Soil Classification System: The World Reference Base for Soil Resources (WRB)

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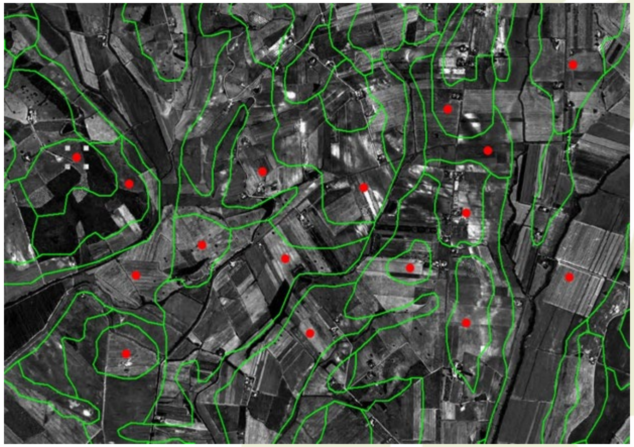
Soil Management for Sustainable Agriculture
Palermo, 24-28 Oct. 2022

WHY WE NEED TO CLASSIFY SOILS?

Soil Cassification start from the need to separate soils we recognize on the field inside the soil-mantle continuum

The soil is a living, heterogeneous and dynamic system that includes physical, chemical, biological components, and their interactions. Therefore, to assess its quality it is necessary to measure, describe, and classify its properties.



Soil classification is necessary to predict its behavior and identify limitations that allow us to make correct management decisions in the agricultural, livestock, forestry, urban, environmental, and health fields to name a few of the most important. IUSS soil scientists understood all that and the consequent urgent necessity to create an international soil classification system for name soils and create soil map legends based on a global reference system.

From FAO to WRB: the classification system "evolution" over time

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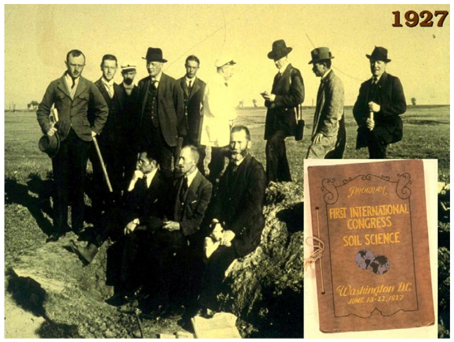
1. Background and basics: History

1. The World Reference Base for Soil Resources (WRB) is based on the Legend (FAO-Unesco, 1974) and the Revised Legend (FAO, 1988) of the Soil Map of the World (FAO-Unesco, 1971-1981).
2. In 1980, the International Society of Soil Science formed a Working Group ‘International Reference Base for Soil Classification’ for further elaboration of a science-based international soil classification system. The Working Group presented the first edition of the WRB in 1998 (FAO, 1998), the second edition in 2006 (IUSS Working Group WRB, 2006) and the third edition in 2014/15 (IUSS Working Group WRB, 2015). The third edition of the WRB was presented at the 20th World Congress of Soil Science 2014 in Jeju, Korea. In 2015, an Update was published online, which is the valid WRB from 2015 to 2022.
3. Since 2014, several WRB field workshops were organized to test the third edition: 2014 -Ireland; 2017 - Latvia and Estonia; 2018 - Romania; 2019 - Mongolia; 2022 - Iceland.
4. The field tours associated with the meetings of the IUSS Commission on Soil Classification in South Africa (2016) and Mexico (2022) were additional tests of the third edition and also the tours offered with the 21st World Congress of Soil Science 2018 in Brazil. Now, after 8 years, a fourth edition 2022 was published and presented at the 22nd World Congress of Soil Science in Glasgow.

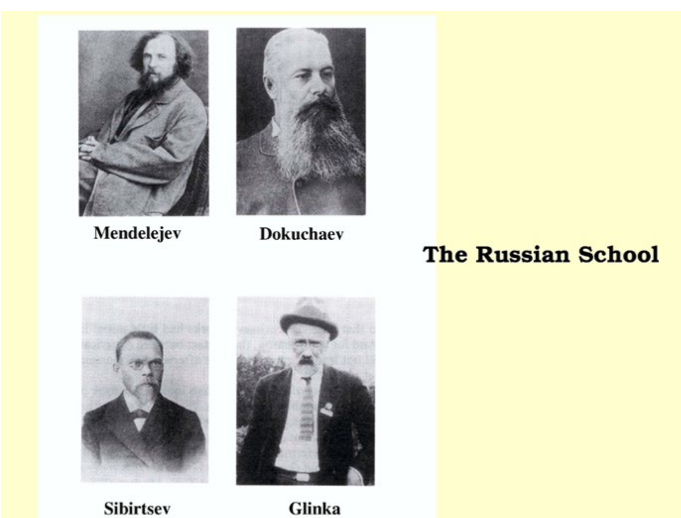
1. Background and basics: History

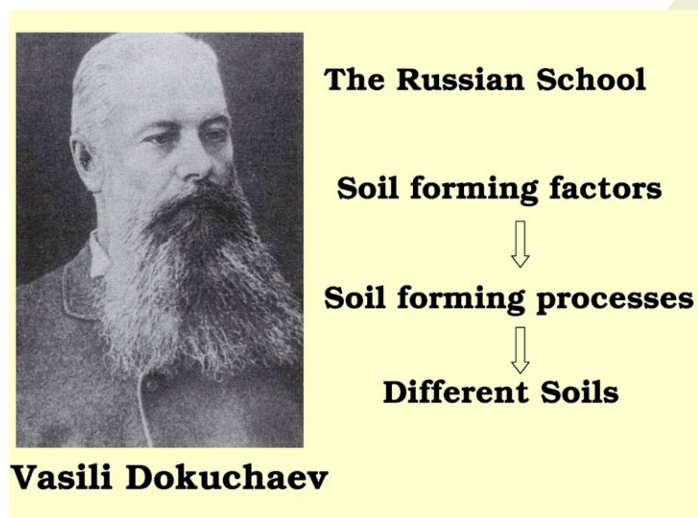
Soil classification over time, as results of human thinking, reflects the knowledge and needs inside Soil Science Community

Improve of knowledge over time



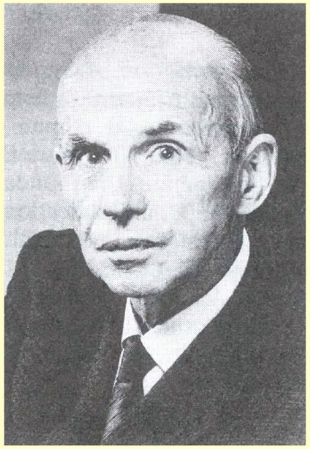
Soil classification schemes started, at the end of 19th century, on "genetic" basis, following the soil forming processes and factors (Russian School)





1. Background and basics: History

The US. Americans followed with the Jenny Function (1941)

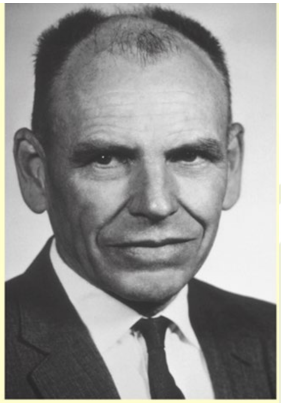


Hans Jenny:
Factors of soil formation (1941)

$$S = f\,(cl, o, r, p, t..)$$

(climate, organisms, topography, parent material, time)

In 1952 Guy Smith presented his diagnostic approach in Belgium "time zero of modern soil classification"



Guy Smiths

"The process that go on can rarely be observed or measured. Nevertheless, the genesis of soils is extremely important both to the taxonomy of soils and to the mapping in the field. Genesis is important to the classification partly because it produces the observable or measurable differences that can be used as differentiae. Genesis does not appear in the definitions of the taxa but it lies behind them"

1. Background and basics: Main Concepts

MODERN DIAGNOSTIC APPROACH

Soil processes are poorly understood, and specific pedogenic processes occur simultaneously in a given soil, reinforcing or contradicting one another.

It is also assumed that polygenesis likely has occurred in most, if not all soils, making genetic interpretations difficult.

"Soil diagnostic properties result from soil processes and are more readily quantifiable than soil processes"

This approach is used in the two main systems The World Reference Base and The US. Soil Taxonomy, and many other national classification systems

soil-forming factors
↓
soil-forming processes
↓
diagnostic horizons, properties, materials
↓
soil taxonomic system

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WRB 2022: MAIN APPLICATIVE PURPOSES

1. SOIL CLASSIFICATION: "the Reference Base is organized in two main hierarchical levels: Reference Groups and Qualifiers (Architecture of the system)"

2. SOIL CORRELATIONS: "*The Reference Base is not meant to substitute for national soil classification systems but rather to serve as a common denominator for communication at an international level*"

3. COMMUNICATION AND SHARE OF SOIL INFO: *"In addition to serving as a link between existing classification systems, the WRB also serves as a consistent communication tool for compiling global soil databases and for the inventory and monitoring of the world's soil resources"*

4. *SOIL MAPPING (General Rules)*

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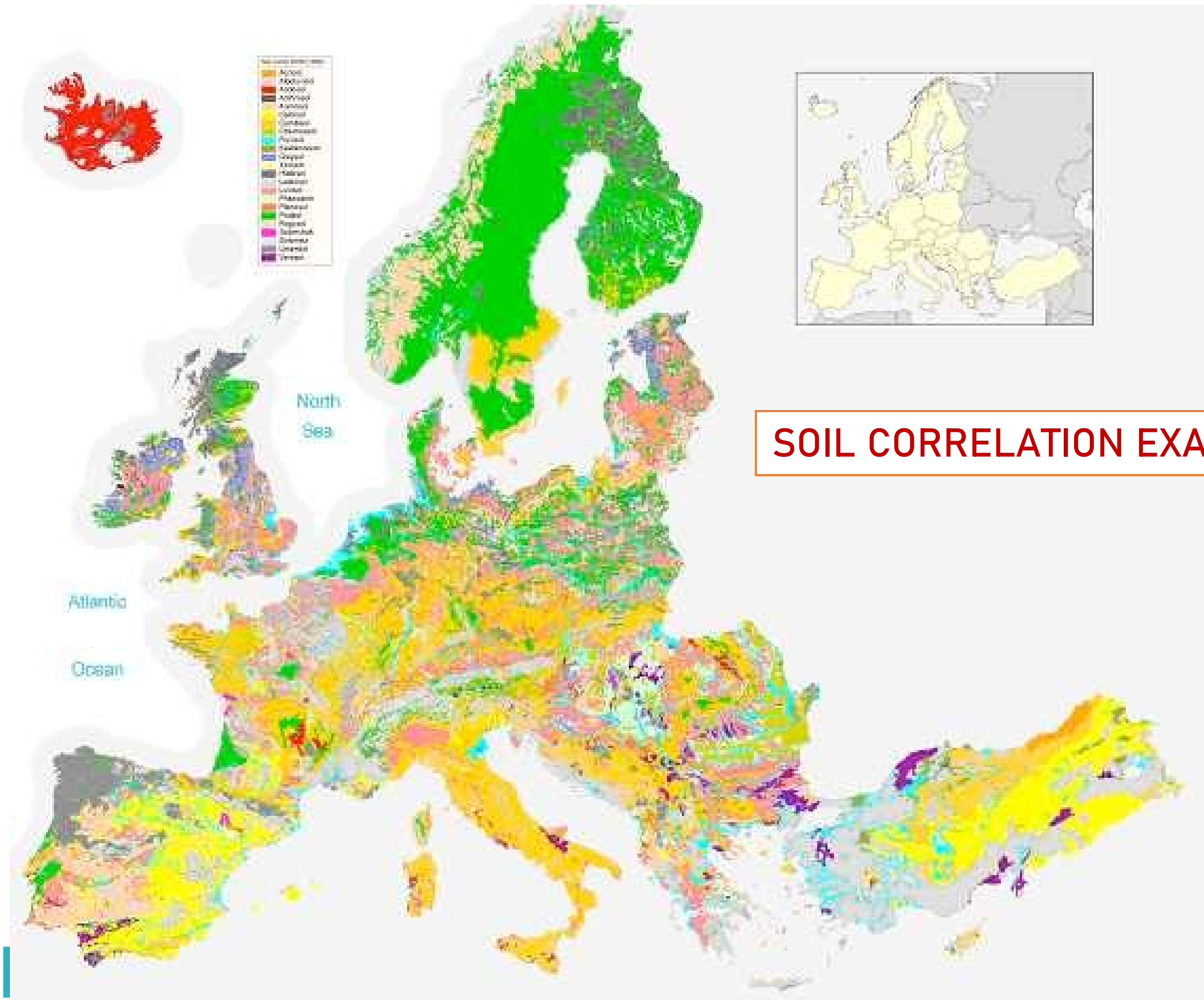
WRB INTERNATIONAL MAPS: EU 1.1 M SCALE



SOIL CORRELATION EXAMPLE 1

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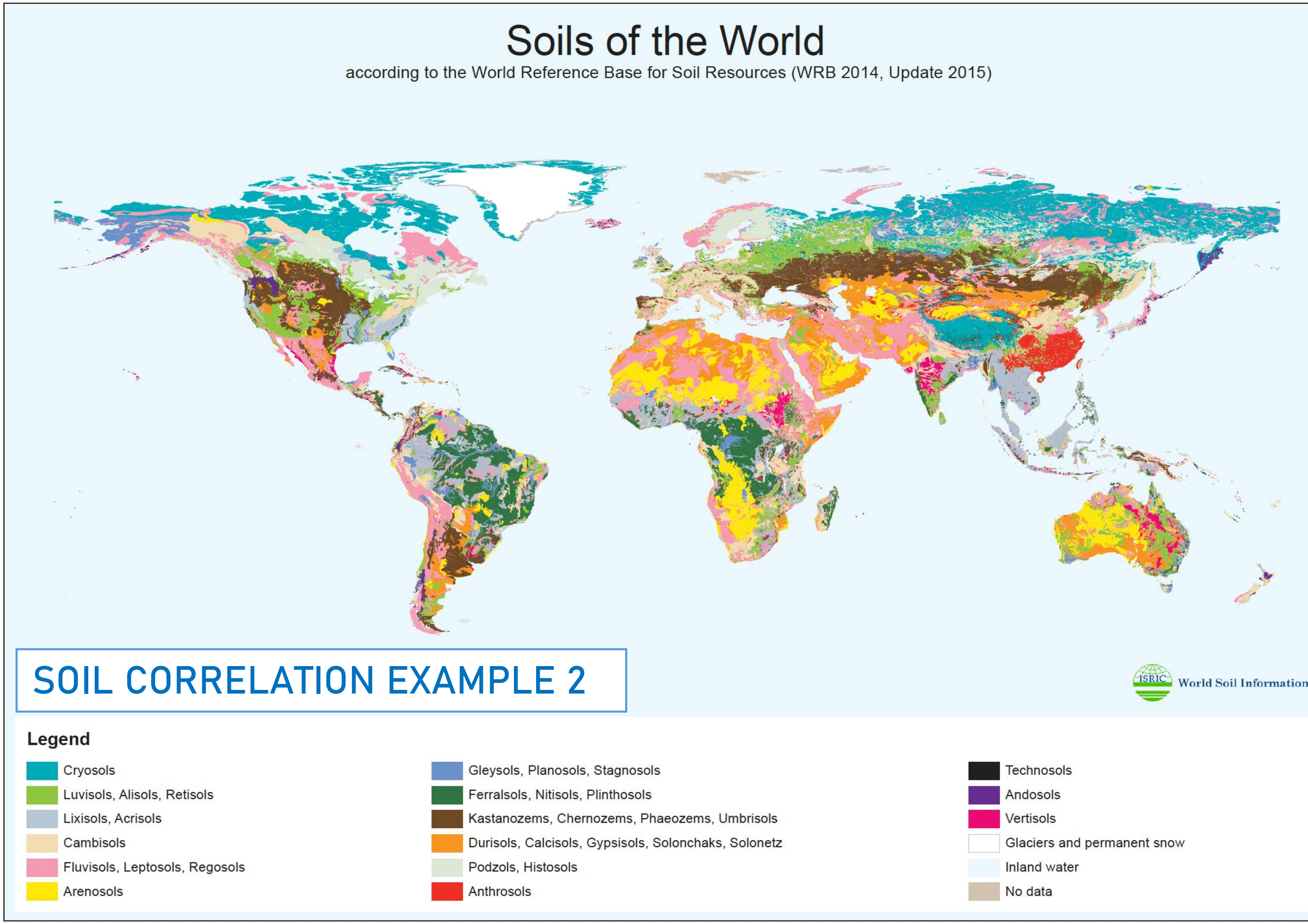
WRB INTERNATIONAL MAPS: WORLD SOIL MAP (FAO 2014)



SOIL CORRELATION EXAMPLE 2

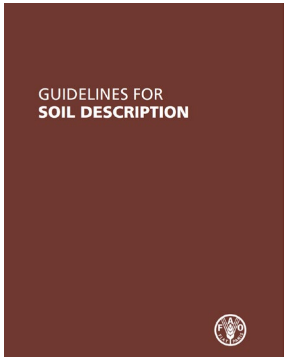
World Reference Base: How to start from the field

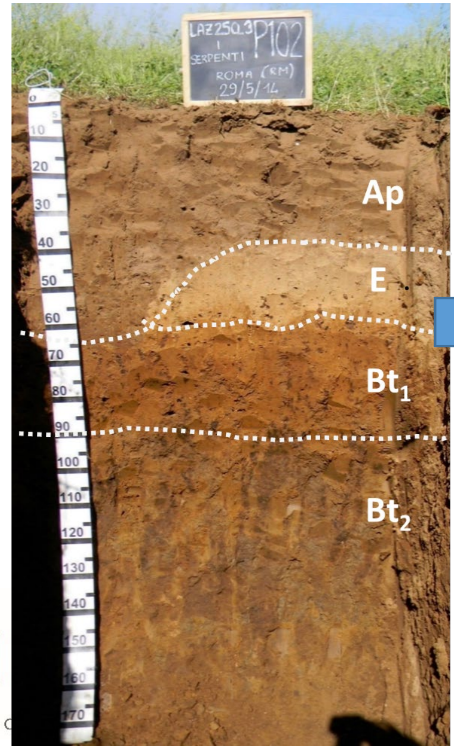
The soil profile description and sampling

Step one – Description of site and horizons properties and macro/micro morphological features – GUIDELINE FOR SOIL DESCRIPTION (FAO rev. Annex 1 WRB manual)

Step two – Sampling main horizons to make the lab determinations (chemical, physical, biochemical, etc.) following the Reference Methods as described in the Appendix of the Manual

Annex 1: Field Guide





Sampling

Annex 2: Summary of analytical procedures for soil characterization

WORLD REFERENCE BASE: Basic General Principles

- The classification of soils is based on soil properties defined in terms of diagnostic horizons, diagnostic properties and diagnostic materials (together called the diagnostics), which to the greatest extent possible should be measurable and observable in the field.

- The selection of diagnostic characteristics takes into account their relationship with soil-forming processes. *An understanding of soil-forming processes contributes to a better characterization of soils but these processes should not, as such, be used as differentiating criteria*.

- To the extent possible at a high level of generalization, diagnostic features that are of significance for soil management are selected.

- Climate parameters are not applied in the classification of soils. It is understood that they should be used for interpretation purposes, in combination with soil properties, but they should not form part of soil definitions. *The classification of soils is therefore not subordinated to the availability of climate data*. The name of a certain soil will not become obsolete due to global or local climate change. (*lack of knowledge on Hydric and Temperature Regimes*)

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WRB 2022: Basic General Principles

Overview of the diagnostics "Anthropogenics Horizons" list

Anthropogenic diagnostic horizons (all are mineral)	
anthraquic horizon	in paddy soils: the layer comprising the puddled layer and the plough pan, both showing a reduced matrix and oxidized root channels
hortic horizon	dark, high content of organic matter and P, high animal activity, high base saturation; resulting from long-term cultivation, fertilization and application of organic residues
hydragric horizon	in paddy soils: the layer below the anthraquic horizon showing redoximorphic features and/or an accumulation of Fe and/or Mn
irragric horizon	uniformly textured, at least moderate content of organic matter, high animal activity; gradually built up by sediment-rich irrigation water
plaggic horizon	dark, at least moderate content of organic matter, sandy or loamy; resulting from application of sods and excrements
pretic horizon	dark, at least moderate content of organic matter and P, high contents of exchangeable Ca and Mg, with black carbon; including Amazonian Dark Earths
terric horizon	evidence of addition of substantially different material, at least moderate content of organic matter, high base saturation; resulting from adding mineral material (with or without organic residues) and cultivation

WRB 2022: Basic General Principles

Overview of the diagnostics “Organic and Mineral/Organic Horizons”” list

Organic diagnostic horizons	
folic horizon	organic layer, not water-saturated and not drained
histic horizon	organic layer, water-saturated or drained
Diagnostic horizons that may be organic or mineral	
calcic horizon	accumulation of secondary carbonates, not continuously cemented
cryic horizon	perennially frozen (visible ice or, if not enough water, < 0°C)
salic horizon	high amounts of readily soluble salts
thionic horizon	with sulfuric acid and a very low pH value

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WRB 2022: Basic General Principles

Overview of the diagnostics "Surface Mineral Horizons" list

Surface mineral diagnostic horizons	
chernic horizon	thick, very dark-coloured, high base saturation, moderate to high content of organic matter, well developed soil structure or structural elements created by agricultural practices, high animal activity (special case of the mollic horizon)
mollic horizon	thick, dark-coloured, high base saturation, moderate to high content of organic matter, at least some soil structure or structural elements created by agicultural practices
umbric horizon	thick, dark-coloured, low base saturation, moderate to high content of organic matter, at least some soil structure or structural elements created by agricultural practices

WRB 2022: Basic General Principles

Overview of the diagnostics "Horizons with accumulation of substances due to (vertical or lateral) migration processes" list

Horizons with accumulation of substances (migration processes) - 1	
argic horizon	subsurface layer with distinctly higher clay content than the overlying layer without a lithic discontinuity and/or presence of illuvial clay minerals (with or without a lithic discontinuity)
duric horizon	concretions or nodules, cemented by secondary silica, and/or fragments of a broken-up petroduric horizon
ferric horizon	by silica ferric horizon ≥ 5% reddish to blackish concretions and/or nodules and/or ≥ 15% reddish to blackish coarse masses, with accumulation of Fe (and Mn) oxides
gypsic horizon	accumulation of secondary gypsum, not continuously cemented
limonic horizon	accumulation of Fe and/or Mn oxides in a layer that has or had gleyic properties; at least partially cemented
natric horizon	subsurface layer with distinctly higher clay content than the overlying layer without a lithic discontinuity and/or presence of illuvial clay minerals (with or without a lithic discontinuity); high content of exchangeable Na
petrocalcic horizon	accumulation of secondary carbonates, relatively continuously cemented
petroduric horizon	accumulation of secondary silica, relatively continuously cemented

WRB 2022: Basic General Principles

Overview of the diagnostics "Horizons with accumulation of substances due to (vertical or lateral) migration processes" list

Horizons with accumulation of substances (migration processes) - 2	
petrogypsic horizon	accumulation of secondary gypsum, relatively continuously cemented
petroplinthic horizon	consists of oximorphic features inside (former) soil aggregates that are at least partially interconnected and have a yellowish, reddish and/or blackish colour; high contents of Fe oxides at least in the oximorphic features; relatively continuously cemented
pisoplinthic horizon	≥ 40% at least moderately cemented yellowish, reddish, and/or blackish concretions and/or nodules, with accumulation of Fe oxides, and/or fragments of a broken-up petroplinthic horizon
plinthic horizon	has in ≥ 15% of its exposed area oximorphic features inside (former) soil aggregates that are black or have a redder hue and a higher chroma than the surrounding material; high contents of Fe oxides, at least in the oximorphic features; not continuously cemented
sombric horizon	subsurface accumulation of organic matter other than in spodic or natric horizons; not a buried surface horizon
spodic horizon	subsurface accumulation of Al with Fe and/or organic matter
tsitelic horizon	lateral accumulation of Fe, usually derived from Planosols and Stagnosols further upslope

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WRB 2022: Basic General Principles

Overview of the diagnostics "Other Mineral Horizons" list

Other Mineral diagnostic horizons	
albic horizon	light-coloured; loss of coloured substances (e.g. oxides, organic matter) due to soil-forming processes
cambic horizon	evidence of soil-forming processes; not meeting the criteria of diagnostic horizons that indicate stronger alteration or accumulation processes
cohesic horizon	massive or subangular blocky structure, root penetration restricted, drainage normally free, rich in kaolinite, poor in organic matter
ferralic horizon	strongly weathered, dominated by kaolinites and oxides
fragic horizon	with large soil aggregates, roots and percolating water penetrate the soil only in between these aggregates, not or only partially cemented
nitic horizon	rich in clay minerals and Fe oxides, moderate to strong structure, shiny soil aggregate surfaces
panpaic horizon	buried mineral surface horizon with a significant content of organic matter
protovertic horizon	influenced by swelling and shrinking clay minerals
vertic horizon	dominated by swelling and shrinking clay minerals

WRB 2022: Basic General Principles

Overview of the diagnostics "Properties and Materials" list

Surface Diagnostic Properties and between two layers
Takyric, Yermic , Abrupt textural difference, Albeluvic glossae, Lithic discontinuity, Retic
Other Diagnostic Properties
Andic, Anthric, Continous rock, Gleyic, Protocalcic, Protogypsic, Reducing conditions, Shrink-swell cracks, Sideralic, Stagnic, Vitric
Materials related to Organic Carbon/Artefacts
Mineral, Mulmic, Organic, Organotechnic, Soil organic carbon, Claric (related to light-colour)
Technogenic Materials
Artefacts, Technic hard material
Other Materials
Aeolic, Calcaric, Dolomitic, Fluvic, Gypsiric, Hyopersulfidic, Hyposulfidic, Limnic, Ornithoigenic, Solimovic, Tephric

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EXAMPLE OF DIAGNOSTIC DEFINITION – CHERNIC HORIZON - 1

3.1.6 Chernic horizon

General description

A chernic horizon (from Russian *chorniy*, black) is a relatively thick, well-structured, very dark-coloured surface horizon, with a high base saturation, a high animal activity and a moderate to high content of organic matter.

Diagnostic criteria

A chernic horizon is a surface horizon consisting of *mineral material* and has:

1. ≥ 50% (by volume, weighted average, related to the whole soil) of fine earth and does not consist of *mulmic material*;
   and
2. single or in combination, in ≥ 90% (by volume):
   a. granular structure; ***or***
   b. subangular blocky structure with an average aggregate size of ≤ 2 cm; ***or***
   c. cloddy structure or other structural elements created by agricultural practices;

   and
3. ≥ 1% *soil organic carbon*;
   and
4. one of the following:
   a. in ≥ 90% of the exposed area of the entire horizon or of the subhorizons below any plough layer, a Munsell colour value of ≤ 3 moist, and ≤ 5 dry, and a chroma of ≤ 2 moist;
      or
   b. all of the following:
      i. ≥ 15 and < 40% calcium carbonate equivalent; ***and***
      ii. in ≥ 90% of the exposed area of the entire horizon or of the subhorizons below any plough layer, a

WRB 2022: Basic General Principles

EXAMPLE OF DIAGNOSTIC DEFINITION – CHERNIC HORIZON - 2

Field identification

A chernic horizon may easily be identified by its blackish colour, caused by the accumulation of organic matter, its well-developed granular or subangular blocky structure, an indication of high base saturation (e.g. $pH_{water} > 6$), and its thickness.

Relationships with some other diagnostics

The chernic horizon is a special case of the *mollic horizon* with a higher content of *soil organic carbon*, a lower chroma, generally better developed soil structure, a minimum content of fine earth and a greater minimum thickness. The upper limit of the content of *soil organic carbon* is 20%, which is the lower limit for *organic material*.

WRB Classification: The Architecture of the System

- The WRB comprises two levels of categorical detail:
- 1. the First Level having 32 Reference Soil Groups (RSGs);
- 2. the Second Level, consisting of the name of the RSG combined with a set of principal and supplementary qualifiers.

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WRB Classification: The Reference Soil Groups (1 Level)

- Overview of the 32 RSGs

Reference Soil Groups							
Acrisol	AC	Chernozem	CH	Leptosol	LP	Regosol	RG
Alisol	AL	Durisol	DU	Lixisol	LX	Retisol	RT
Andosol	AN	Ferralsol	FR	Luvisol	LV	Solonchak	SC
Anthrosol	AT	Fluvisol	FL	Nitisol	NT	Solonetz	SN
Arenosol	AR	Gleysol	GL	Phaeozem	PH	Stagnosol	ST
Calcisol	CL	Gypsisol	GY	Planosol	PL	Technosol	TC
Cambisol	CM	Histosol	HS	Plinthosol	PT	Umbrisol	UM
Cryosol	CR	Kastanozem	KS	Podzol	PZ	Vertisol	VR

Rationale for the sequence of the RSGs in the WRB Key: Start from the first RSGs and verify if it fulfill all the requested conditions: if they are not, you pass below, and so on, until the right Group is located

RSG 1
RSG 2
RSG 3
……….
……….

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WRB Classification: The Qualifiers (2 Level) - Type

- In the WRB, a distinction is made between typically associated qualifiers, intergrades and other qualifiers.
- Typically associated qualifiers are referred to in the Key to the particular RSGs, e.g. Hydragric or Plaggic for the Anthrosols.
- Intergrade qualifiers are those that reflect important diagnostic criteria of another RSG. The WRB Key will, in that case, dictate the choice of the RSG and the intergrade qualifier will provide the bridge to the other RSG.
- Other qualifiers are those not typically associated with an RSG and that do not link to other RSGs, e.g. Geric or Posic for Ferralsols. This group reflects characteristics such as colour, base status, and other chemical and physical properties provided that they are not used as a typically associated qualifier in that particular group.

WRB Classification: Rationale to use the Qualifiers - 1

- A two-tier system is used for the qualifier level, comprising:

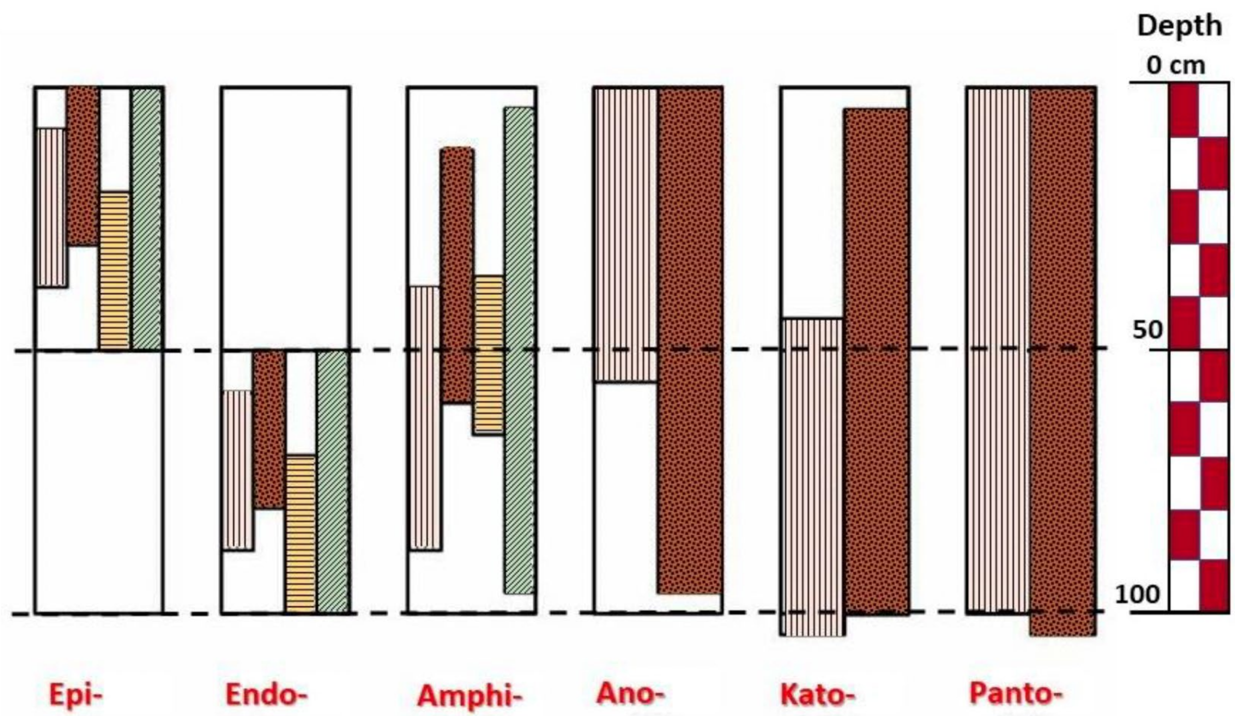
- Principal qualifiers: typically associated qualifiers and intergrade qualifiers; the sequence of the intergrade qualifiers follows that of the RSGs in the WRB Key, with the exception of Arenosols; this intergrade is ranked with the textural suffix qualifiers (see below). Haplic closes the prefix qualifier list indicating that neither typically associated nor intergrade qualifiers apply.

- Supplementary qualifiers: other qualifiers, sequenced as follows: (1) qualifiers related to diagnostic horizons, properties or materials; (2) qualifiers related to chemical characteristics; (3) qualifiers related to physical characteristics; (4) qualifiers related to mineralogical characteristics; (5) qualifiers related to surface characteristics; (6) qualifiers related to textural characteristics, including coarse fragments; (7) qualifiers related to colour; and (8) remaining qualifiers.

WRB Classification: Rationale to use the Qualifiers - 2

- Principal qualifier names are always put before the RSG;
- Supplementary qualifier names are always placed between brackets following the RSG name. Combinations of qualifiers that indicate a similar status or duplicate each other are not permitted, such as combinations of Thionic and Dystric, Calcaric and Eutric, or Rhodic and Chromic.
- Specifiers such as Epi-, Endo-, Amphi-, Ano-, Kato-, Panto- are used to indicate a certain location of the qualifier related to the Horizon sequence inside the Soil Pedon.
- The qualifier listing for each RSG accommodates most cases. Where not listed qualifiers are needed, the cases should be documented and reported to the WRB Working Group.

Specifiers to construct optional subqualifiers related to depth requirements and referring to a particular layer (Bathy- not illustrated),



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World Reference Base How to Use the Qualifiers (2 Level)

Example of use of the Principal and Supplementary Qualifiers in the WRB System: use-Case of Vertisols RSG

Key to the Reference Soil Groups	Principal qualifiers	Supplementary qualifiers
Other soils having: 1. a *vertic horizon* starting ≤ 100 cm from the mineral soil surface; *and* 2. ≥ 30% clay between the mineral soil surface and the *vertic horizon* throughout; *and* 3. *shrink-swell cracks* that start: a. at the mineral soil surface; *or* b. at the base of a plough layer; *or* c. directly below a layer with strong granular structure or strong angular or subangular blocky structure with an aggregate size of ≤ 1 cm (self-mulching surface); *or* d. directly below a surface crust; *and* extend to the *vertic horizon*. **VERTISOLS**	Salic Sodic Leptic Petroduric/ Duric Gypsic Petrocalcic Calcic Hydragric/ Anthraquic/ Irragric Pellic Chromic Haplic	Alcalic/ Endodystric Aric Chernic/ Mollic Dolomitic/ Calcaric Drainic Hypereutric Epic/ Endic Ferric Fractic Gilgaic Gleyic Grumic/ Mazic/ Pelocrustic Gypsiric Humic/ Ochric Magnesic Novic Oxyaquic Pyric Raptic Skeletic Stagnic Sulfidic Technic/ Kalaic Takyric Thionic Toxic

Es. Chromic Pellic Vertisol (Hypereutric)

LEVEL 1: THE REFERENCE SOIL GROUPS (RSG) - 1

TYPE OF SOILS	NAME	CODE
1. Soils with thick organic layers:	Histosols	HS
2. Soils with strong human influence		
Soils with long and intensive agricultural use:	Anthrosols	AT
Containing significant amounts of artefacts:	Technosols	TC
3. Soils with limited rooting due to shallow permafrost or stoniness		
Permafrost-affected:	Cryosols	CR
Shallow or extremely gravelly soils:	Leptosols	LP
Alternating wet-dry conditions, rich in swelling clays:	Vertisols	VR
Alkaline soils:	Solonetz	SN
Salt enrichment upon evaporation:	Solonchaks	SC

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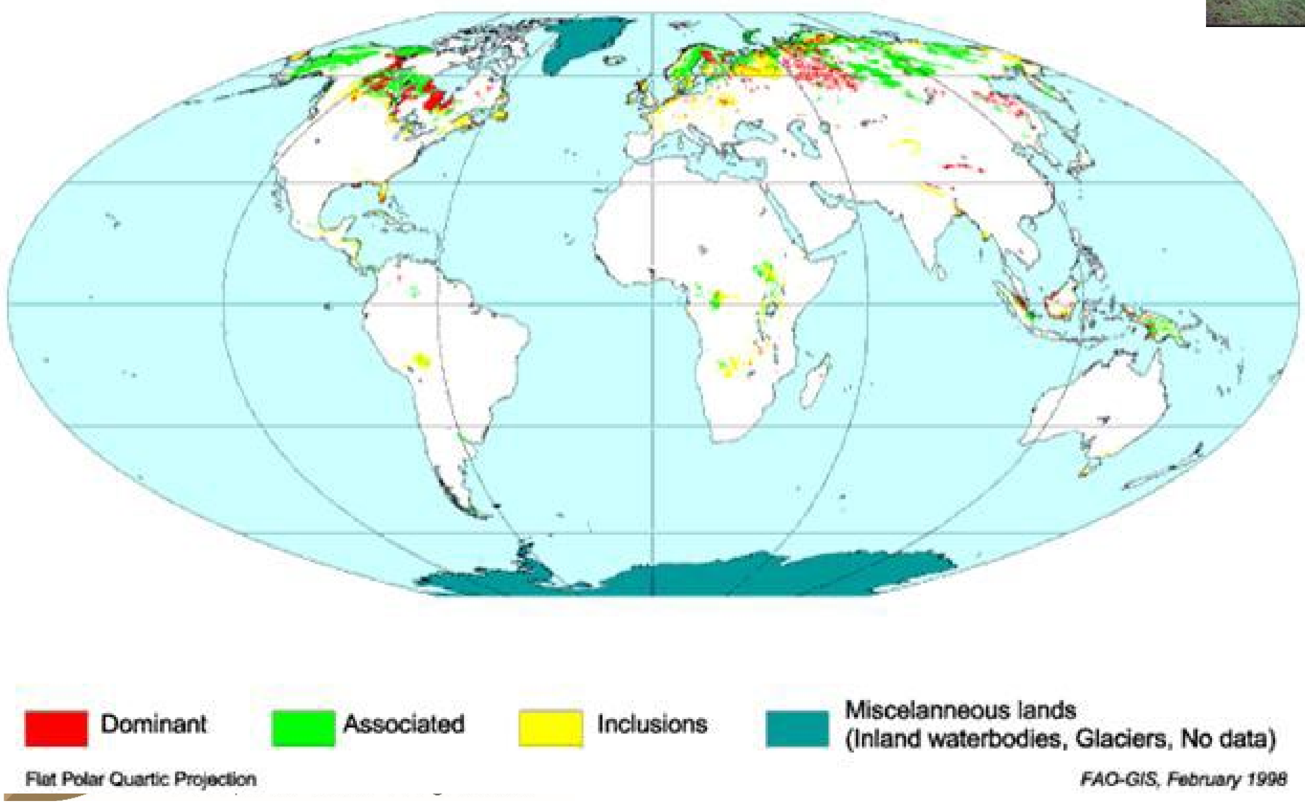
HISTOSOLS DISTRIBUTION

The total extent of Histosols in the world is estimated at some 325–375 million ha, the majority located in the boreal, subarctic and low arctic regions of the Northern Hemisphere. Most of the remaining Histosols occur in temperate lowlands and cool montane areas; only one-tenth of all Histosols are found in the tropics. Extensive areas of Histosols occur in the United States of America and Canada, Western Europe and northern Scandinavia and in the West Siberian Plain.

Fibric Histosols (Ireland - Connemara)



Fibric Salic Histosols (Italy)

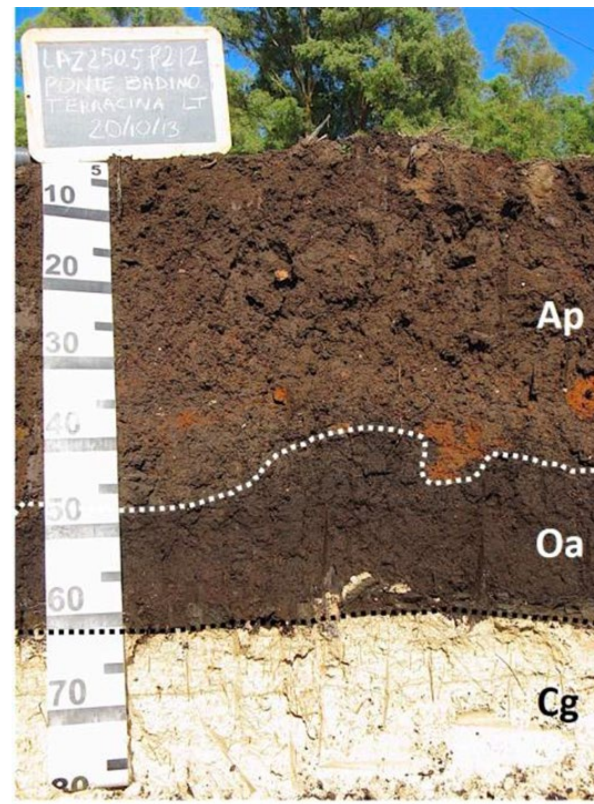
ANTHROSOLS

Anthrosols are found wherever people have practised agriculture for a long time. Anthrosols with plaggic horizons are most common in northwestern central Europe. Together with Anthrosols with a terric horizon, they cover more than 500 000 ha. Anthrosols with irragric horizons are found in irrigation areas in dry regions, e.g. in Mesopotamia, in oases in desert regions of Central Asia and in parts of India. Anthrosols with an anthraquic horizon overlying a hydragric horizon (paddy soils) occupy vast areas in China and in parts of South and Southeast Asia (e.g. Sri Lanka, Viet Nam, Thailand and Indonesia). Anthrosols with hortic horizons are found all over the world where humans have fertilized the soil with household wastes and manure. The Terra Preta de Indio in the Amazon Region commonly has a pretic horizon.

Plaggic Anthrosols (Belgium)

Hydragric Anthrosol (Indonesia – Bali Island)

Terric Anthrosol (Italy – reclaimed coastal area)



TECHNOSOLS

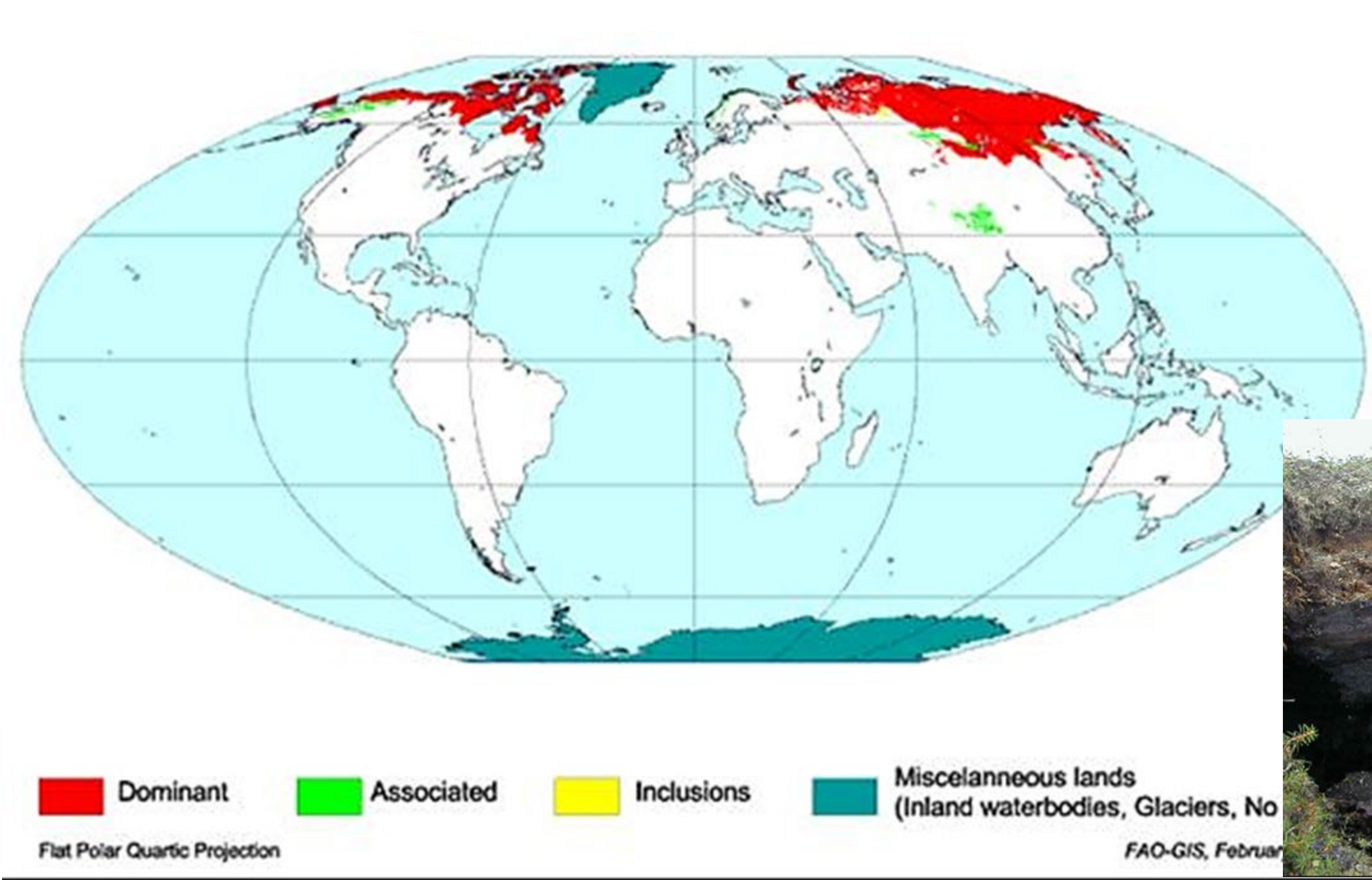
Soils constituted by almost one or several horizons of Technic Materials. Technic material is material transported for urban, industrial, handcraft, infrastructural, mining and military purposes and contains at least 50 % (by volume) of artefacts. Artefacts are materials like bricks, concrete, plaster, waste, plastics, slags, industrial sludges, or hydrocarbonates (e.g.Diesel).

Metal-toxi anthrostratic Technosol

Cyanide-toxi epialloic Technosol

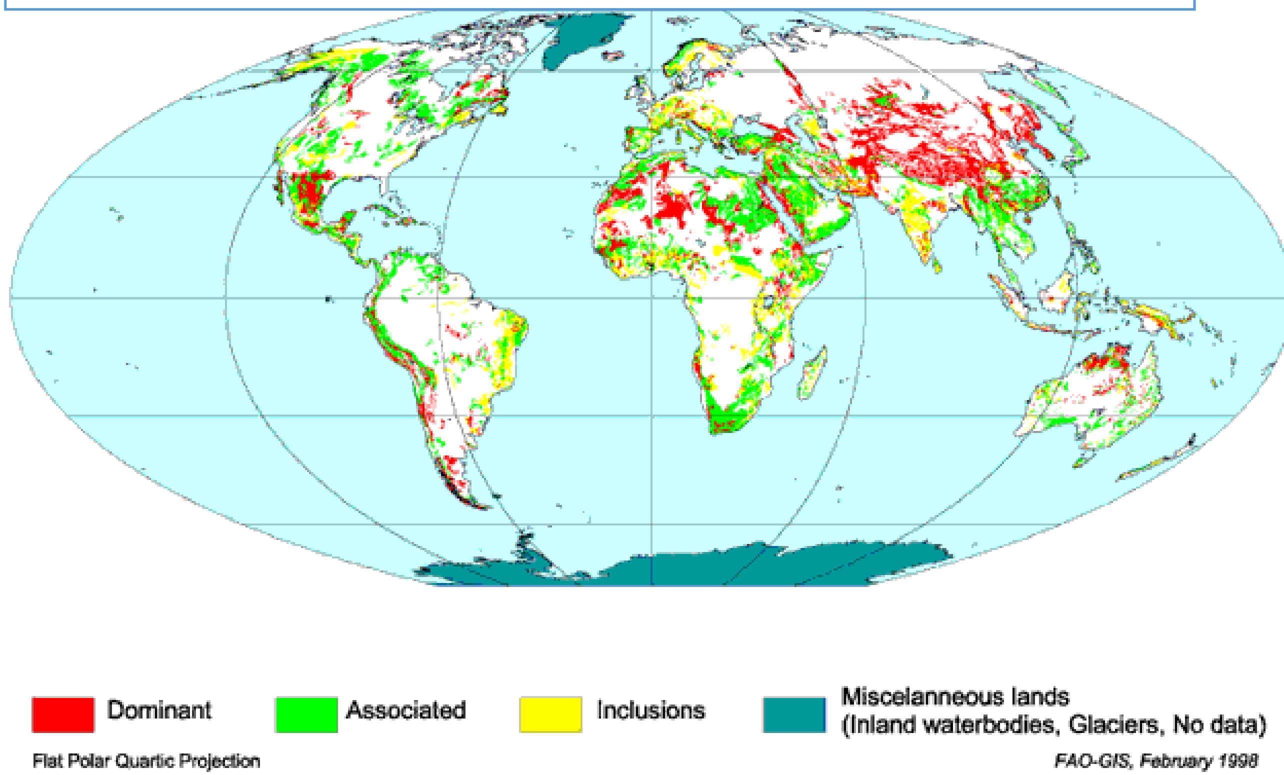
CRYOSOLS DISTRIBUTION

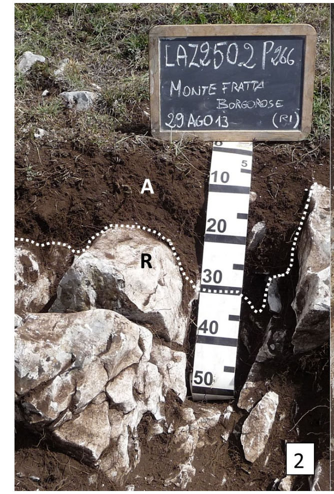
Geographically, Cryosols are circumpolar in both the Northern and Southern Hemispheres. They cover an estimated 1 800 million ha or about 13 percent of the global land surface. Cryosols are widespread in the Arctic, subarctic and boreal zone and sporadic in more temperate mountainous regions. Major areas with Cryosols are found in the Russian Federation (1 000 million ha), Canada (250 million ha), China (190 million ha), Alaska (110 million ha) and in parts of Mongolia. Smaller occurrences have been reported from northern Europe, Greenland and the ice-free areas of Antarctica.

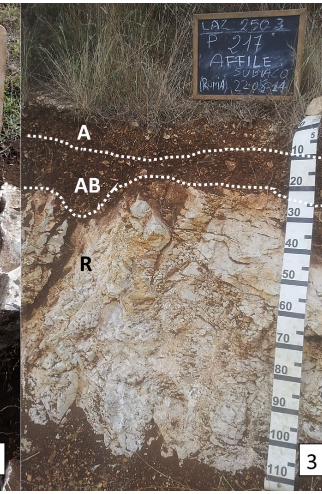


LEPTOSOLS DISTRIBUTION

Leptosols are the most extensive RSG on earth, extending over about 1 655 million ha. Leptosols are found from the tropics to the polar regions and from sea level to the highest mountains. Leptosols are particularly widespread in montane areas, notably in Asia and South America, in the Sahara and the Arabian deserts, the Ungava Peninsula of northern Canada and in the Alaskan mountains. Elsewhere, Leptosols can be found on rocks that are resistant to weathering or where erosion has kept pace with soil formation or has removed the top of the soil profile. Leptosols with continuous rock at less than 10 cm depth in montane regions are the most extensive Leptosols.

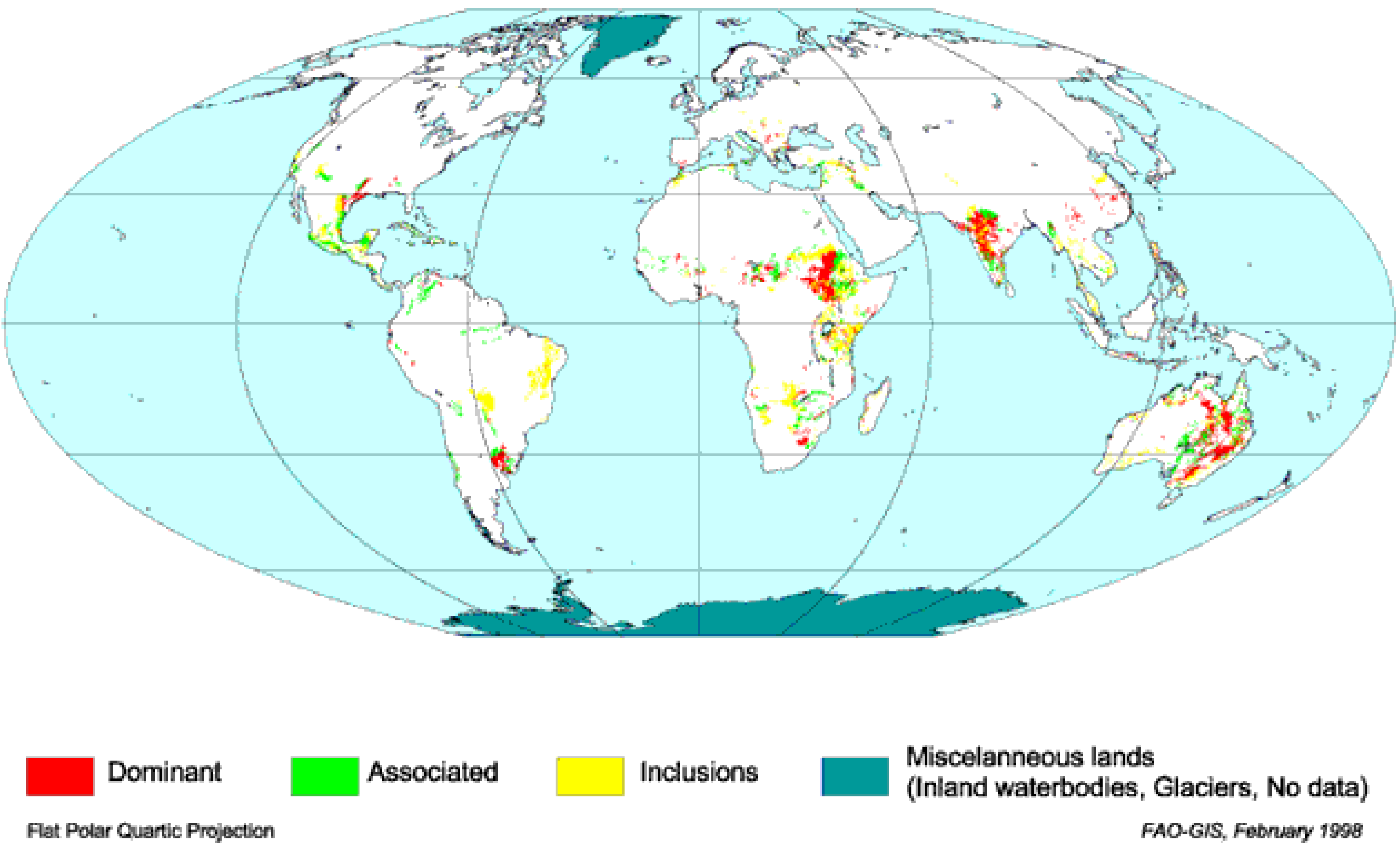






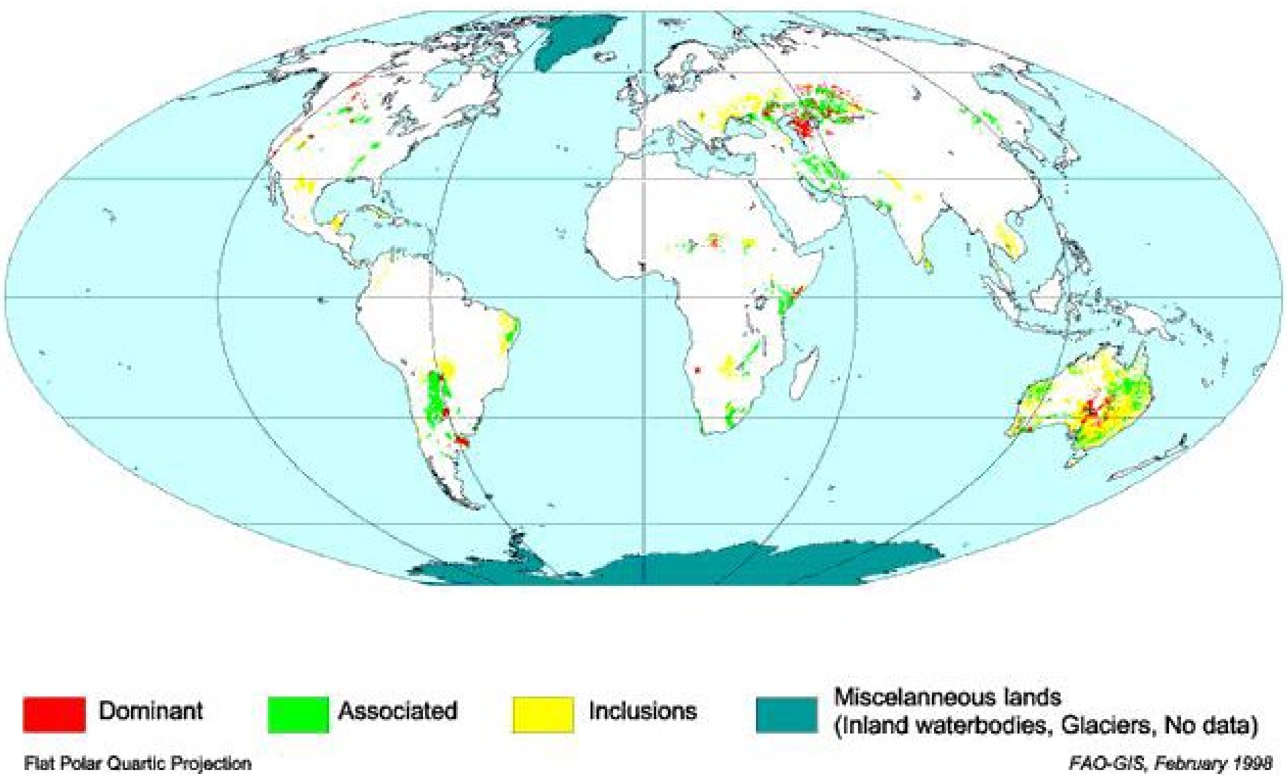
VERTISOLS DISTRIBUTION

Vertisols cover 335 million ha worldwide. Most Vertisols occur in the semi-arid tropics with an average annual rainfall of 500–1 000 mm, but Vertisols are also found in the wet tropics, e.g. Trinidad (where annual rainfall amounts to 3 000 mm). The largest Vertisol areas are in Australia, India and South Sudan. They are also prominent in Ethiopia, China, southern United States of America (Texas), Uruguay, Paraguay, Argentina and South Africa. Vertisols are commonly associated with sediments that have a high content of smectitic clays or that produce such clays upon post-depositional weathering (e.g. in South Sudan and Australia) and on extensive basalt plateaus (e.g. in India and Ethiopia.



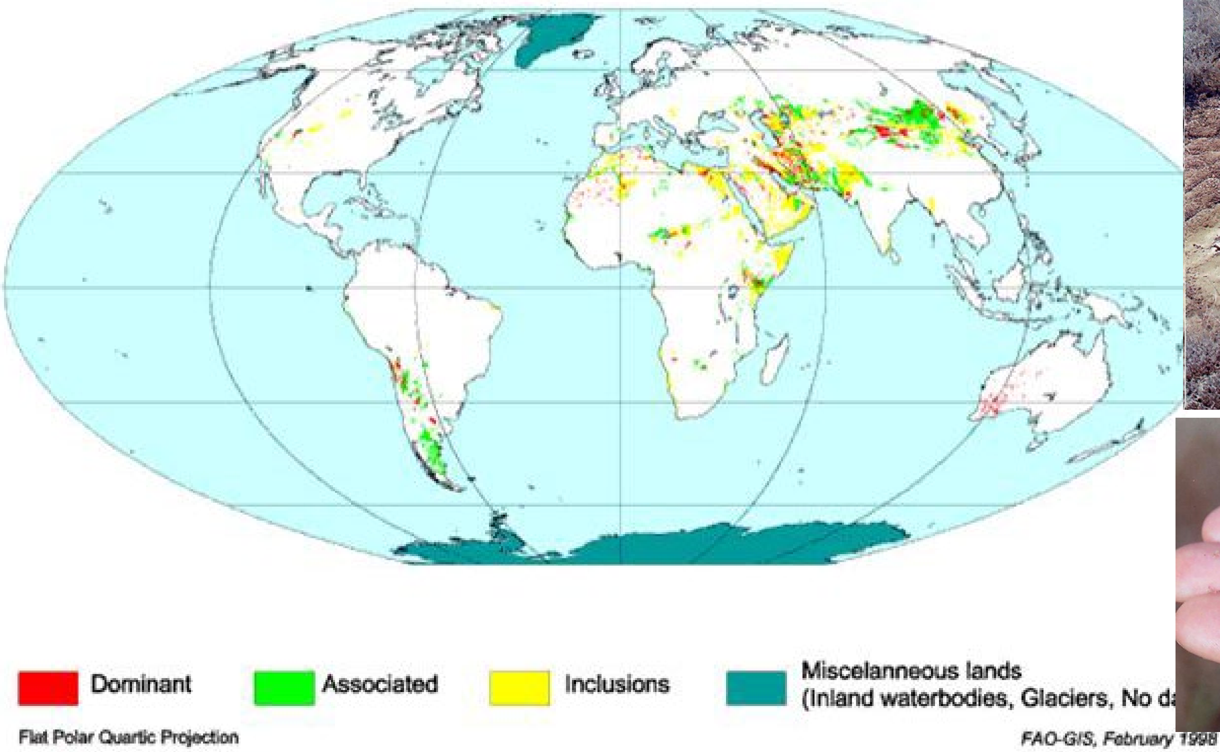
SOLONEZ DISTRIBUTION

Solonetz occur in areas with a semi-arid temperate continental climate (dry summers and an annual precipitation of not more than 400–500 mm), in particular in flat lands with impeded vertical and lateral drainage. They are also present in dry tropical and subtropical areas. Smaller occurrences are found on saline parent materials (e.g. marine clays or saline alluvial deposits). Worldwide, Solonetz cover some 135 million ha. Major Solonetz areas are found in Ukraine, the Russian Federation, Kazakhstan, Hungary, Bulgaria, Romania, China, the United States of America, Canada, South Africa, Argentina and Australia.



SOLONCHAKS DISTRIBUTION

The total extent of Solonchaks in the world is estimated at about 260 million ha. Solonchaks are most extensive in the Northern Hemisphere, notably in the arid and semiarid parts of northern Africa, the Near East, the former Soviet Union and Central Asia; they are also widespread in Australia and the Americas.



LEVEL 1: THE REFERENCE SOIL GROUPS (RSG) - 2

TYPE OF SOILS	NAME	CODE
4. Soils distinguished by Fe/Al chemistry		
Groundwater-affected, underwater or in tidal areas:	Gleysols	GL
Allophanes or Al-humus complexes:	Andosols	AN
Cheluviation and chilluviation:	Podzols	PZ
Accumulation of Fe under hydromorphic conditions:	Plinthosols	PT
Low-activity clay. P fixation. strongly structured:	Nitisols	NT
Dominance of kaolinite and sesquioxides:	Ferralsols	FR
Abrupt textural discontinuity:	Planosols	PL
Structural or moderate textural discontinuity:	Stagnosols	ST

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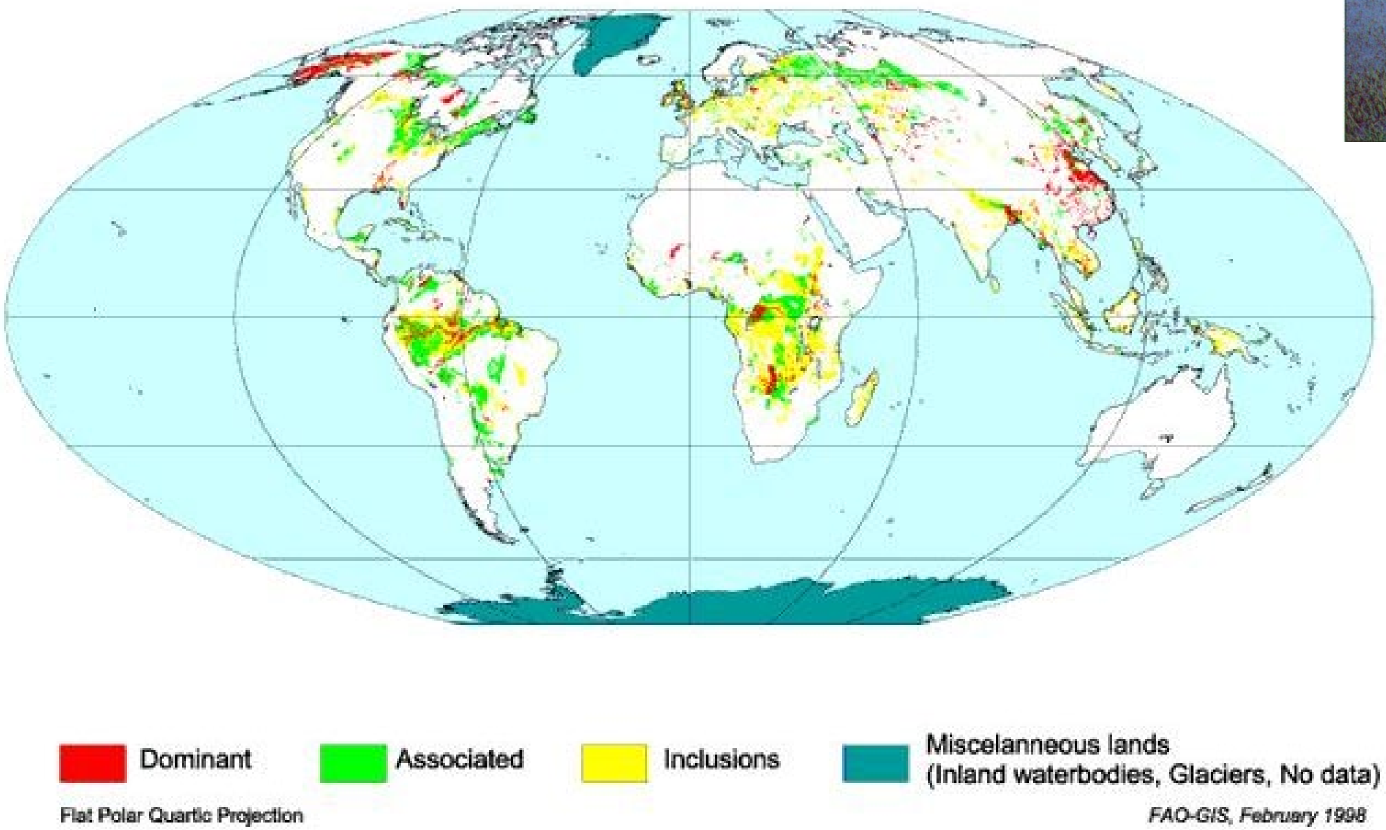
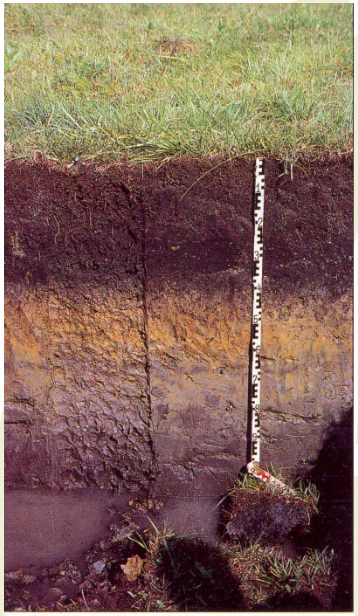
GLEYSOLS DISTRIBUTION

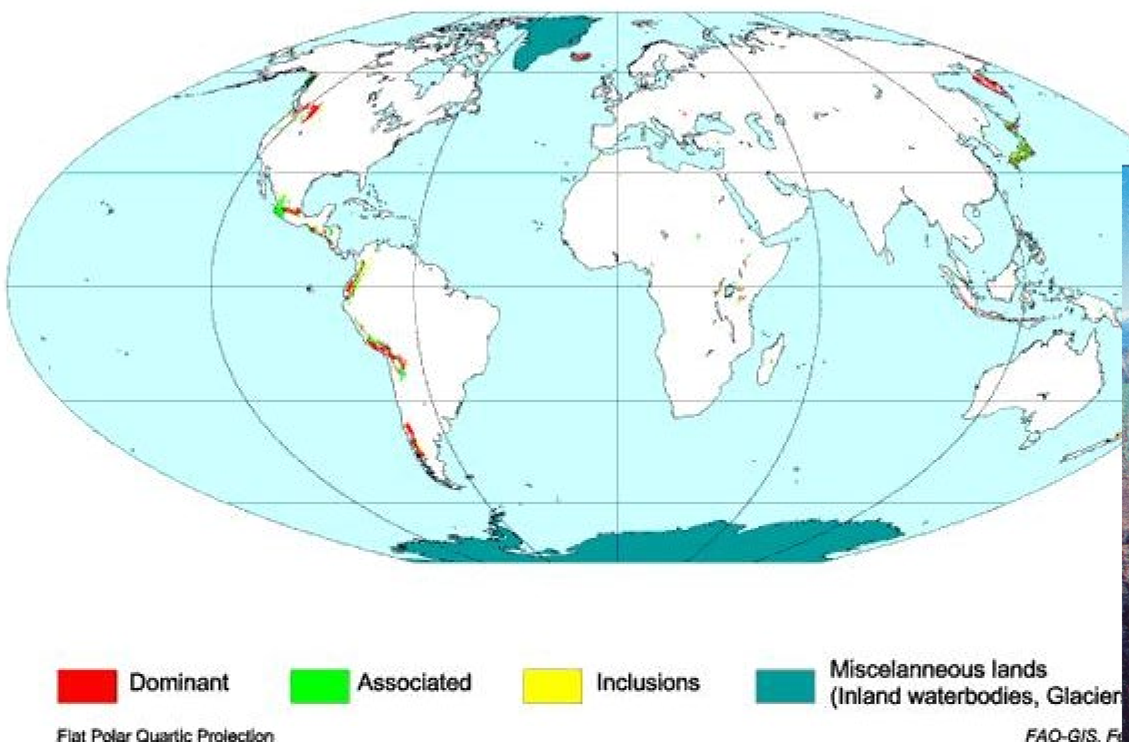
Gleysols occupy more than 720 million ha worldwide. They occur at all latitudes and in nearly all climates, from perhumid to arid. The largest extent of Gleysols is in subarctic areas in the north of the Russian Federation, Canada and Alaska, and in humid temperate and subtropical lowlands, e.g. in China and Bangladesh. An estimated 200 million ha of Gleysols are found in the tropics, mainly in the Amazon region, equatorial Africa and the coastal swamps of Southeast Asia. Larger tidal areas are found along the coast of the North Sea.

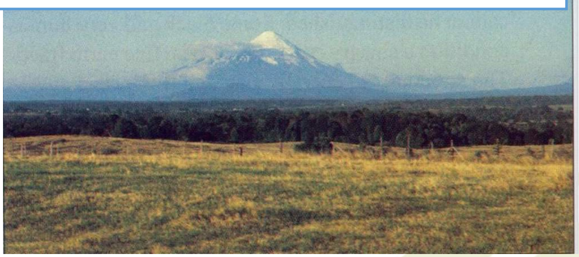


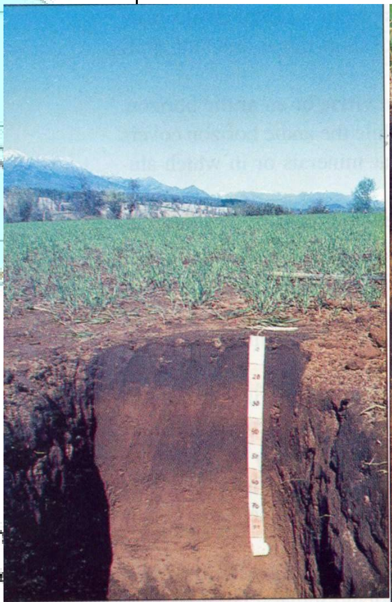


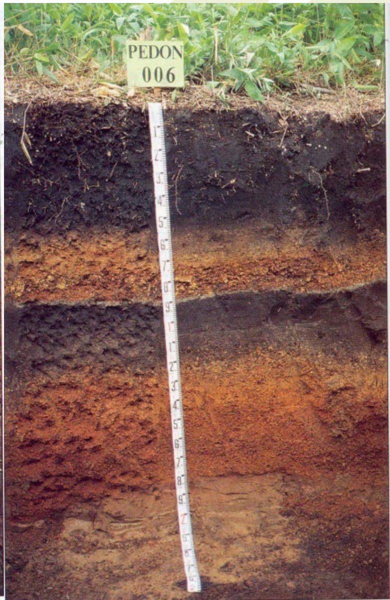
ANDOSOLS DISTRIBUTION

Andosols occur in volcanic regions all over the world. Important concentrations are found around the Pacific rim ('Pacific ring of fire'): on the west coast of South America, in Central America, Mexico, the United States of America (the Rocky Mountains, Alaska), Kamchatka, Japan, the Philippine Archipelago, Indonesia, Papua New Guinea and New Zealand. They are also prominent on many islands in the Pacific: Fiji, Vanuatu, New Caledonia, Samoa and Hawaii. In Africa, major occurrences of Andosols are found along the East African Rift Valley in Kenya, Rwanda and Ethiopia, but also in Cameroon and in Madagascar. In Europe, Andosols occur in Italy, France, Germany and Iceland. The total area with Andosols is estimated at some 110 million ha or less than 1 percent of the global land surface. More than half of this area is situated in the tropics. Andosols originating from parent materials other than glass-rich volcanic ejecta occur in humid (often mountainous) regions, e.g. in Rio Grande do Sul, Southeast Brazil.



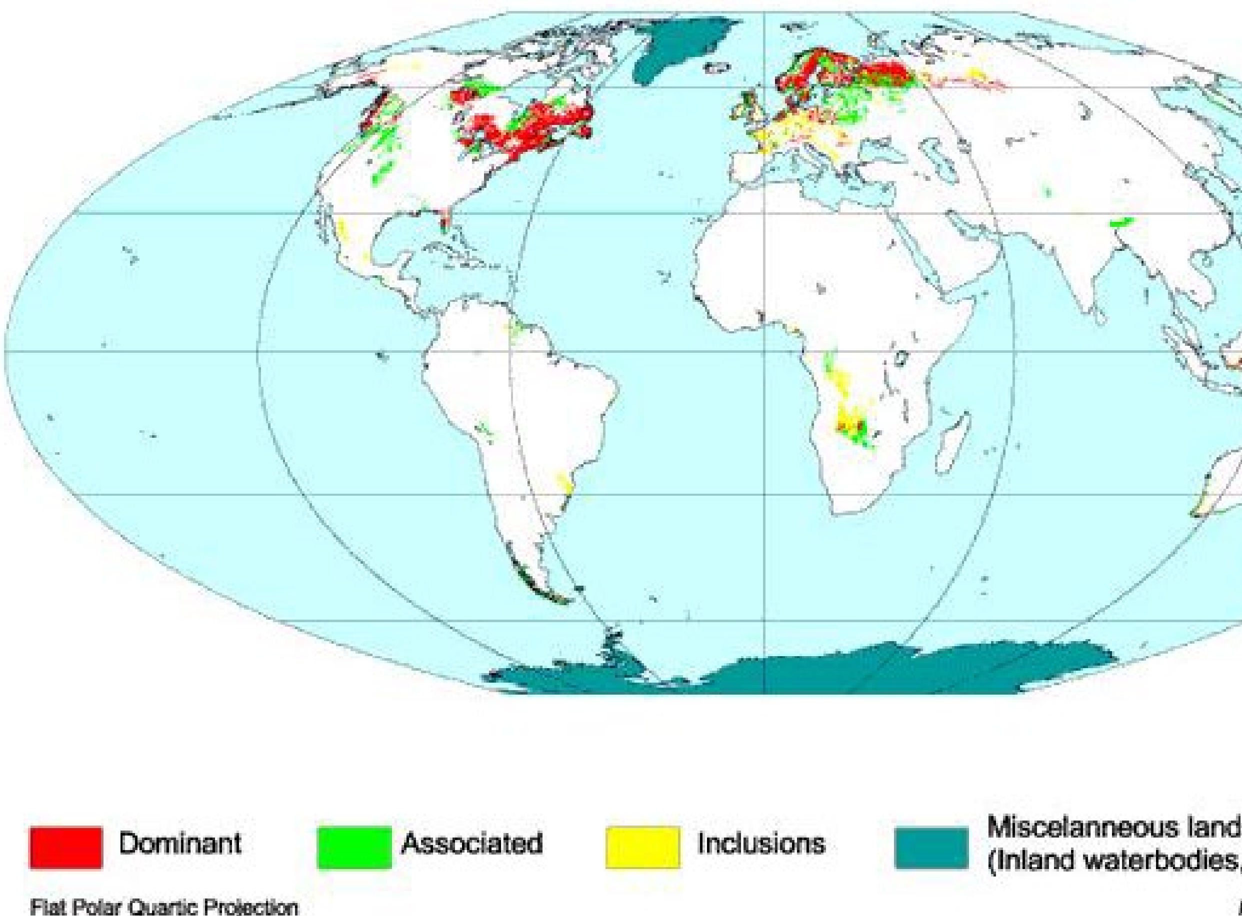


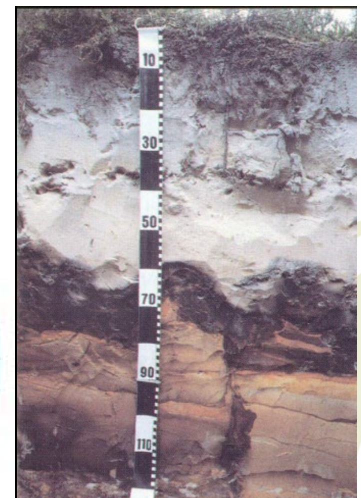




PODZOLS DISTRIBUTION

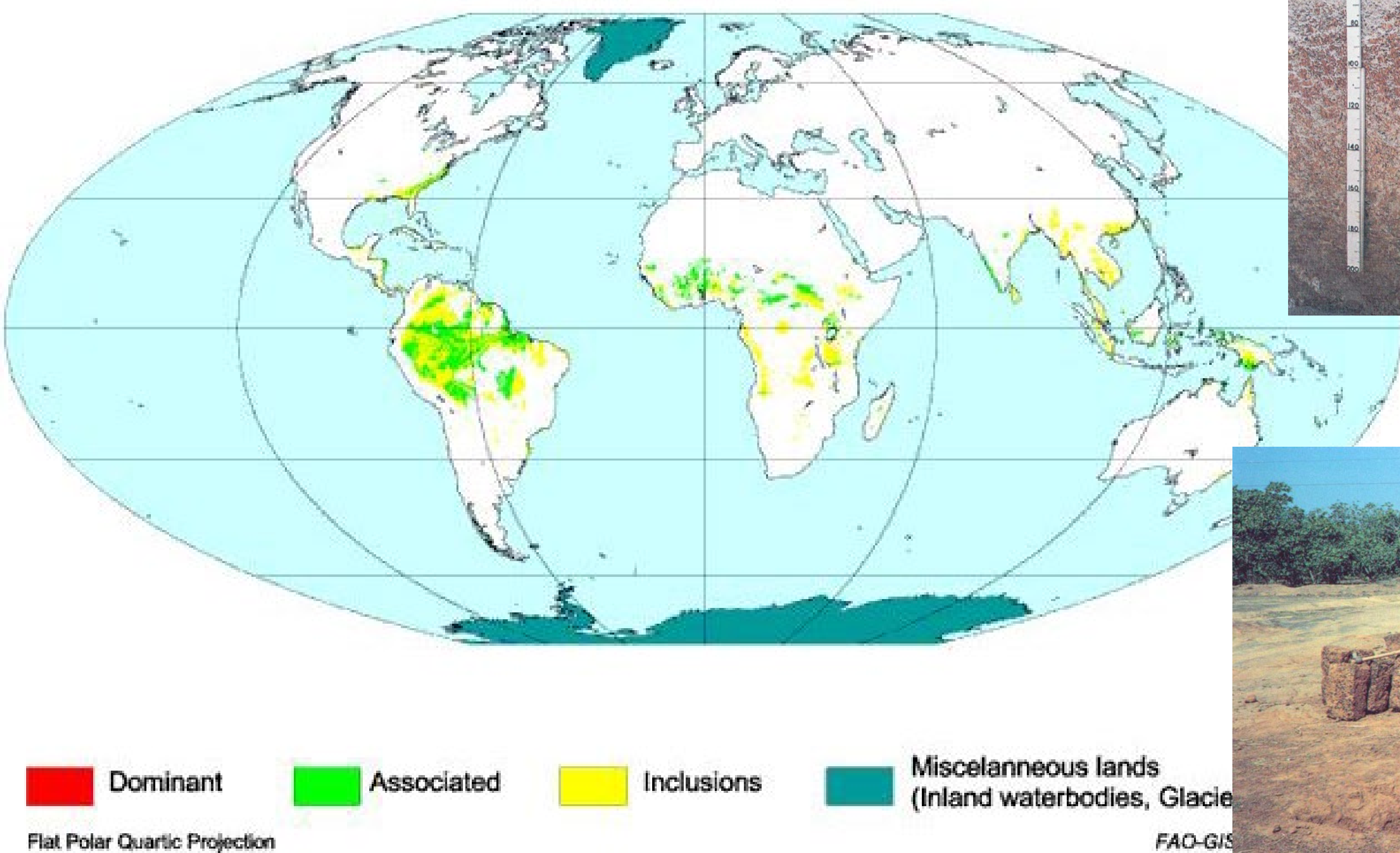
Podzols cover an estimated 485 million ha worldwide, mainly in the temperate and boreal regions of the Northern Hemisphere. They are extensive in Scandinavia, the northwest of the Russian Federation and Canada. Podzols are also present in humid temperate climates and in the humid tropics.
Tropical Podzols occur on less than 10 million ha, mainly in residual sandstone weathering in perhumid regions and in alluvial quartz sands, e.g. in uplifted coastal areas. The exact distribution of tropical Podzols is not known; important occurrences are found along the Rio Negro and in French Guiana, Guyana and Suriname in South America, in Southeast Asia (Kalimantan, Sumatra), in Papua New Guinea and in northern and eastern Australia. They seem to be less common in Africa.





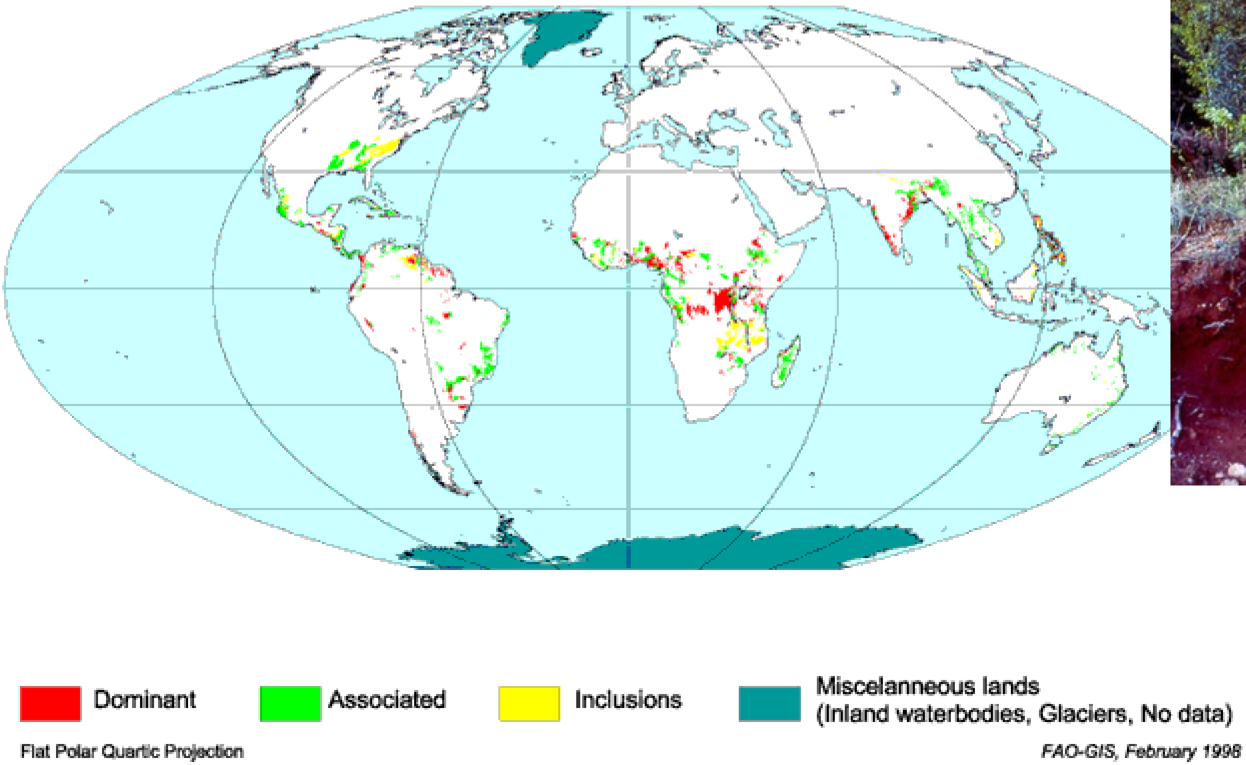
PLINTHOSOLS DISTRIBUTION

The global extent of Plinthosols is estimated at some 60 million ha. Soft plinthite is most common in the wet tropics, notably in the eastern Amazon basin, the central Congo basin and parts of Southeast Asia. Extensive areas with pisoliths and petroplinthite occur in the Sudano-Sahelian zone, where petroplinthite forms hard caps on top of uplifted/exposed landscape elements. Similar soils occur in the southern African savannah, the South American cerrado region, on the Indian subcontinent and in drier parts of Southeast Asia and northern Australia.



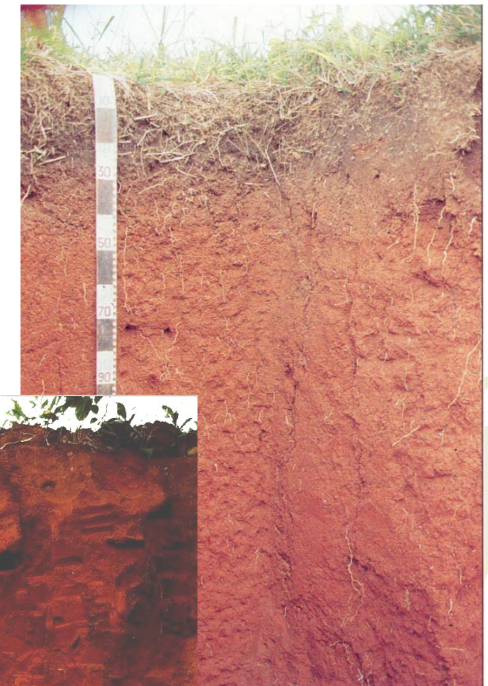
NITISOLS DISTRIBUTION

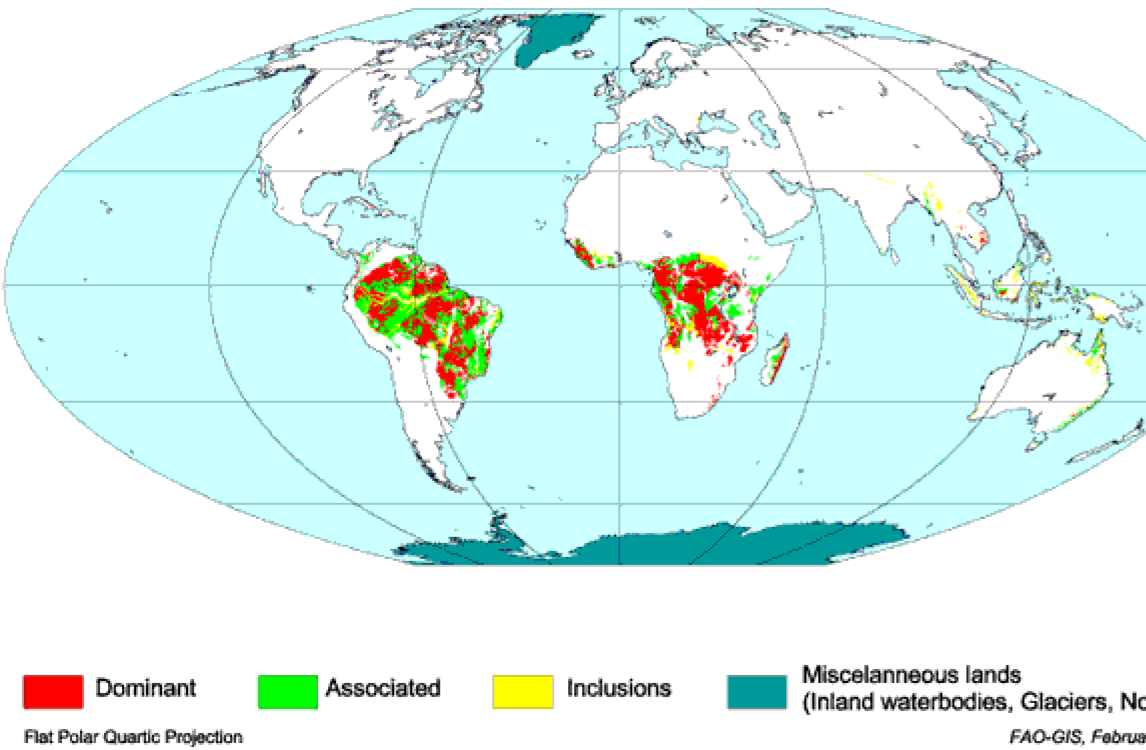
There are about 200 million ha of Nitisols worldwide. More than half of all Nitisols are found in tropical Africa, notably in the highlands (> 1 000 m) of Ethiopia, Kenya, Congo and Cameroon. Elsewhere Nitisols are well represented at lower altitudes, e.g. in tropical Asia, South America, Central America, Southeast Africa and Australia.



FERRALSOLS DISTRIBUTION

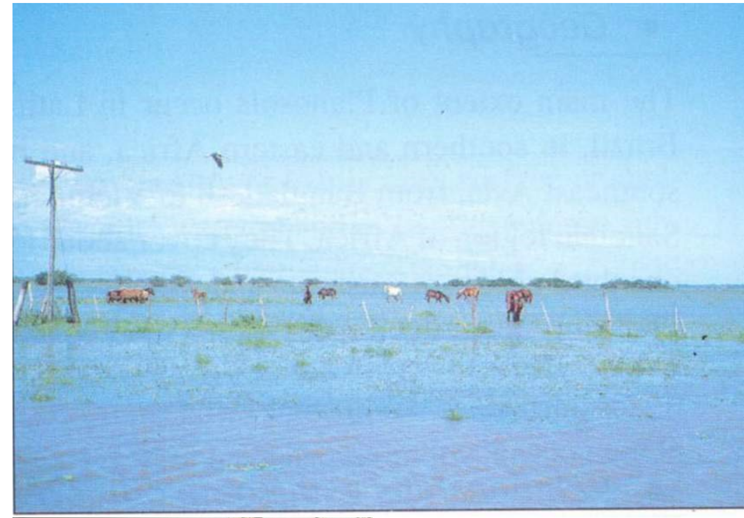
The worldwide extent of Ferralsols is estimated at some 750 million ha, almost exclusively in the humid tropics on the continental shields of South America (especially Brazil) and Africa (especially Congo, Democratic Republic of the Congo, southern Central African Republic, Angola, Guinea and eastern Madagascar). Outside the continental shields, Ferralsols are restricted to regions with easily weathering basic rock and a hot and humid climate, e.g. in Southeast Asia.

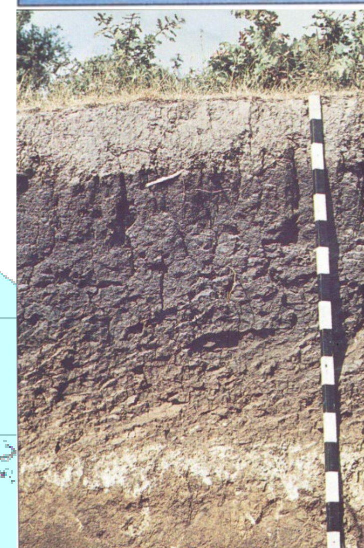


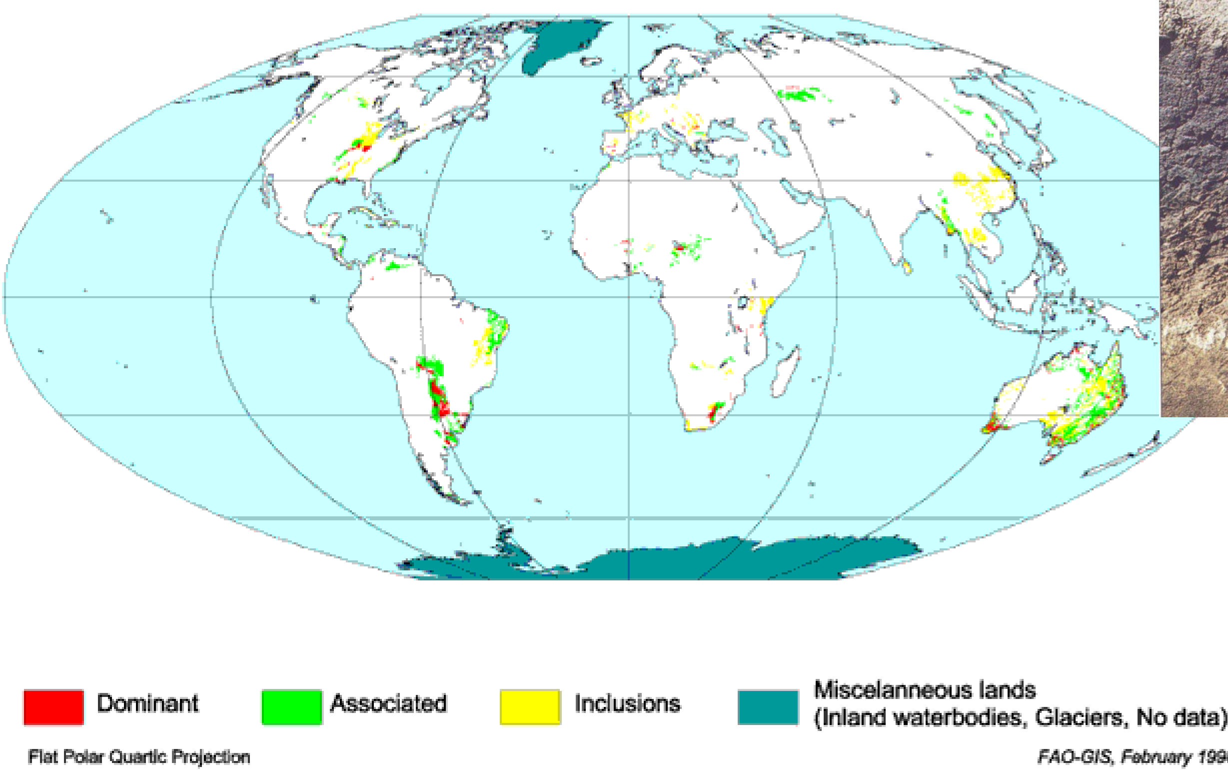


PLANOSOLS DISTRIBUTION

The world's major Planosol areas occur in subtropical and temperate regions with clear alternation of wet and dry seasons, e.g. in Latin America (southern Brazil, Paraguay and Argentina), Africa (Sahelian zone, eastern and southern Africa), the east of the United States of America, Southeast Asia (Bangladesh and Thailand) and Australia. Their total extent is estimated at some 130 million ha.







STAGNOSOLS DISTRIBUTION

Stagnosols cover 150–200 million ha worldwide; for the greater part in humid to perhumid temperate regions of West and Central Europe, North America, southeastern Australia, and Argentina, associated with Luvisols as well as silty to clayey Cambisols and Umbrisols. They also occur in humid to perhumid subtropical regions, associated with Acrisols and Planosols.

LEVEL 1: THE REFERENCE SOIL GROUPS (RSG) - 3

TYPE OF SOILS	NAME	CODE
5. Pronounced accumulation of organic matter in the mineral topsoil		
Very dark topsoil, secondary carbonates:	Chernozems	CH
Dark topsoil, secondary carbonates:	Kastanozems	KS
Dark topsoil, no secondary carbonates (unless very deep), high base status:	Phaeozems	PH
Dark topsoil, low base status:	Umbrisols	UM

TYPE OF SOILS	NAME	CODE
6. Accumulation of moderately soluble salts or non-saline substances		
Accumulation of, and cementation by, secondary silica:	Durisols	DU
Accumulation of secondary gypsum:	Gypsisols	GY
Accumulation of secondary carbonates:	Calcisols	CL

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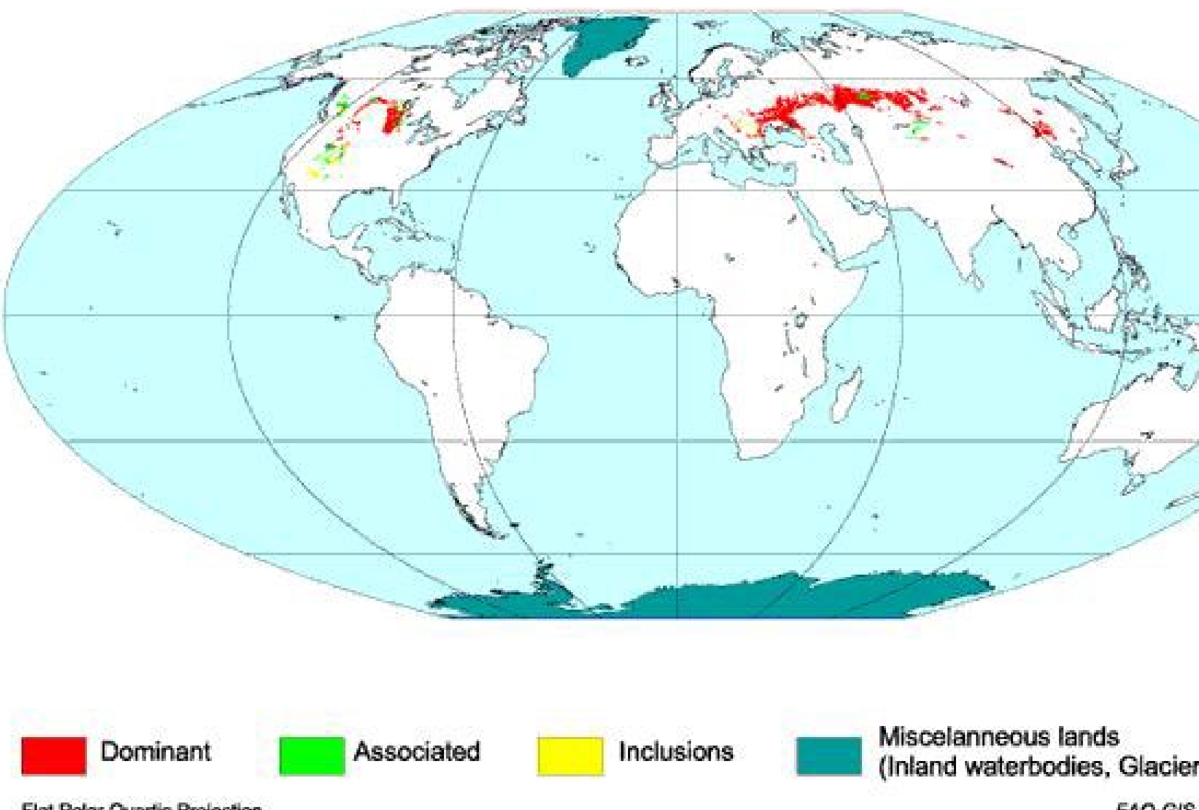
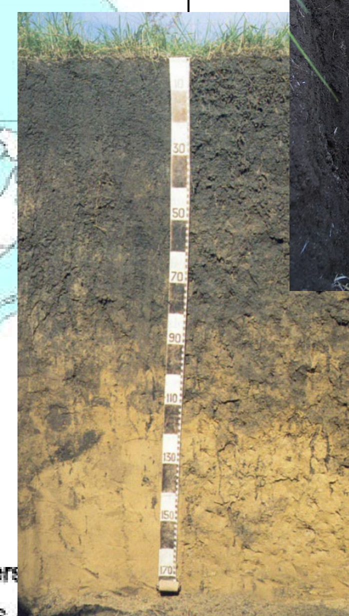
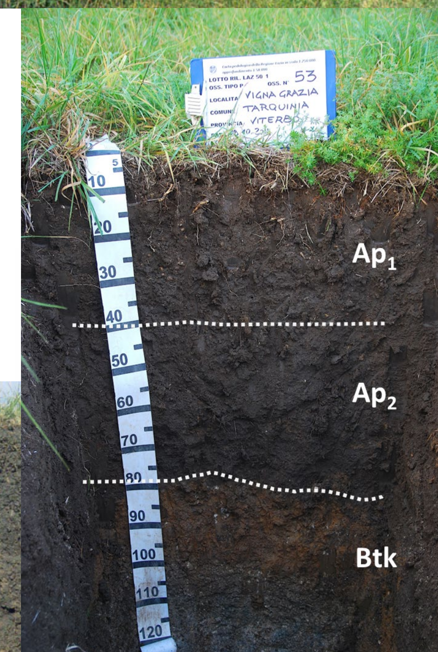
CHERNOZEMS DISTRIBUTION

Chernozems cover an estimated 230 million ha worldwide, mainly in the mid-latitude steppes of Eurasia (north of the zone with Kastanozems) and North America.

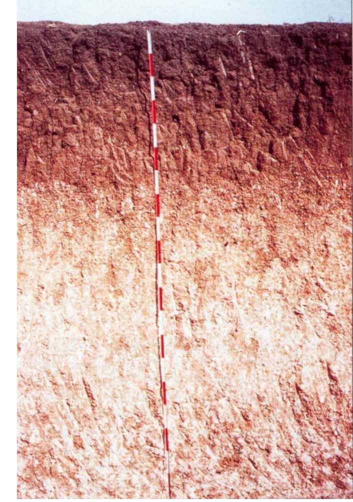


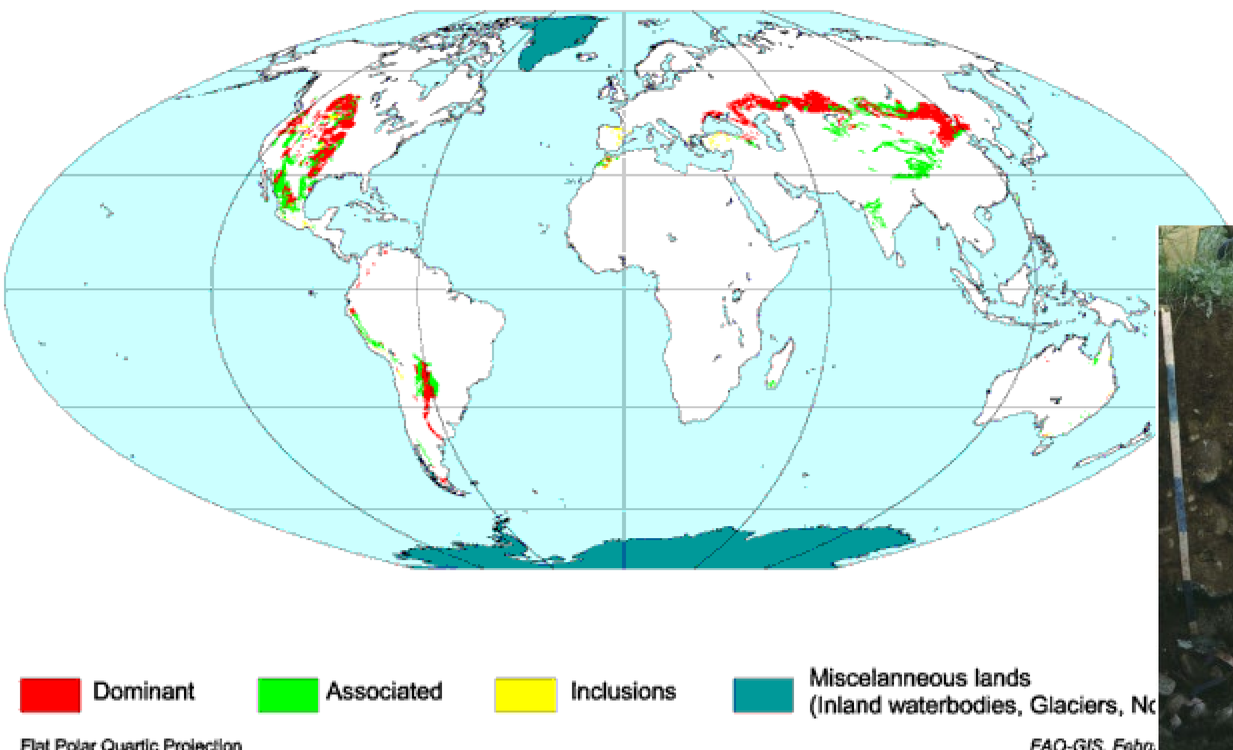




KASTANOZEMS DISTRIBUTION

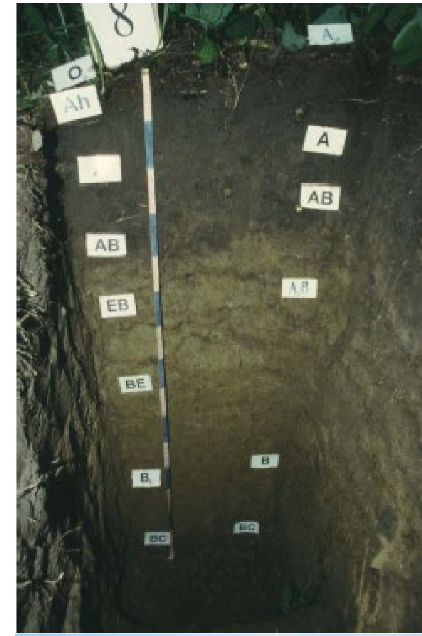
The total extent of Kastanozems is estimated to be about 465 million ha. Major areas are in the Eurasian short-grass steppe belt (southern Ukraine, the south of the Russian Federation, Kazakhstan and Mongolia), in the Great Plains of the United States of America, Canada and Mexico, and in the pampas and chaco regions of northern Argentina, Paraguay and southeastern Bolivia.

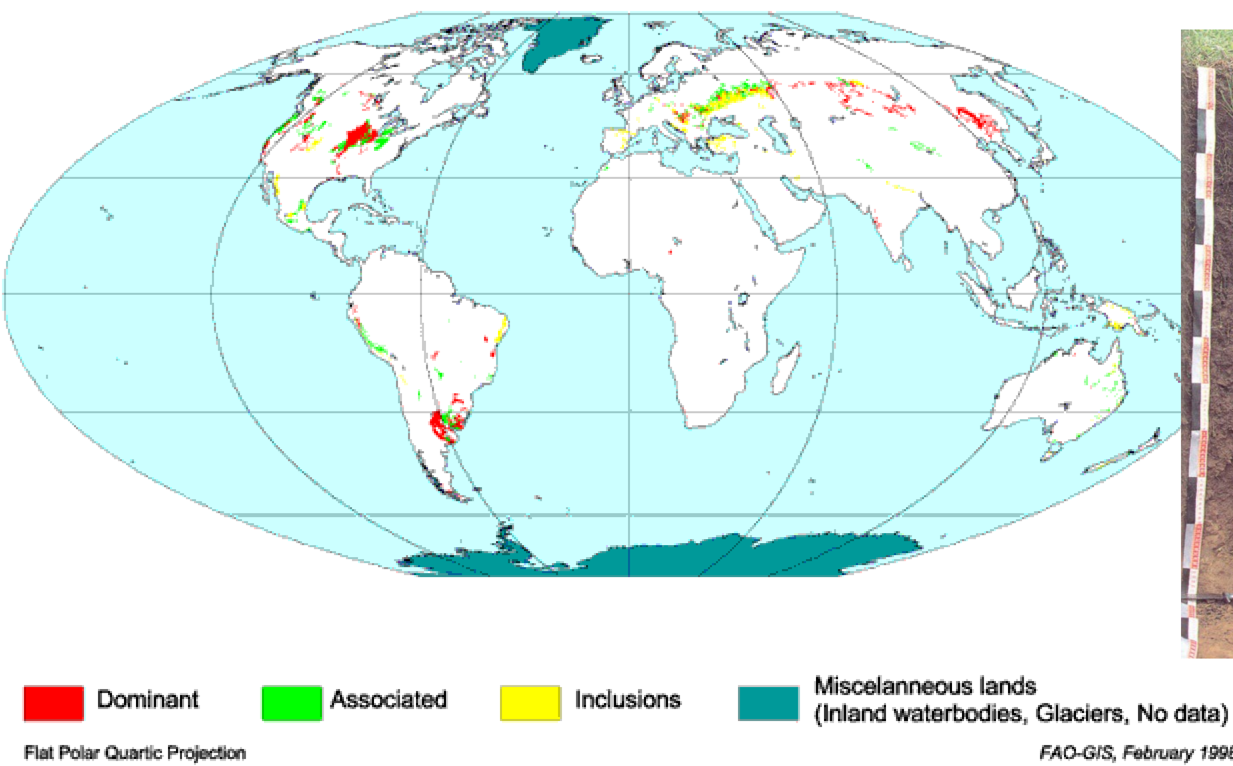


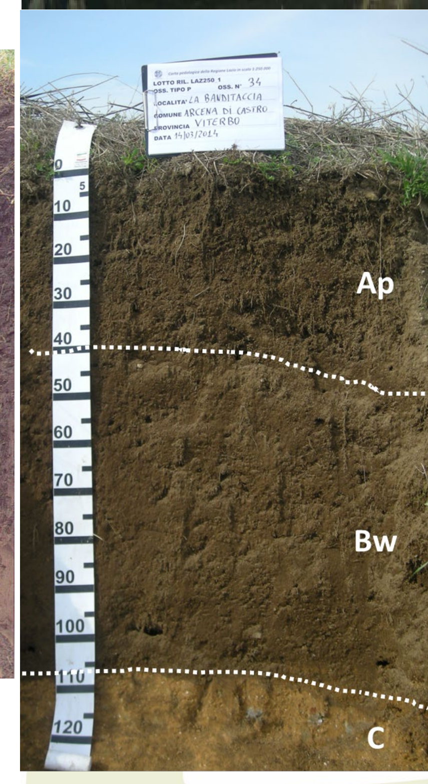


PHAEOZEMS DISTRIBUTION

Phaeozems cover an estimated 190 million ha worldwide. Some 70 million ha of Phaeozems are found in the humid and subhumid Central Lowlands and easternmost parts of the Great Plains of the United States of America. Another 50 million ha of Phaeozems are in the subtropical pampas of Argentina and Uruguay. The third largest area of Phaeozems (18 million ha) is in northeastern China, followed by discontinuous areas in the centre of the Russian Federation. Smaller, mostly discontinuous areas are found in Central Europe, notably the Danube area of Hungary and adjacent countries and in montane areas in the tropics.

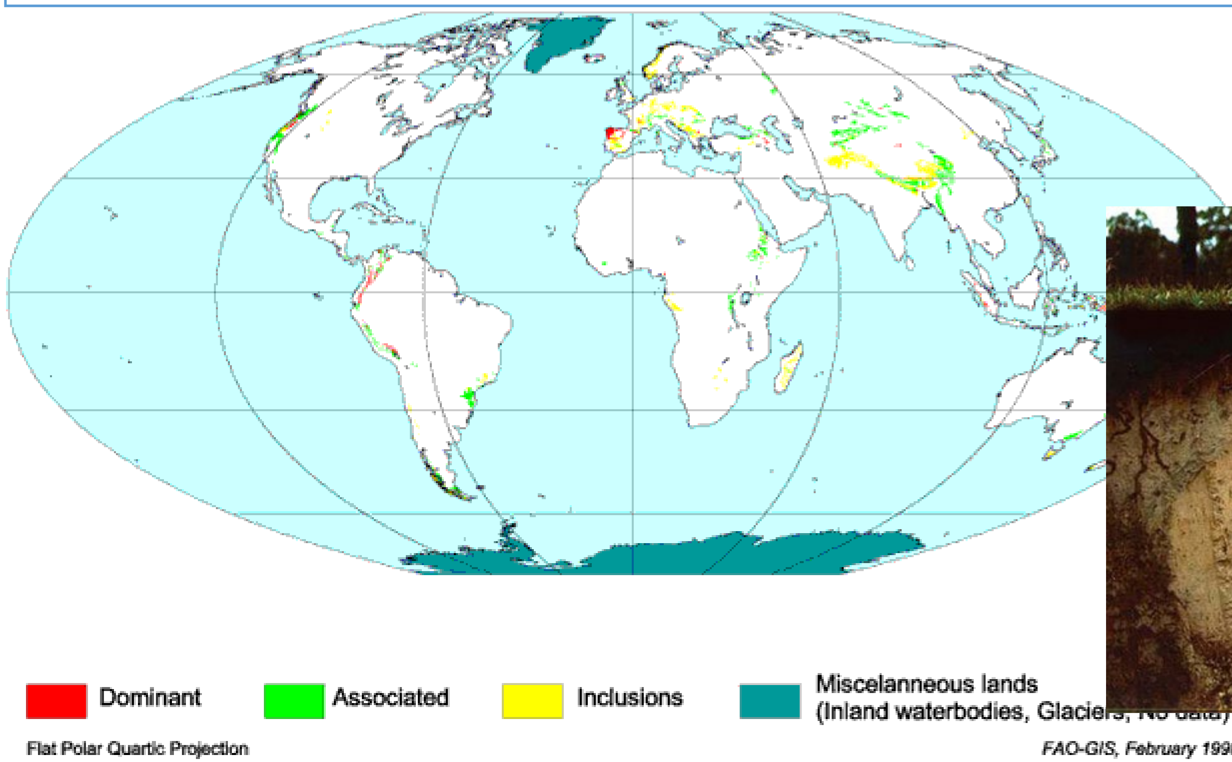






UMBRISOLS DISTRIBUTION

Umbrisols occur in cool to temperate humid regions, mostly mountainous and with little or no soil moisture deficit. They occupy about 100 million ha throughout the world. In South America, Umbrisols are common in the Andean ranges of Colombia, Ecuador, and to a lesser extent, in Venezuela, Bolivia and Peru. They also occur in Brazil, e.g. in the Serra do Mar. Umbrisols in North America are confined largely to the northwest Pacific seaboard. In Europe, Umbrisols occur along the northwest Atlantic seaboard, e.g. in Iceland, on the British Isles and in northwestern Portugal and Spain and in the Main Caucasus Ridge. In Asia, they are found in the mountain fringes of the Himalayas, notably in India, Nepal, China and Myanmar. Umbrisols occur at lower altitudes in Manipur (eastern India), in the Chin Hills (western Myanmar) and in Sumatra (Barisan range). In Oceania, Umbrisols are found in southeastern Australia and in the eastern parts of South Island, New Zealand.



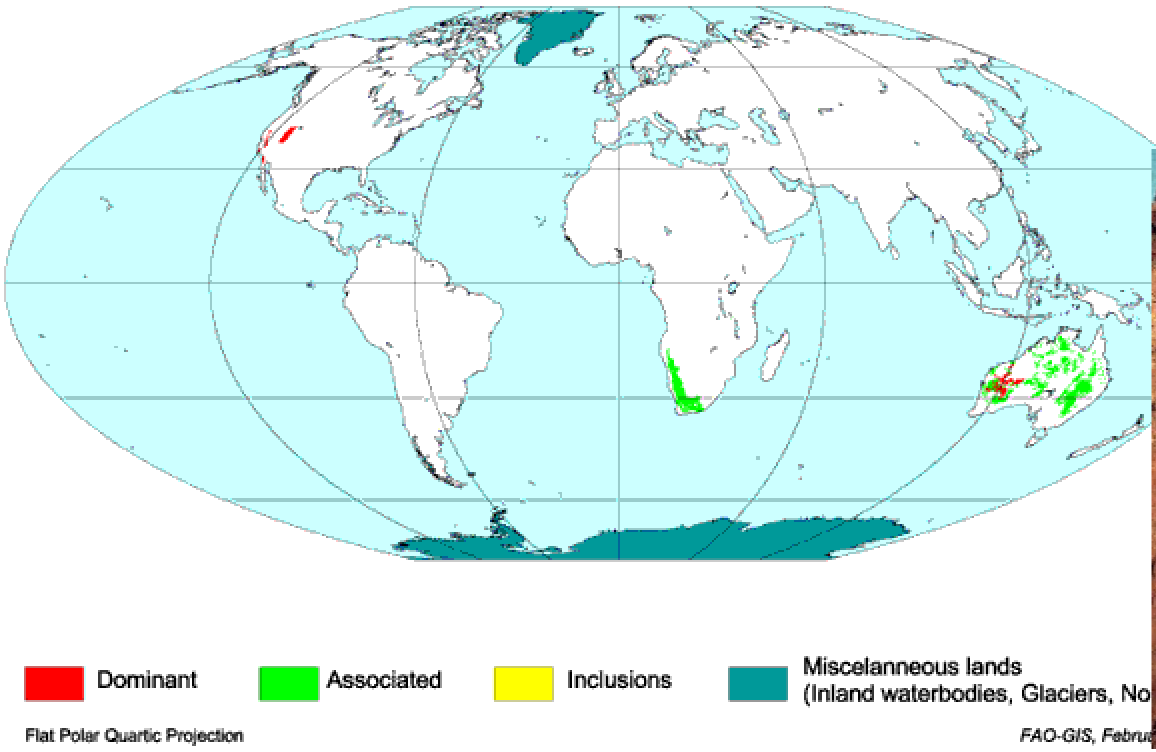
DURISOLS DISTRIBUTION

Extensive areas of Durisols occur in Australia, in South Africa and Namibia and in the United States of America (notably Nevada, California and Arizona); minoroccurrences have been reported from Mexico, Central and South America and from Kuwait. Durisols have only recently been introduced into international soil classifications and have not often been mapped as such. A precise indication of their extent is not yet available.

Chromic Durisol, Corsica (FR)

Luvi-Endopetric Durisol (Chromic), USA

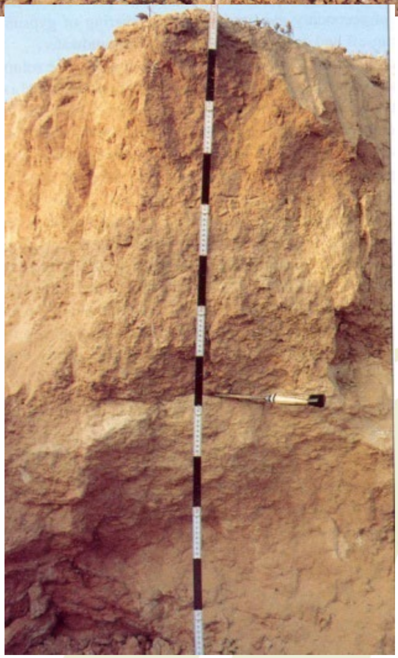
Chromi-Epipetric Durisol, South Africa

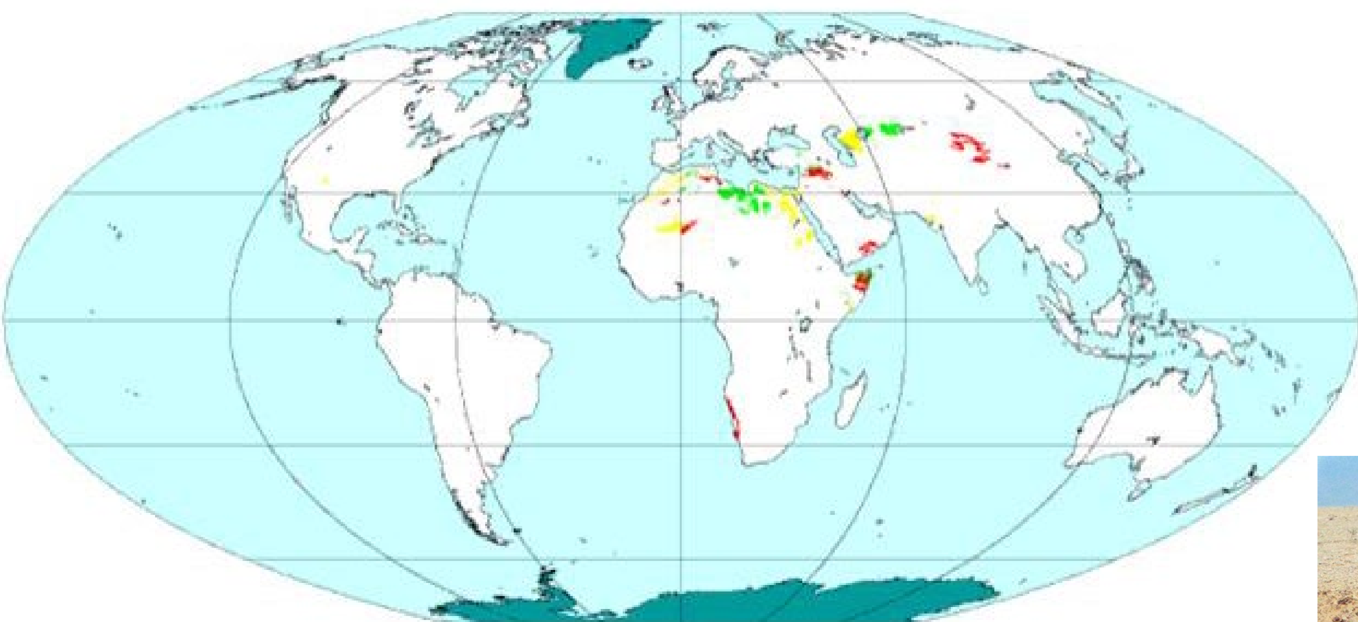


GYPSISOLS DISTRIBUTION

Gypsisols are restricted to arid regions; their worldwide extent is probably of the order of 100 million ha. Major occurrences are in the Near East, Kazakhstan, Turkmenistan, Uzbekistan, in the Libyan and Namib deserts, in southern and central Australia and in the southwest of the United States of America.

Petric Gypsisols
Ethiopia

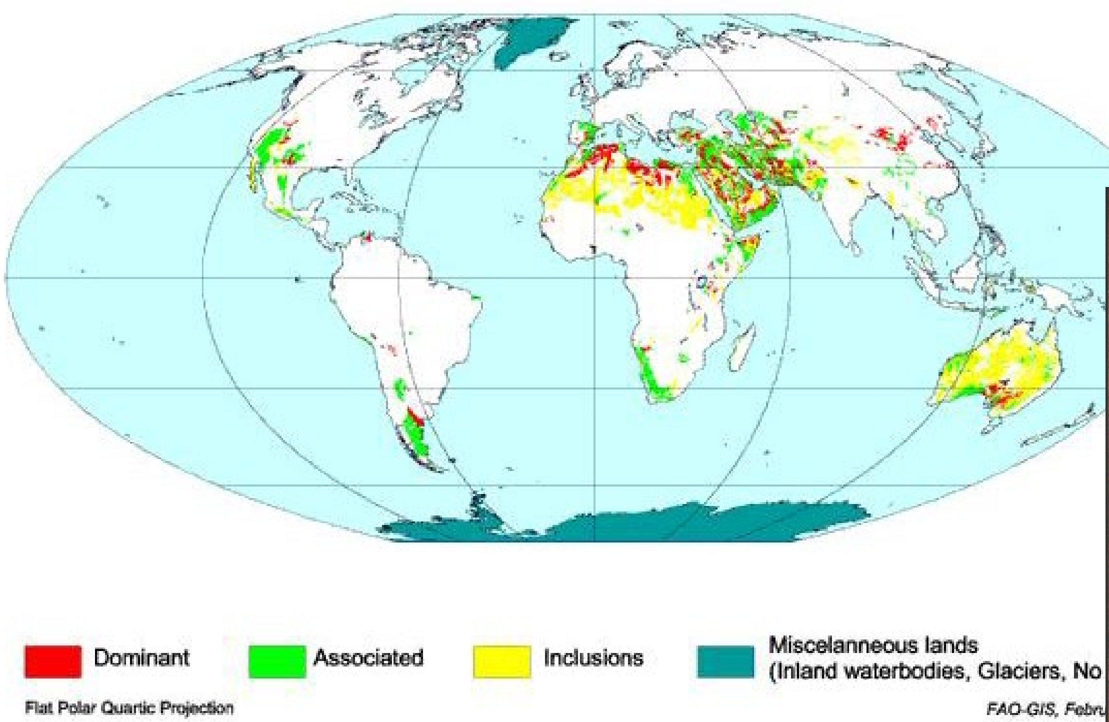


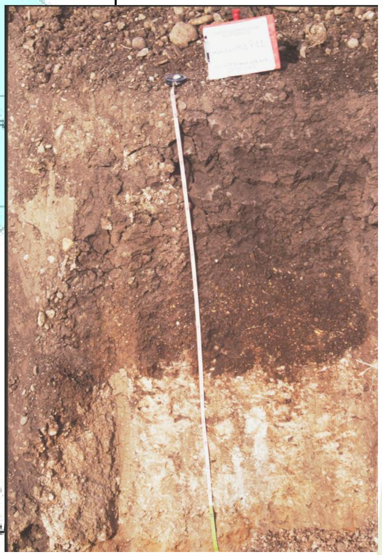


Petric Gypsisols
Namib Desert

CALCISOLS DISTRIBUTION

It is difficult to quantify the worldwide extent of Calcisols with any measure of accuracy. Many Calcisols occur together with Solonchaks that are actually salt-affected Calcisols, and/or with other soils having accumulations of secondary carbonates not sufficient to key out as Calcisols. The total Calcisol area may well amount to some 1 000 million ha, most of them in the arid and semi-arid tropics and subtropics of both hemispheres.





Endo-Petric Calcisols
Italy (Basilicata)

LEVEL 1: THE REFERENCE SOIL GROUPS (RSG) - 4

TYPE OF SOILS	NAME	CODE
7. Soils with clay-enriched subsoil		
Interfingering of coarser-textured, lighter-coloured material into a finer-textured, stronger coloured layer: (former Albeluvisols)	Retisols	RT
Low-activity clays, low base status:	Acrisols	AC
Low-activity clays, high base status:	Lixisols	LX
High-activity clays, low base status:	Alisols	AL
High-activity clays, high base status:	Luvisols	LV

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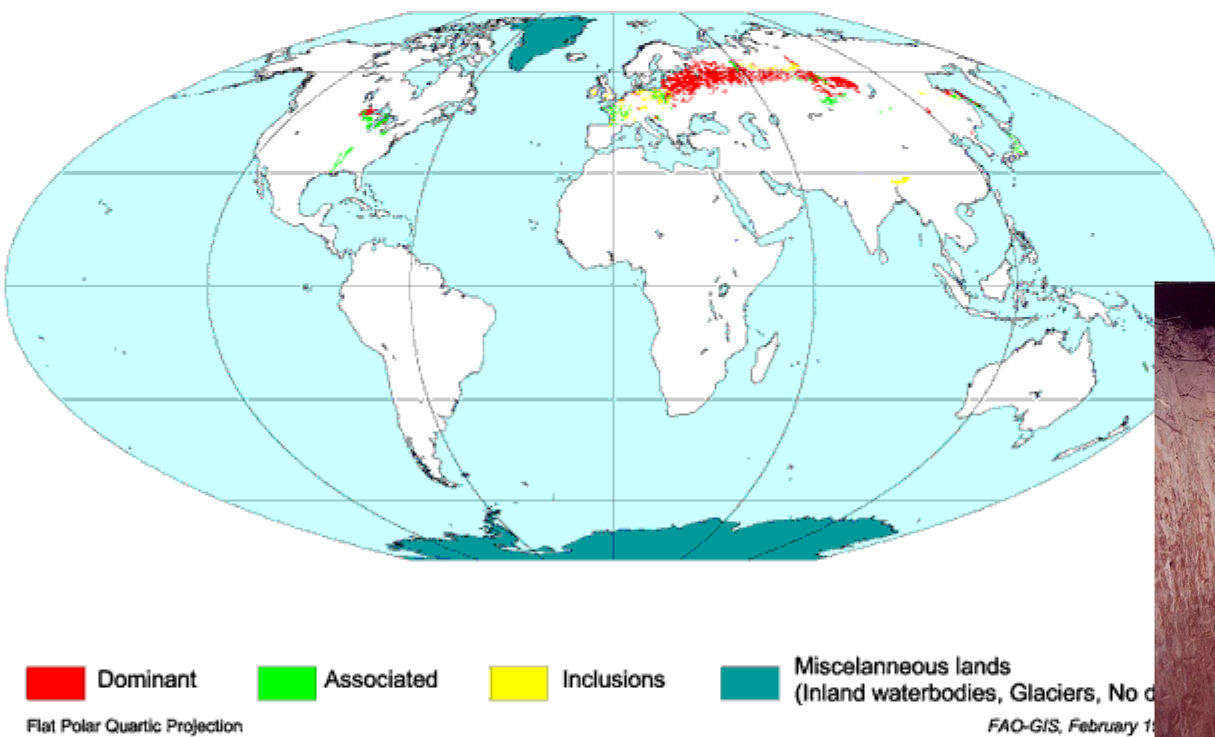
RETISOLS DISTRIBUTION

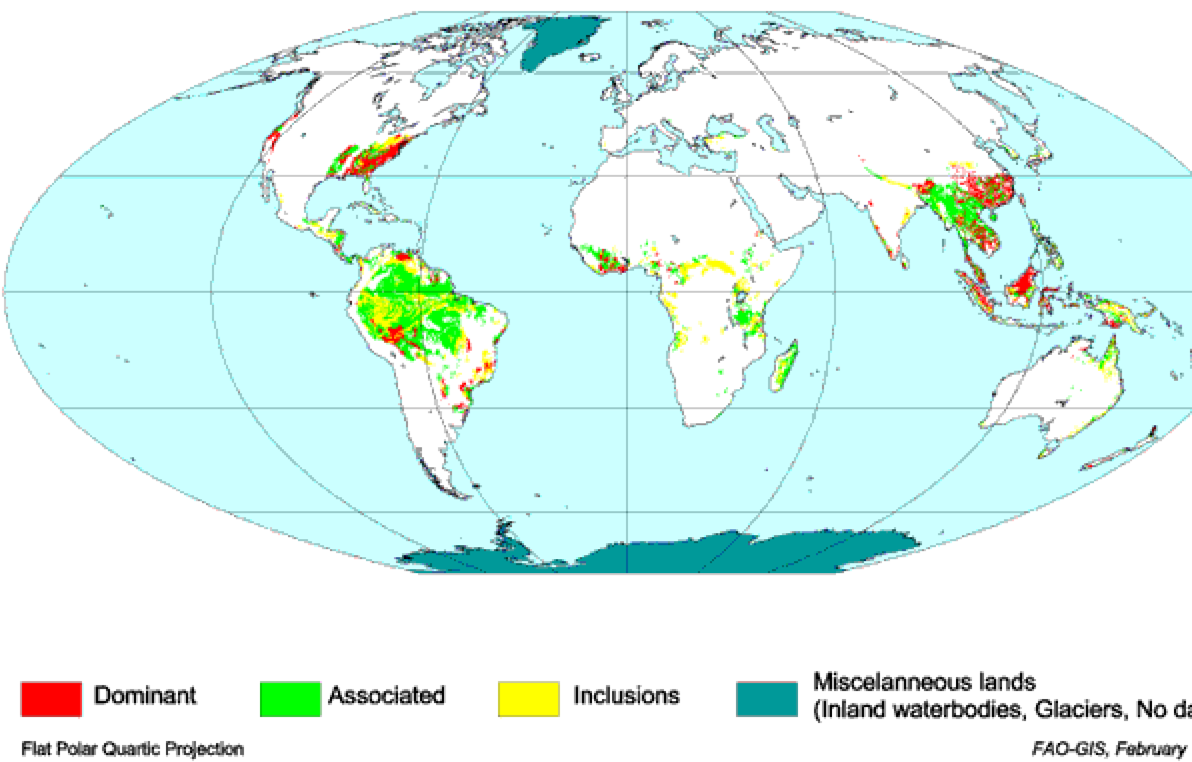
Retisols cover an estimated 320 million ha in Europe, North Asia and Central Asia, with minor occurrences in North America. Retisols are concentrated in two regions, each having a particular set of climate conditions:

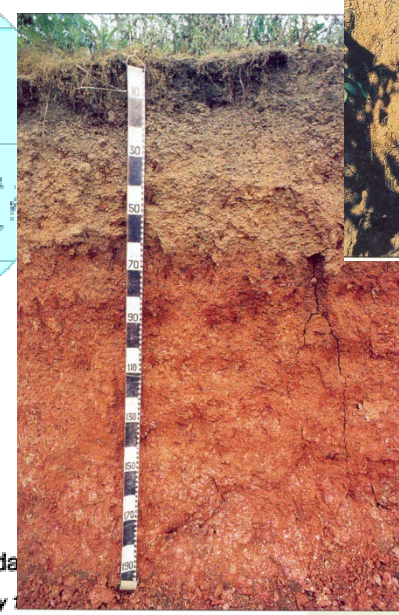
- the continental regions that had permafrost in the Pleistocene of northeastern Europe, northwestern Asia and southern Canada, which constitute by far the largest areas of Retisols;
- the loess and cover sand areas and old alluvial areas in moist temperate regions, such as France, central Belgium, the southeast of the Netherlands and the west of Germany



ACRISOLS DISTRIBUTION

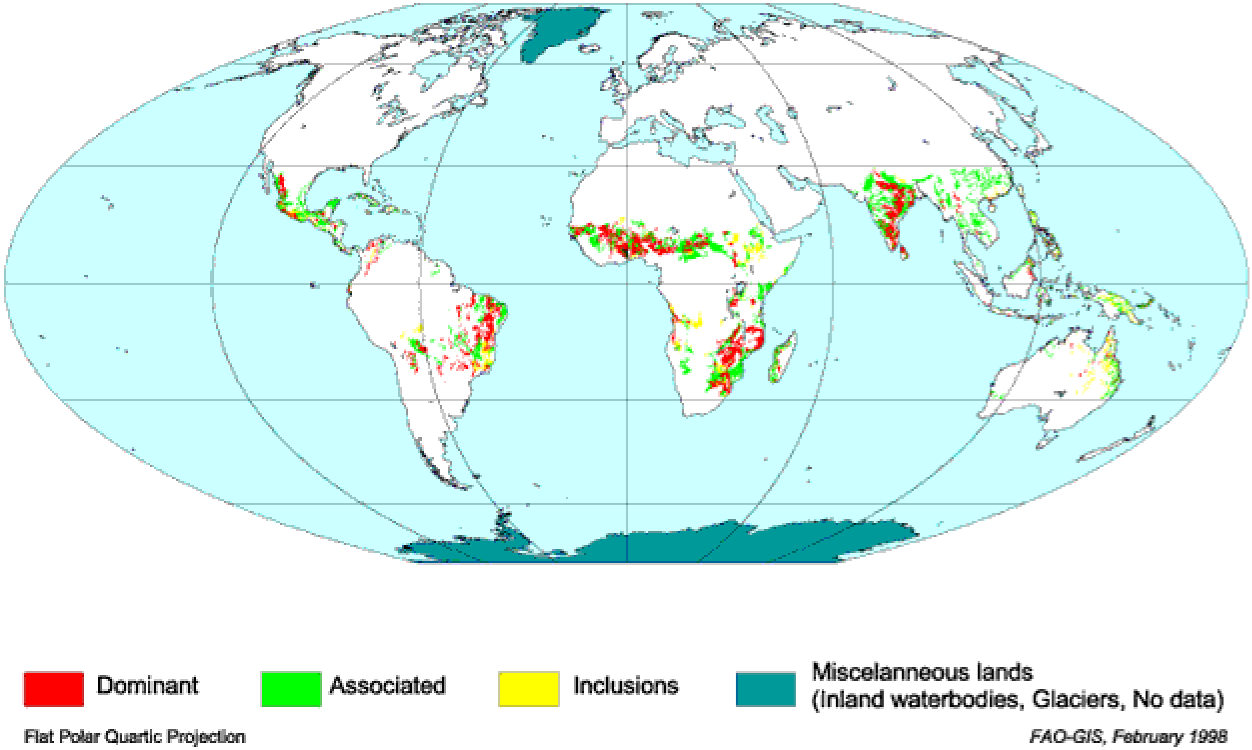
Acrisols are found in humid tropical, humid subtropical and warm temperate regions and are most extensive in Southeast Asia, the southern fringes of the Amazon Basin, the southeast of the United States of America and in both East and West Africa. There are about 1 000 million ha of Acrisols worldwide.

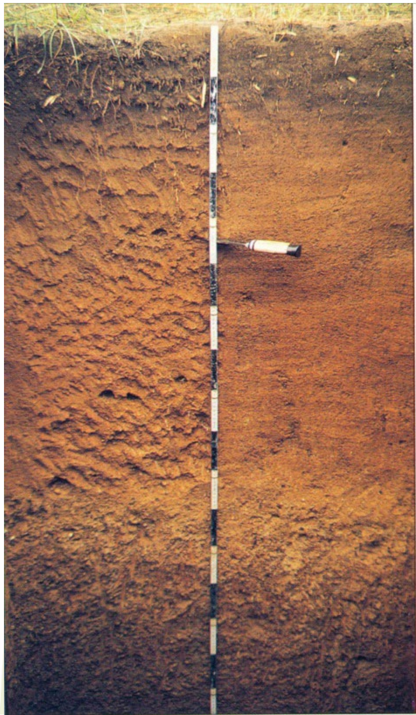




LIXISOLS DISTRIBUTION

Lixisols are found in seasonally dry tropical, subtropical and warm temperate regions on Pleistocene and older surfaces. These soils cover a total area of about 435 million ha, of which more than half occur in (sub-)Sahelian and East Africa, about one-quarter in South and Central America, and the remainder on the Indian subcontinent and in Southeast Asia and Australia.

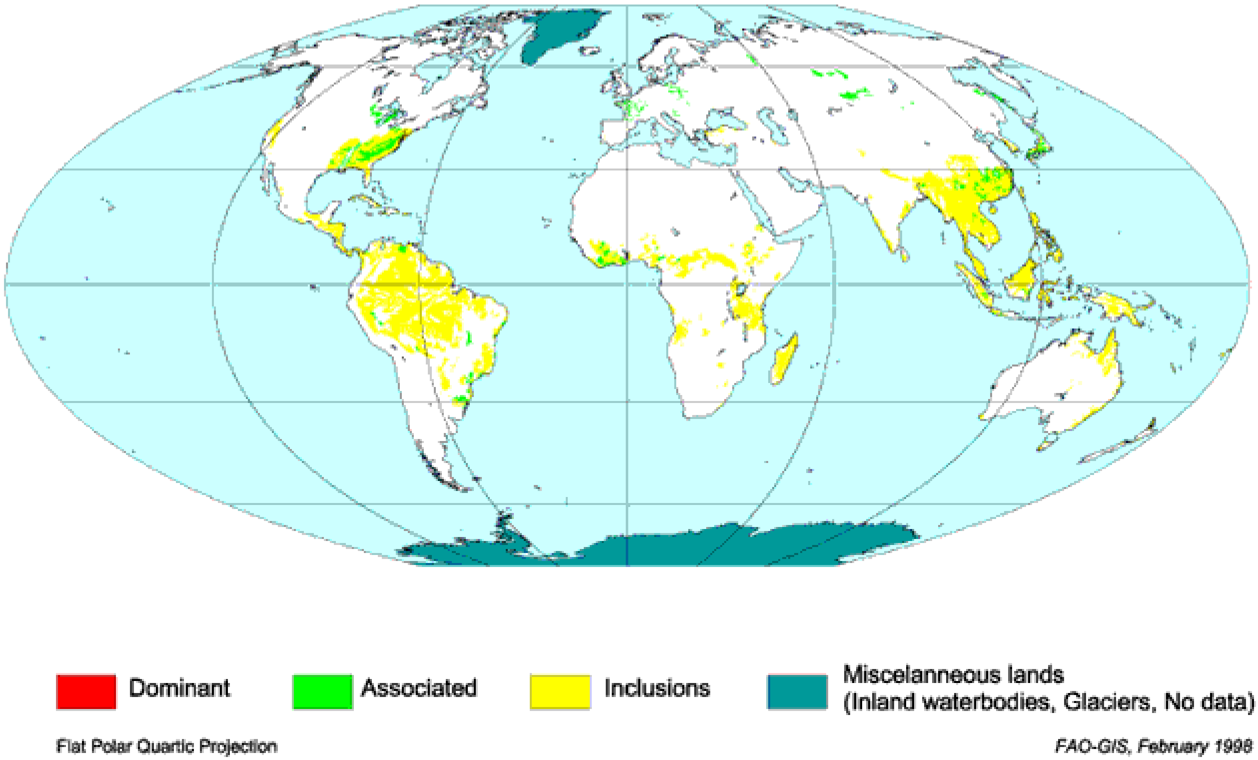




ALISOLS DISTRIBUTION

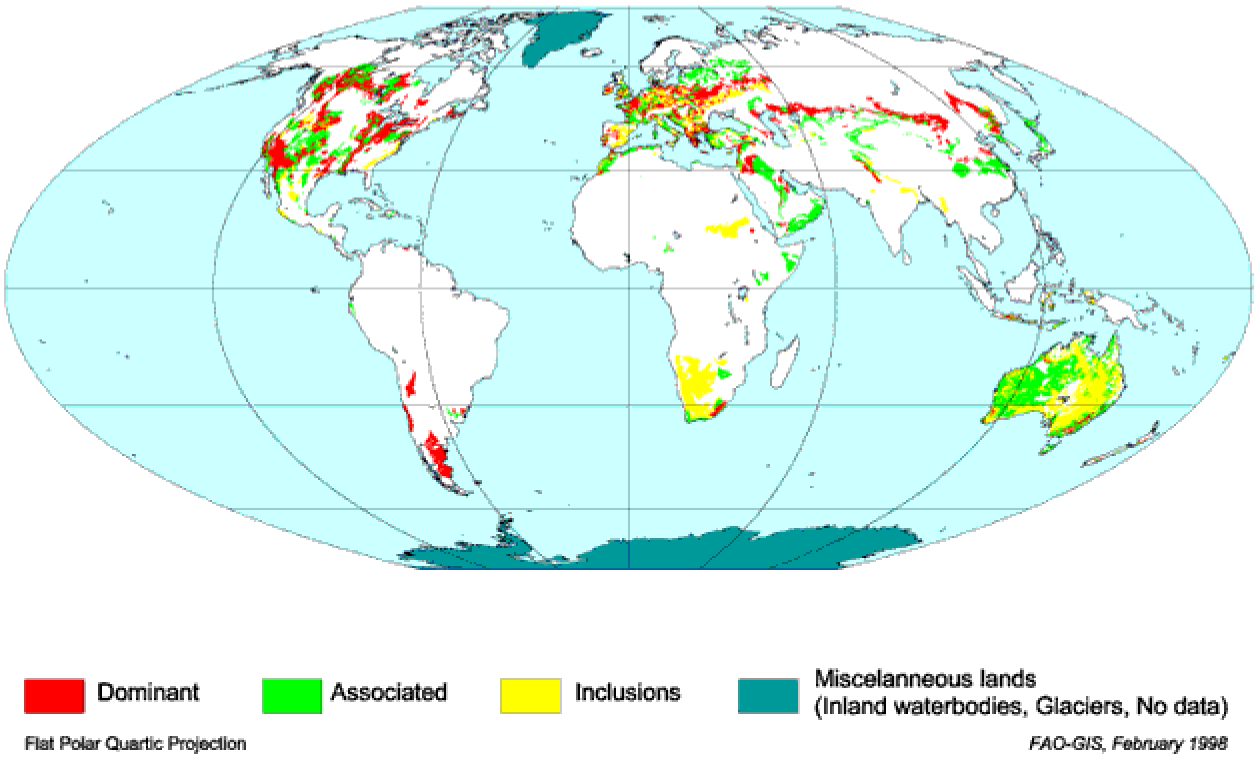
Major occurrences of Alisols are in Latin America (Ecuador, Nicaragua, Venezuela, Colombia, Peru and Brazil), in the West Indies (Jamaica, Martinique and Saint Lucia), in West Africa, the highlands of East Africa, Madagascar and in Southeast Asia and northern Australia. FAO (2001a) estimates that about 100 million ha of these soils are used for agriculture in the tropics.

Alisols occur also in subtropical regions; they are found in China, Japan and the southeast of the United States of America and minor occurrences have been reported from around the Mediterranean Sea (Italy, France and Greece). They also occur in humid temperate regions.



LUVISOLS DISTRIBUTION

Luvisols extend over 500–600 million ha worldwide, mainly in temperate regions such as in the East European Plain and parts of the West Siberian Plain, the North-East of the United States of America, and Central Europe, but also in the Mediterranean region and southern Australia. In subtropical and tropical regions, Luvisols occur mainly on young land surfaces.



LEVEL 1: THE REFERENCE SOIL GROUPS (RSG) - 5

TYPE OF SOILS	NAME	CODE
8. Soils with little or no profile differentiation		
Moderately developed:	Cambisols	CM
Stratified fluviatile, marine or lacustrine sediments:	Fluvisols	FL
Sandy:	Arenosols	AR
No significant profile development:	Regosols	RG

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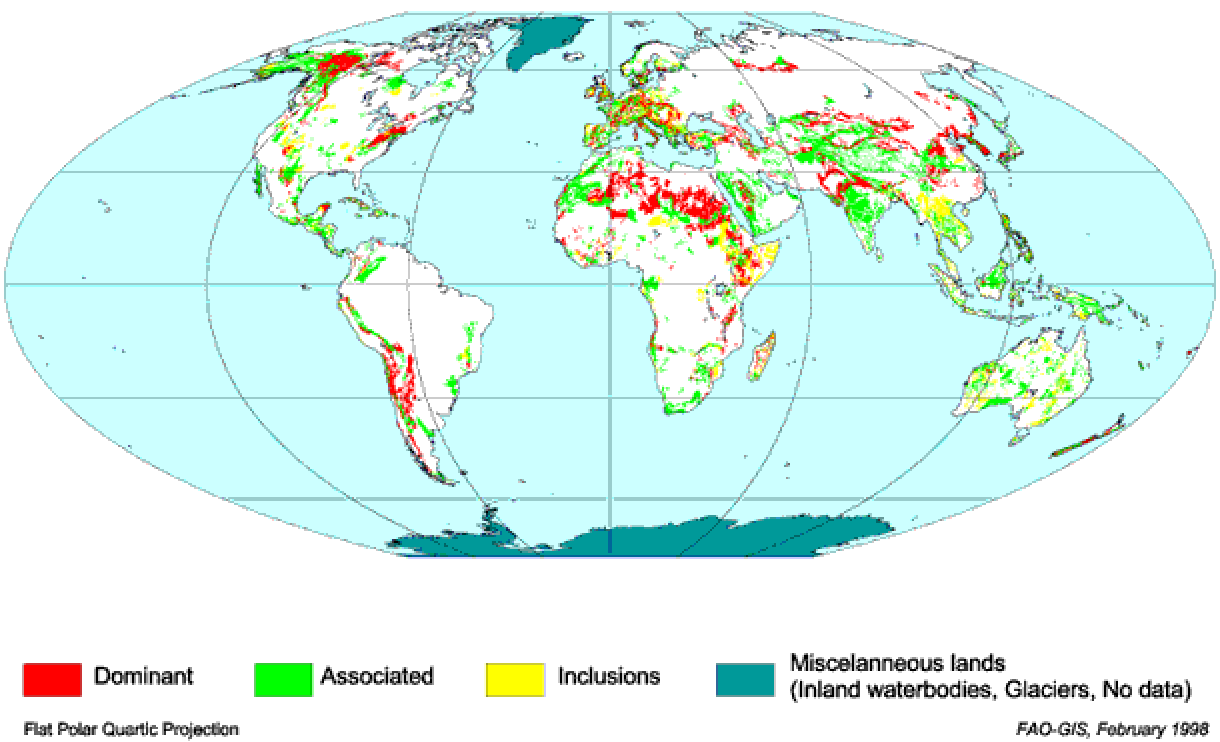
CAMBISOLS DISTRIBUTION

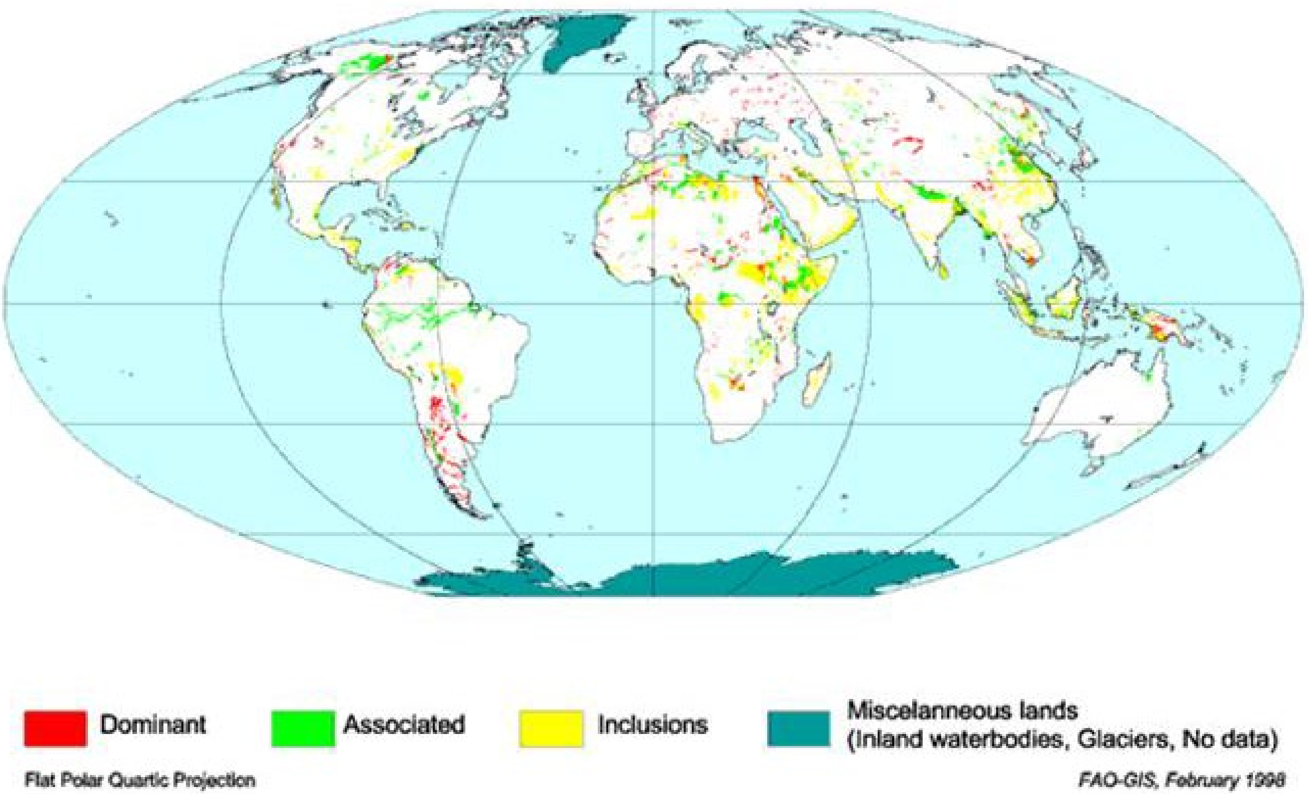
Cambisols cover an estimated 1 500 million ha worldwide. This RSG is particularly well represented in temperate and boreal regions that were under the influence of glaciations during the Pleistocene, partly because the parent material of the soil is still young, but also because soil formation is slow in cool regions. Erosion and deposition cycles explain the occurrence of Cambisols in mountain regions. Cambisols also occur in dry regions but are less common in the humid tropics and subtropics where weathering and soil formation proceed at much faster rates than in temperate, boreal and dry regions. The young alluvial plains and terraces of the Ganges–Brahmaputra system are probably the largest continuous surface of Cambisols in the tropics. Cambisols are also common in areas with active geologic erosion, where they may occur in association with mature tropical soils.

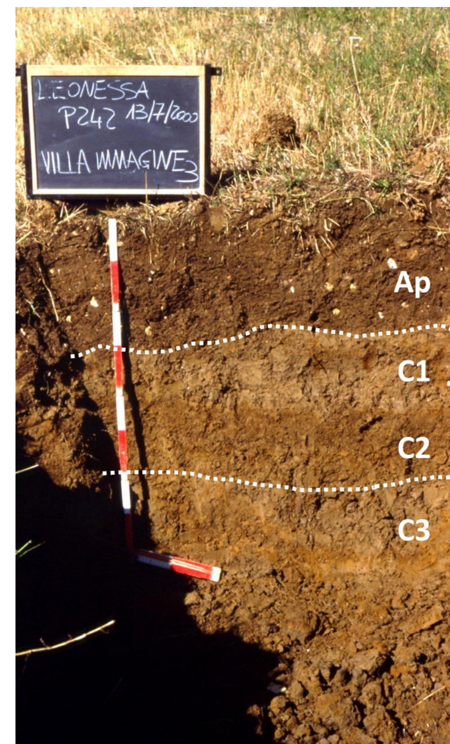


FLUVISOLS DISTRIBUTION

Fluvisols occur on all continents and in all climates. They occupy less than 350 million ha worldwide, of which more than half are in the tropics. Major areas of Fluvisols are found:

- along rivers and lakes, e.g. in the Amazon basin, the plains near Lake Chad in Central Africa, the Ganges Plain of India and in eastern China;
- in deltaic areas, e.g. the deltas of the Indus, Ganges–Brahmaputra, Mekong, Lena, Nile, Niger, Zambezi, Mississippi, Orinoco, Plate, Volga, Po and Rhine;
- in areas of recent marine deposits, for example the coastal lowlands of Indonesia (e.g. Sumatra, Kalimantan and Papua province) and Papua New Guinea.

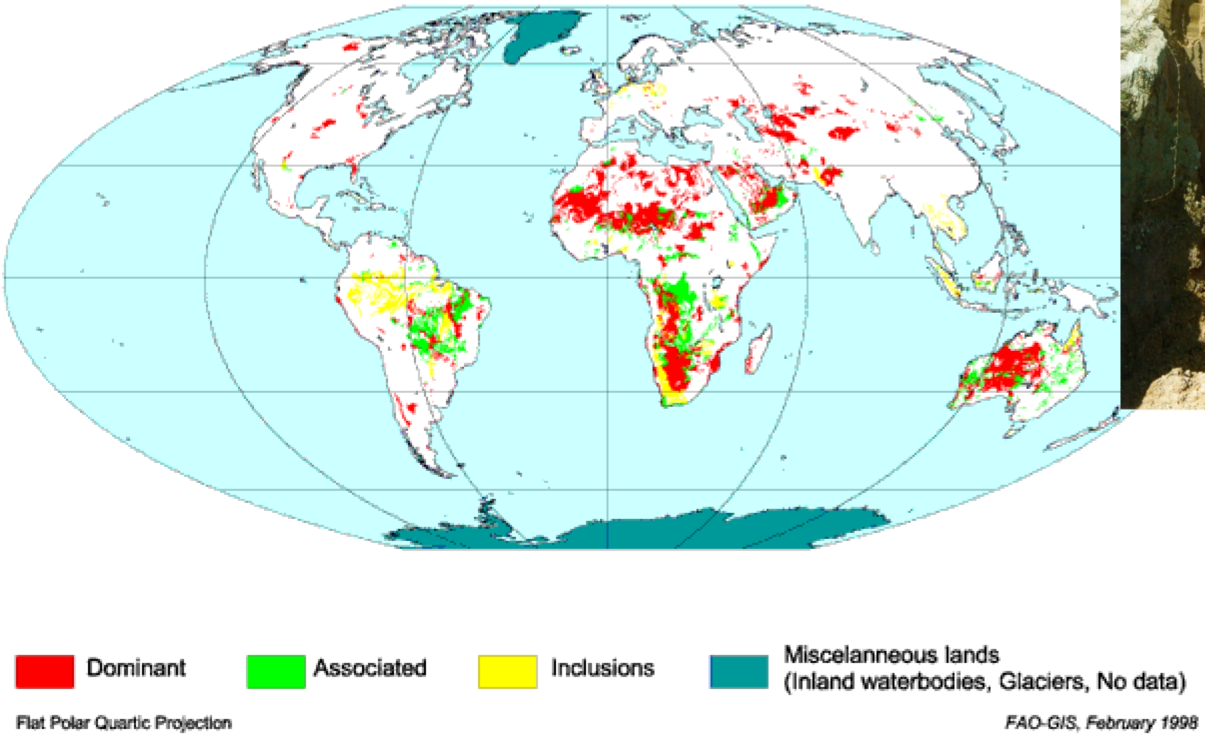




ARENOSOLS DISTRIBUTION

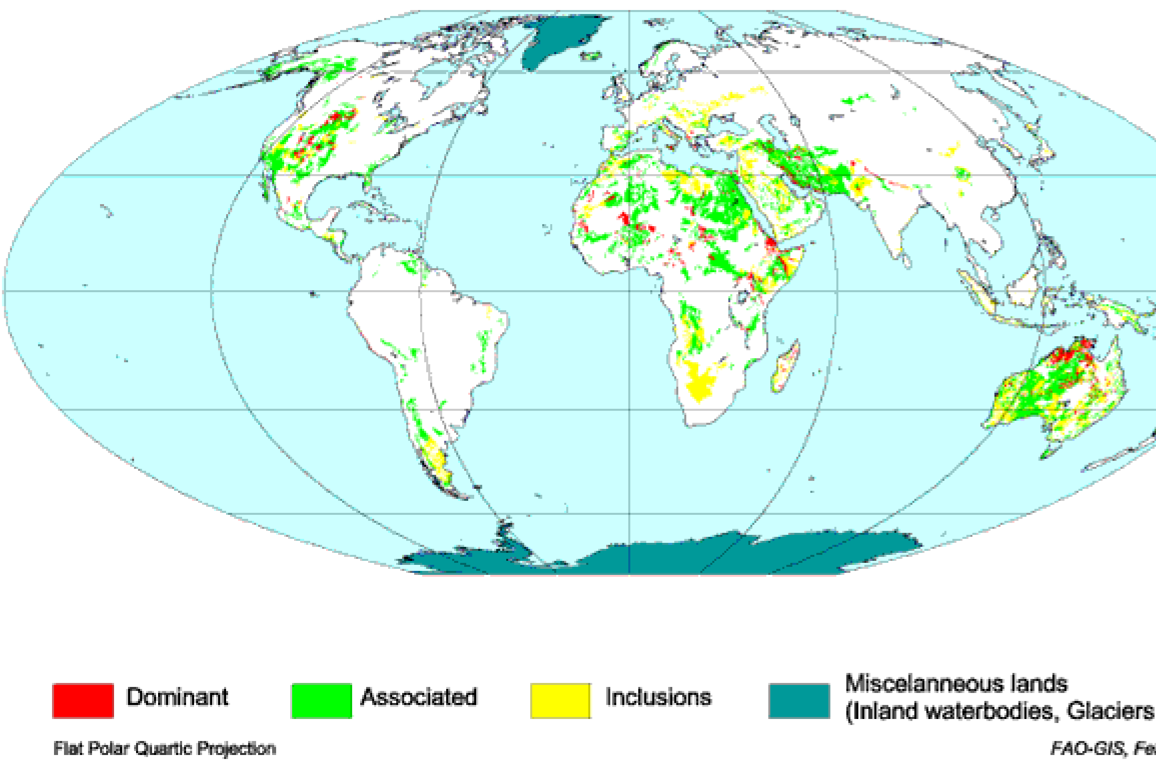
Arenosols are one of the most extensive RSGs in the world; including shifting sands and active dunes, they cover about 1 300 million ha or 10 percent of the land surface. Vast expanses of deep aeolian sands are found on the Central African plateau between the equator and 30 °S. These Kalahari Sands form the largest body of sands on earth.

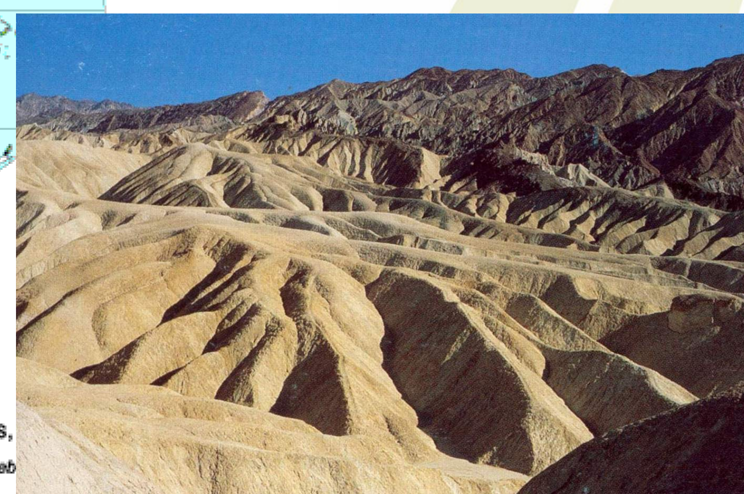
Other areas of Arenosols occur in the Sahelian region of Africa, various parts of the Sahara, central and western Australia, the Near East and western China. Sandy coastal plains and coastal dune areas are of smaller geographic extent.



REGOSOLS DISTRIBUTION

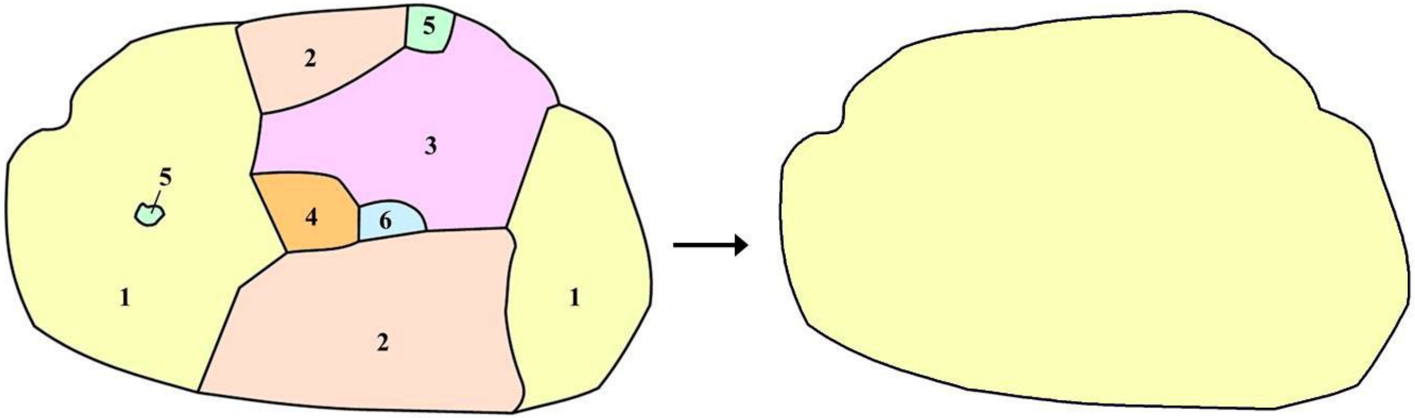
Regosols cover an estimated 260 million ha worldwide, mainly in arid areas in the Midwest of the United States of America, northern Africa, the Near East and Australia. Some 50 million ha of Regosols occur in the dry tropics and another 36 million ha in mountain areas. The extent of most Regosol areas is limited; consequently Regosols are common inclusions in other map units on small-scale maps.





WORLD REFERENCE BASE: Mapping soil, indicators and threats

- The classification of soils is based on soil properties defined in terms of diagnostic horizons, diagnostic properties and diagnostic materials (together called the diagnostics), which to the greatest extent possible should be measurable and observable in the field.
- A landscape usually shows a variety of soils. For a map unit, they often have to be combined. The principles are shown:



Area	Complete soil name	Result
1	Haplic Luvisol (Episiltic, Katoclayic, Aric, Cutanic, Differentic, Epic, Ochric)	dominant soil
2	Eutric Stagnic Leptic Cambisol (Loamic, Humic)	codominant soil
3	Albic Stagnic Luvisol (Anosiltic, Endoclayic, Cutanic, Differentic, Endic, Humic)	associated soil
4	Thyric Technosol (Loamic, Calcaric, Skeletic)	ignored
5	Eutric Luvic Stagnosol (Episiltic, Katoclayic, Humic)	ignored
6	Hortic Anthrosol (Loamic, Eutric)	ignored

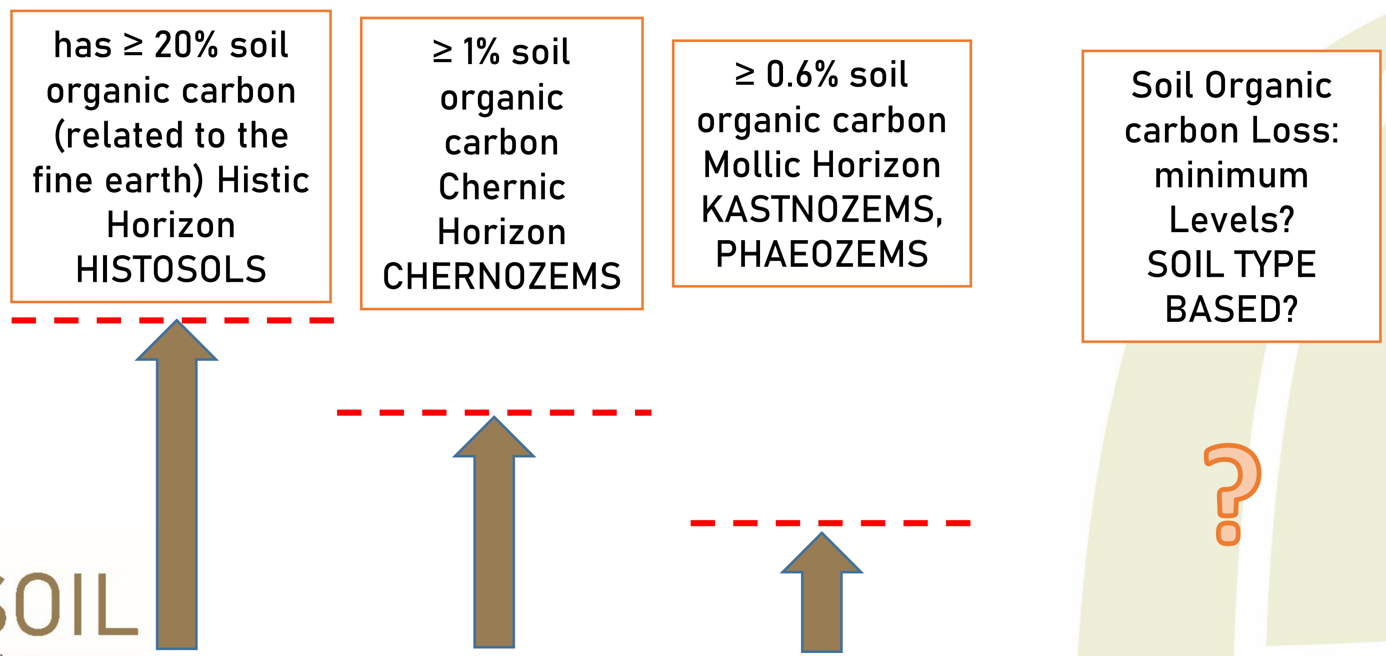
WORLD REFERENCE BASE: Mapping soil, indicators and threats

1. WRB CLASSIFICATION ESTABILISHED DIAGNOSTICS AND LIMITIS (MORPHOLOGICALLY AND/OR ANALITHYCALLY BASED)

2. INDICATORS OF MAJOR SOIL THREATS ARE GOING TO BE IDENTIFIED WITH THRESHOLD VALUES

- WE MUST TRY TO USE THE FIRST (DIAGNOSTIC LIMITS) AS MUCH AS POSSIBLE ALSO FOR DEFINING THE SECOND (THRESHOLDS FOR SOIL THREATS), SO TO BE ABLE TO PROPERLY MAP THE THREATS

SOIL CARBON IN THE TOPSOIL



EJP SOIL
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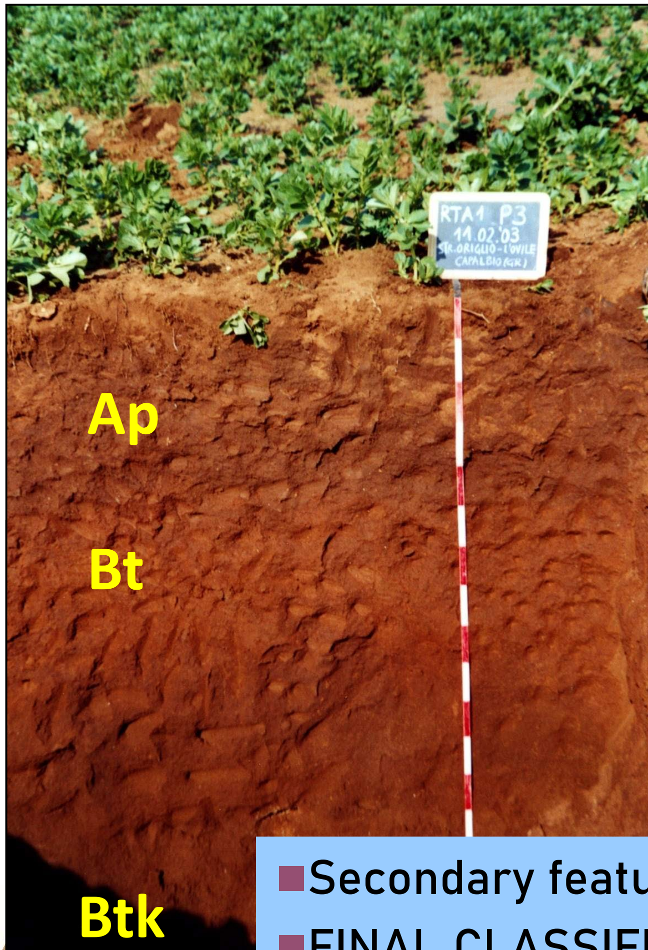
WRB Final Exercise

- Diagnostic horizion: Argic, Calcic (too deep for diagnostic!)
- Diagnostic features: clay cutans within 100 cm from surface



Other soils having an *argic* horizon with a CEC (by 1 *M* NH_4OAc) of 24 $cmol_c\ kg^{-1}$ clay[53] or more throughout or to a depth of 50 cm below its upper limit, whichever is shallower, either starting within 100 cm of the soil surface or within 200 cm of the soil surface if the *argic* horizon is overlain by loamy sand or coarser textures throughout.

LUVISOLS

Lamellic	Anthric
Cutanic	Fragic
Albic	Manganiferric
Escalic	Ferric
Technic	Abruptic
Leptic	Ruptic
Vertic	Humic
Gleyic	Sodic
Vitric	Epidystric
Andic	Hypereutric
Nitic	Turbic
Stagnic	Gelic
Calcic	Oxyaquic
Haplic	Greyic
	Profondic
	Hyperochric
	Skeletic
	Arenic
	Siltic
	Clayic
	Rhodic
	Chromic
	Novic

- Secondary features: red colour (2.5YR)
- FINAL CLASSIFICATION: CUTANIC LUVISOL (Rhodic)