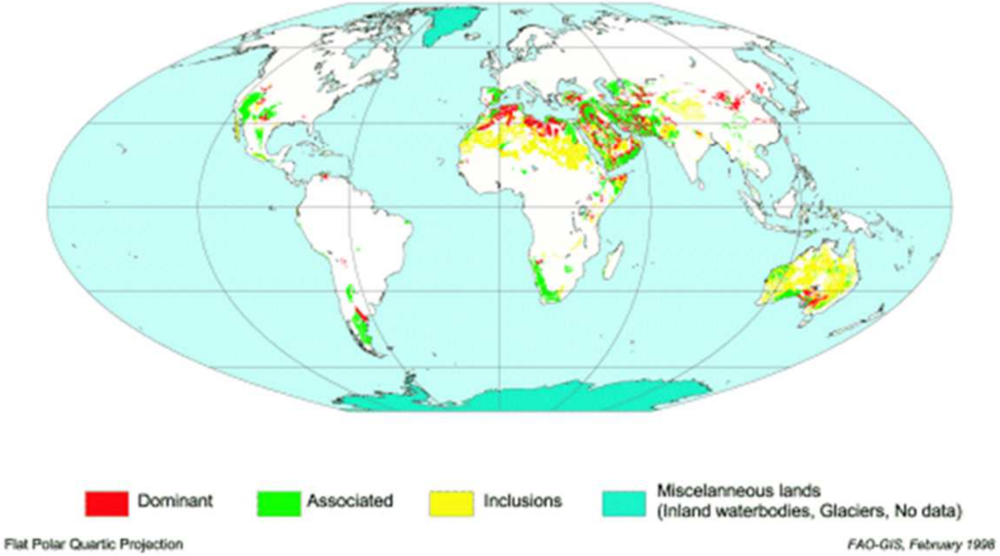
Other mechanims are also present, **carbonate dissolution** is very important

Carbonate presence can be assessed in the field by pouring hydrochloric acid on the soil.
If the soil has carbonates, it bubbles.
If a carbonates are present the soil pH ranges from 7 to 8.5

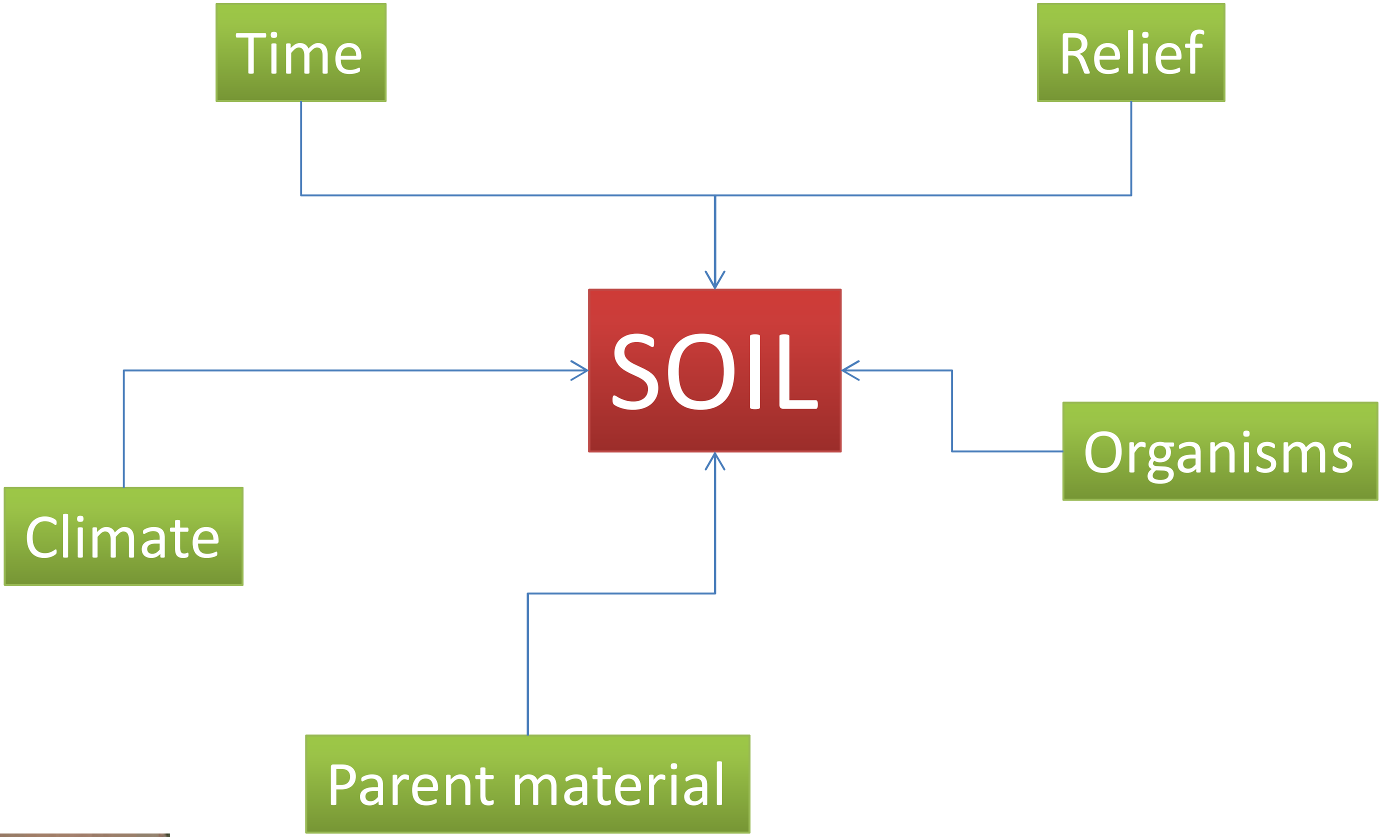


If carbonates are present in the soil they are very active in buffering acidity.
They can be found in soils developed on calcareous rocks or in soils of drylands

Calcisols



Variability in soil properties and soil variability



Time

Relief

SOIL

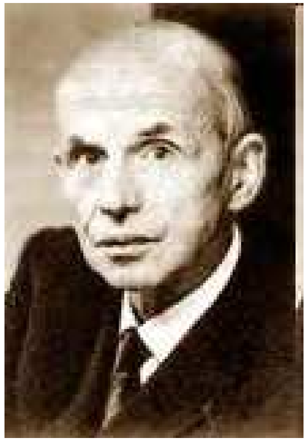
Climate

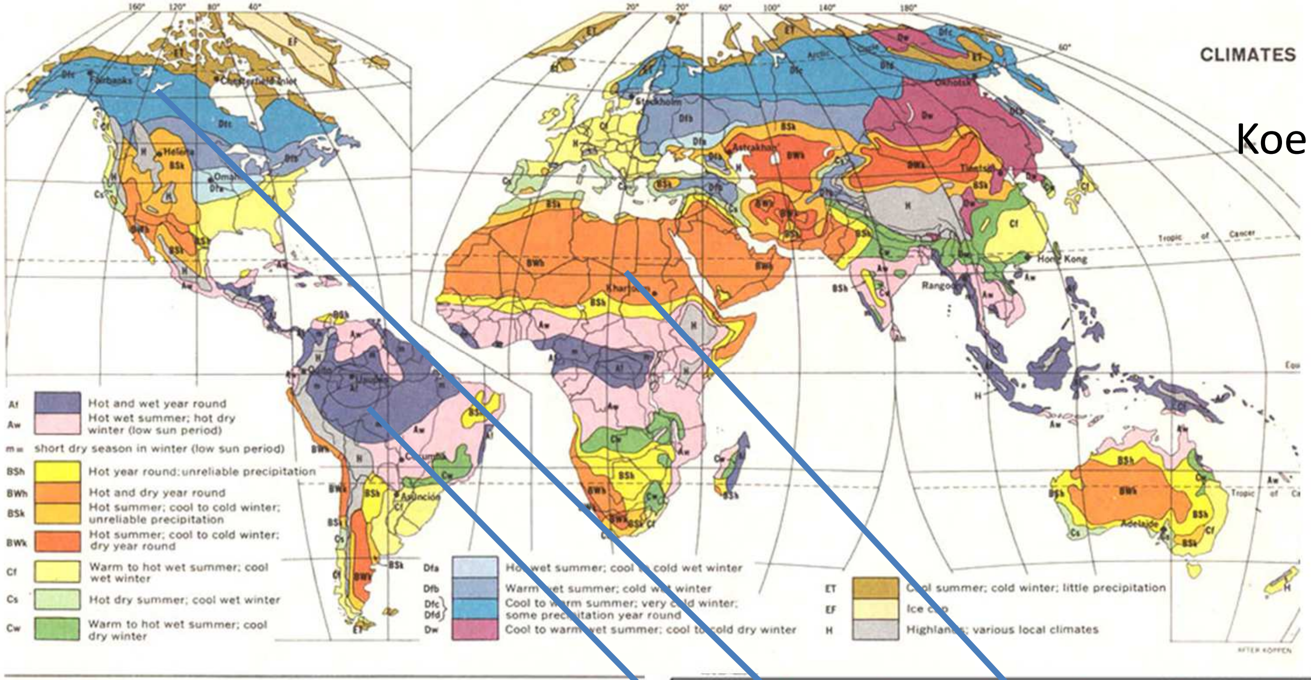
Organisms

Parent material

Васúлий Васúльевич Докучáев (1845 – 1902)

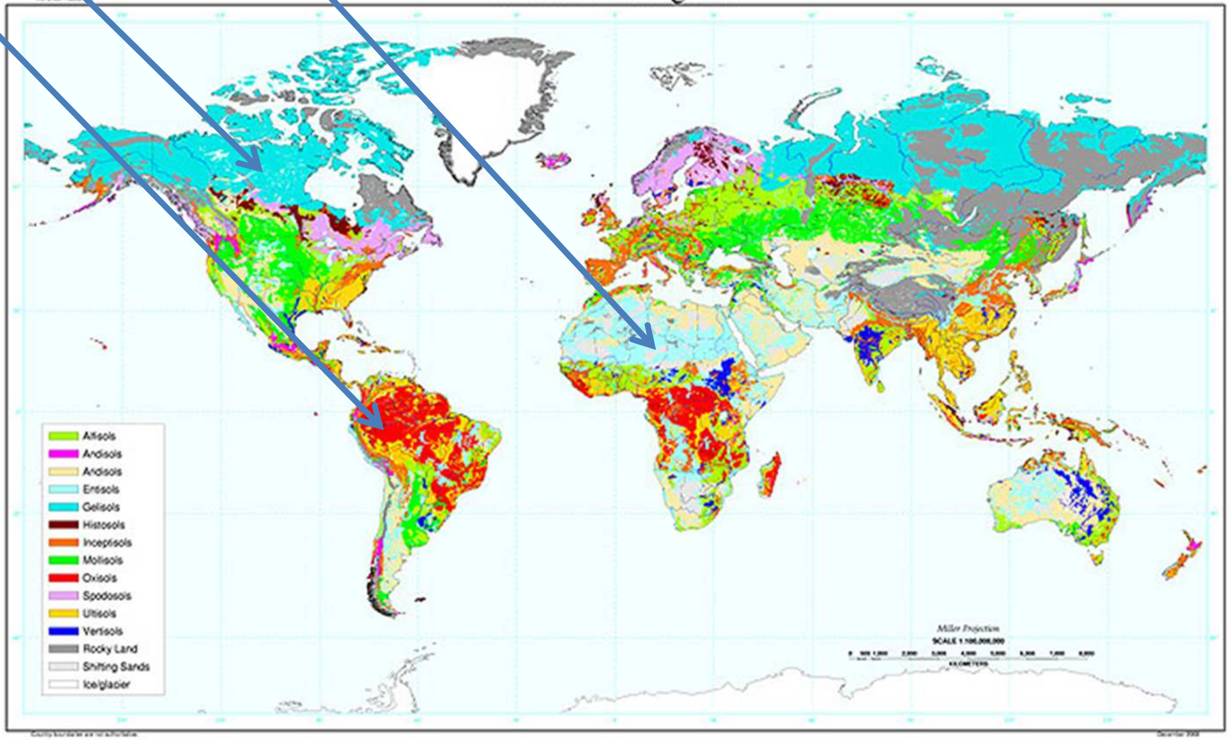
Hans Jenny (1904-1972)



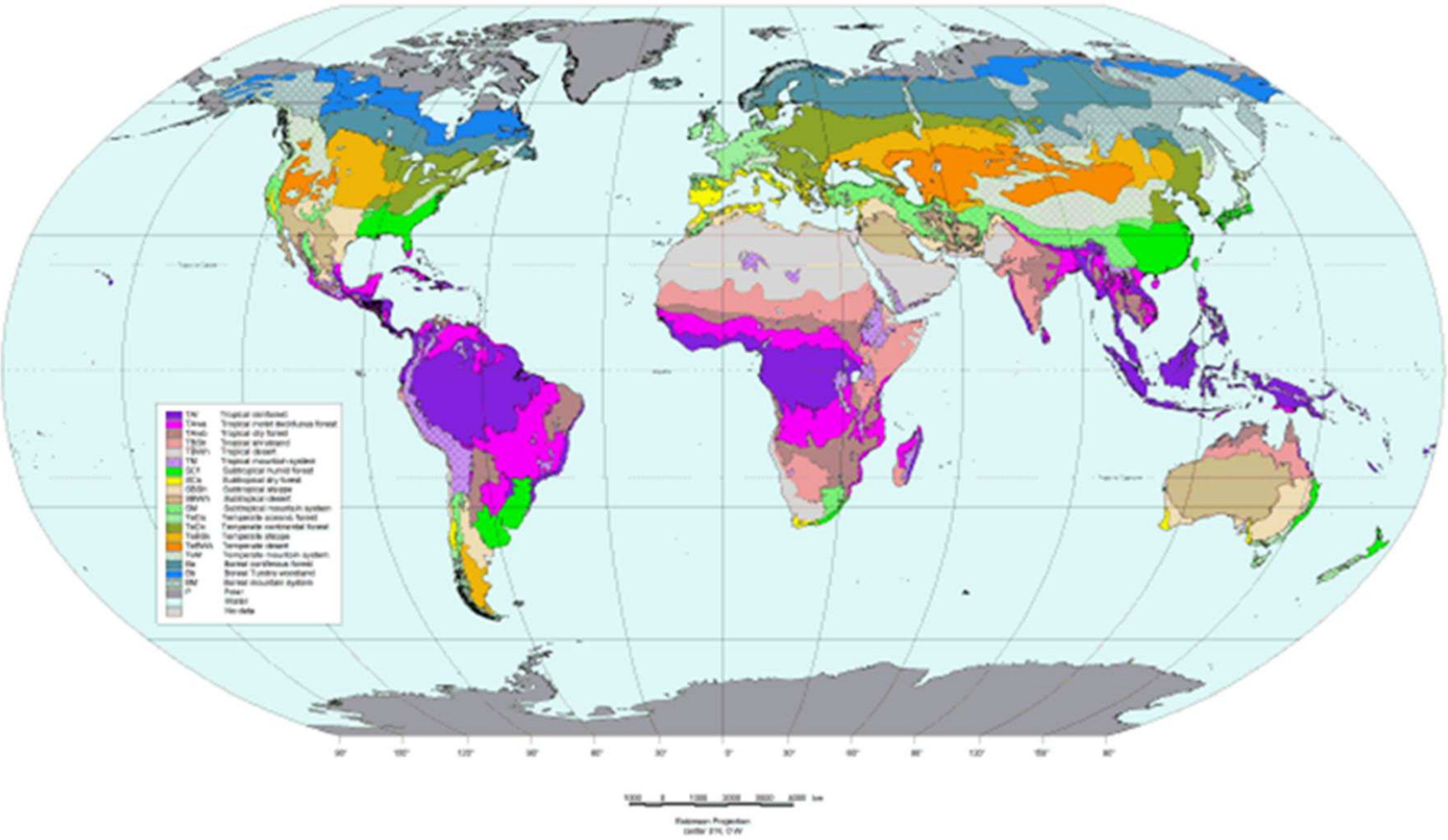


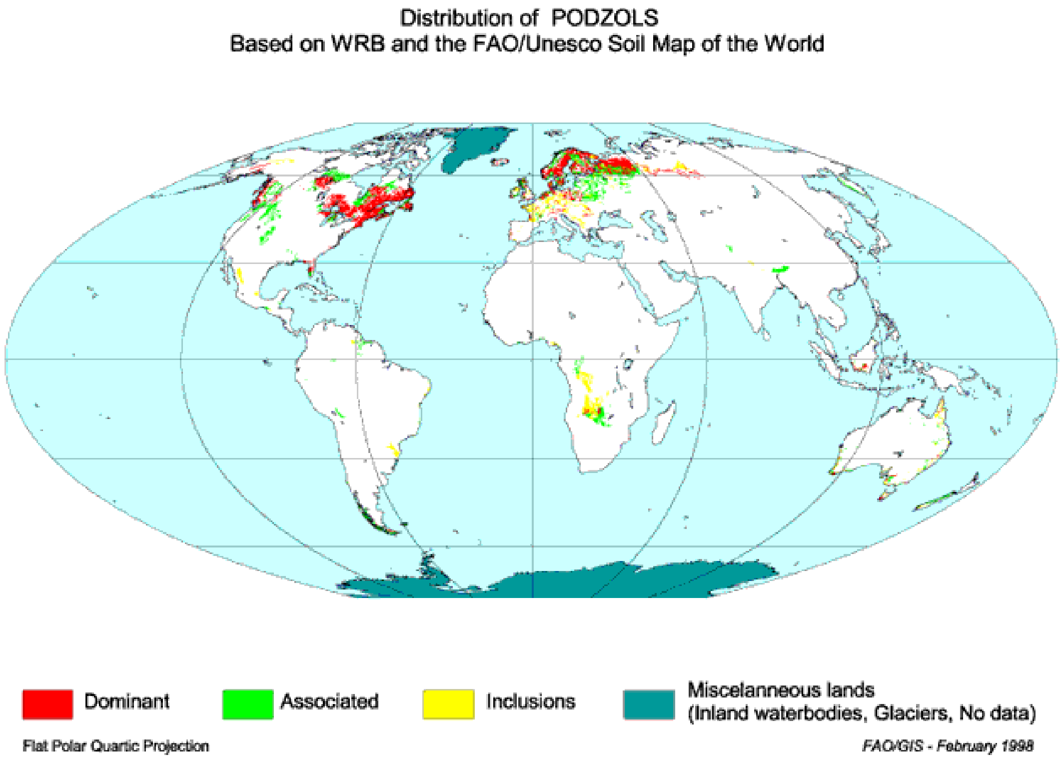
Koeppen's climatic classification

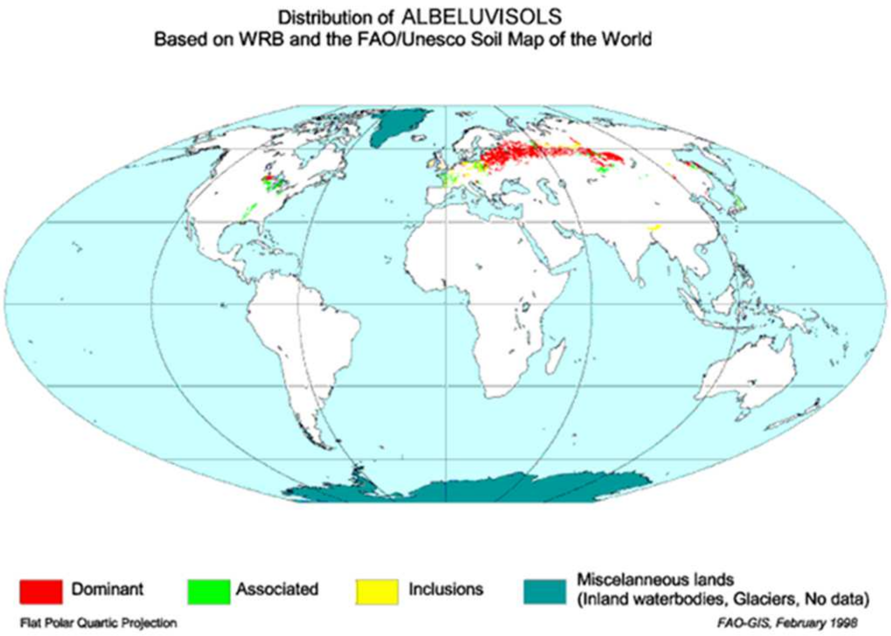
Global soil regions (USDA)

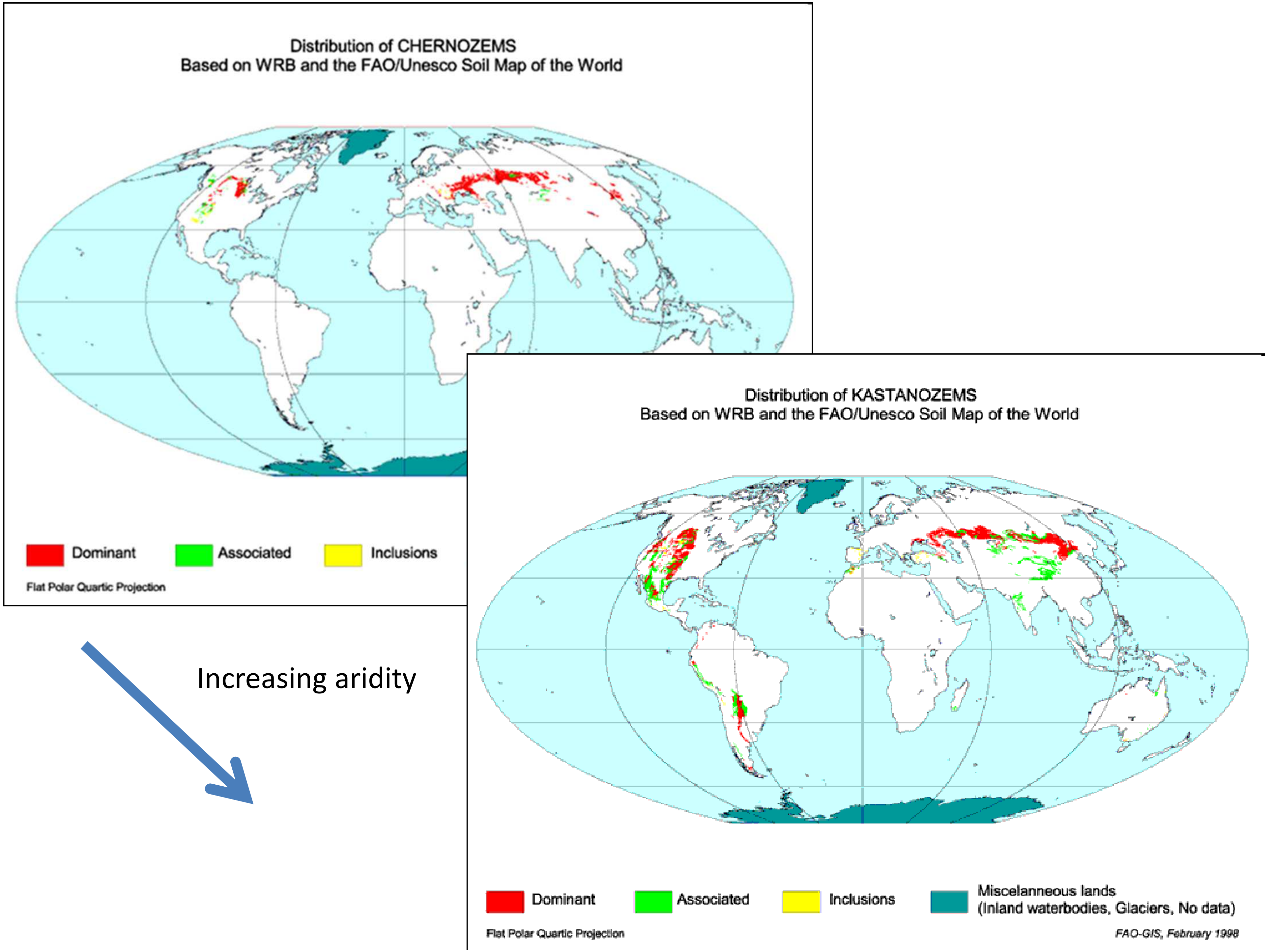


GLOBAL ECOLOGICAL ZONES




Distribution of PODZOLS
Based on WRB and the FAO/Unesco Soil Map of the World
🟥 Dominant
🟩 Associated
🟨 Inclusions
Miscelanneous lands
(Inland waterbodies, Glaciers, No data)
Flat Polar Quartic Projection
FAO/GIS - February 1998


Distribution of ALBELUVISOLS
Based on WRB and the FAO/Unesco Soil Map of the World
🟥 Dominant
🟩 Associated
🟨 Inclusions
Miscellaneous lands
(Inland waterbodies, Glaciers, No data)
Flat Polar Quartic Projection
FAO-GIS, February 1998



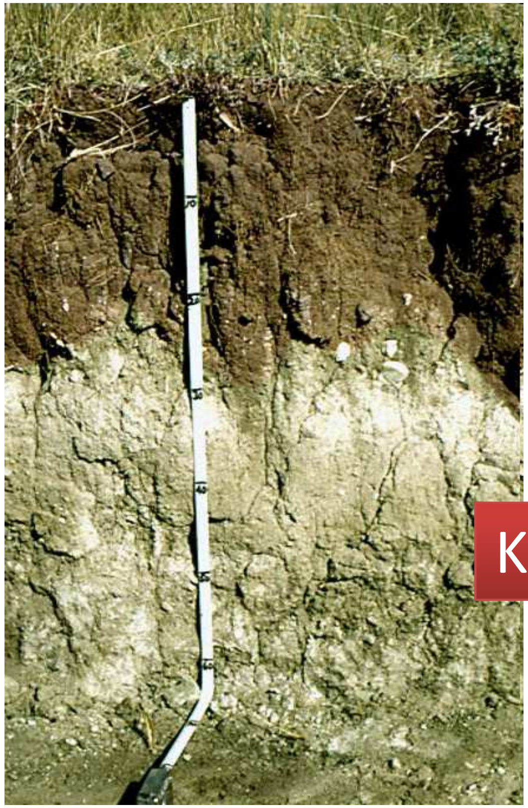
Distribution of CHERNOZEMS
Based on WRB and the FAO/Unesco Soil Map of the World

Distribution of KASTANOZEMS
Based on WRB and the FAO/Unesco Soil Map of the World

Increasing aridity

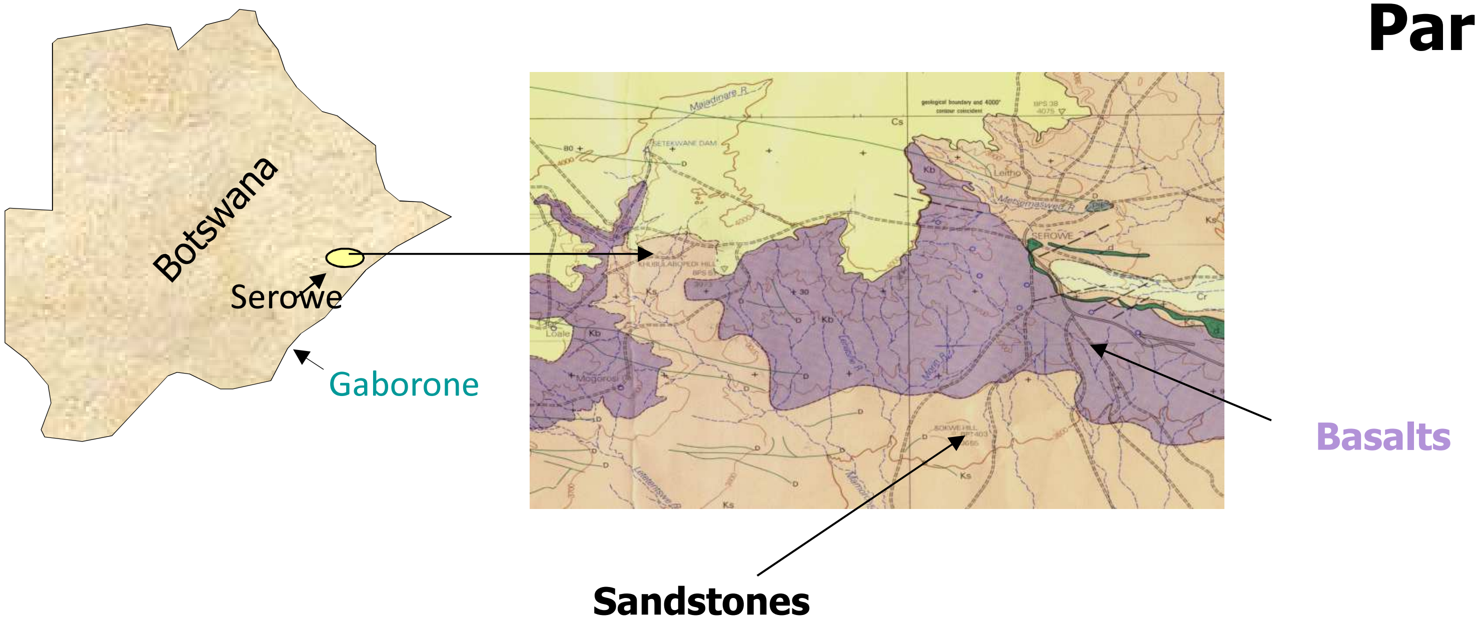
STEPPE

CHERNOZEM



KASTANOZEM

Parent material



Mean

HORIZON	CORG	N	CN	CEC	PHH2O	CSAND	FSAND	CSILT	FSILT	CLAY
A	1.03	.10	10.37	16.92	7.07	26.30	58.90	4.83	6.63	3.33
B	.55	.05	11.00	18.70	7.20	24.40	57.40	3.70	6.70	7.80
C	.53	.06	8.73	31.20	7.58	47.33	39.53	5.23	5.55	2.38
Total	.72	.07	9.63	24.28	7.34	36.58	49.03	4.89	6.10	3.41

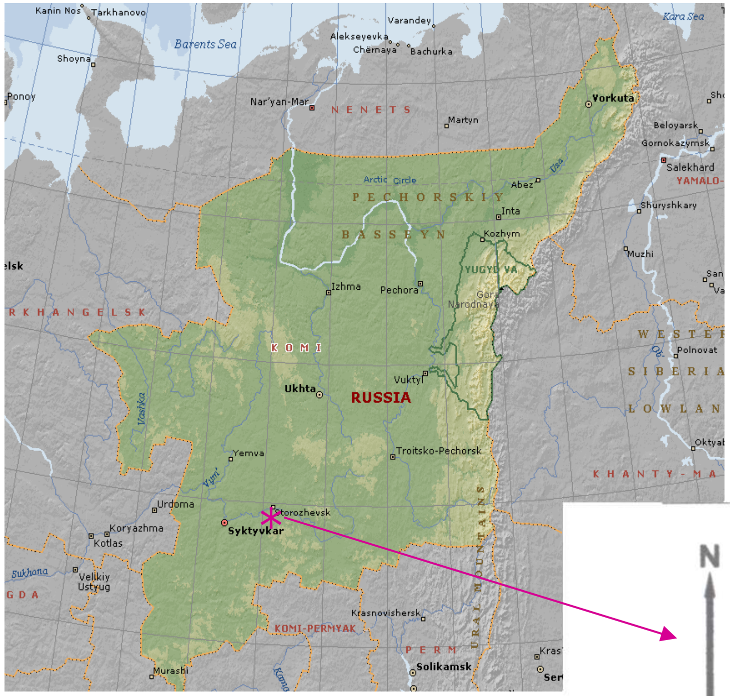
Basalts

Mean

HORIZON	CORG	N	CN	CEC	PHH2O	CSAND	FSAND	CSILT	FSILT	CLAY
A	.44	.04	9.49	2.58	5.78	51.26	43.36	.85	1.06	3.41
B	.29	.03	9.57	3.20	6.53	46.90	42.80	.87	1.67	7.77
C	.16	.02	7.19	1.97	5.60	46.91	47.02	.54	1.09	4.37
C surf	.71	.07	10.63	3.22	5.70	59.42	35.89	.93	1.46	2.36
Total	.32	.03	8.40	2.36	5.71	49.80	44.31	.70	1.16	3.99

Sandstones

Relief



~ 100 m

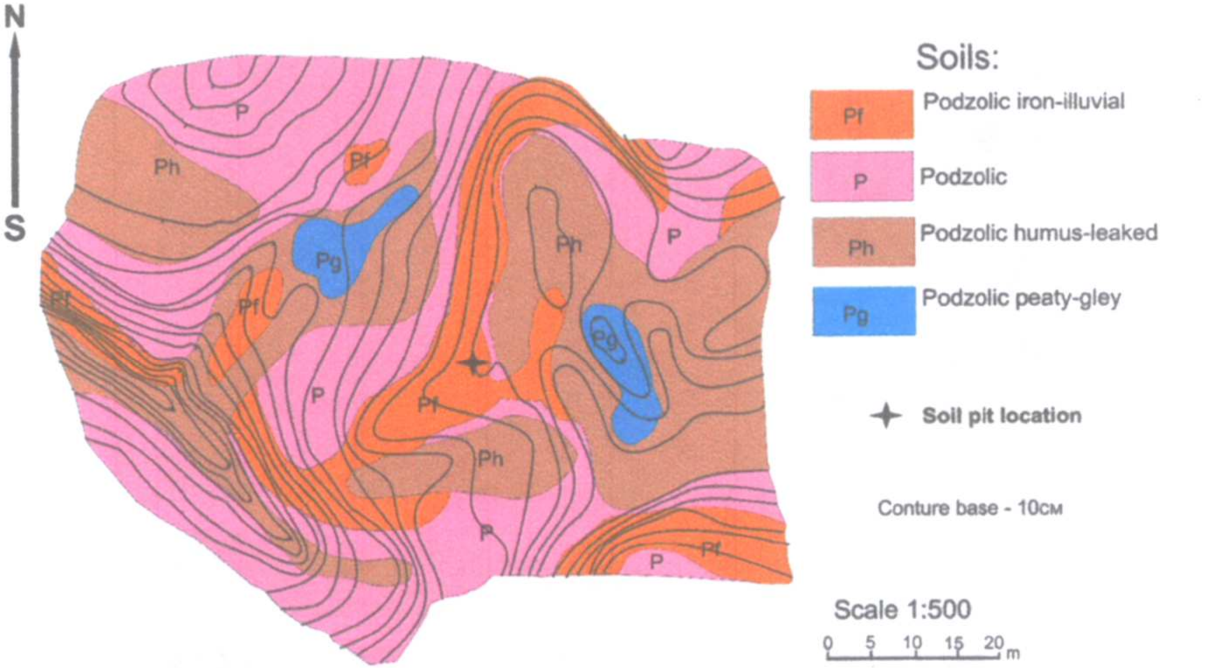


Figure 3: Soil map of pristine spruce forest site.

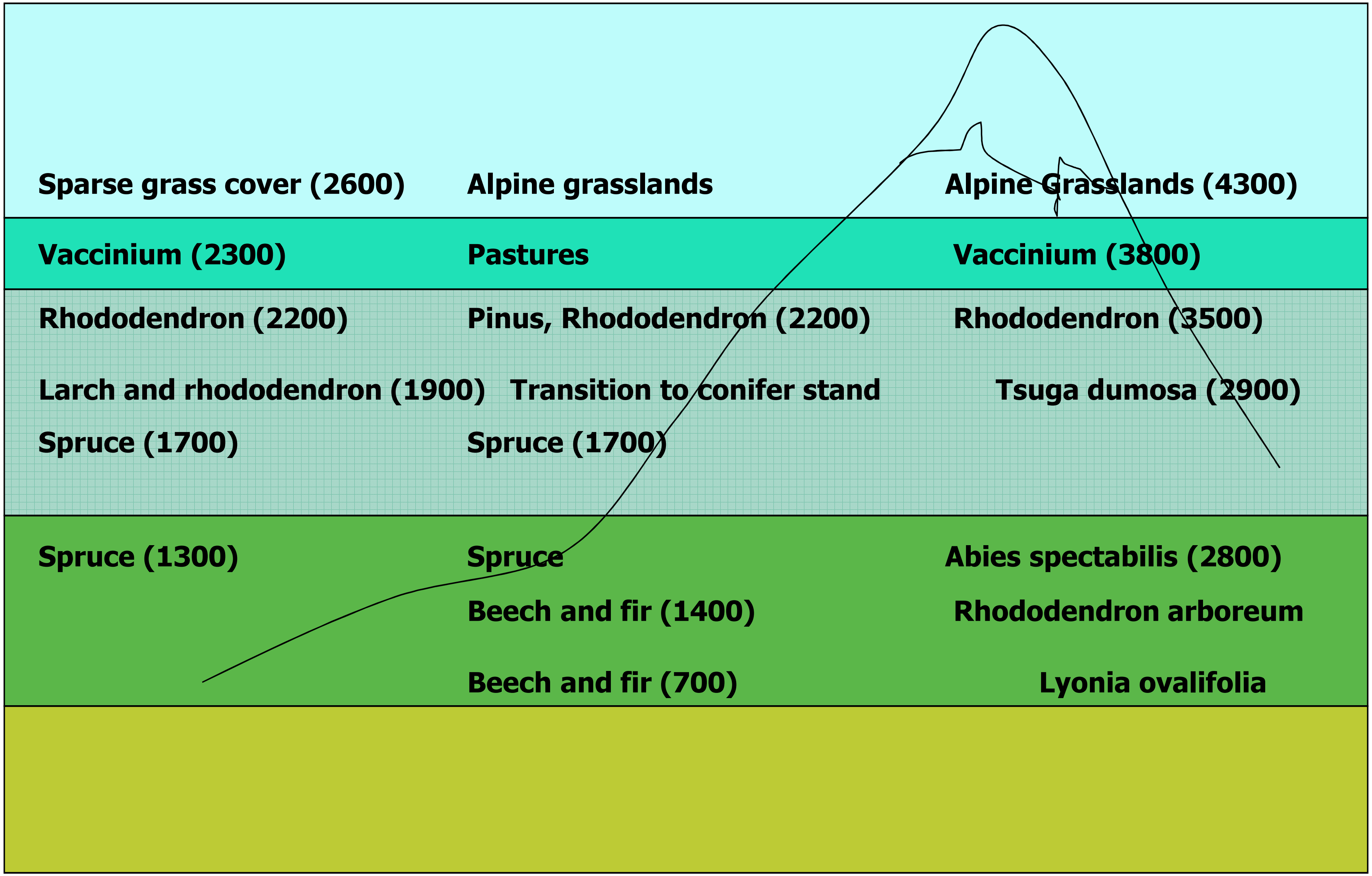
Simonov et al. (2007)

D’Amico et al., 2013

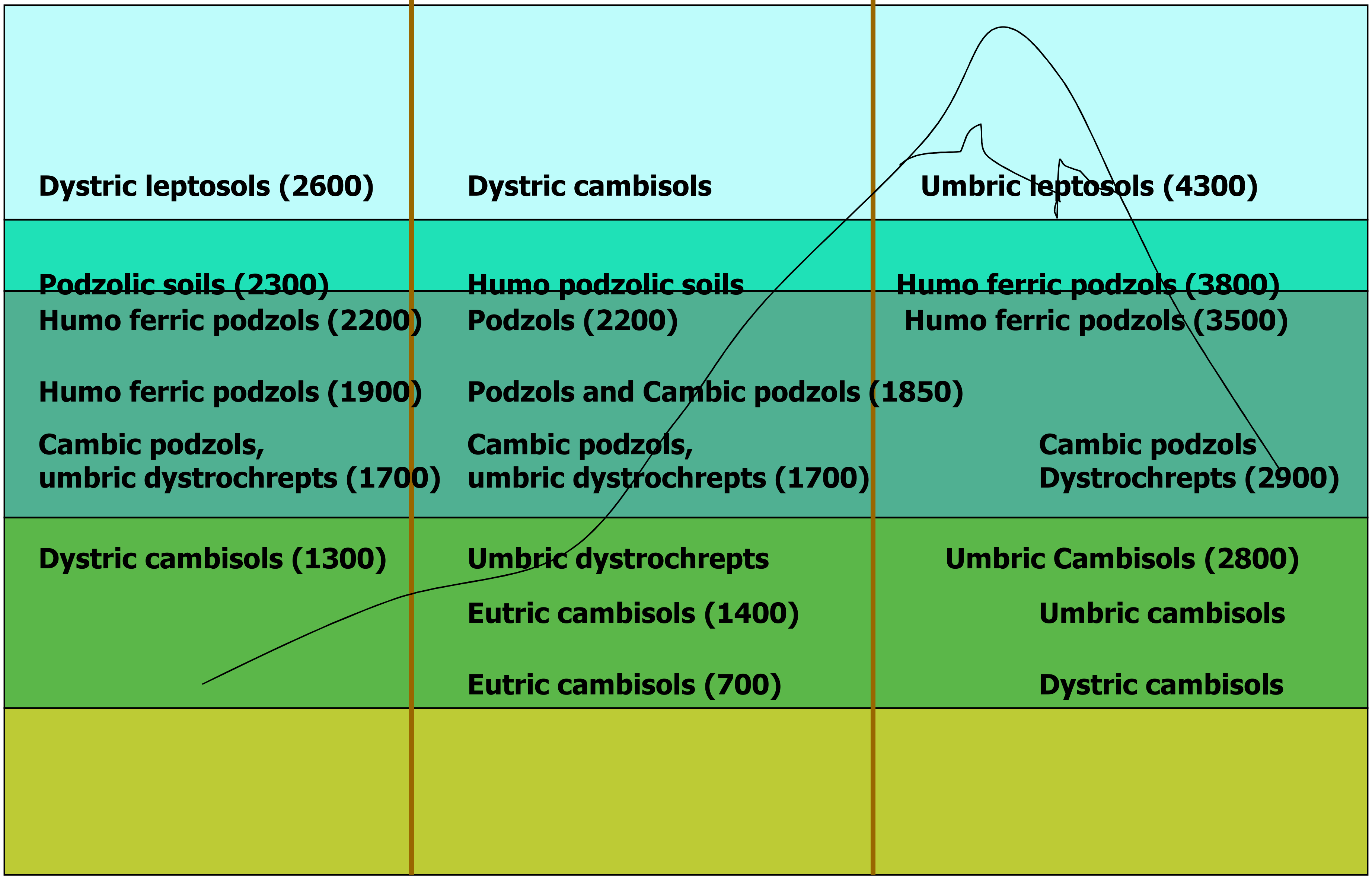
Time

SOIL Variability at the watershed level

1. Elevation (climate and vegetation)
2. Geology (parent material)
3. Topography (relief and time)

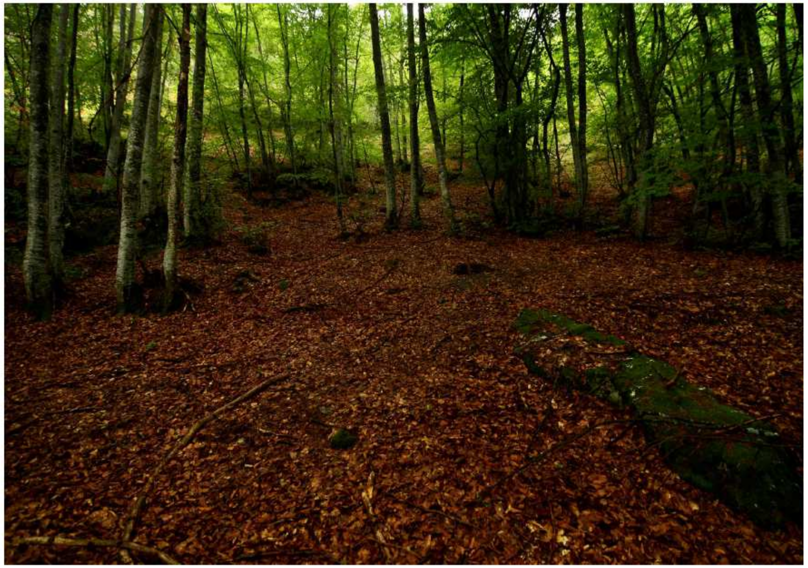


French Alps (granite)	*Carpathians (micas, silty clay deposits)*	*Himalaya (shales, schists and gneiss)*
Sparse grass cover (2600)	Alpine grasslands	Alpine Grasslands (4300)
Vaccinium (2300)	Pastures	Vaccinium (3800)
Rhododendron (2200)	Pinus, Rhododendron (2200)	Rhododendron (3500)
Larch and rhododendron (1900)	Transition to conifer stand	Tsuga dumosa (2900)
Spruce (1700)	Spruce (1700)	
Spruce (1300)	Spruce	Abies spectabilis (2800)
	Beech and fir (1400)	Rhododendron arboreum
	Beech and fir (700)	Lyonia ovalifolia

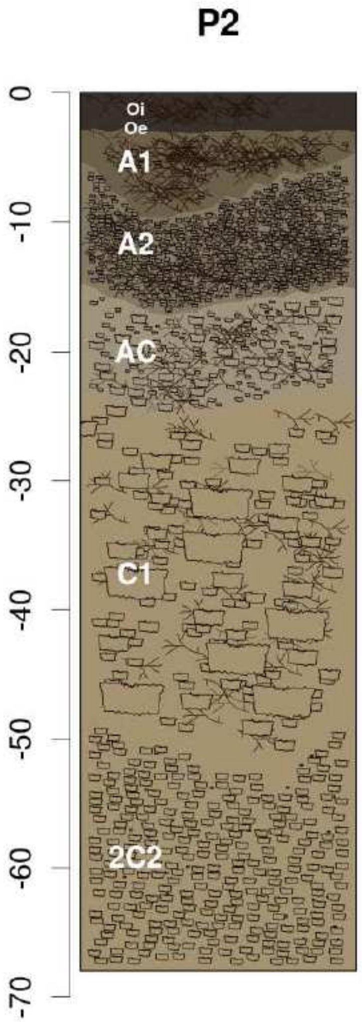


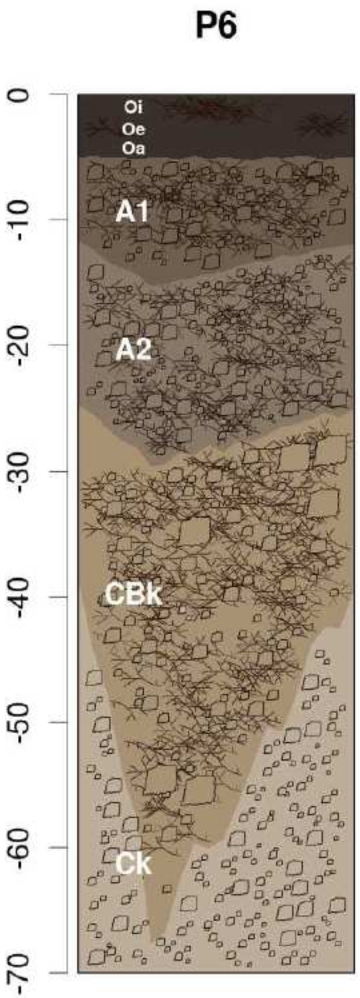
French Alps (granite)	Carpathians (micas, silty clay deposits)	Himalaya (shales, schists and gneiss)
Dystric leptosols (2600)	Dystric cambisols	Umbric leptosols (4300)
Podzolic soils (2300)	Humo podzolic soils	Humo ferric podzols (3800)
Humo ferric podzols (2200)	Podzols (2200)	Humo ferric podzols (3500)
Humo ferric podzols (1900)	Podzols and Cambic podzols (1850)	
Cambic podzols, umbric dystrochrepts (1700)	Cambic podzols, umbric dystrochrepts (1700)	Cambic podzols Dystrochrepts (2900)
Dystric cambisols (1300)	Umbric dystrochrepts	Umbric Cambisols (2800)
	Eutric cambisols (1400)	Umbric cambisols
	Eutric cambisols (700)	Dystric cambisols

ORMEA AREA
EFFECT OF PARENT MATERIAL

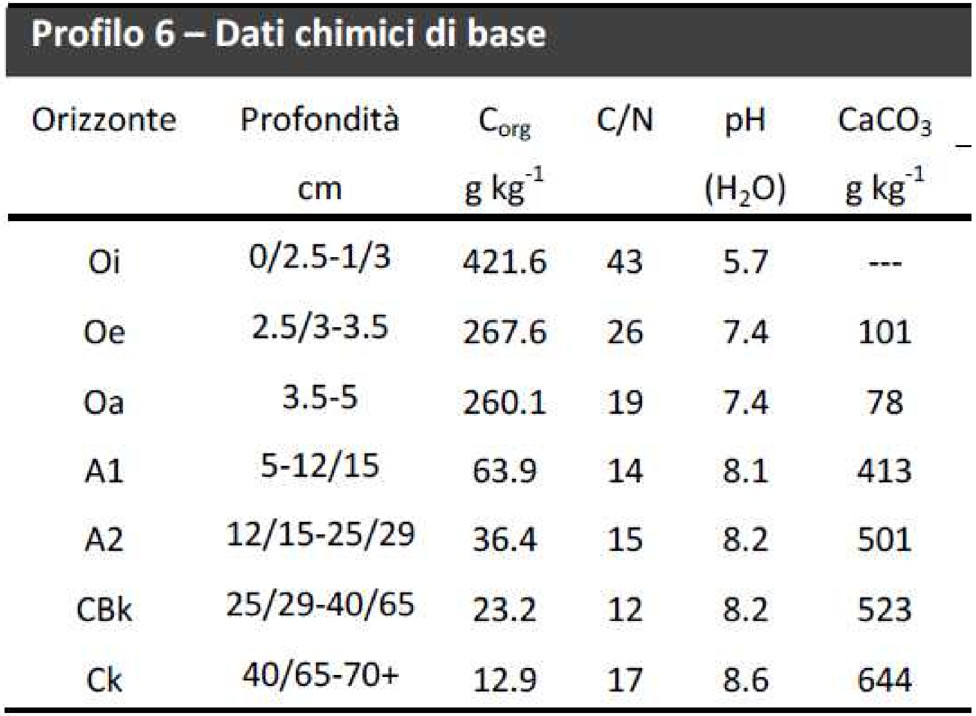


Non calcareous slates





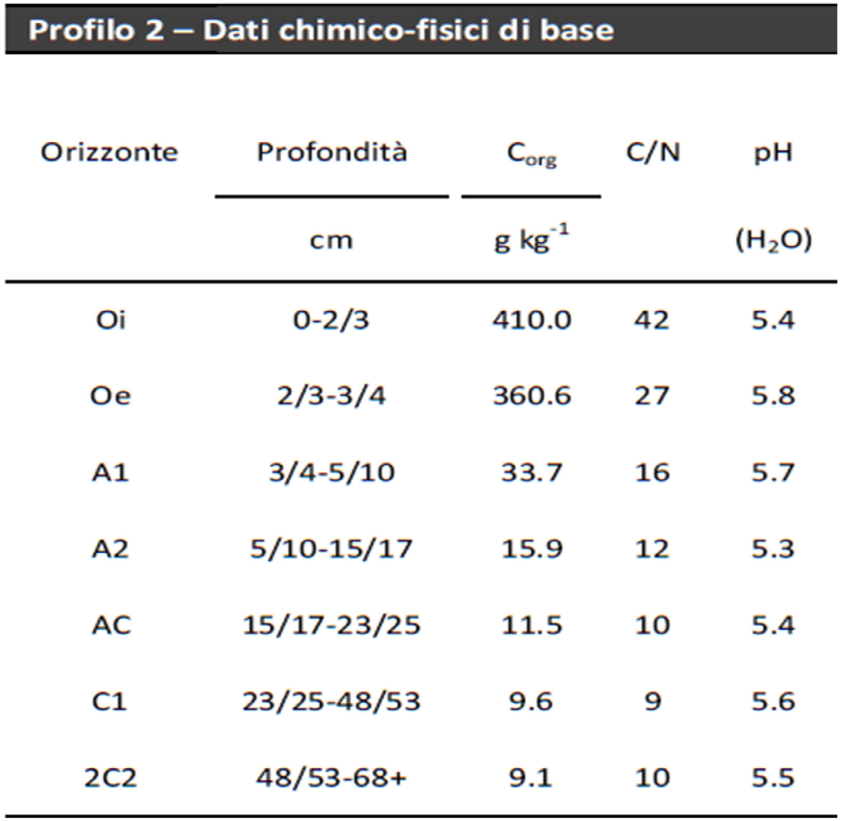
Calcareous deposits



Profilo 6 – Dati chimici di base

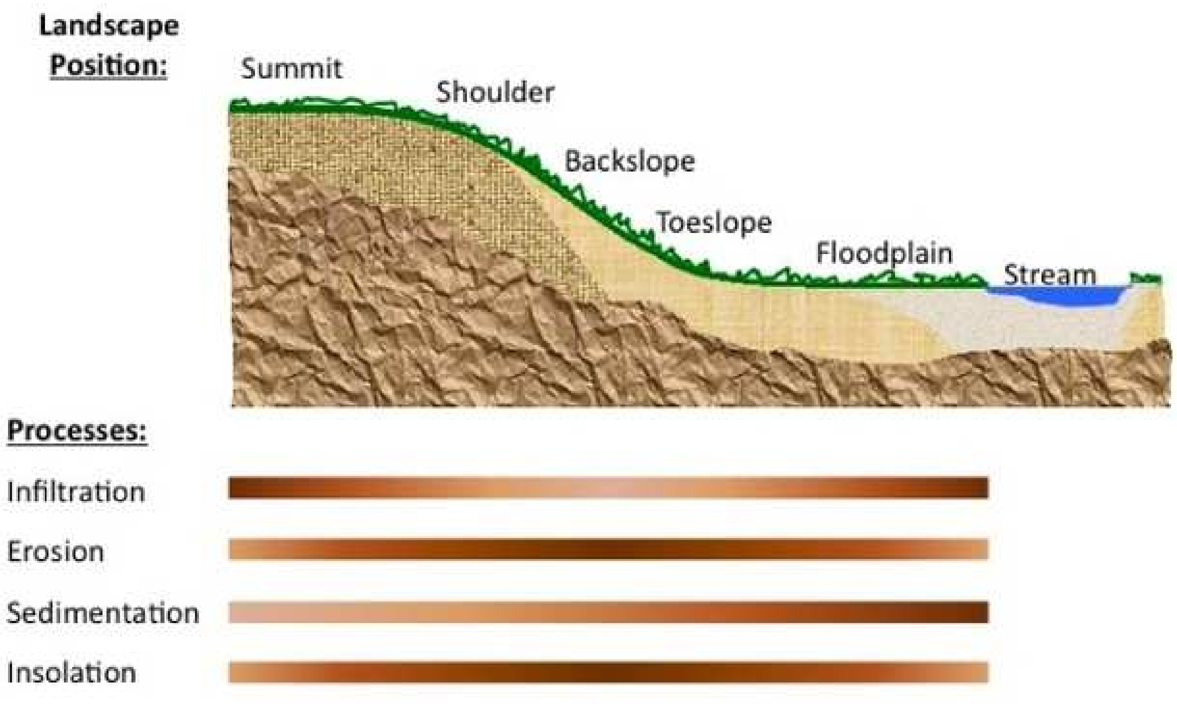
Orizzonte	Profondità	C_{org}	C/N	pH	$CaCO_3$
	cm	g kg^{-1}		(H_2O)	g kg^{-1}
Oi	0/2.5-1/3	421.6	43	5.7	---
Oe	2.5/3-3.5	267.6	26	7.4	101
Oa	3.5-5	260.1	19	7.4	78
A1	5-12/15	63.9	14	8.1	413
A2	12/15-25/29	36.4	15	8.2	501
CBk	25/29-40/65	23.2	12	8.2	523
Ck	40/65-70+	12.9	17	8.6	644

Different pH, amounts of carbonates



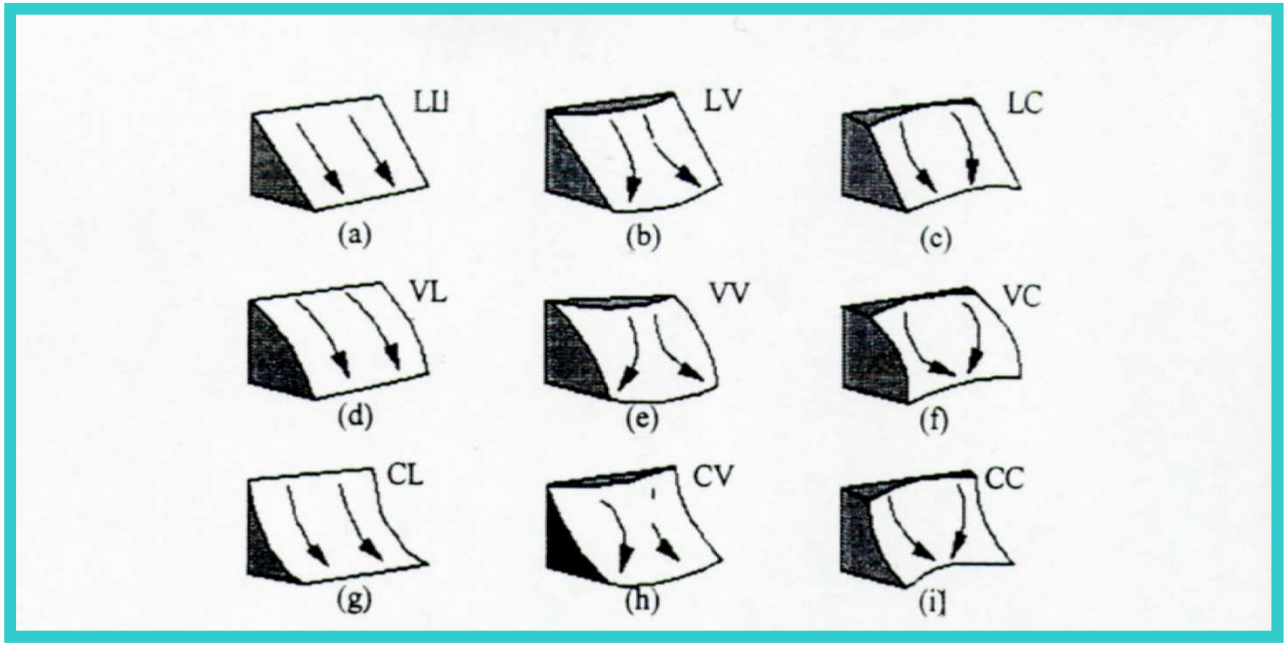
Profilo 2 – Dati chimico-fisici di base

Orizzonte	Profondità	C_{org}	C/N	pH
	cm	g kg^{-1}		(H_2O)
Oi	0-2/3	410.0	42	5.4
Oe	2/3-3/4	360.6	27	5.8
A1	3/4-5/10	33.7	16	5.7
A2	5/10-15/17	15.9	12	5.3
AC	15/17-23/25	11.5	10	5.4
C1	23/25-48/53	9.6	9	5.6
2C2	48/53-68+	9.1	10	5.5

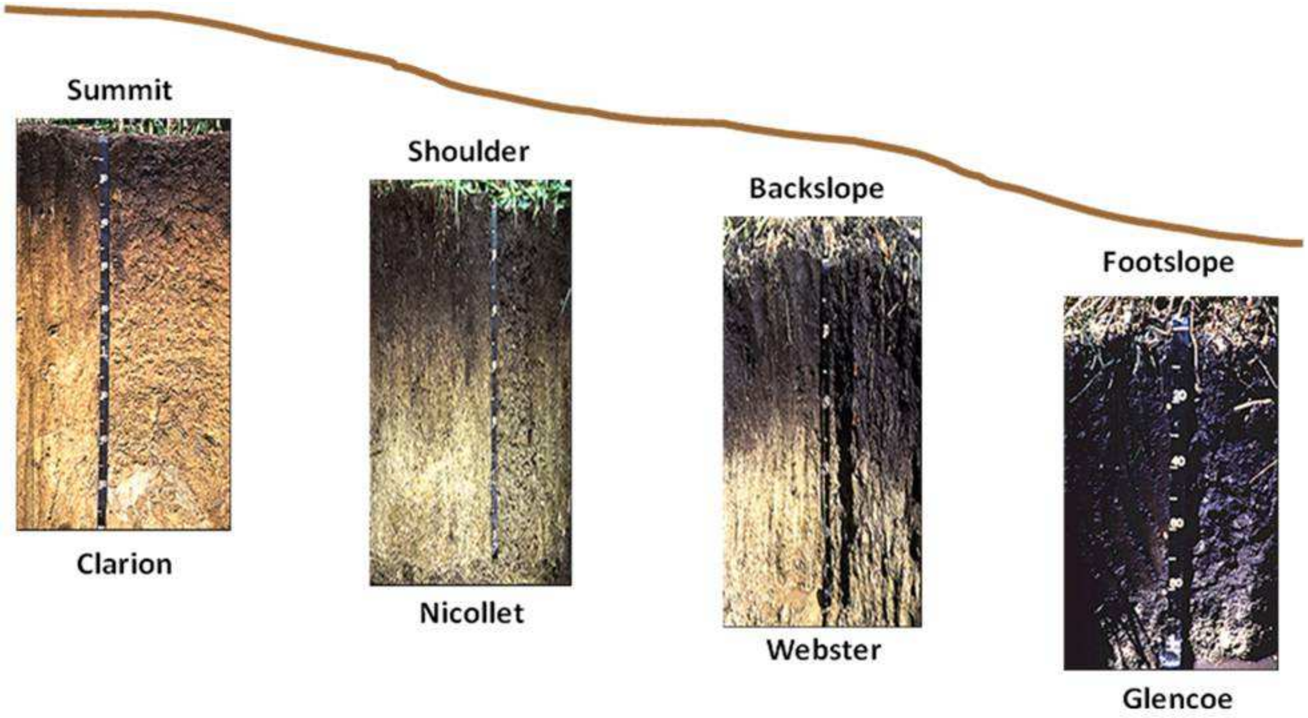


Slope positions with different stability. In some position transport dominates, in other sedimentation is more important

The shape of the slope influences where transported particles are accumulated



Clarion-Nicollet-Webster Catena Soil Profiles (Minnesota)



http://serc.carleton.edu/details/images/12506.html

Along a slope soil colours change from oxides ones to gley, soil water saturation increases
Typically clay increases towards the bottom of the slope

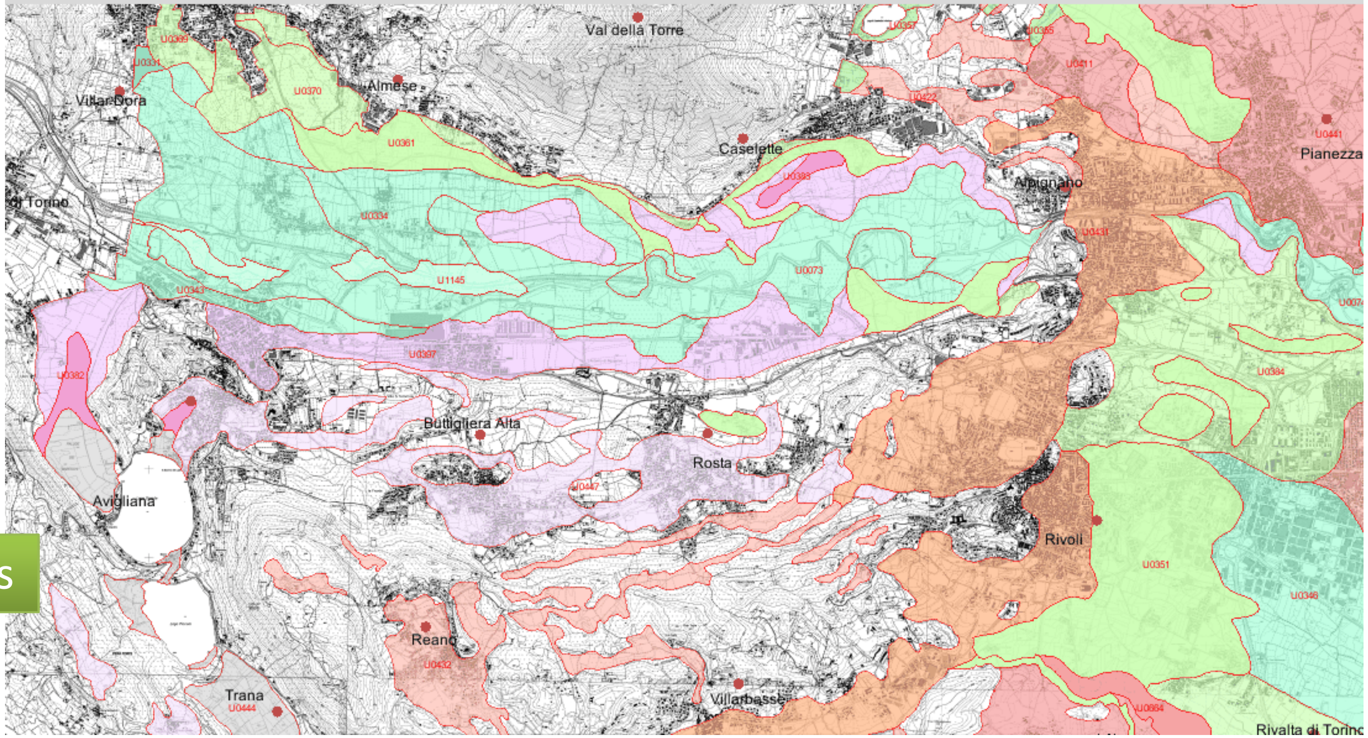
Evaluation of soil varibility → **SOIL MAPS**

To create a soil map, soil description, sampling and classification is done on homogeneous surfaces for all factors that influence soil variability: parent material, vegetation, relief, climate and time.
The scale sets which are the factors to be taken into account.

Different soil types

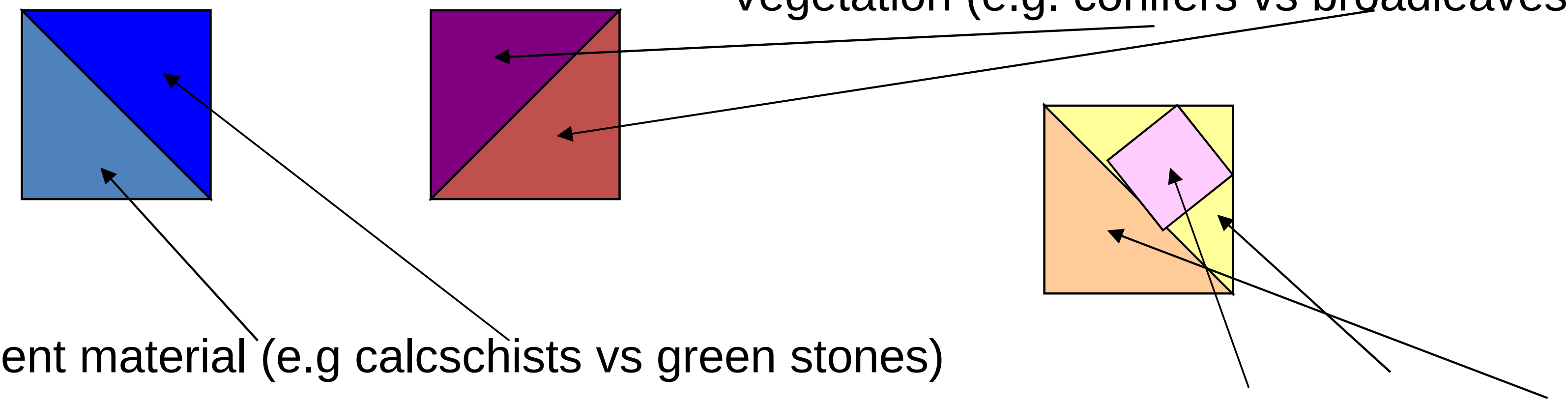
↓

Different soil properties



THE HOMOGENEOUS SURFACES are called Soil Mapping Units (or Land Mapping Units)

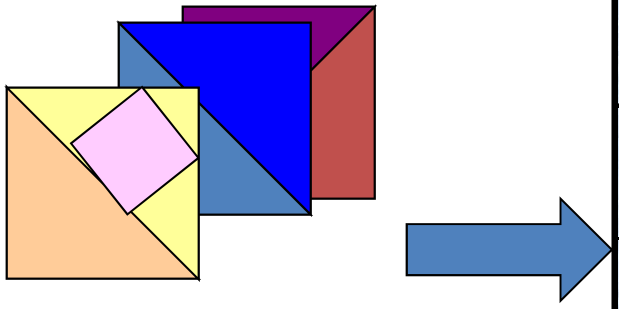
Building up of Land Mapping Units



Vegetation (e.g. conifers vs broadleaves)

Parent material (e.g calcschists vs green stones)

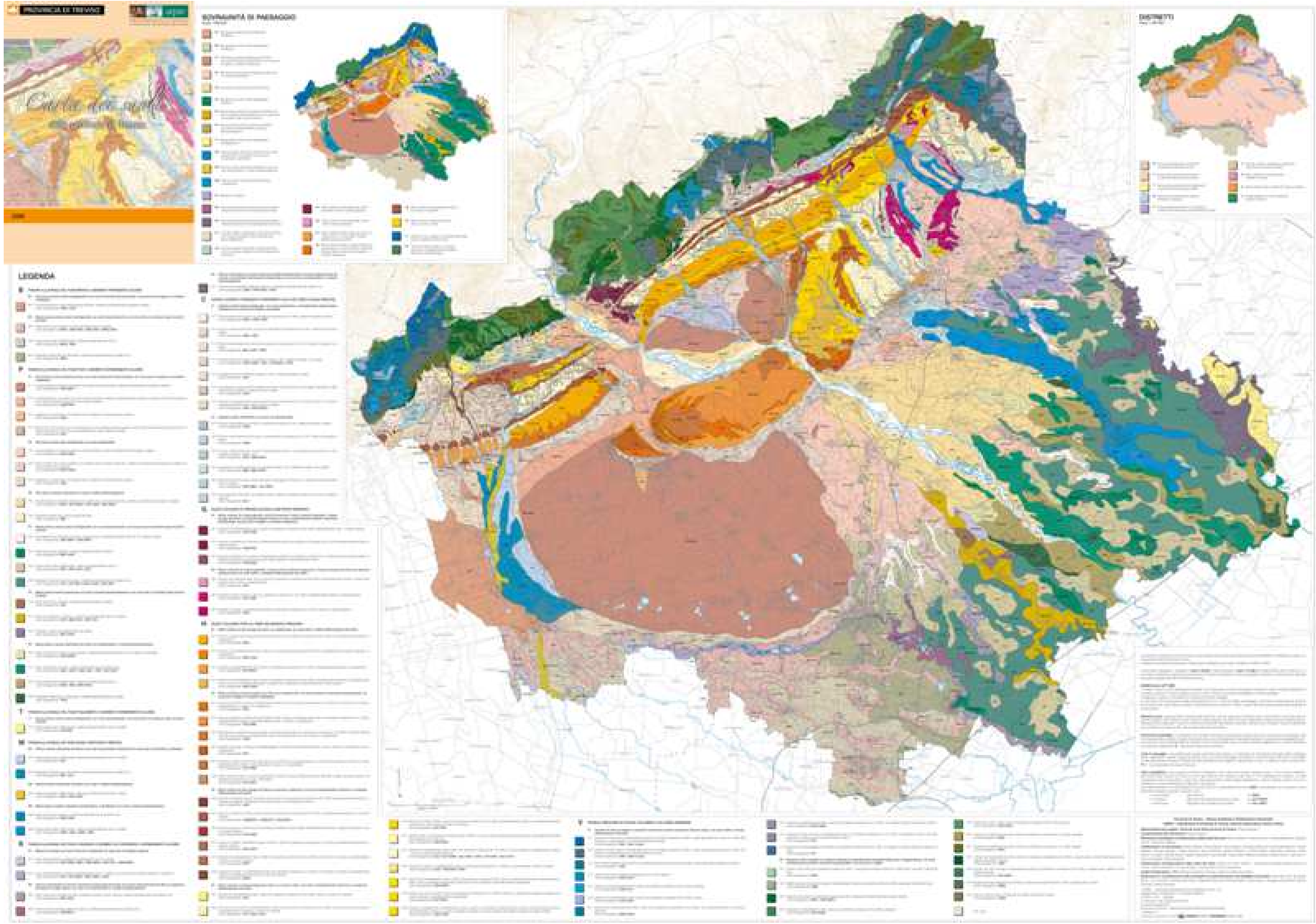
Slope class (e.g. >40%, 20-40%; <20%)



Conifers Broadleaves	>40%	20-40%	<20%
calcschists			1 2
Greenstones	5 6	3 4	

12 potential LMU but only 6 are actually present

An example of a soil map



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Dipartimento di Scienze Agrarie, Forestali e Alimentari

Soils and watershed management in mountain areas

Eleonora Bonifacio
University of Torino – DISAFA
Eleonora.bonifacio@unito.it

Mountain Partnership

IPROMO
12-23 July 2013 – Ormea (Italy)

Understanding Upland Watershed Management

SOIL EROSION: GENERAL CONCEPTS

Soil erosion refers to all processes that act on the soil surface and lead to losses of soil material by particle detachment and transport. The erored material is at least partially deposited in other areas.

Soil erosion is a natural process, occurring over geological time. With respect to soil degradation, most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased mostly by human activity.

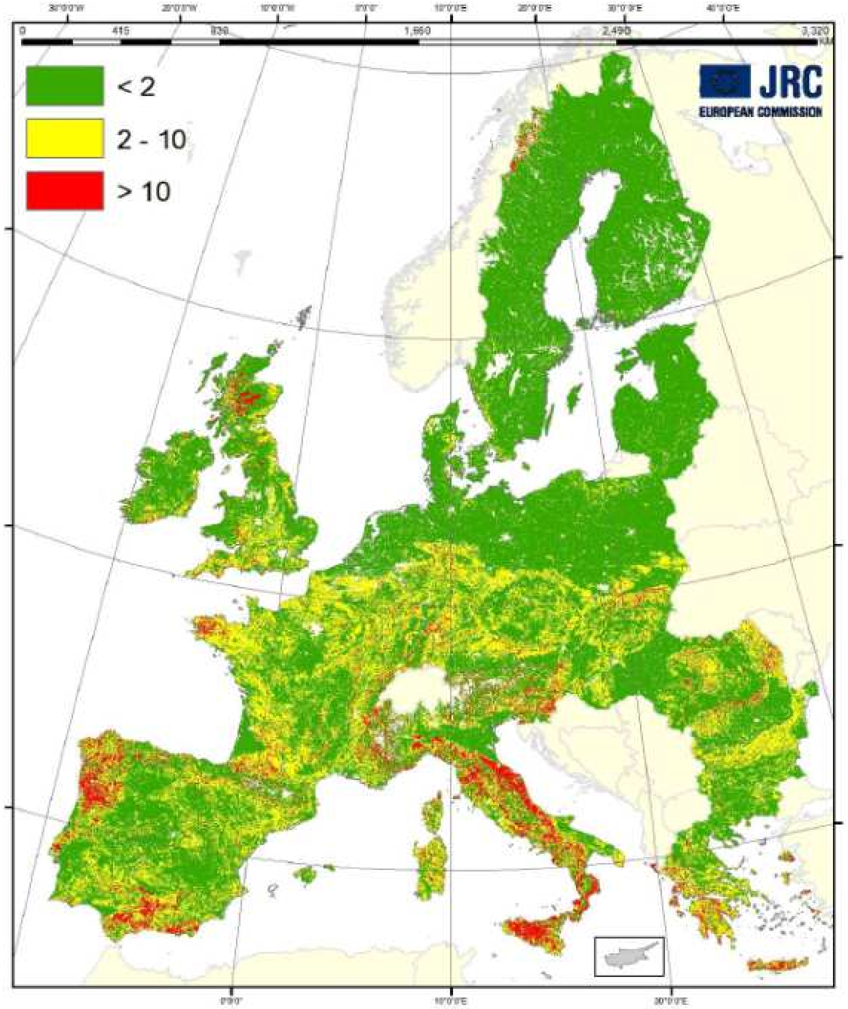
The processes of soil erosion involve detachment of material and transport either by saltation through the air or by overland water flow. Runoff is the most important direct driver of severe soil erosion by water and therefore processes that influence runoff play an important role in any analysis of soil erosion intensity.

By removing the most fertile topsoil, erosion reduces soil productivity and, where soils are shallow, may lead to an irreversible loss of this the resource. The soil removed by runoff accumulates below the eroded areas, in severe cases blocking roadways or drainage channels and inundating buildings.

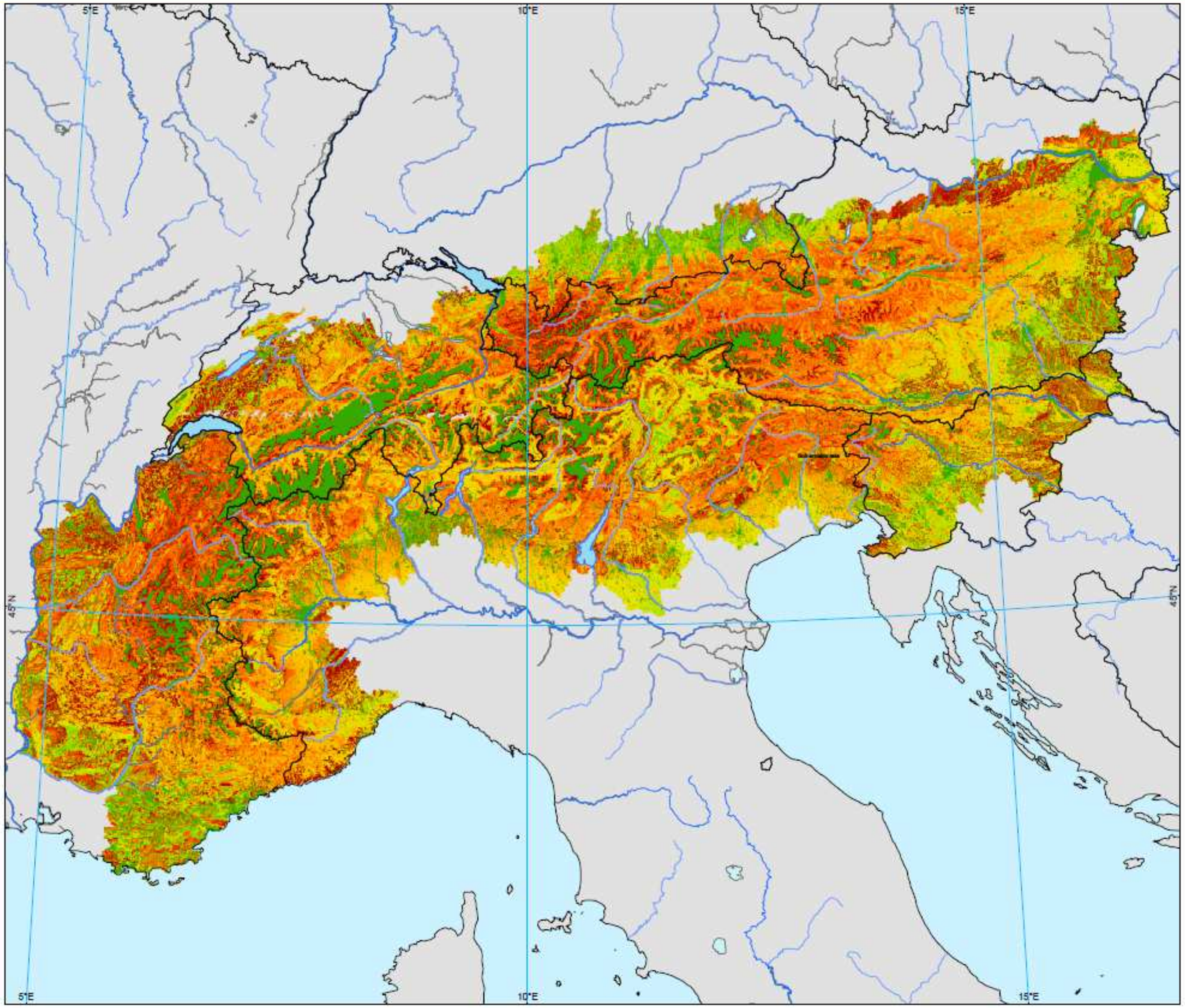
With a very slow rate of soil formation, any soil loss of more than 1 t ha^{-1}yr^{-1} can be considered as irreversible within a time span of 50-100 years. Losses of 20 to 40 t ha^{-1} in individual storms, that may happen once every two or three years, are measured regularly in Europe with losses of more than 100 t ha^{-1}in extreme events.

The main causes of soil erosion are still inappropriate agricultural practices, deforestation, overgrazing, forest fires and construction activities.

Figura 3: Erosione del suolo per azione dell'acqua nell'UE (t/ha/anno).



Soil Erosion in the Alps



Erosion Rate in the Alps

Soil Erosion (t / ha yr)

- 🟩 0 - 0.5
- 🟩 0.5 - 1
- 🟩 1 - 3
- 🟨 3 - 5
- 🟨 5 - 10
- 🟧 10 - 20
- 🟥 20 - 50
- 🟥 > 50
- ☐ Country boundary
- — Rivers (large)
- — Rivers (medium)
- 🟦 Lake (large)
- 🟦 Major water

N

This map shows the rate of soil erosion by water in the alpine territory.
This map is derived from the RUSLE model which calculates the actual sediment loss by soil erosion.
The index values indicate the intensity of the change in the soil erosion rate.

MAP INFORMATION

Spatial coverage : Alps as defined by Convention for Alps protection
Pixel size: 100 m
Projection: Lambert Azimuthal Equal Area

Input data - source

Climatic data - The rainfall measurement data have been provided by the International Centre for Theoretical Physics (ICTP) of Trieste. These data are the output of a prevision model of the climatic change (RegCM, Regional Climate Model), that provides the daily rainfall values for the years 1960 – 1990.

Soil data - European Soil Database

Land use - CORINE Land Cover 1990 and 2000

Topography - DEM SRTM (Shuttle Radar Topography Mission) has been used. The accuracy of the DEM is 90 m.

Model used : RUSLE (Revised Universal Soil Loss Equation)

BIBLIOGRAPHIC INFORMATION

Author(s) : Claudio Bosco, Ezio Rusco, Luca Montanarella, Stefano Oliveri & Panos Panagos
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For more information:

Dr. Luca Montanarella, European Commission, Joint Research Centre, Institute of Environment and Sustainability, Land Management & Natural Hazards Unit, Ispra, Italy.
Email: Luca.Montanarella@jrc.it

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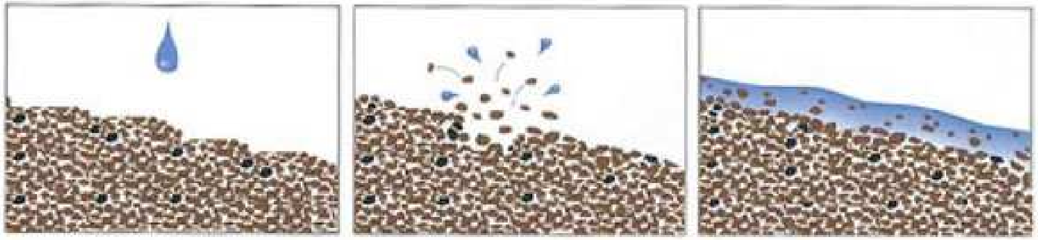
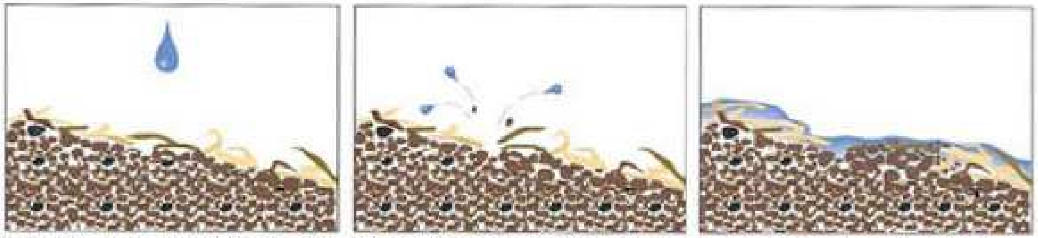


With no protective cover, raindrops can splash soil particles up to 3’ away. Soil particles and aggregates that have been detached are then transported down the slope by runoff water.



Residue cover cushions the fall of raindrops and reduces or eliminates splash erosion. Small natural dams are formed that cause ponding of runoff. Sediment is deposited in these ponds and remains in the field.

Manure application can result in improved soil aggregation which reduces the splash effect of raindrops and increases infiltration with reduced runoff.

Plant & Soil Sciences eLibrary^{PRO}
http://passel.unl.edu/pages/index.php?category=top0

Splash erosion or rain drop impact represents the first stage in the erosion process.

Erosion rate is very sensitive to **topography**, **climate** and **land use**.

Regions having long dry periods followed by heavy bursts of erosive rain are particularly prone to erosion. In other areas soil erosion is less because rain is evenly distributed throughout the year.

If the rainfall event provides more water than the amount that can enter the soil, the excess is accumulated on the soil surface and, depending on the slope gradient, runoff originates.

Runoff is the most important direct driver of severe soil erosion by water and therefore processes that influence runoff play an important role in any analysis of soil erosion intensity.

Runoff is mitigated by vegetation growing on the soil and by agricultural practices (e.g. mulching). Bare soils do not have any protection from runoff. Timing of agricultural and forestry practices is extremely important

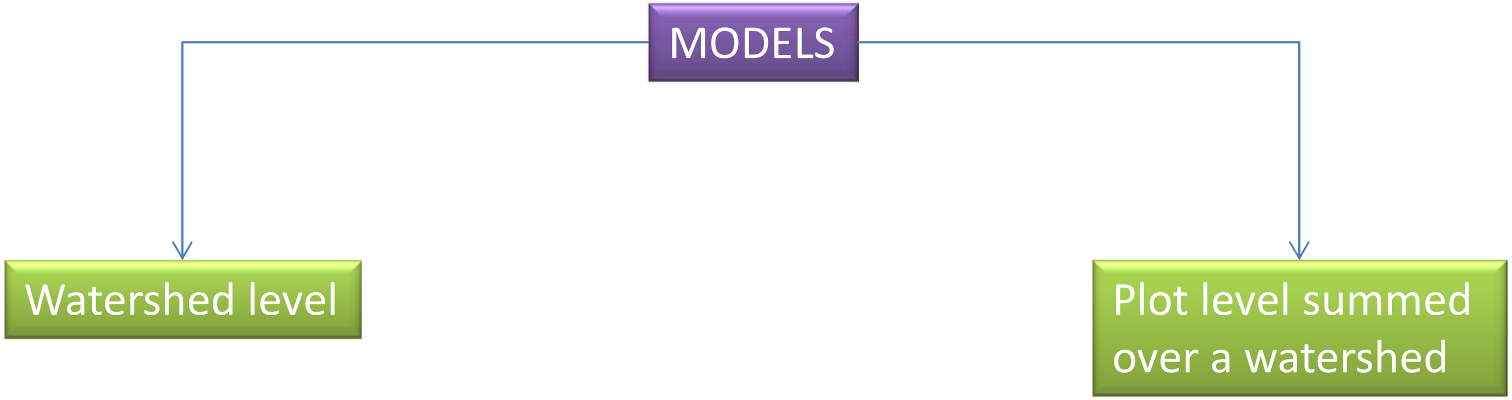
Sheet erosion: Detachment of soil particles by raindrop impact and their removal downslope by water flowing overland as a *sheet* instead of in definite channels or rills.

Rill erosion: process by which numerous sub-parallel and randomly occurring small channels are formed on slopes by running water.

Gully erosion occurs when running water erodes soil to form channels deeper than 30 cm.

How to evaluate soil erosion?

Direct measurements are complicated (sediment traps, isotopes….) thus very often modelling is used. We do not have evaluation we have estimates.



MODELS

Watershed level

Plot level summed over a watershed

- PSIAC (Pacific Southwest Inter Agency Committee, 1968)
- Gavrilovich (1971)

- USLE (Pacific Southwest Inter Agency Committee, 1968)
- Gavrilovich (1971)

Other models have been developed which are more physically based, but they often require so many parameters that their application is complicated and, often, unprecise. An example is EUROSEM http://www.eurosem-soil-erosion.org/

Pacific Southwest

INTER - AGENCY COMMITTEE

Report of the Water Management Subcommittee

Rating of determining factors at the watershed level then conversion to sediment yield

Factor	Rating classes
Surface Geology	10-5-0
Soils	10-5-0
Climate	10-5-0
Runoff	10-5-0
Topography	20-10-0
Ground cover	10-0-(-10)
Land use	10-0-(-10)
Upland erosion	25-10-0
Channel erosion and sediment transport	25-10-0

____________ Watershed ______ State ____________ Condition

____________ Subwatershed   Name ____________

________ Acres

PSIAC – 1968

Date ____________

SEDIMENT YIELD FACTOR RATING

SURFACE GEOLOGY (a)	SOILS (b)	CLIMATE (c)	RUNOFF (d)	TOPOGRAPHY (e)
(10) a. Marine shales and related mudstones and siltstones	(10) a. Fine textured; easily dispersed; saline-alkaline; high shrink-swell characteristics b. Single grain silts and fine sands	(10) a. Storms of several days' duration with short periods of intense rainfall b. Frequent intense convective storms c. Freeze-thaw occurrence	(10) a. High peak flows per unit area b. Large volume of flow per unit area	(20) a. Steep upland slopes (in excess of 30%) b. High relief; little or no floodplain development
(5) a. Rocks of medium hardness b. Moderately weathered c. Moderately fractured	(5) a. Medium textured soil b. Occasional rock fragments c. Caliche layers	(5) a. Storms of moderate duration and intensity b. Infrequent convective storms	(5) a. Moderate peak flows per unit area b. Moderate volume of flow per unit area	(10) a. Moderate upland slopes (less than 20%) b. Moderate fan or floodplain development
(0) a. Massive, hard formations	(0) a. High percentage of rock fragments b. Aggregated clays c. High in organic matter	(0) a. Humid climate with rainfall of low intensity b. Precipitation in form of snow c. Arid climate, low intensity storms d. Arid climate; rare convective storms	(0) a. Low peak flows per unit area b. Low volume of runoff per unit area c. Rare runoff events	(0) a. Gentle upland slopes (less than 5%) b. Extensive alluvial plains
Factor value				

GROUND COVER (f)	LAND USE (g)	UPLAND EROSION (h)	CHANNEL EROSION AND SEDIMENT TRANSPORT (i)
(10) Ground cover does not exceed 20% a. Vegetation sparse; little or no litter b. No rock in surface soil	(10) a. More than 50% cultivated b. Almost all of area intensively grazed c. All of area recently burned	(25) a. More than 50% of the area characterized by rill and gully or landslide erosion	(25) a. Eroding banks continuously or at frequent intervals with large depths and long flow duration b. Active headcuts and degradation in tributary channels
(0) Cover not exceeding 40% a. Noticeable litter b. If trees present understory not well developed	(0) a. Less than 25% cultivated b. 50% or less recently logged c. Less than 50% intensively grazed d. Ordinary road and other construction	(10) a. About 25% of the area characterized by rill and gully or landslide erosion b. Wind erosion with deposition in stream channels	(10) a. Moderate flow depths, medium flow duration with occasionally eroding banks or bed
(−10) a. Area completely protected by vegetation, rock fragments, litter b. Little opportunity for rainfall to reach erodible material	(−10) a. No cultivation b. No recent logging c. Low intensity grazing	(0) a. No apparent signs of erosion	(0) a. Wide shallow channels with flat gradients and short flow duration b. Channels in massive rock, large boulders, or well vegetated c. Artificially controlled channels
Factor value			

	Subtotal (a) – (g)	Subtotal (h) – (i)	TOTAL RATING – – – = – – . – ac.ft./sq. mi./yr.

(Instructions on reverse)

SHEET _____ OF _____

GENERAL INSTRUCTIONS

District Office prepares one copy for District file.

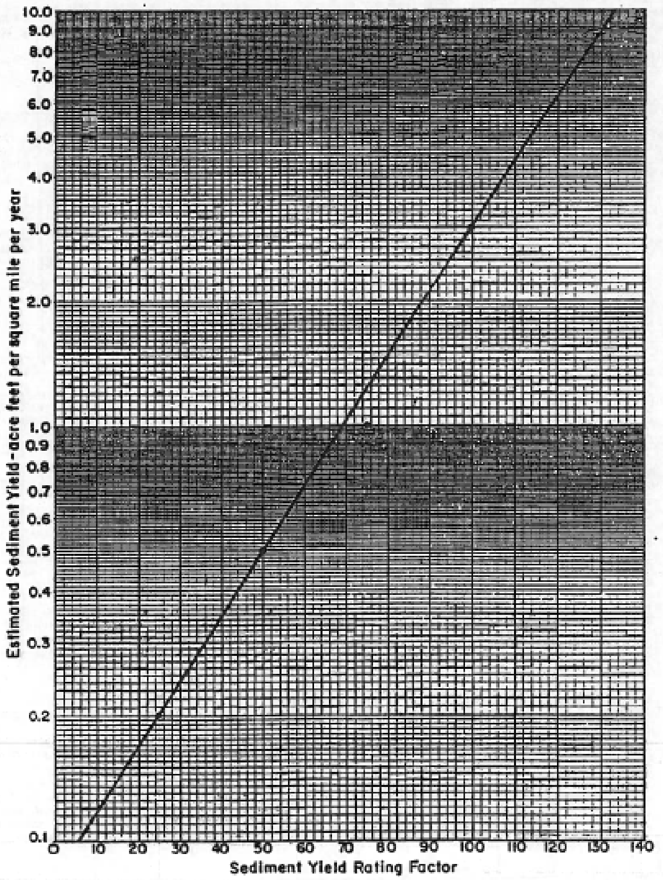
SPECIFIC INSTRUCTIONS

(Items not listed are self-explanatory)

Numbers indicate values assigned appropriate characteristics. Letters a, b, c, and d refer to independent characteristics to which full value may be assigned.

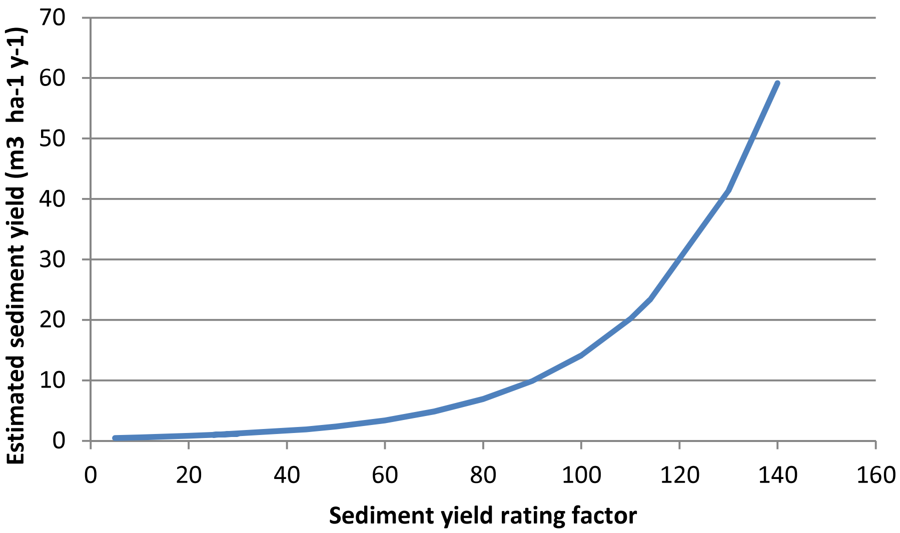
Interpolation between the sediment yield levels may be made. High values for columns (a) through (g) should correspond to high values for (h) and (i). If they do not, factors (a) through (g) should be reevaluated. If they do not correspond, then a special erosion condition exists.

Convert *Total Rating* to sediment yield by use of graph.



$Y = 0.0816\, e^{0.0353X}$

GPO 836-319



$$Y = 0.3939\, e^{0.0358\, x}$$

Rating Factor	Erosion Class	Sediment yield ($m^3ha^{-1}y^{-1}$)
> 100	1	>14.29
75-100	2	4.76-14.29
50-75	3	2.38-4.76
25-50	4	0.95-2.38
0-25	5	<2.38

1 $m^3ha^{-1}y^{-1}$ correspond to a loss of 0.1 mm of soil
Assuming a bulk density of 1.3 T m^{-3} a loss of 1 m^3 ha^{-1} y^{-1} correspond to 1.3 T ha^{-1} y^{-1}

Gavrilovich developed a method that was applied to southern and south-eastern watersheds of Jugoslavia

The basic principles are similar to those of the PSIAC model, but a lower degree of expert judgement is required, as many ratings are found from their relationships with quantitative variables.

$$W = T \times h \times \pi \times \sqrt{Z^3 \times F}$$

W = sediment yield (m^3)
T = temperature coefficient (from average mean annual temperature)
H = annual rainfall (mm)
Z = geologic-pedologic and topographic factor (obtained from tables)
F= watershed surface (Km^2)

It’s an empirical model, it needs to be tested before being applied to other environments

The U.S.L.E Model

(Universal Soil Loss Equation)

$$\boxed{A = R \times K \times LS \times C \times P}$$

A = annual soil loss [t ha $^{-1}$ y^{-1}]

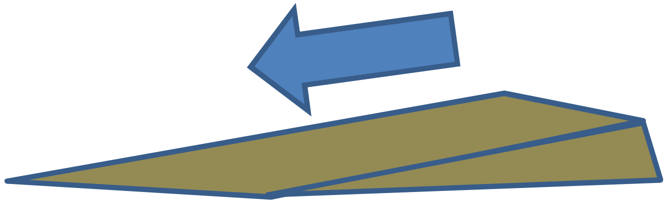
R = rainfall erosivity [MJ mm h^{-1} ha^{-1} y^{-1}]

K = soil erodibility [t ha h MJ^{-1} mm^{-1}]

LS = topographic factor

C = protection factor (land cover)

P = erosion control factor



It’s an empirical equation that was originally formulated based on more than 10000 data on erosion plots in 46 areas of the Great Plains .
Since its original development (Wischmeier & Smith, 1960, 1978) it has been revised (RUSLE, 1985) to allow its application in different environments. Moreover it may be used on GIS (imprtant for topographic factors in a watershed or in a non-agricultural lanscape)

$$A = R \times K \times LS \times C \times P$$

R is the rainfall erosivity index, it takes into account both the kinetic energy of rain drops and rainfall intensity

If all other parameters are held constant, soil losses during a rainfall event are linearly related to a kinetic Energy-Intensity factor (EI). For multiple events EI values are additive.
EI indicates how particle detachment is combined with transport capacity.

$$EI = 0.119 + 0.0873\ \log_{10} I$$

EI in MJ ha^{-1} mm^{-1}

$$R = EI \times I_{30}$$

I_{30} is the maximum rainfall intensity during an event of at least 30'

Practically, becuase of lack of rainfall data, a number of estimates have been developed

R = (4.17 X MFI – 152) X 17.02 (Arnoldus, 1980)

Monthly rainfall

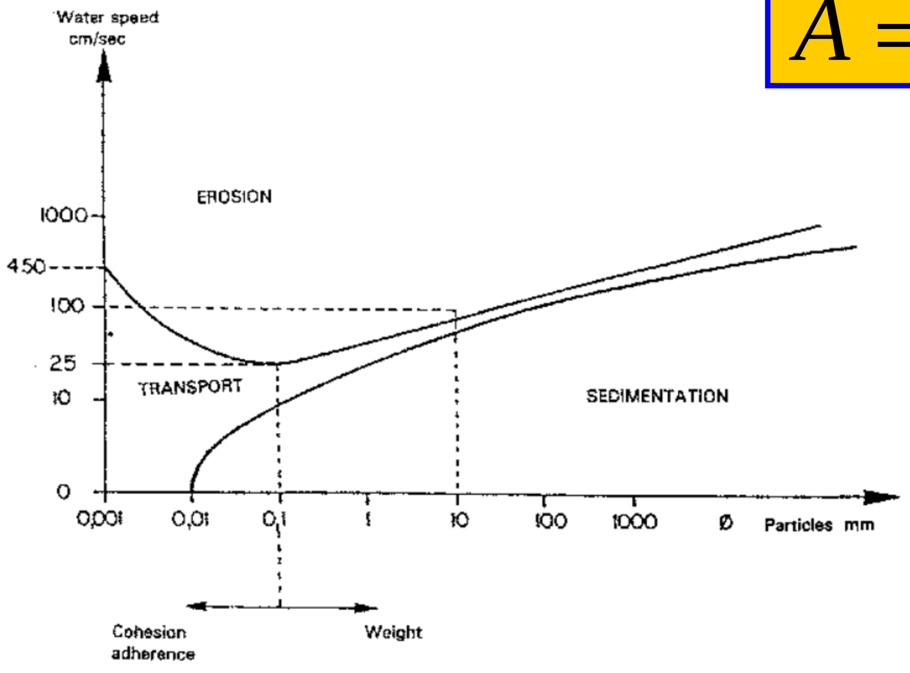
Where MFI is the *Modified Fournier Index*

$$MFI = \frac{\sum {p_i}^2}{P}$$

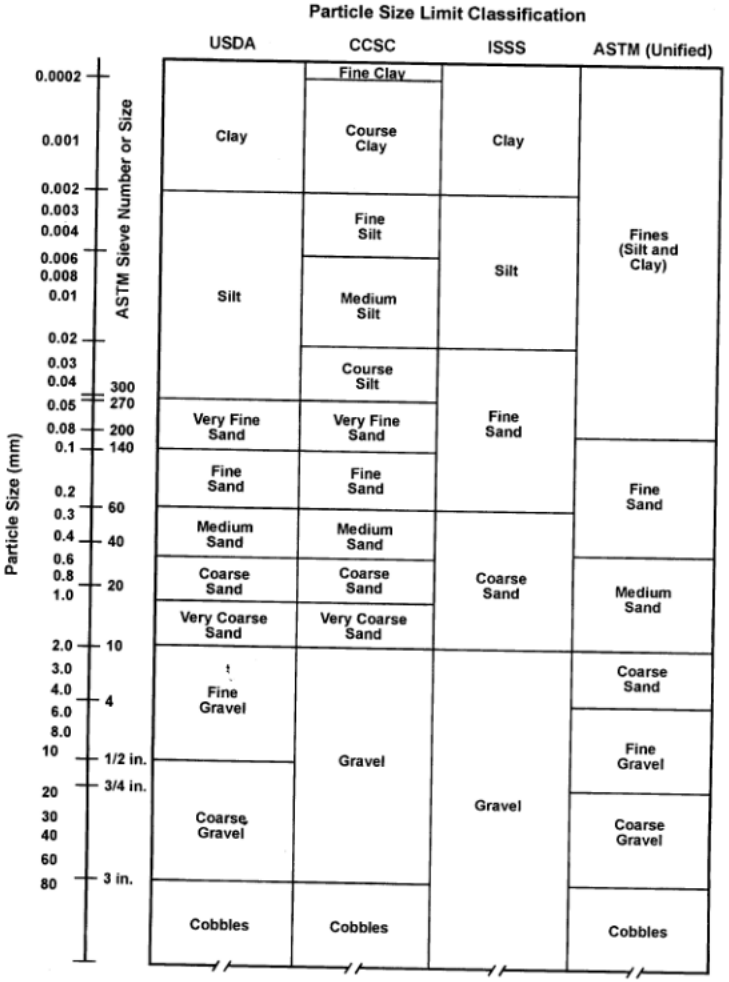
Annual rainfall

And the coefficients allow the transformation from mmm to MJ mm ha^{-1} y^{-1}

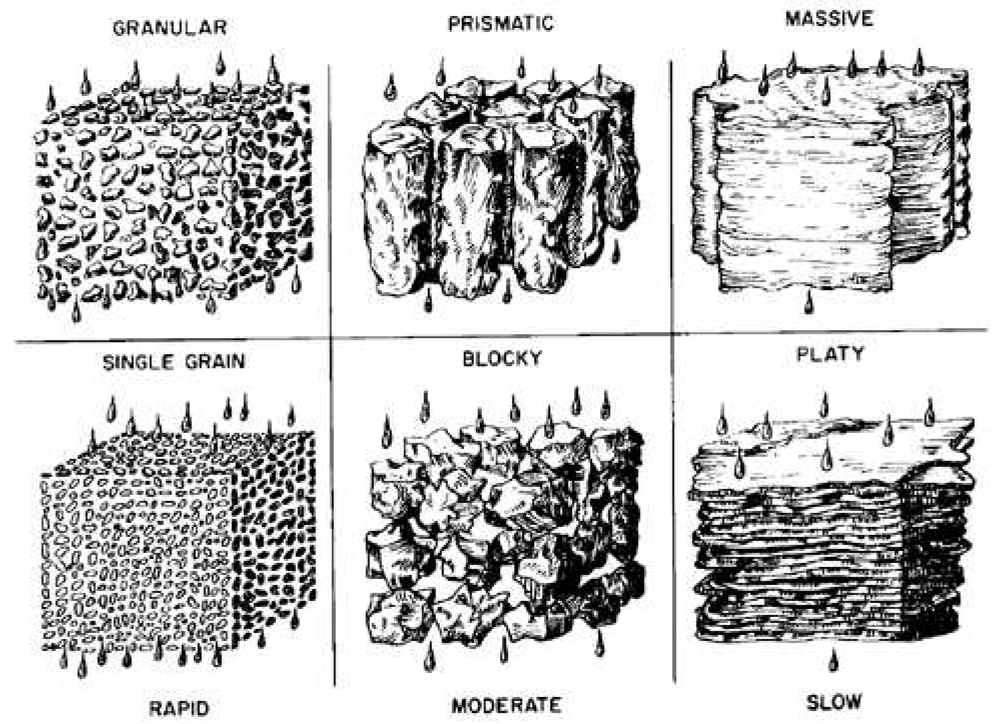
$$A = R \times K \times LS \times C \times P$$



- Very fine sand (0.1-0.05 mm) is the most sensitive to erosion particle size class. Silt (0.05-0.002 mm) is also easily eroded. In addition soil texture affects soil permeability.
- Aggregation contrasts splash erosion and organic matter is the most important aggregating agent in many soils.
- Aggregation is visible in the field through soil structure. Structure also affects permeability



Soil pemeability (P)		Soil structure (S)	
1	Fast (> 12.7 cm h^{-1})	1	Very fine granular
2	From moderate to fast (6.4-12.7 cm h^{-1})	2	Fine granular
3	Moderate (2.0-6.4 cm h^{-1})	3	Medium granular
4	From slow to moderate (0.5-2.0 cm h^{-1})	4	Blocky, platy or massive
5	Slow (0.1-0.5 cm h^{-1})		
6	Very slow (<0.1 cm h^{-1})		



P and S are highly interrelated!

P depends on soil texture and soil structure.
S in turns depends on texture, organic matter and other factors such as biotic activity (e.g earthworms) and man

$$A = R \times K \times LS \times C \times P$$

K (soil erodibility) in T h MJ^{-1} mm^{-1}

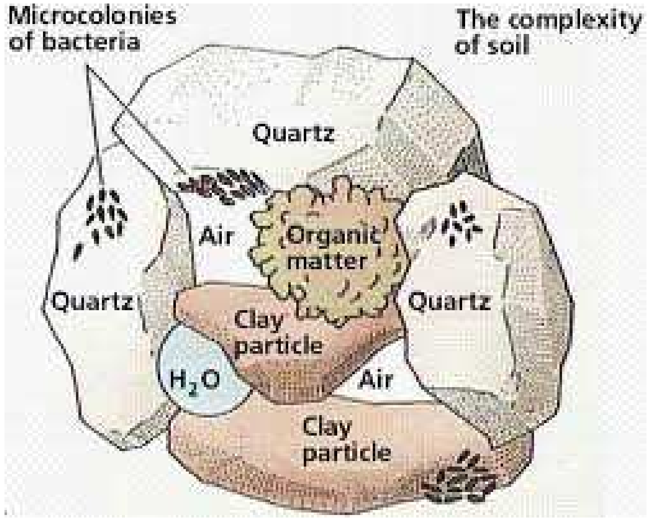
$$K = \frac{2.1 \times 10^{-4} \times (12 - OM) \times M^{1.14} + 3.25 \times (S-2) + 2.5 \times (P-3)}{7.59 \times 100}$$

Where OM is soil organic matter

M is (silt + very fine sand) x (100 – clay)

P ranges from 1 to 6 increasing with decreasing soil permeability
S ranges from 1 to 4 depending on soil structure

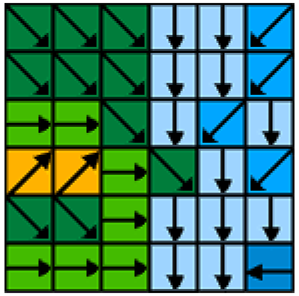
Wang et al., 2001



$$\boxed{A = R \times K \times LS \times C \times P}$$

Erosion increases with increasing lenghth and slope. LS is a dimensionless topographic factor, it takes into account the length and the slope of the plot
It is now computed using GIS that allow the calculation of the additional parameters related to erosion.

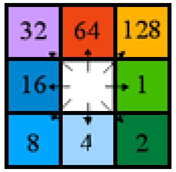
Flow accumulation (F) represents the n of cells contributing flow to a specific cell


Flow direction

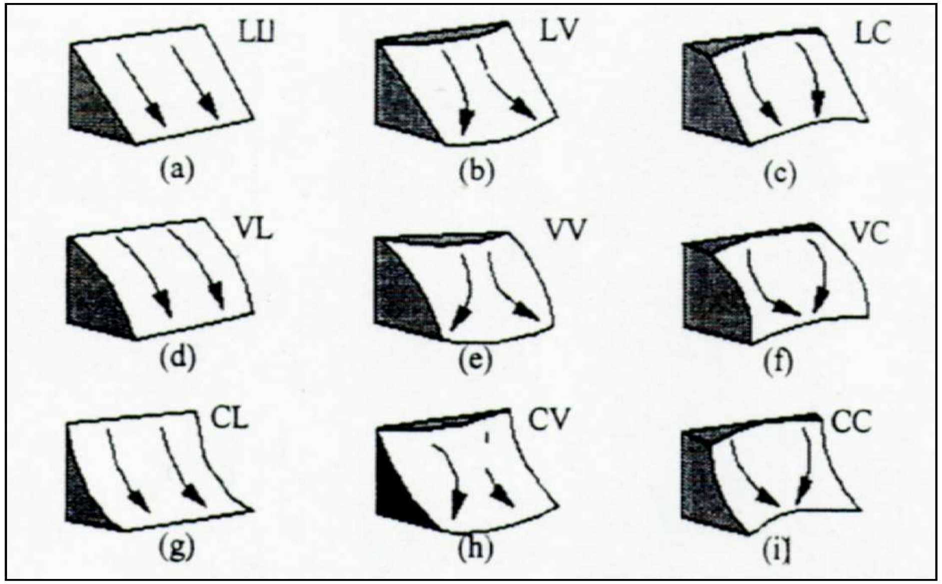
→

0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2

Flow accumulation



Direction coding



$$LS = \left(\frac{F \times C}{22.13}\right)^{0.4} \times \left(\frac{\sin S}{0.09}\right)^{1.3}$$

C length of cell side
S slope

$$A = R \times K \times LS \times C \times P$$

The C factor takes into account soil cover and the protection offered towards erosion. Practically it's the ratio between soil losses under a specific land use and the losses from a bare soil surface.

Forest land use	C	
Shrubs	0.05	Stone & Hilborn, 2000
Mixed forests, 75-100% canopy cover, 90-100 % ground cover by litter	0.002	Wischmeier & Smith, 1978
Mixed forests, 45-70% canopy cover, 75-85 % ground cover by litter	0.003	Wischmeier & Smith, 1978
Mixed forests, 20-40% canopy cover, 40-70 % ground cover by litter	0.007	Wischmeier & Smith, 1978
Grasslands and pastures	0.02	Stone & Hilborn, 2000
Sparse vegetation and areas with frequent wildfires	0.3	Stone & Hilborn, 2000

$$\boxed{A = R \times K \times LS \times C \times P}$$

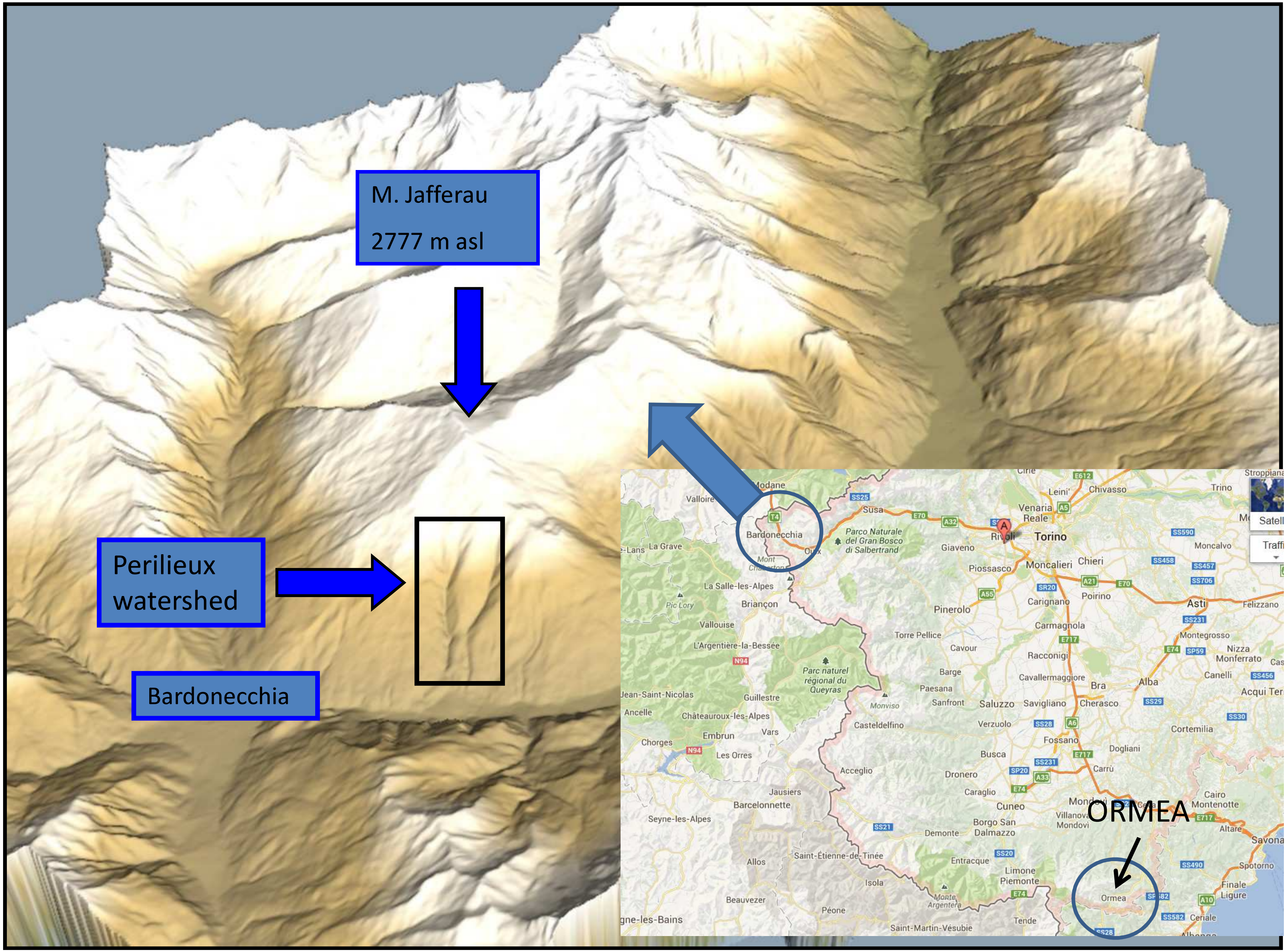
How to apply the USLE equation to a watershed? → Land Mapping Units

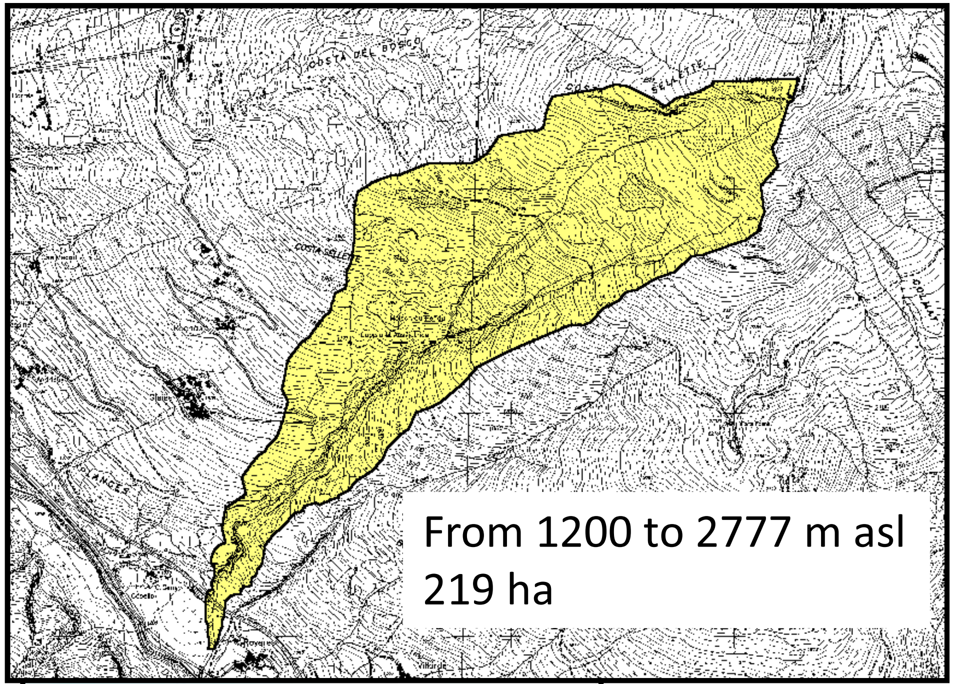
A LMU is a portion of the earth surface that is homogeneous for all properties under consideration

K: Soil particle size distribution and organic matter

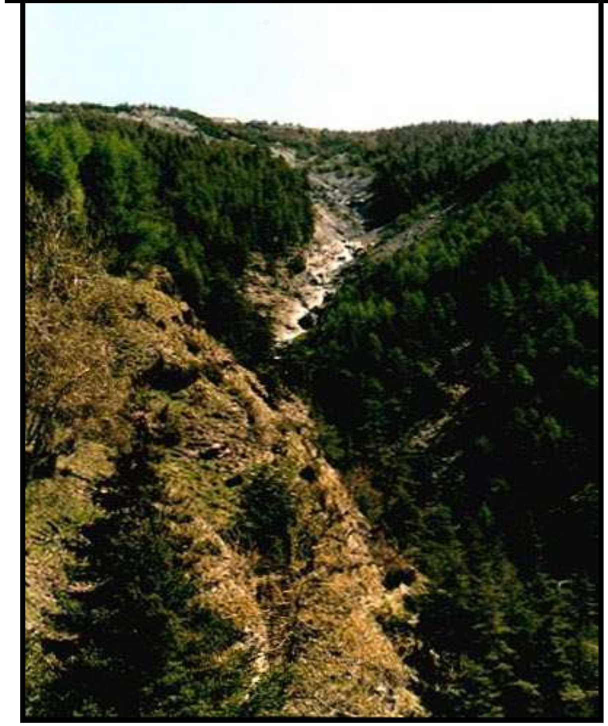
Parent material
Topography (slope class)
Vegetation
Climate
Time

C: land cover/land use


M. Jafferau
2777 m asl
Perilieux watershed
Bardonecchia
ORMEA
Modane
Valloire
Bardonecchia
Oulx
Susa
Parco Naturale del Gran Bosco di Salbertrand
Giaveno
Rivoli
Torino
Venaria Reale
Leinì
Chivasso
Cirié
Trino
Moncalvo
Chieri
Moncalieri
Piossasco
Carignano
Poirino
Asti
Felizzano
Pinerolo
Carmagnola
Torre Pellice
Cavour
Racconigi
Montegrosso
Nizza Monferrato
La Grave
La Salle-les-Alpes
Briançon
Pic Lory
Vallouise
L'Argentière-la-Bessée
Parc naturel régional du Queyras
Guillestre
Jean-Saint-Nicolas
Ancelle
Châteauroux-les-Alpes
Embrun
Vars
Chorges
Les Orres
Barge
Paesana
Sanfront
Monviso
Saluzzo
Savigliano
Cavallermaggiore
Bra
Alba
Cherasco
Canelli
Acqui Terme
Casteldelfino
Verzuolo
Fossano
Cortemilia
Busca
Dogliani
Acceglio
Dronero
Carrù
Caraglio
Cuneo
Mondovì
Villanova Mondovì
Cairo Montenotte
Altare
Savona
Jausiers
Barcelonnette
Seyne-les-Alpes
Demonte
Borgo San Dalmazzo
Allos
Saint-Étienne-de-Tinée
Entracque
Limone Piemonte
Spotorno
Finale Ligure
Isola
Monte Argentera
Ormea
Beauvezer
Péone
Saint-Martin-Vésubie
Tende
Ceriale
Satellite
Traffic

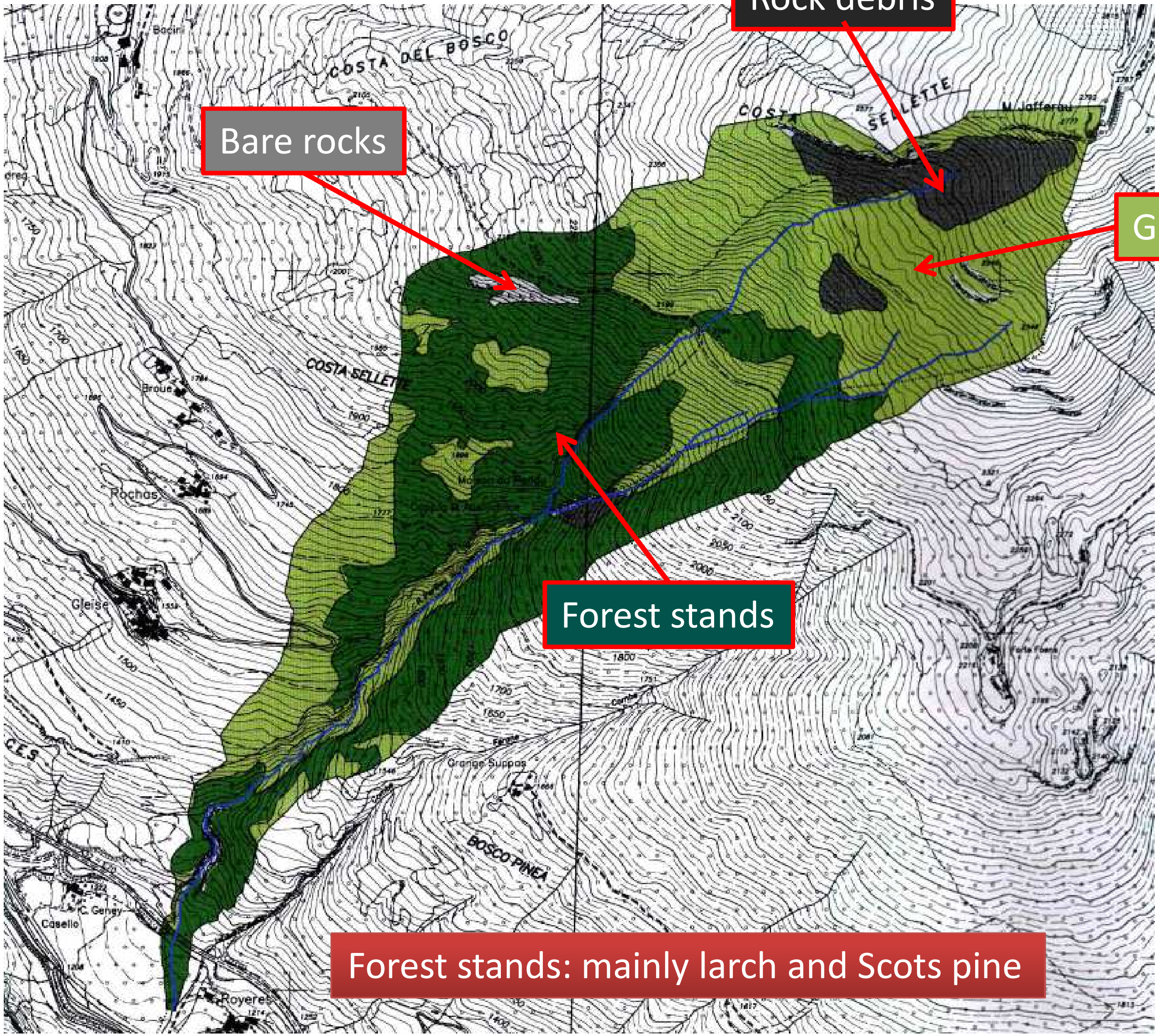


From 1200 to 2777 m asl
219 ha



Climatic data, Bardonecchia (30 years)

Month	Rainfall (mm)	Average Temp. (°C)
January	51	3.1
Febraury	53	3.4
March	54	5.4
April	64	8.7
May	76	12.2
June	65	15.5
July	40	18.6
August	50	17.7
September	63	15.2
October	81	12.4
November	73	6.3
December	54	4.0



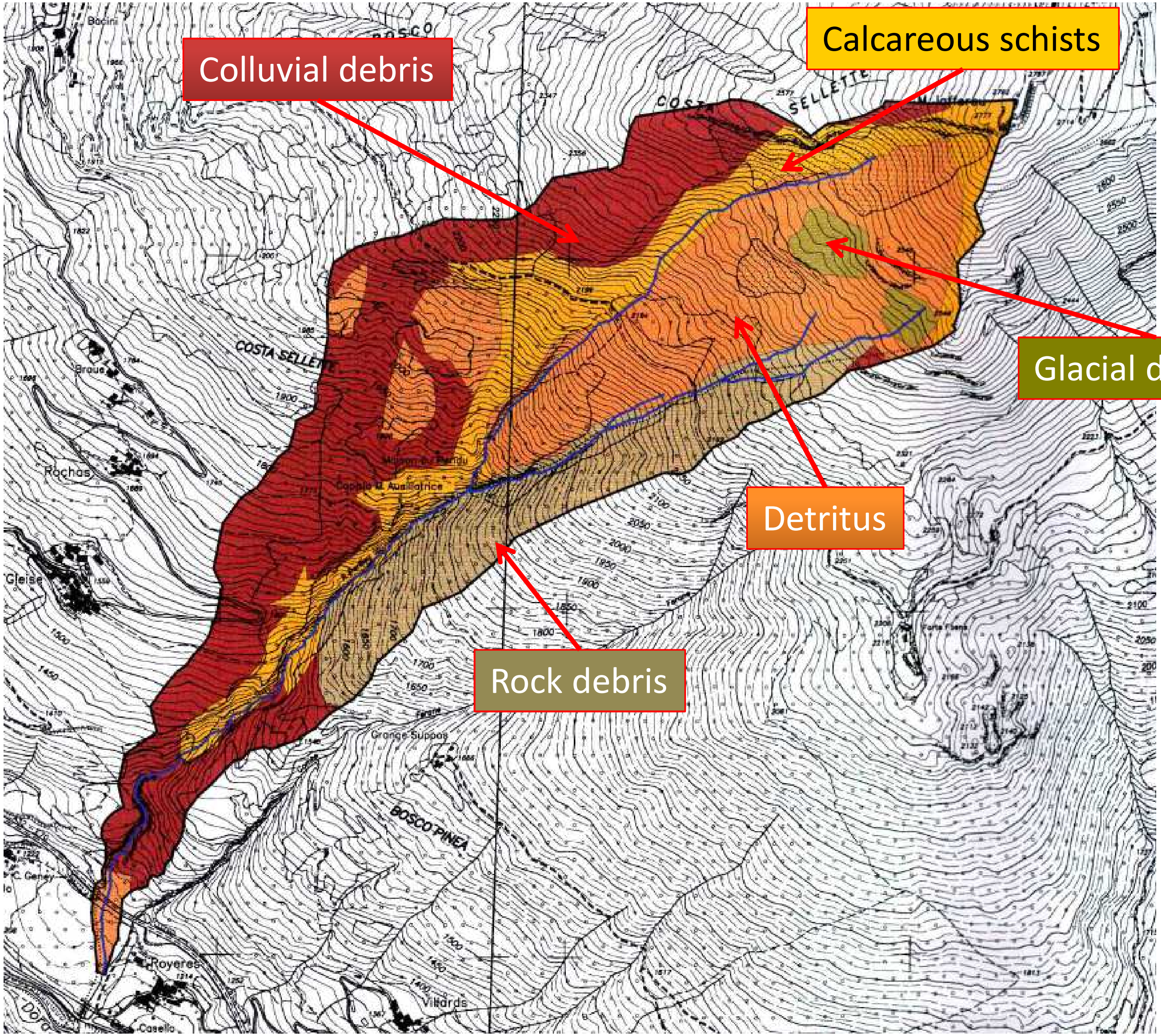
Rock debris

Bare rocks

Grasslands

Forest stands

Forest stands: mainly larch and Scots pine



Colluvial debris

Calcareous schists

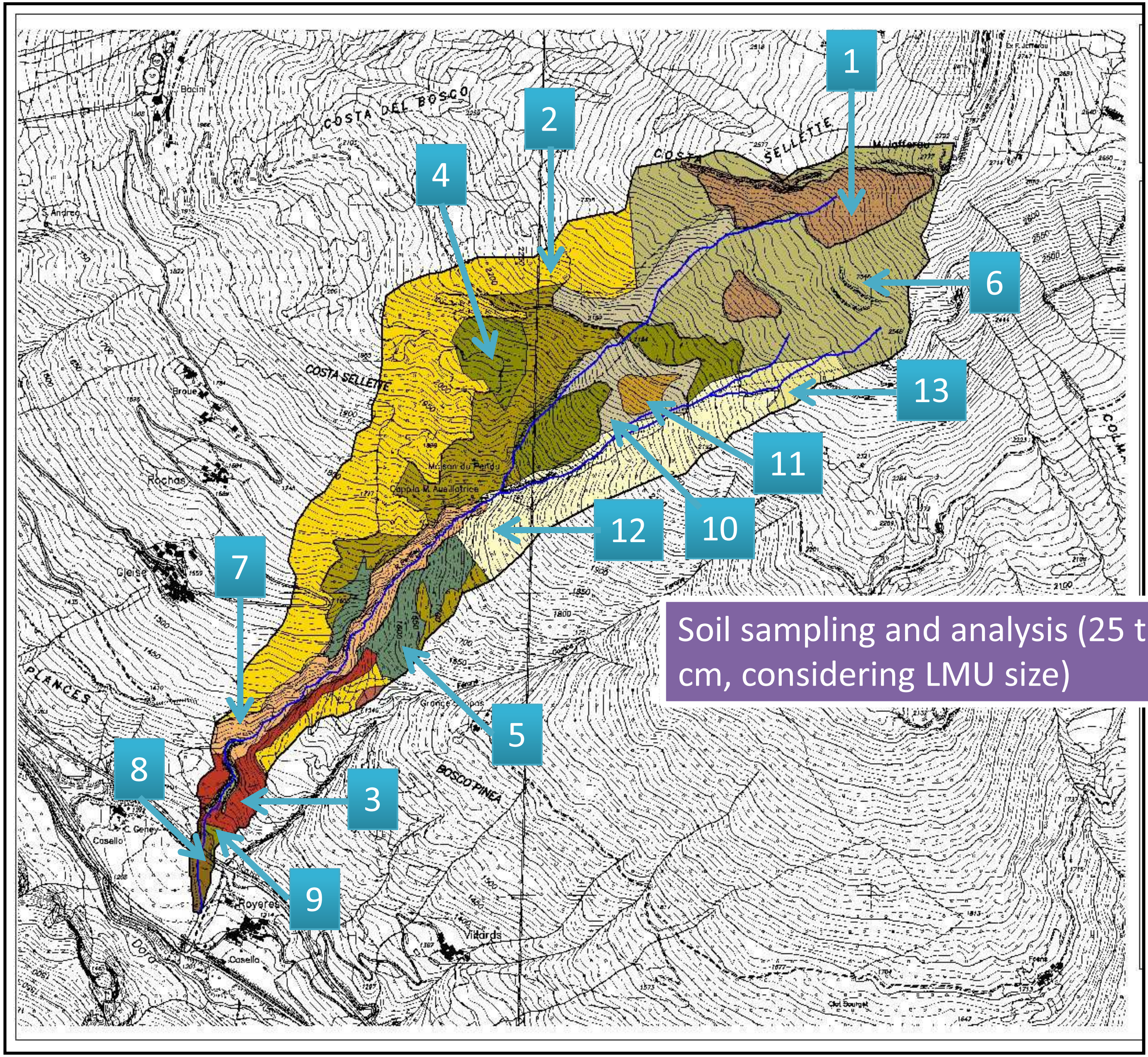
Glacial deposits

Detritus

Rock debris

	Forest stands			**Grassland**			**Bare Rocks**
Slope	*0-16*	*16-32*	*32-48*	*0-16*	*16-32*	*32-48*	
Colluvial debris	1	2	3				
Calcareous schists		4	5	6	7		
Glacial deposits							
Detritus	8	9			10	11	
Rock debris	12				13		

13 Land Mapping Units where soils are expected to have similar characteristics and protection by land cover towards erosion is expected to be the same



Soil sampling and analysis (25 topsoils 0-10 cm, considering LMU size)