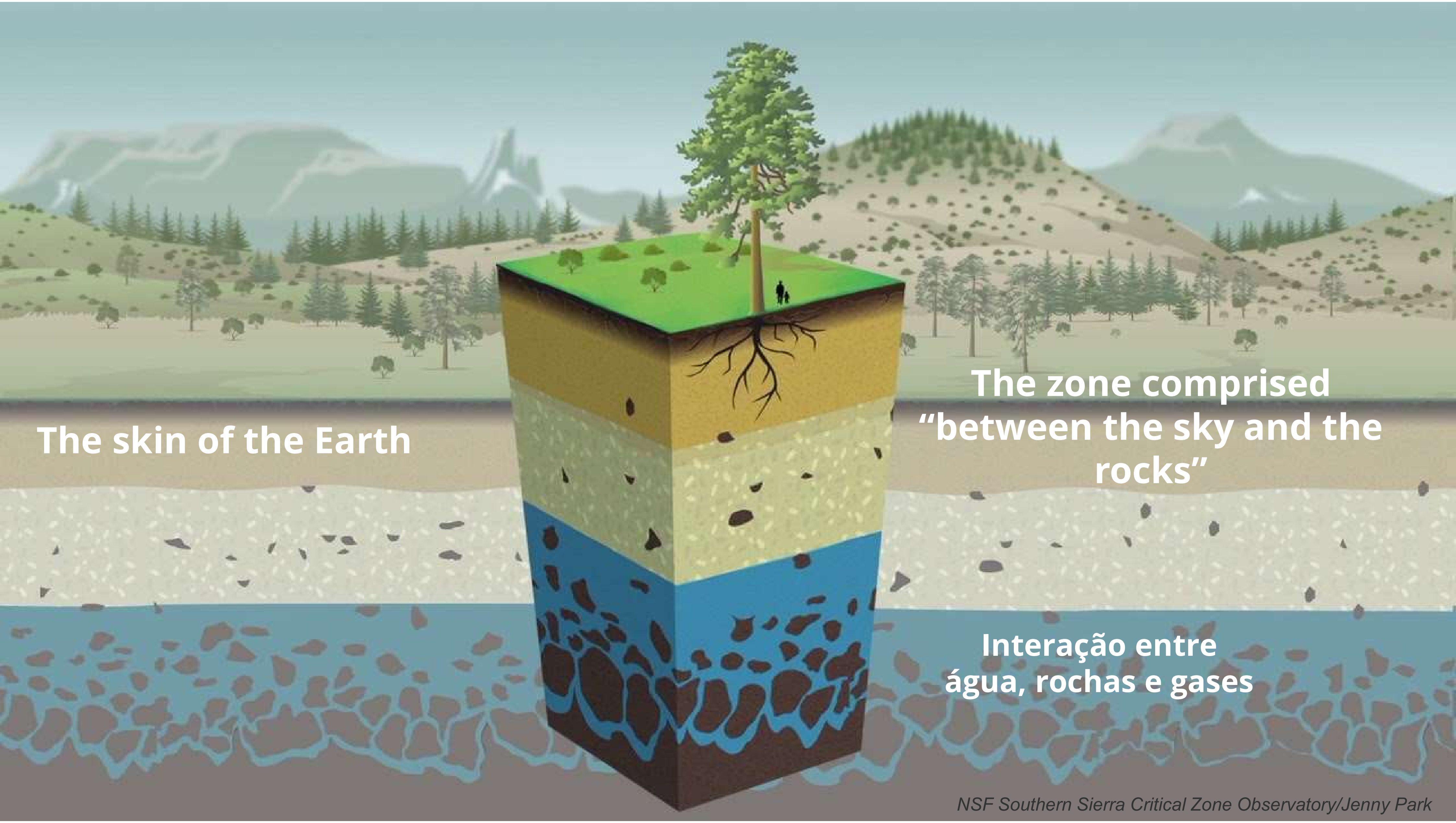
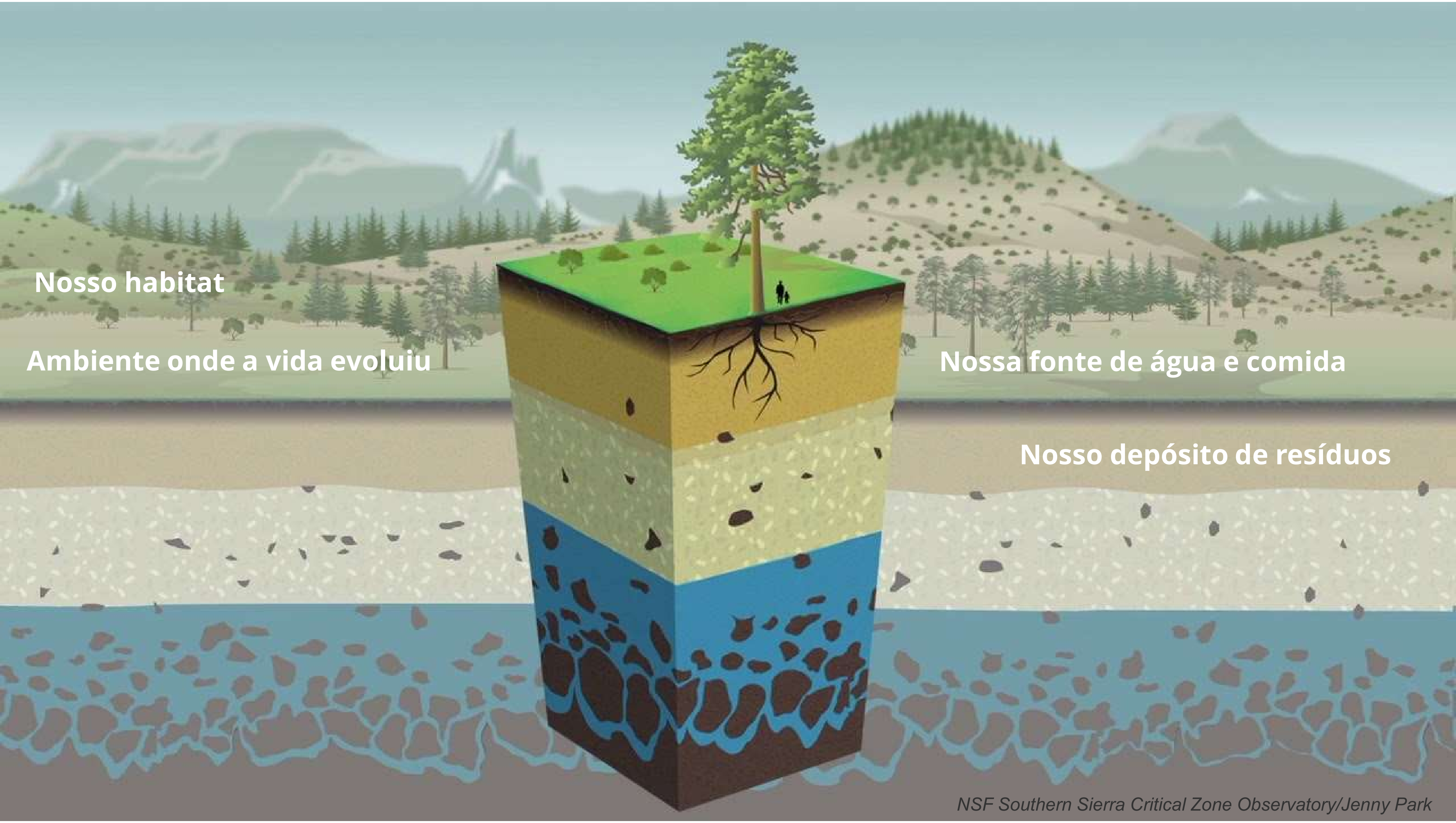
# A Zona Crítica

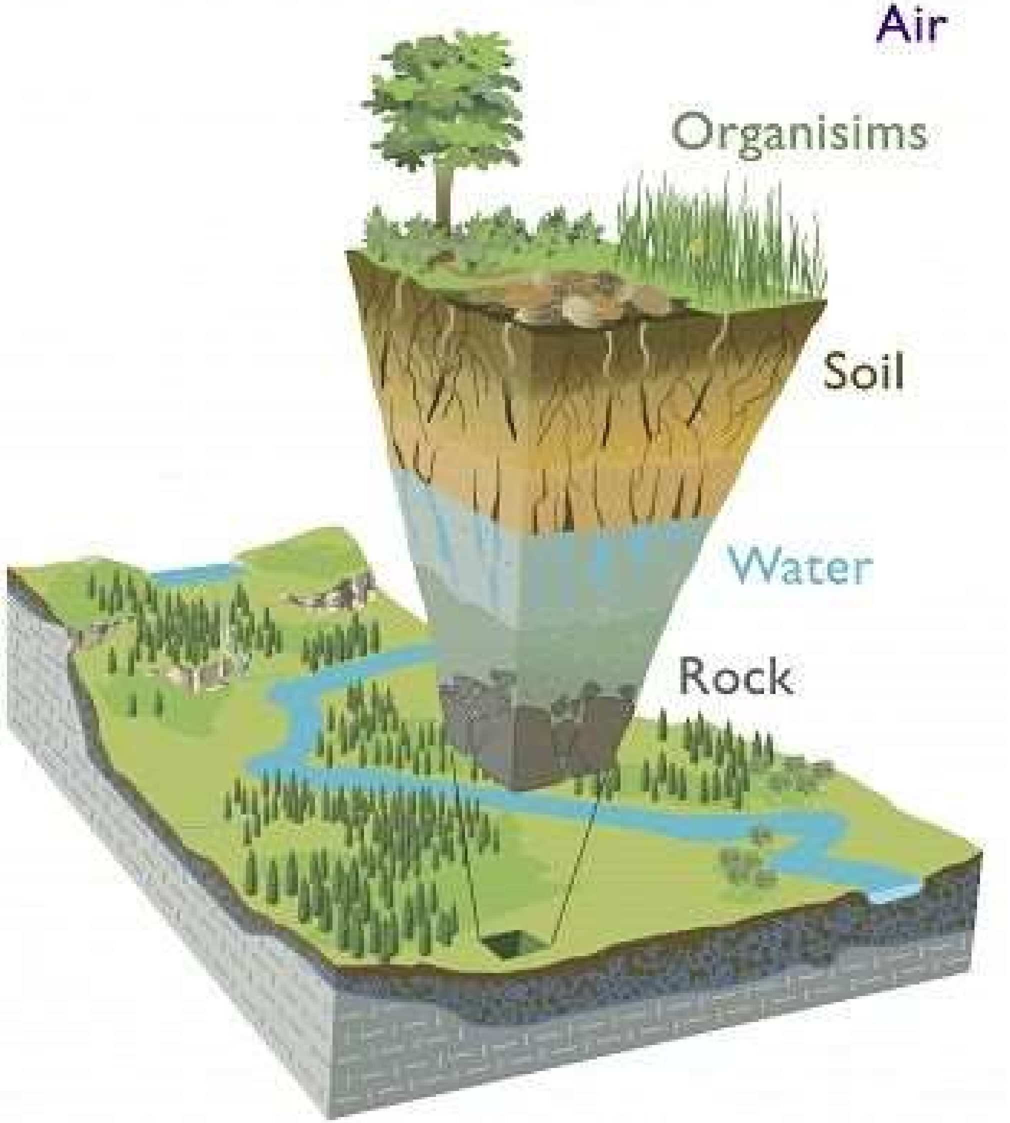
## Da rocha à vida

AGG 0201 Geoquímica de Ambientes Superficiais

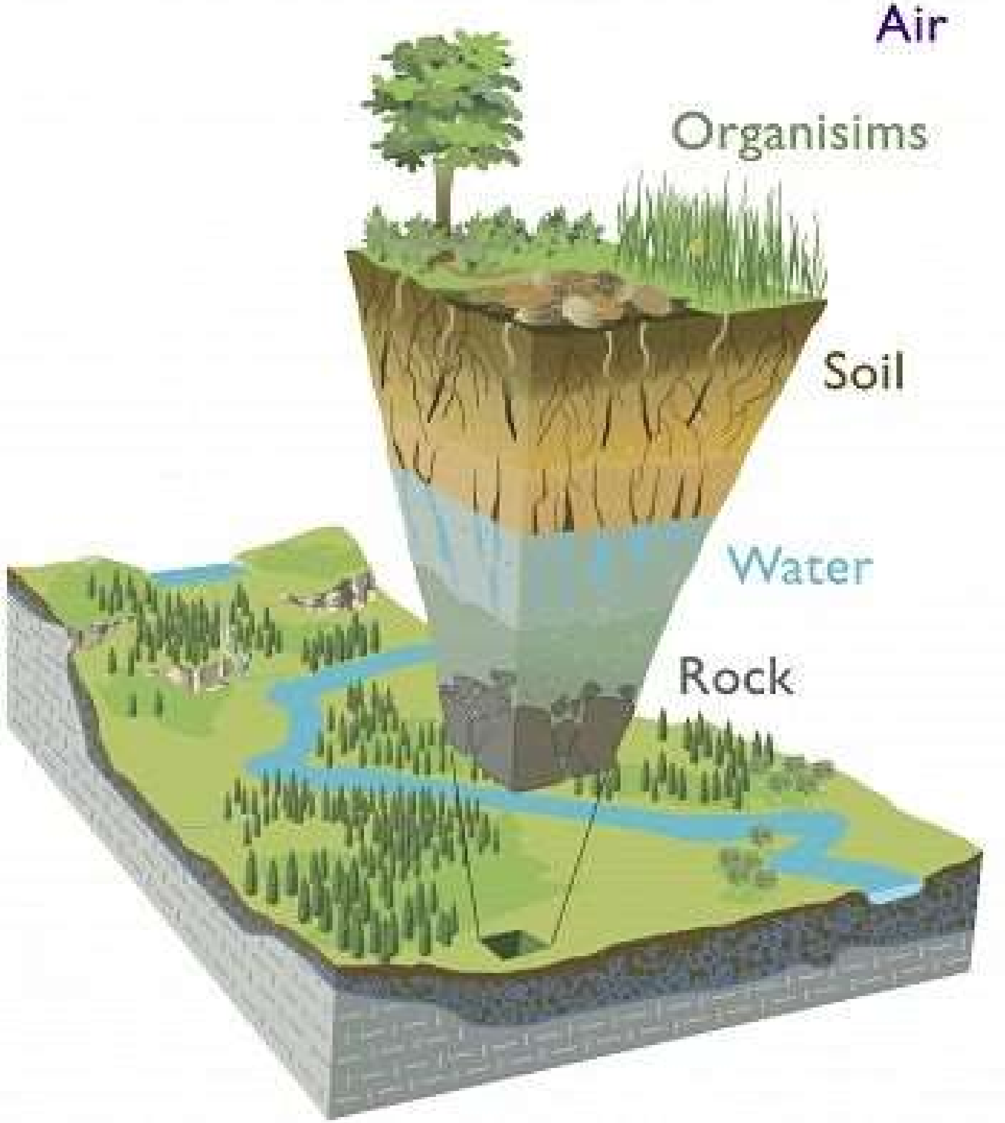
Profa. Andréa Teixeira Ustra


The skin of the Earth
The zone comprised "between the sky and the rocks"
Interação entre água, rochas e gases
NSF Southern Sierra Critical Zone Observatory/Jenny Park

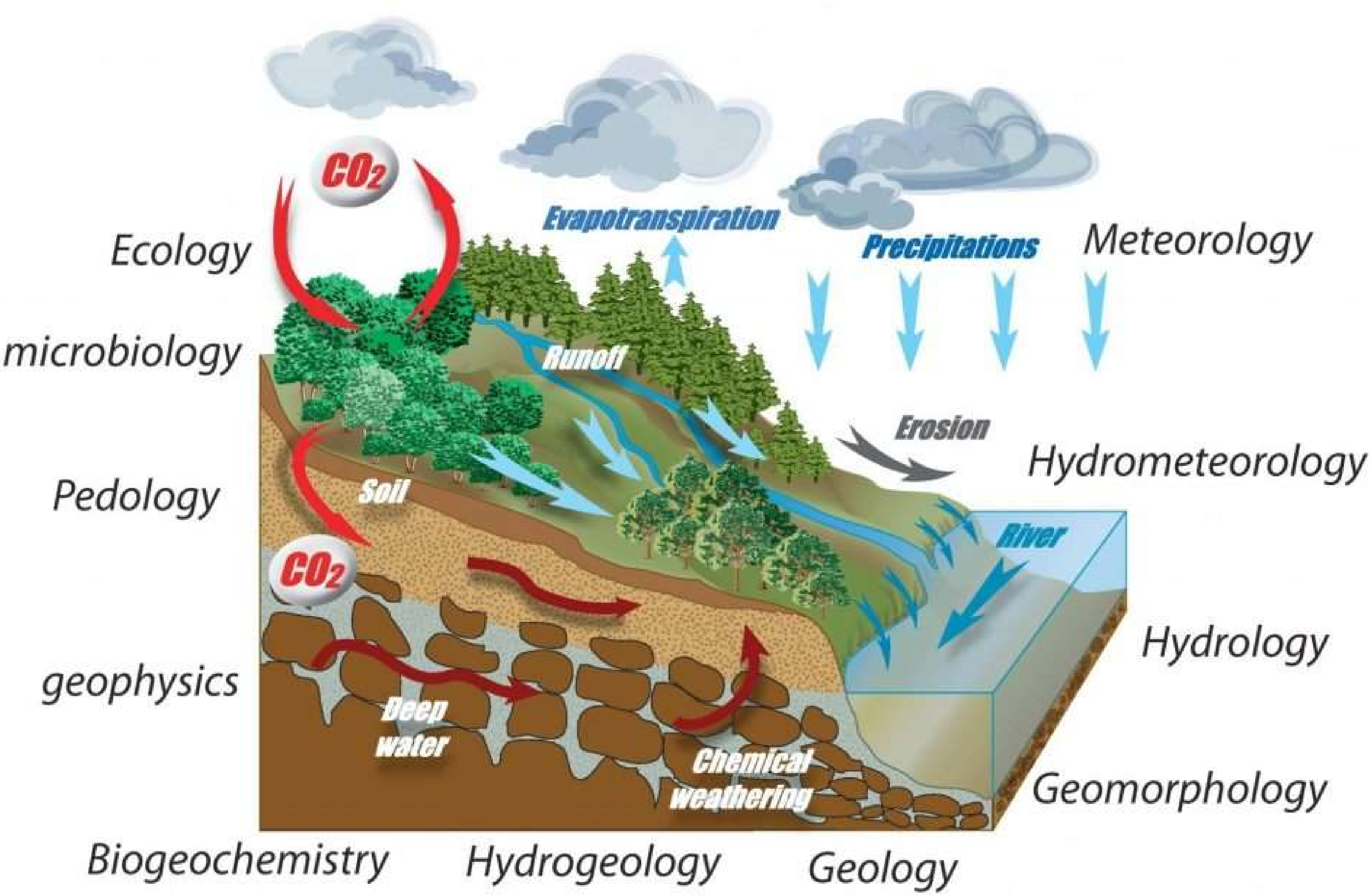

Nosso habitat
Ambiente onde a vida evoluiu
Nossa fonte de água e comida
Nosso depósito de resíduos
NSF Southern Sierra Critical Zone Observatory/Jenny Park




"I called it the critical zone because it's critical for life…Also, it's critical to know more about it because of the potential for damaging it" (Gail Ashley, 1998)




"We should be looking at the Earth's surface as one thing and bringing all those subdisciplines together" (Susan Brantley, 2000)



Ecology
microbiology
Pedology
geophysics
Biogeochemistry
Hydrogeology
Geology
Meteorology
Hydrometeorology
Hydrology
Geomorphology
CO2
Evapotranspiration
Precipitations
Runoff
Erosion
Soil
River
CO2
Deep water
Chemical weathering

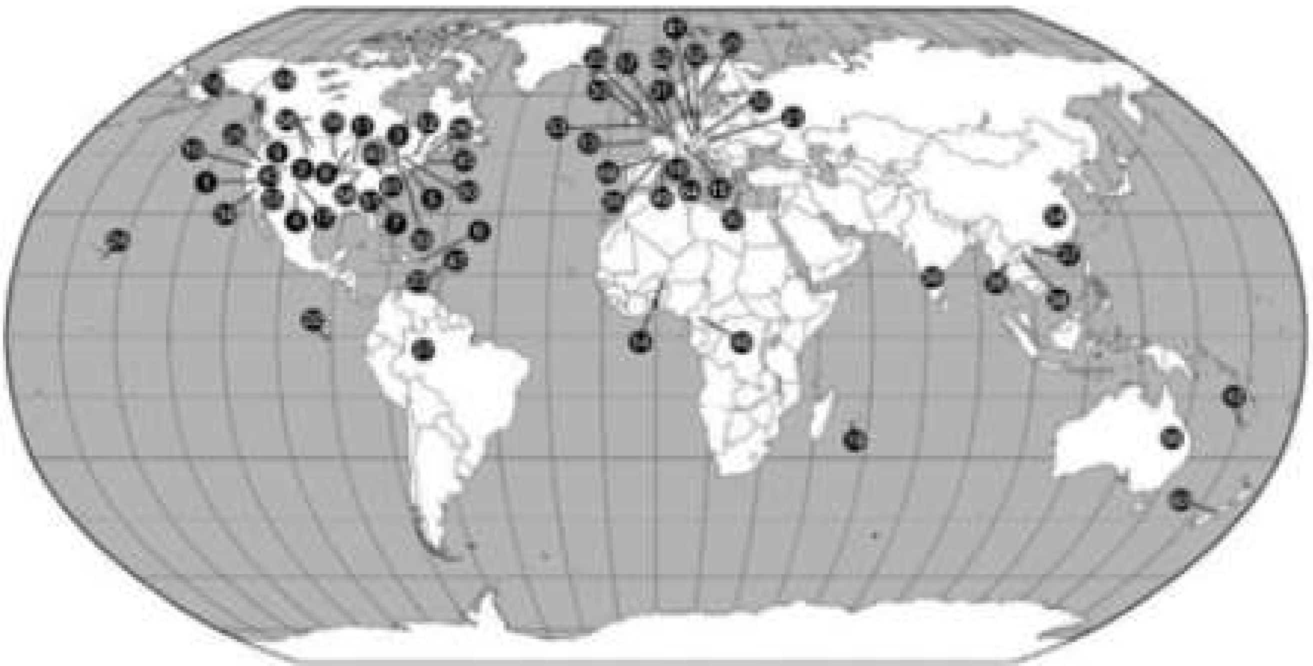
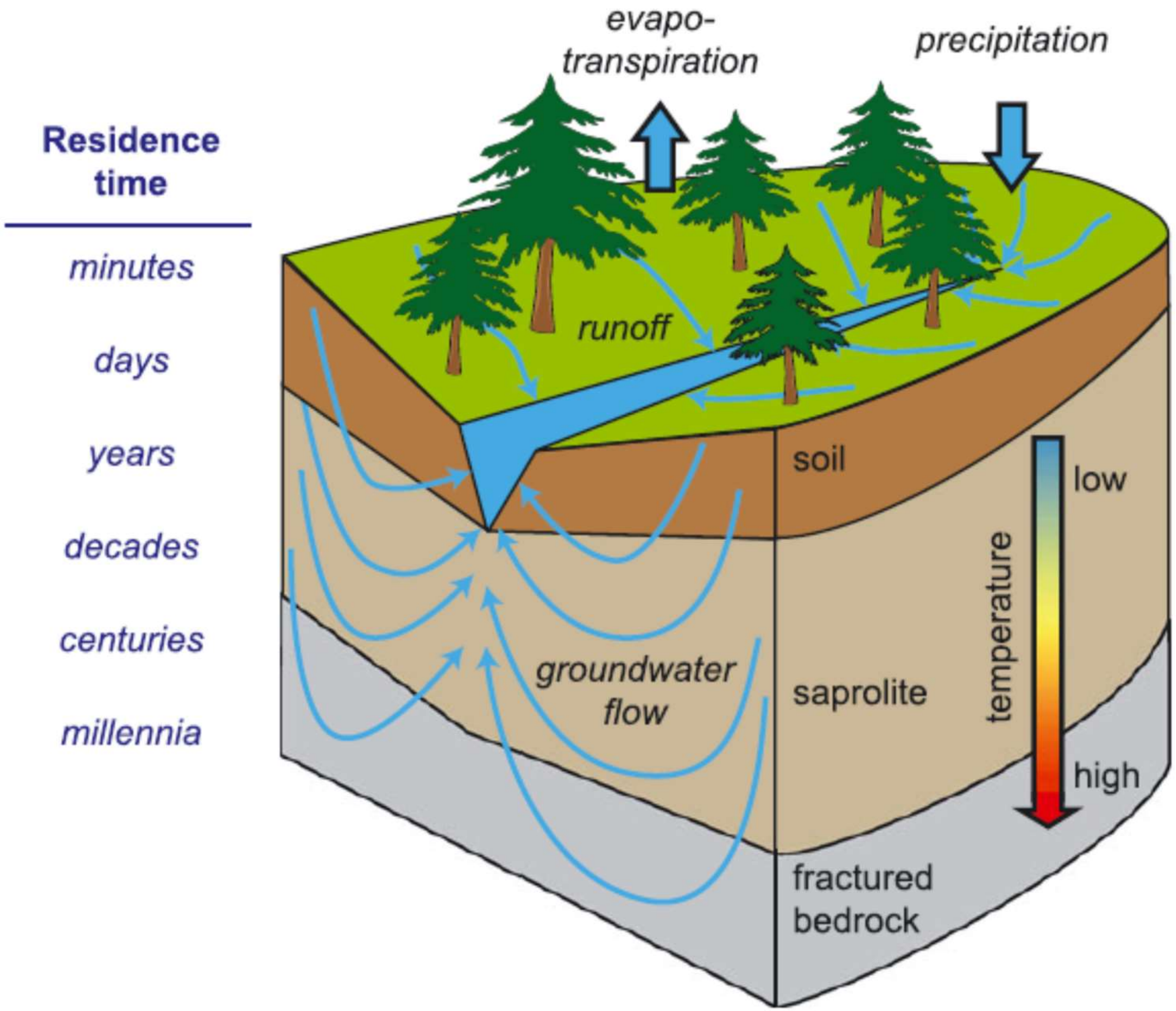


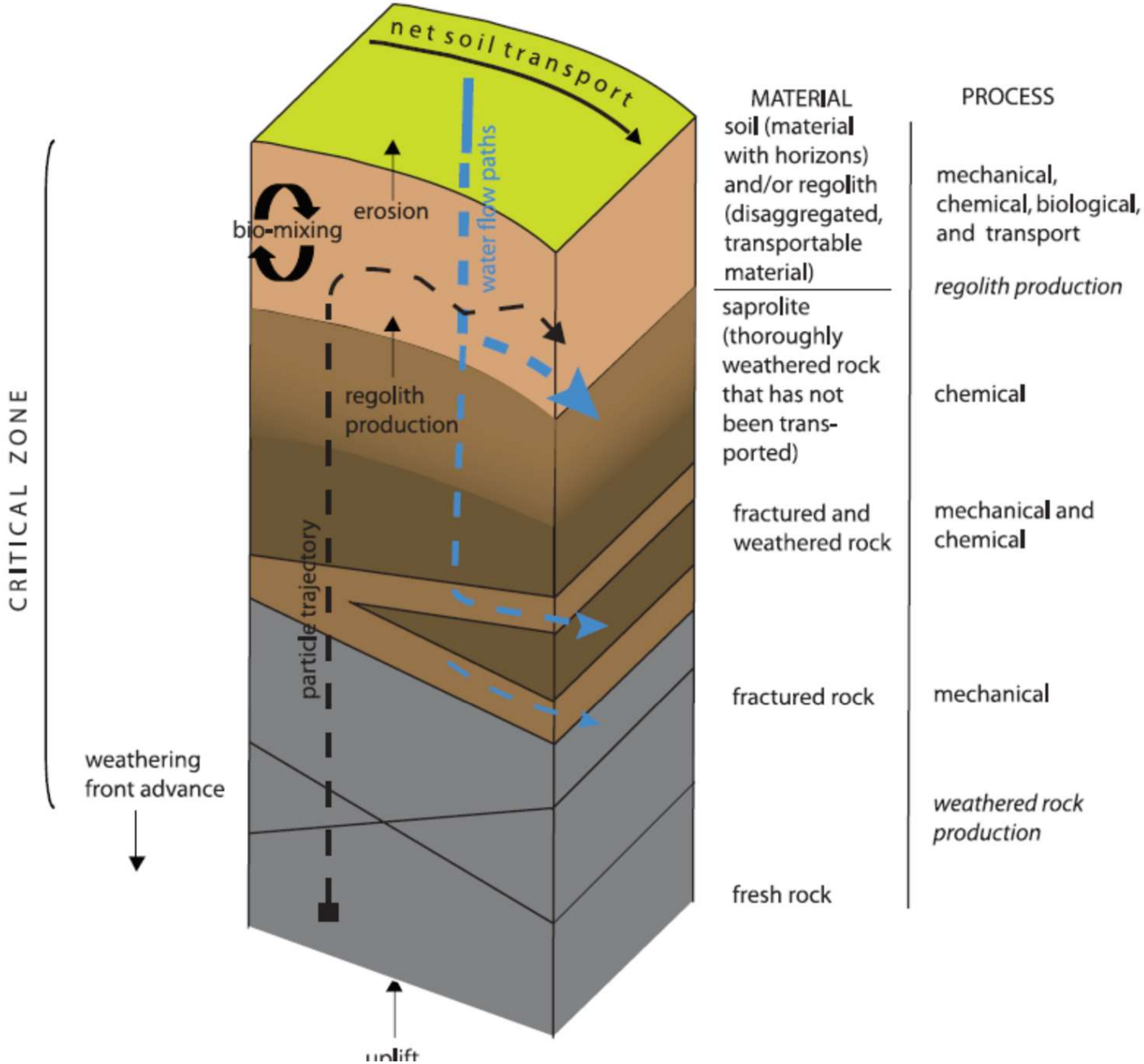
FIGURE 1.2 Locations of Critical Zone sites located around the world.
The number in the marker corresponds to the Critical Zone site listed in the table. Map compiled from Banwart et al. (2013) and NRC (2001).

**TABLE 2.1 Categories of Instrumentation and Measurements Made at the United States CZOs.**

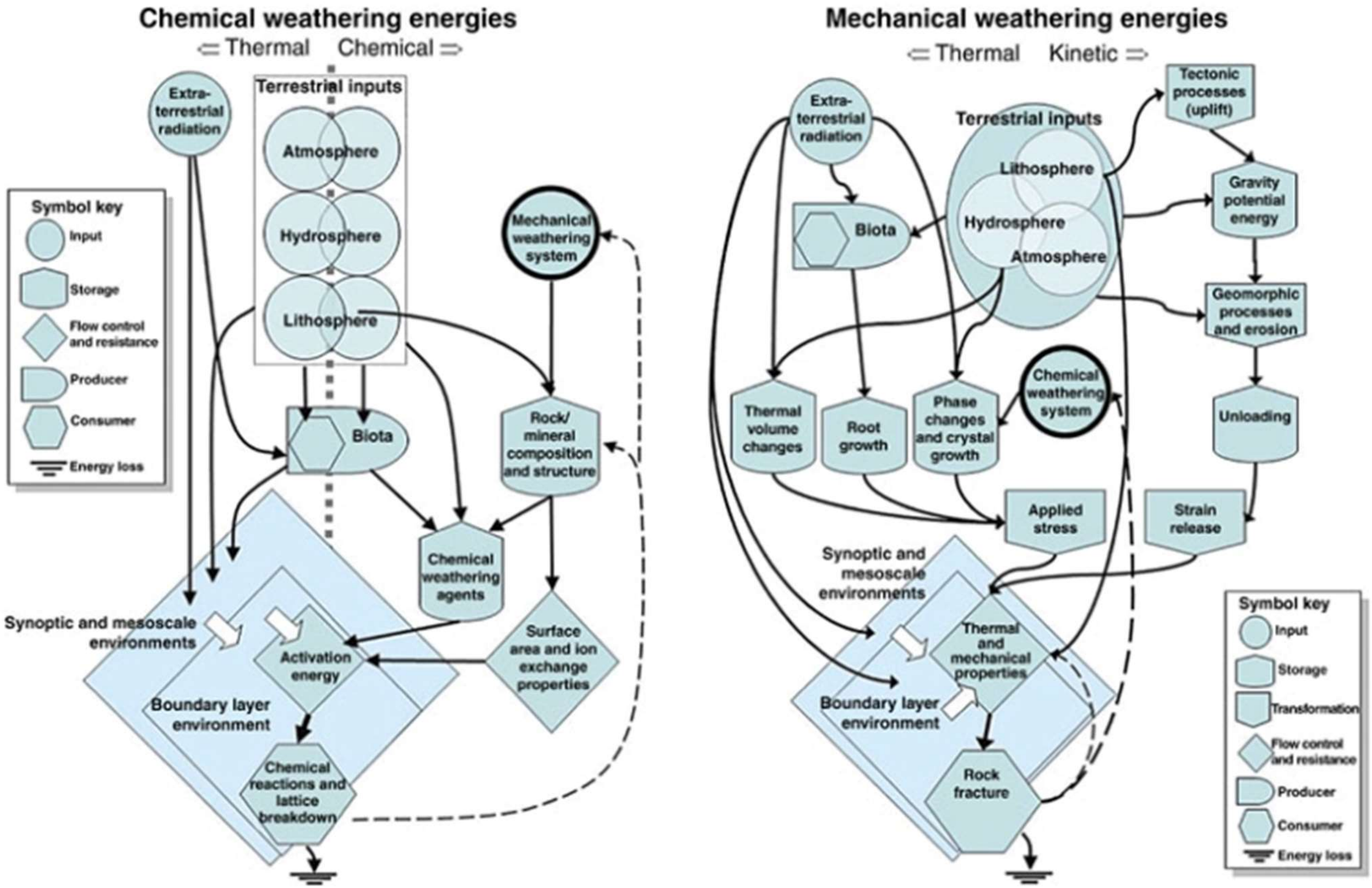
1. Land-atmosphere
   a. LiDAR datasets
   b. Eddy flux for momentum, heat, water vapor, $CO_2$
   c. Wind speed and direction sensors
   d. Solar radiation and temperature sensors
   e. Precipitation and through-fall samplers
   f. Wet and dry deposition samplers
2. Vegetation and associated microbiota
   a. Above- and below-ground vegetative and microbial composition
   b. Relations between ET and species composition and structure
   c. Soil/plant respiration, net ecosystem exchange
3. Soil (vadose zone)
   a. Solid phase (campaign sampling for spatial characterization)
   b. Elemental composition and mineralogy
   c. Texture and physical characterization
   d. Organic-matter content
   e. Stable and radiogenic isotope composition
   f. Fluid phase (sensors and samplers for time series)
   g. Soil moisture (sensors)
   h. Soil temperature (sensors)
   i. Soil-solution chemistry (samplers)
   j. Soil-gas chemistry (samplers/sensors)
   k. Rates of infiltration and groundwater flow
4. Saprolite and bedrock (saturated zone)
   a. Solid phase (campaign sampling for spatial characterization)
   b. Petrology and mineralogy
   c. Elemental-composition and organic-matter content
   d. Texture and other physical and architectural traits
   e. Fluid phase (sensors and samplers for time series)
   f. Potentiometric head and temperature (sensors)
   g. Groundwater chemistry (samplers/sensors)
   h. Gas chemistry (samplers/sensors)
5. Surface water
   a. Discrete and instantaneous discharge (flumes, weirs, with water quality sensors)
   b. Channel morphology
   c. Stream-water chemistry, dissolved and suspended (samplers/sensors)
   d. Sediment and biota (samplers/sensors)




Processos locais e globais, na ampla escala do tempo




**Como os processos químicos e mecânicos interagem para produzir a ZC e suas variações?**



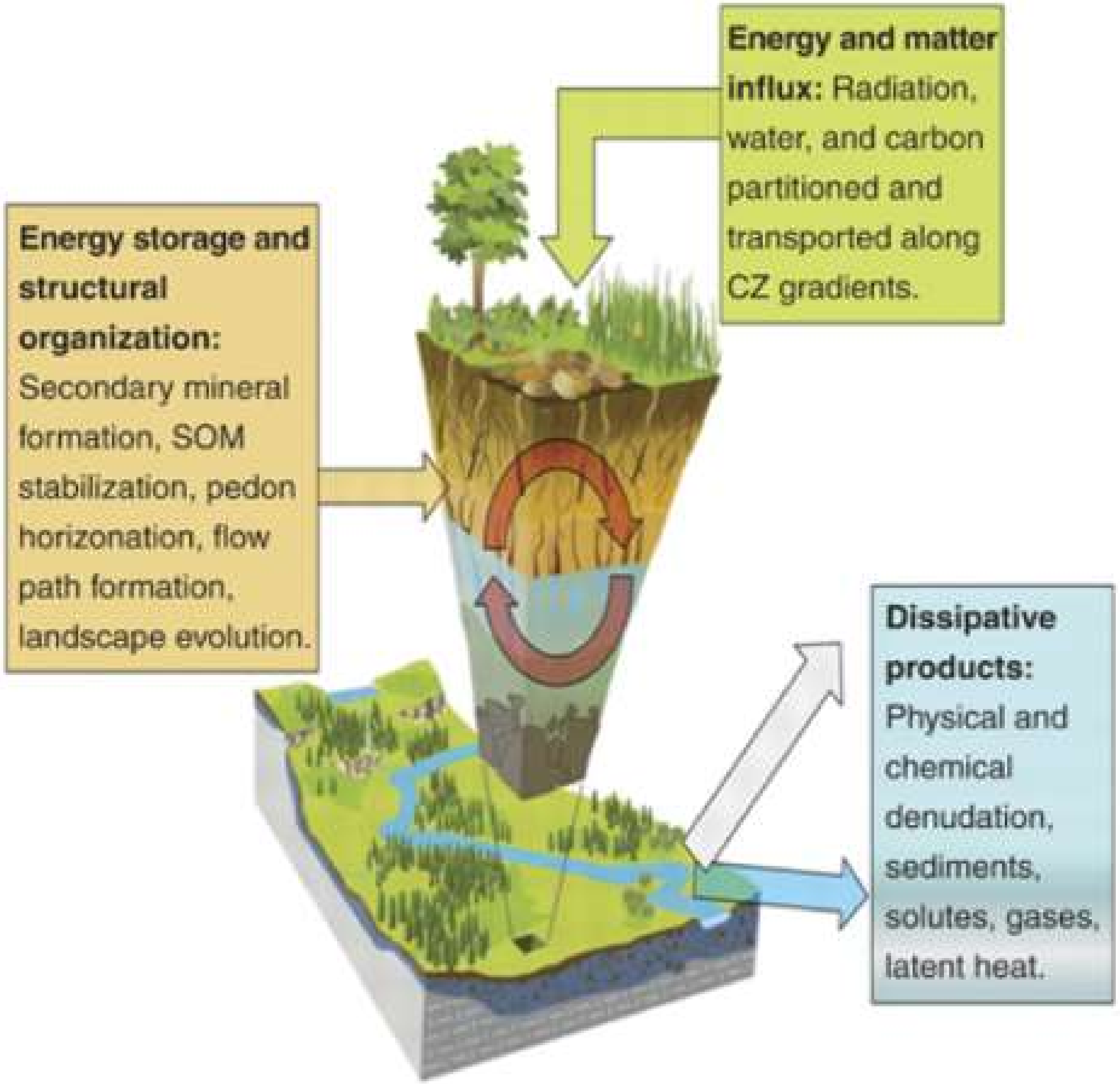
Chemical weathering energies
⇐ Thermal Chemical ⇒
Extra-terrestrial radiation
Terrestrial inputs
Atmosphere
Hydrosphere
Lithosphere
Symbol key
Input
Storage
Flow control and resistance
Producer
Consumer
Energy loss
Mechanical weathering system
Biota
Rock/mineral composition and structure
Chemical weathering agents
Synoptic and mesoscale environments
Activation energy
Surface area and ion exchange properties
Boundary layer environment
Chemical reactions and lattice breakdown
Mechanical weathering energies
⇐ Thermal Kinetic ⇒
Extra-terrestrial radiation
Tectonic processes (uplift)
Terrestrial inputs
Lithosphere
Hydrosphere
Atmosphere
Biota
Gravity potential energy
Geomorphic processes and erosion
Chemical weathering system
Thermal volume changes
Root growth
Phase changes and crystal growth
Unloading
Applied stress
Strain release
Synoptic and mesoscale environments
Thermal and mechanical properties
Boundary layer environment
Rock fracture
Symbol key
Input
Storage
Transformation
Flow control and resistance
Producer
Consumer
Energy loss

# Intemperismo

## Modifica a crosta Terrestre em resposta as condições atmosféricas, hidrológicas e bióticas

- Formação dos solos
- Qualidade das águas
- Condicionamento de ecosistemas
- Regulador climático e ambiental
- Formador de recursos minerais

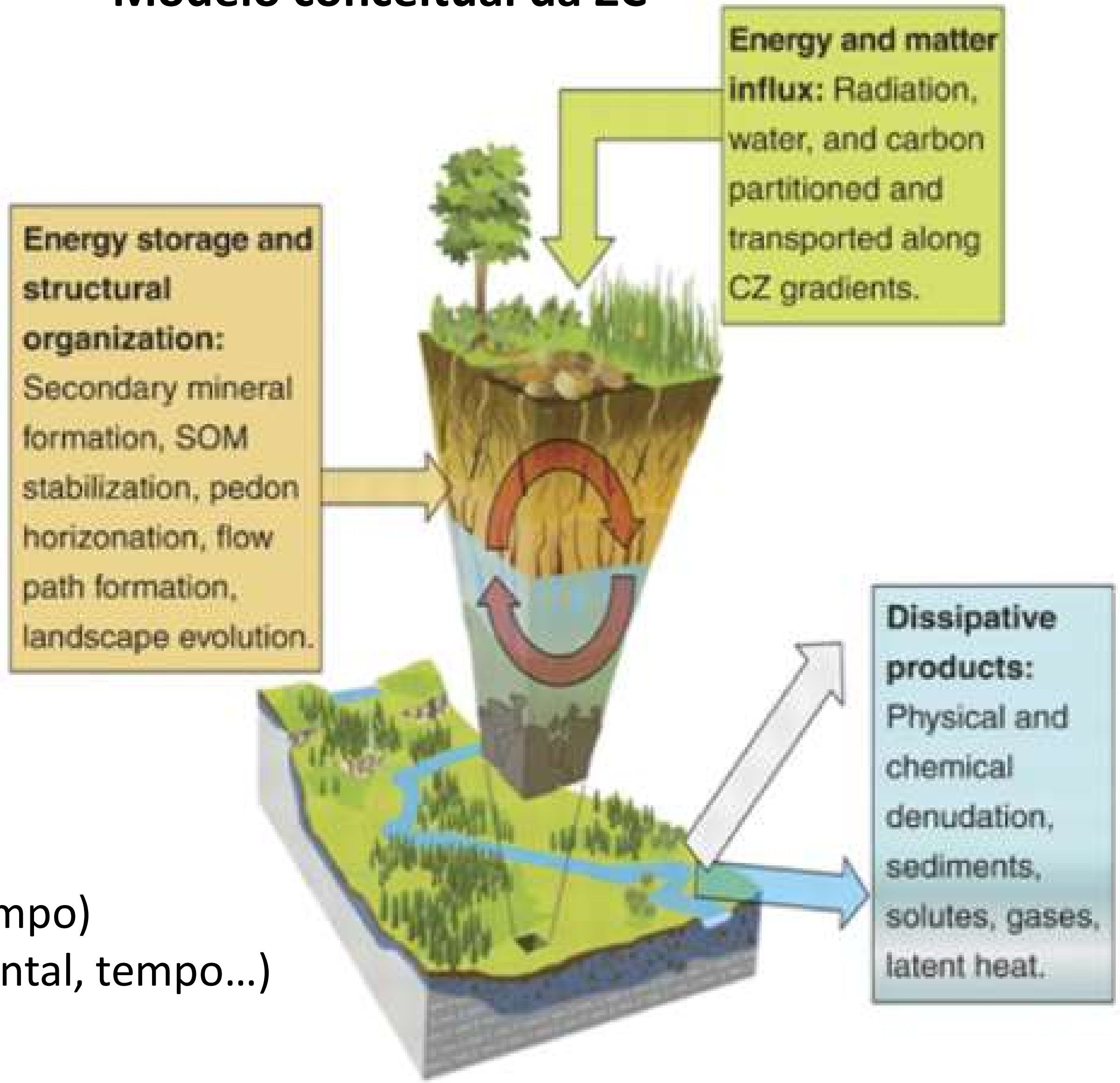
# Solos
# e
# Zona Crítica



## Modelo conceitual da ZC

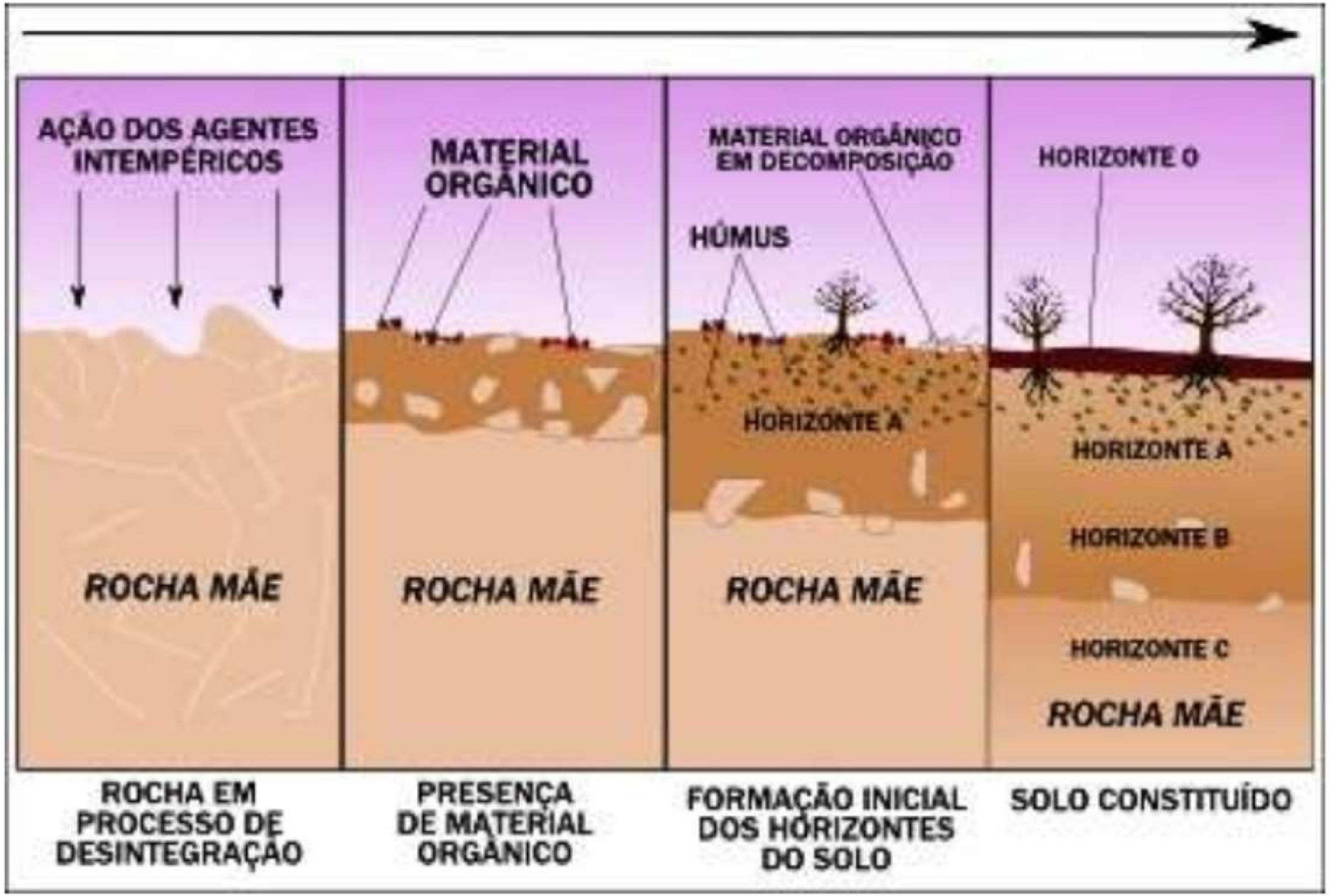
Keny (1941) – Definição de solos

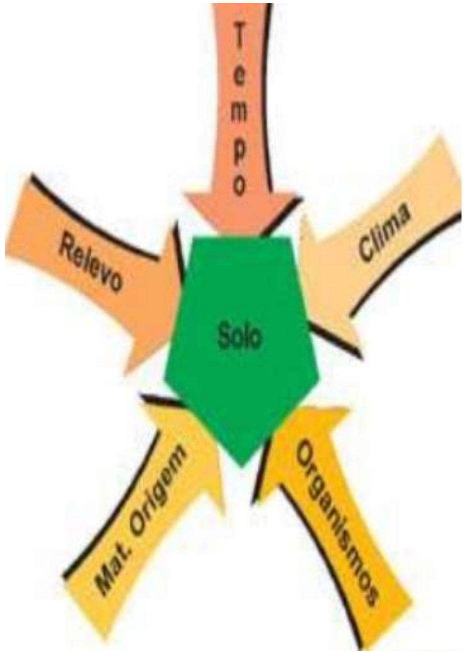
“Sistemas que trocam massa e energia com o entorno”




Solos/ecosistemas
= *f* (estado inicial do sistema, ambiente local, tempo)
= *f* (clima, organismos, topografia, material parental, tempo…)

# Modelo conceitual do desenvolvimento de solos

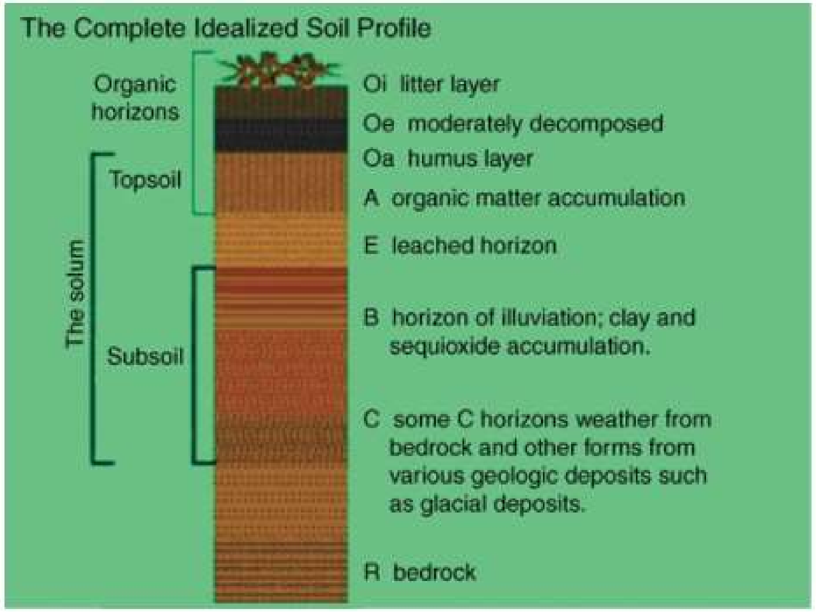



Keny (1941) – Definição de solos

"Sistemas que trocam massa e energia com o entorno"

# Estudando solos



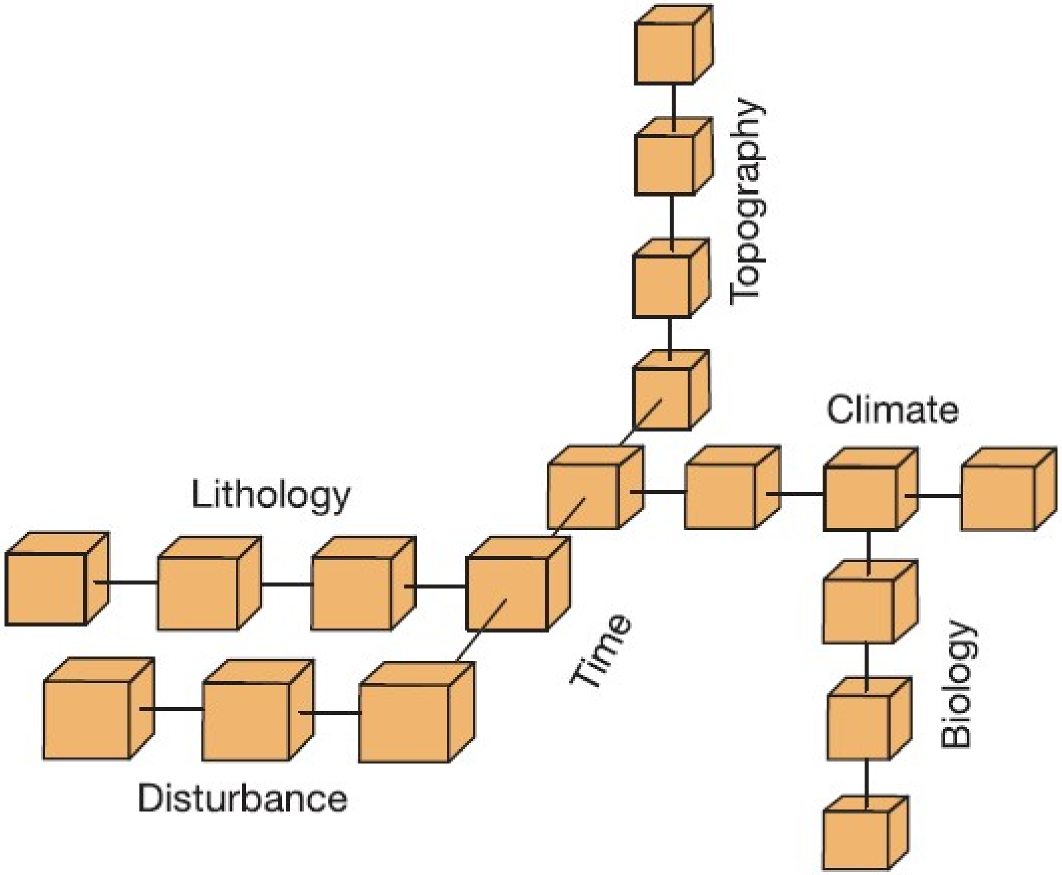

## O que aconteceu?

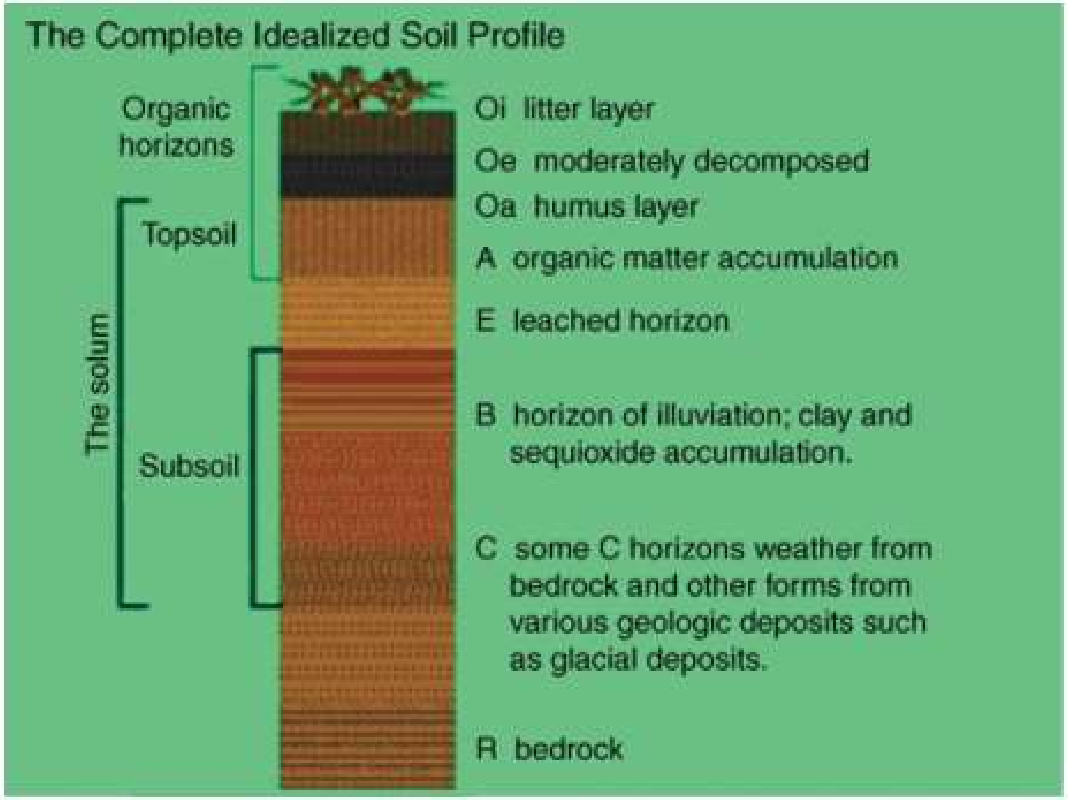
Que propriedades físicas, químicas/mineralógicas e biológicas do perfil de solo são devido a formação de solo?

Com respeito a que o solo difere do material parental?

## Como aconteceu?

Como o solo se formou?
Quais processos formaram o solo?




Solos/ecosistemas = *f* (estado inicial do sistema, ambiente local, tempo) Fatores

= *f* (clima, organismos, topografia, material parental, tempo…) Processos

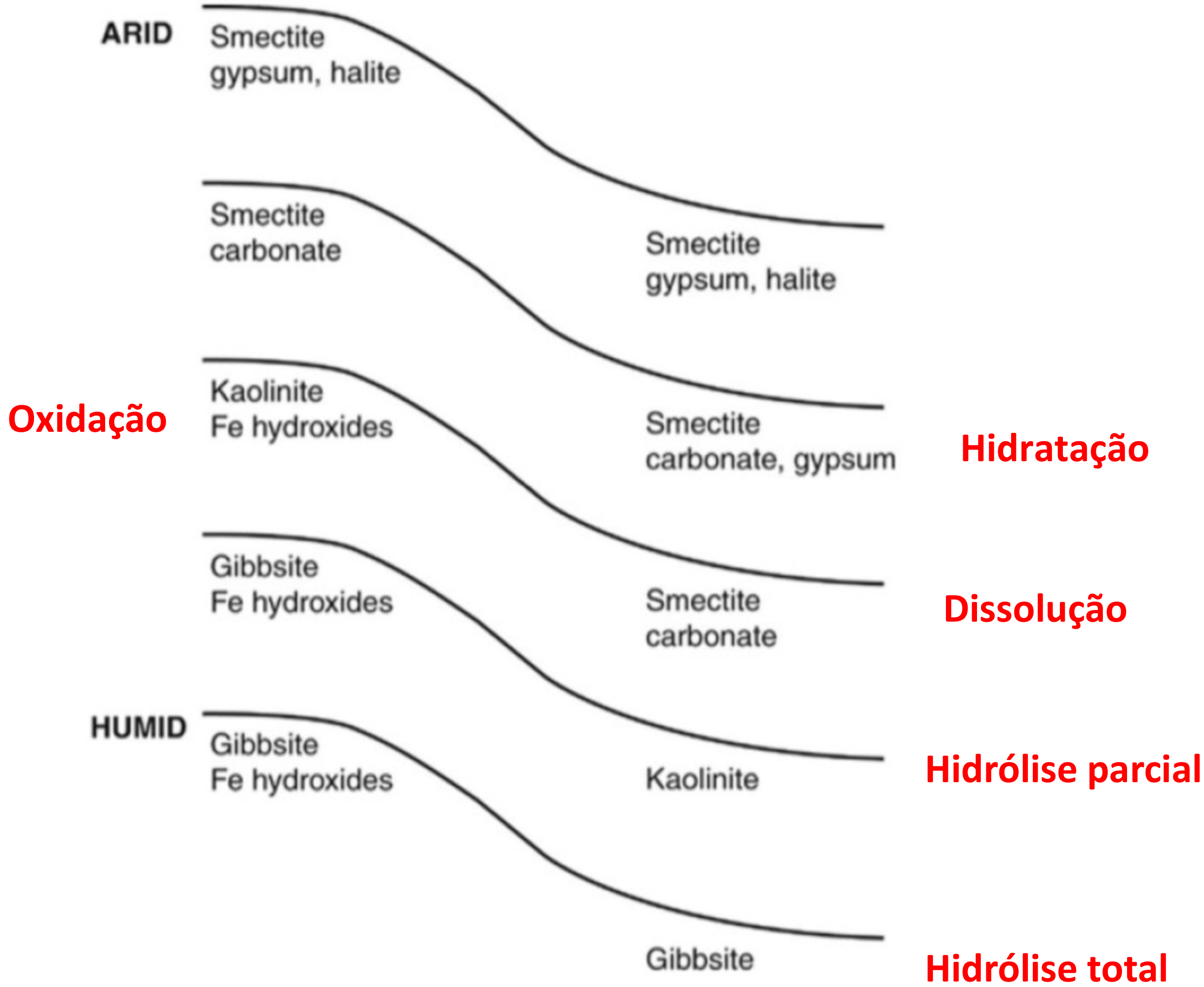
**Tabela 7.2:** Minerais comuns das rochas silicáticas encontradas na superfície dos continentes e sua composição química, expressa por suas fórmulas estruturais.

| | |
|---|---|
| quartzo | $SiO_2$ |
| feldspato alcalino | $K\ Al\ Si_3O_8$ |
| plagioclásio | $(Na, Ca)\ Al\ Si_3O_8$ |
| biotita | $K\ (Fe, Mg)_3\ (Al, Fe)\ Si_3\ O_{10}\ (OH,F)_2$ |
| muscovita | $K\ Al_2\ Si_3\ O_{10}\ (OH,F)_2$ |
| piroxênio | $(Ca, Mg, Fe)\ (Al, Mg, Fe)\ (Si, Al)_2\ O_6$ |
| anfibólio | $(Ca, Na, K)_2\ (Al, Mg, Fe)_5\ (Si, Al)_8\ O_{22}\ (OH, F)_2$ |
| olivina | $(Fe, Mg, Mn)_2\ Si\ O_4$ |
| magnetita | $Fe_2O_3$ |
| calcita | $CaCO_3$ |

**Tabela 7.3:** Minerais comumente formados pelas reações de intemperismo químico e sua composição química, expressa por suas fórmulas estruturais.

| | |
|---|---|
| argilominerais 2:1 | filossilicatos complexos tipo $(Ca, K)\ Si_4\ O_{10}\ (Al, Fe)_2\ (OH)_2$ |
| argilominerais 1:1 | filossilicato mais simples $Si_2Al_2O_5(OH)_4$ |
| goethita | oxi-hidróxido de ferro férrico FeOOH |
| hematita | óxido de ferro férrico $Fe_2O_3$ |
| gibbsita | hidróxido de alumínio $Al(OH)_3$ |

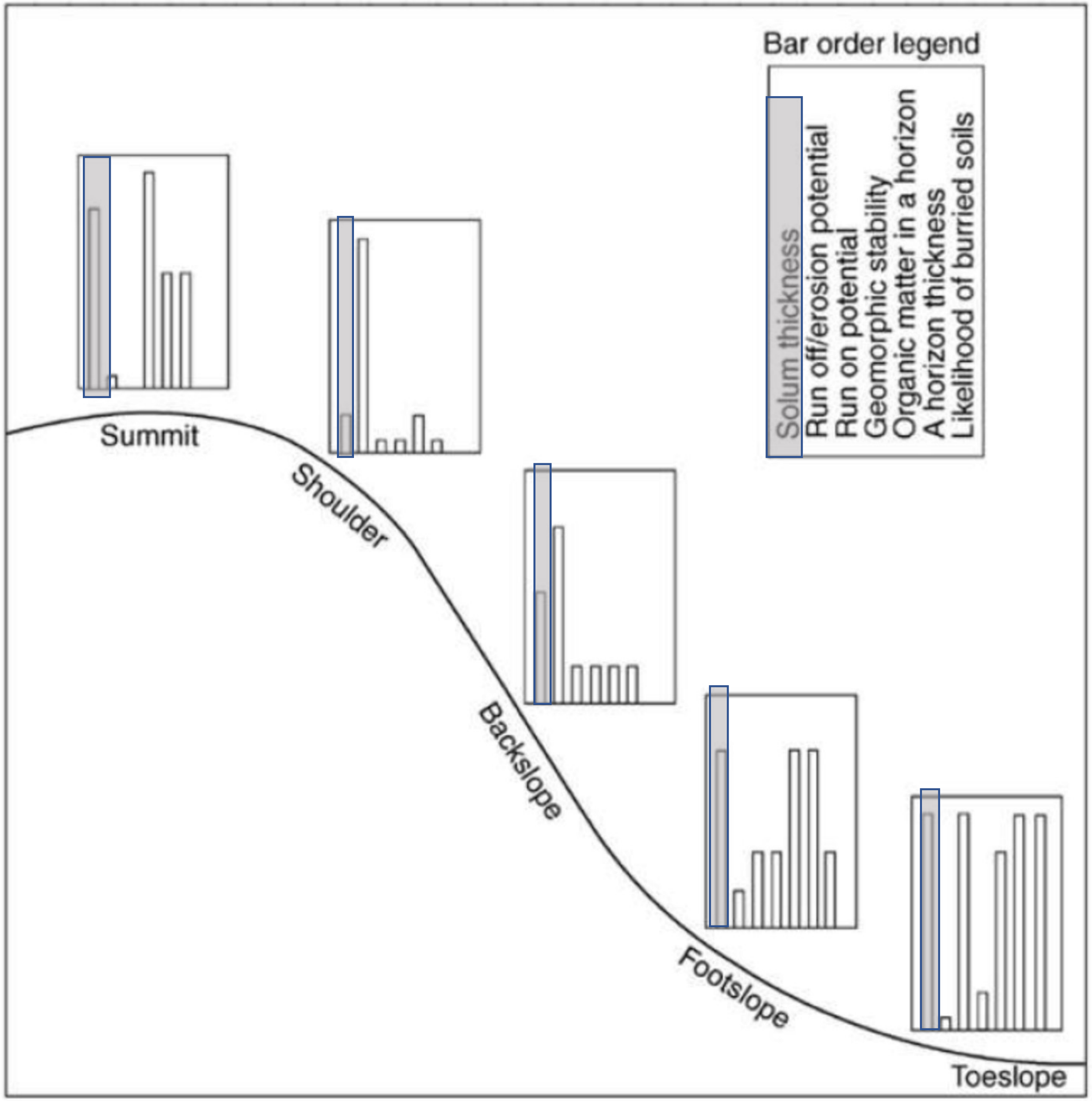
# Clima e topografia

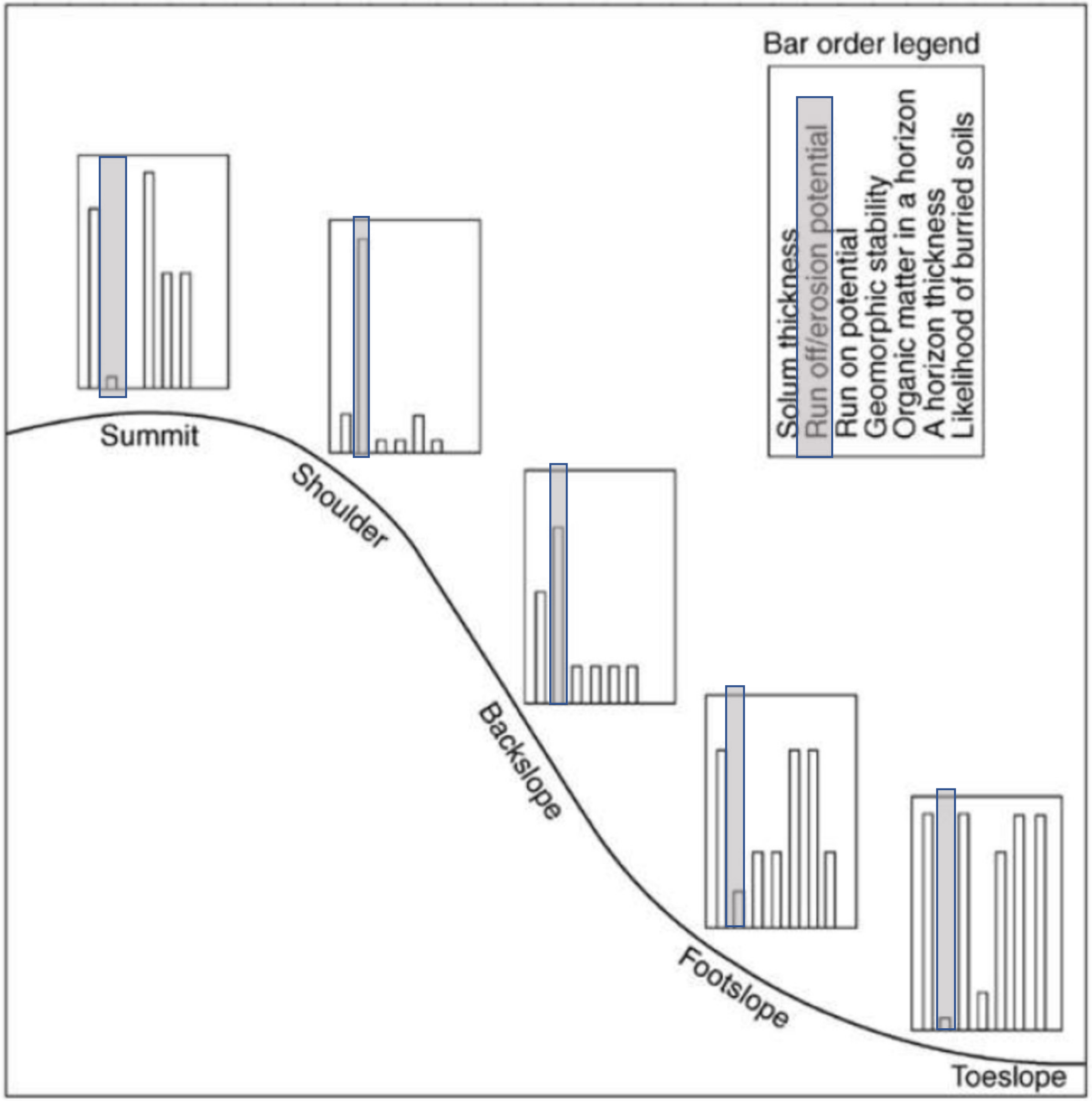


Topografia

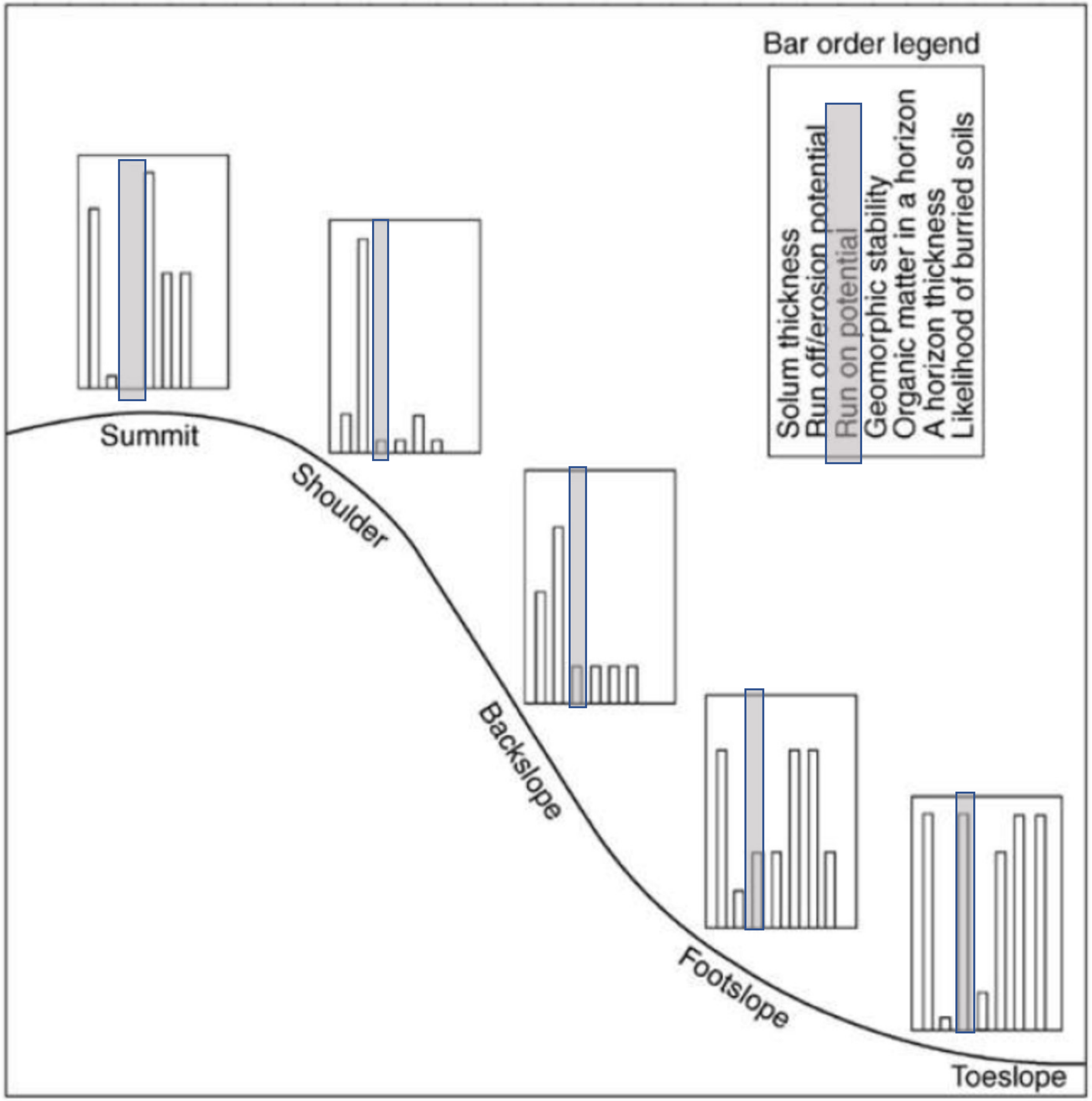
Catena

Clima húmido





Bar order legend
Solum thickness
Run off/erosion potential
Run on potential
Geomorphic stability
Organic matter in a horizon
A horizon thickness
Likelihood of burried soils
Summit
Shoulder
Backslope
Footslope
Toeslope



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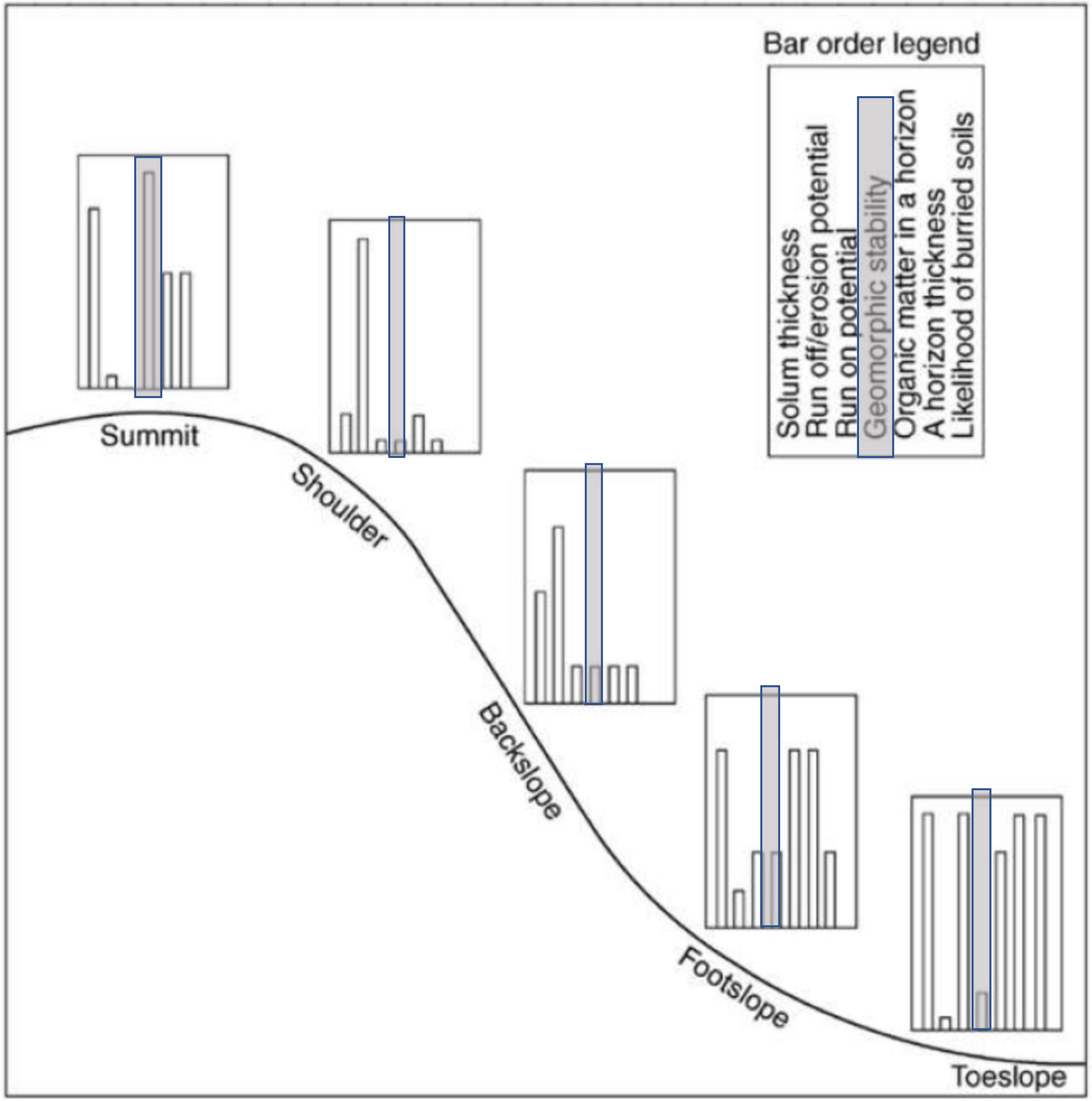

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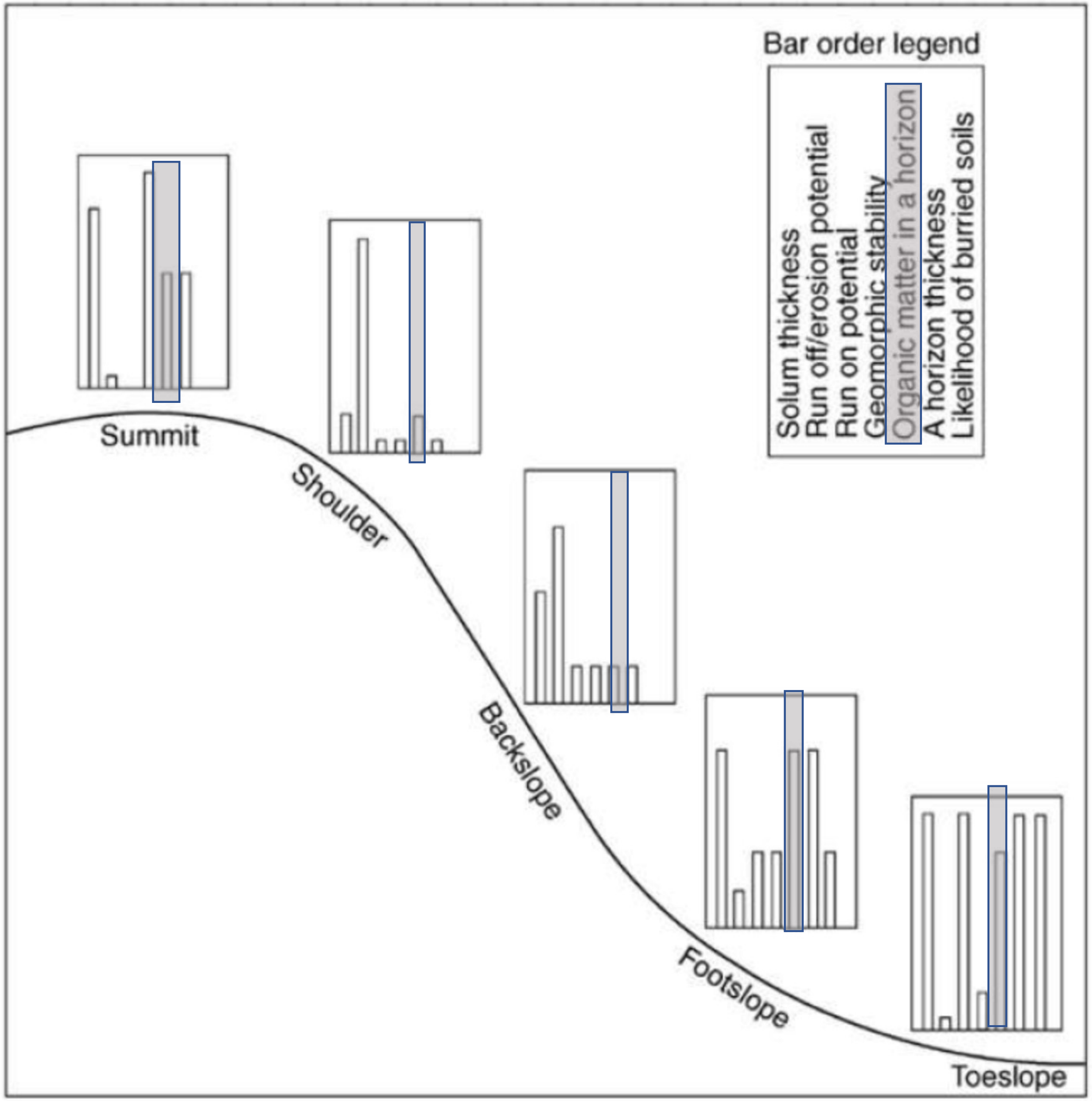

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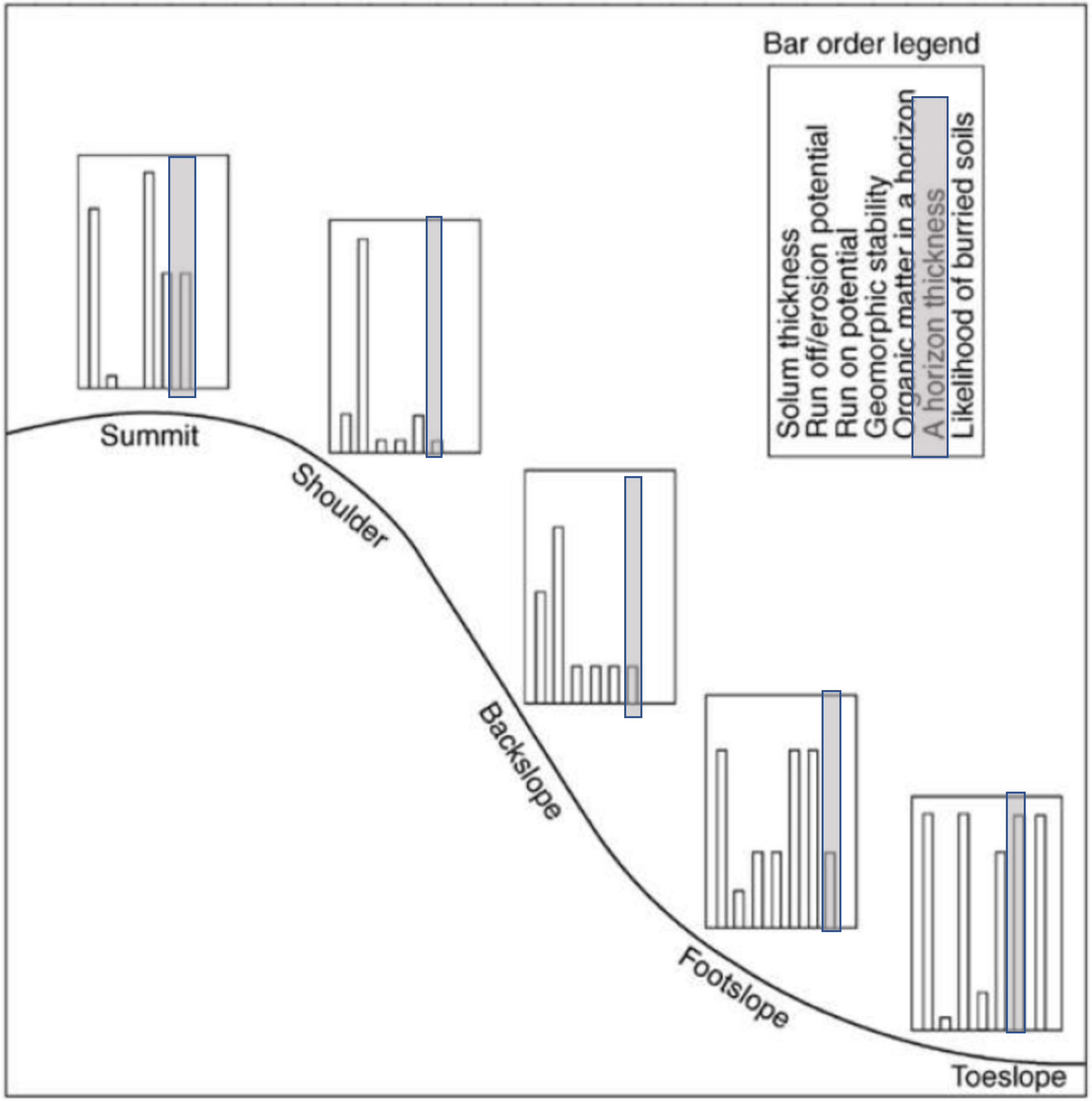

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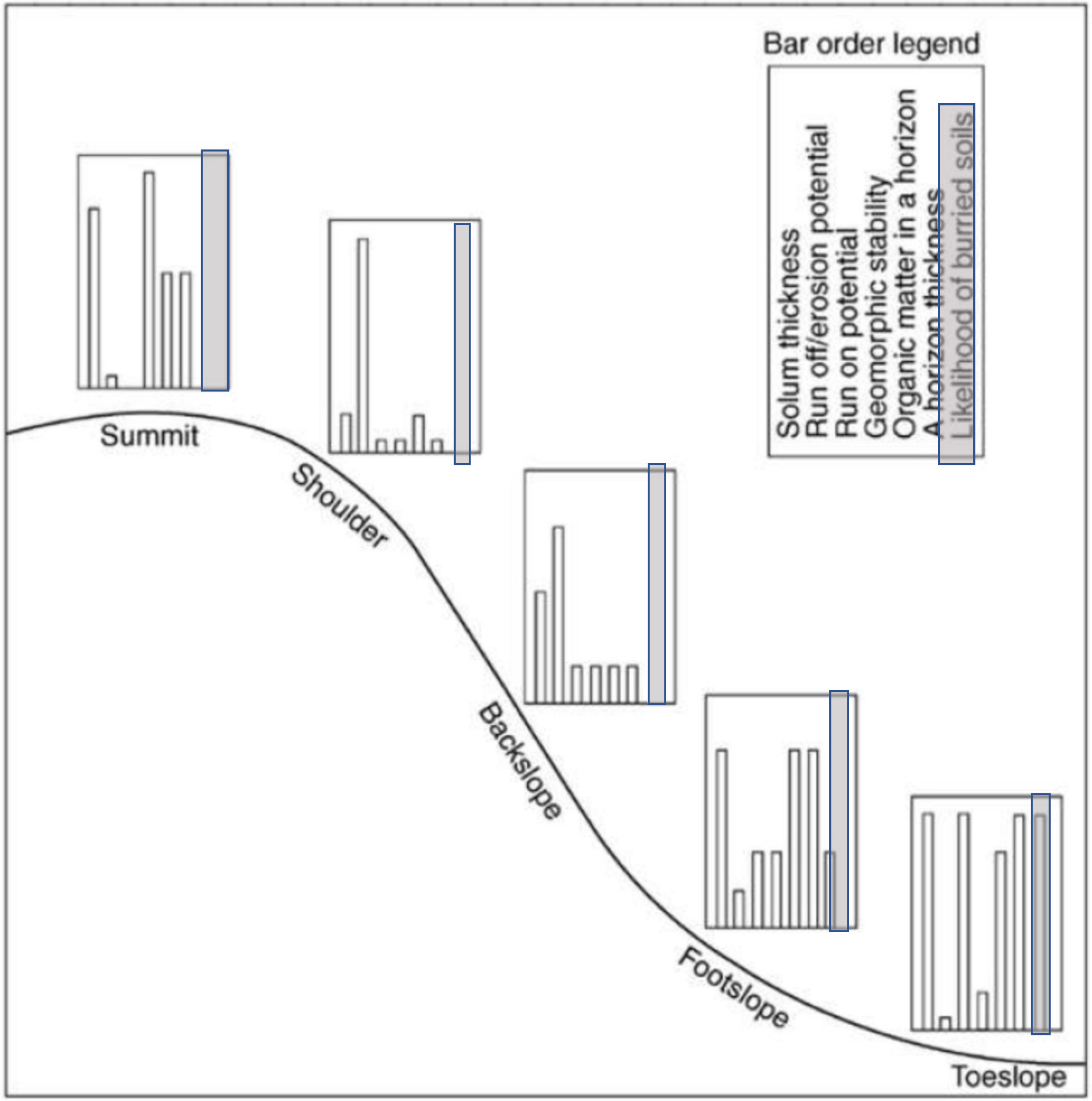
Toeslope



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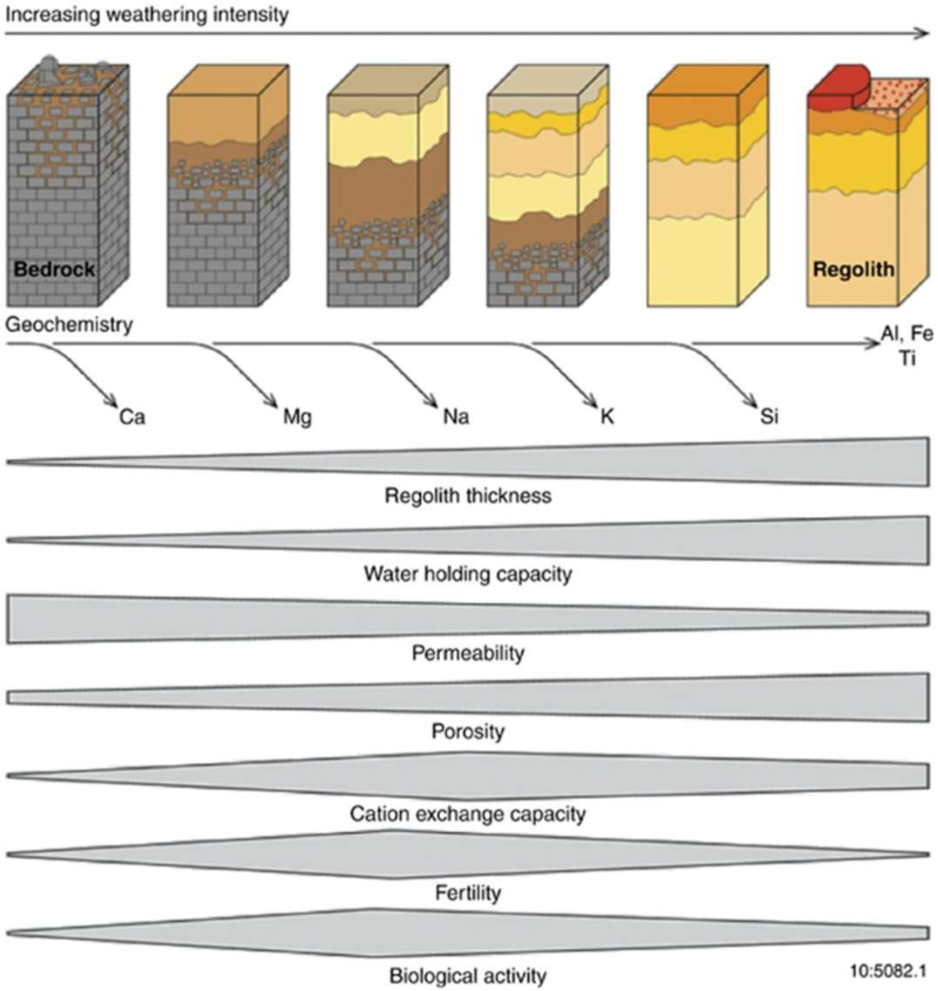
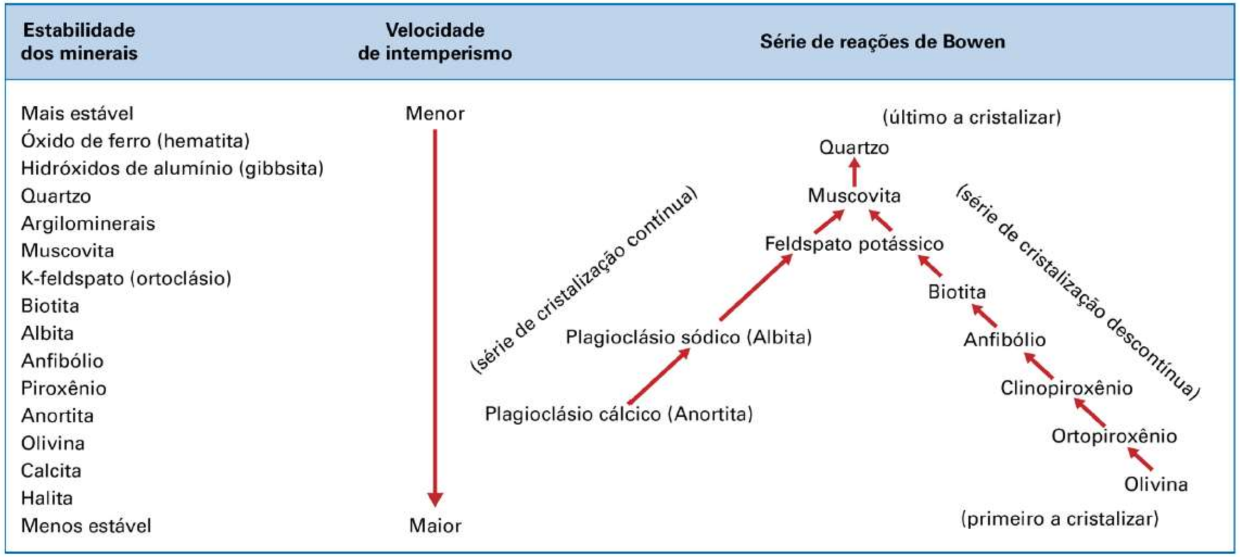
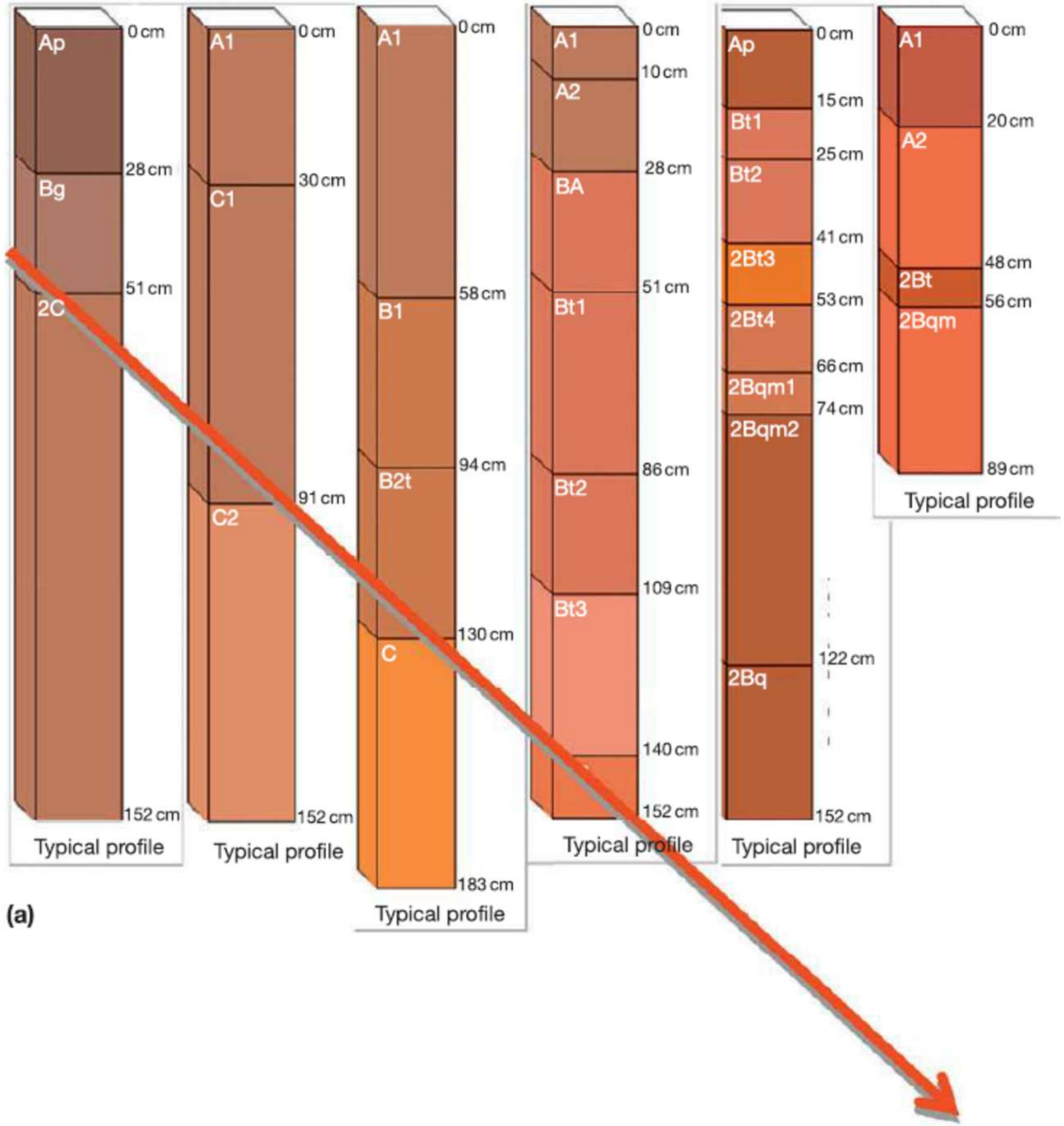



# Evolução no tempo

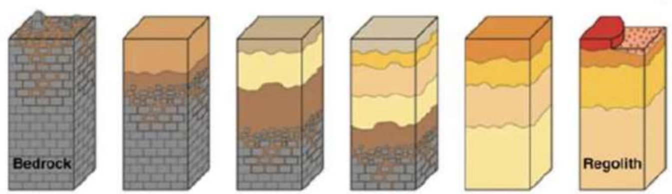
O intemperismo é um processo que progride essencialmente de cima para baixo

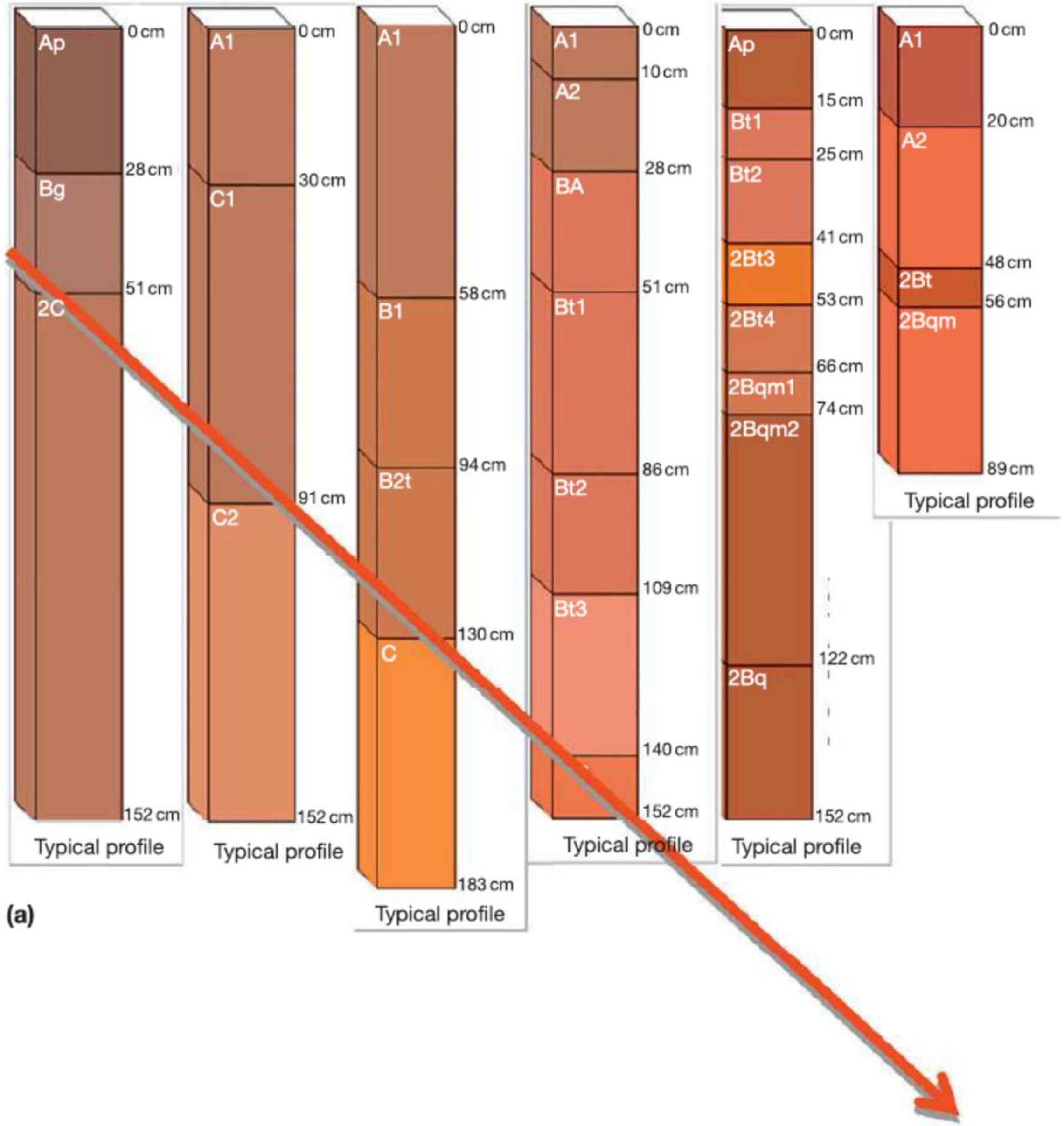




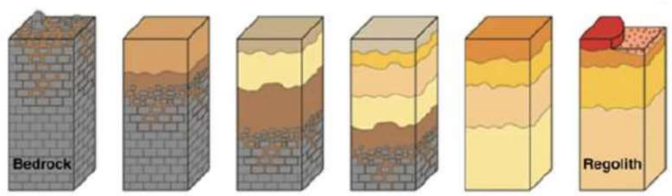

Estágio inicial do desenvolvimento de solos é dominado pela adição de matéria orgânica.

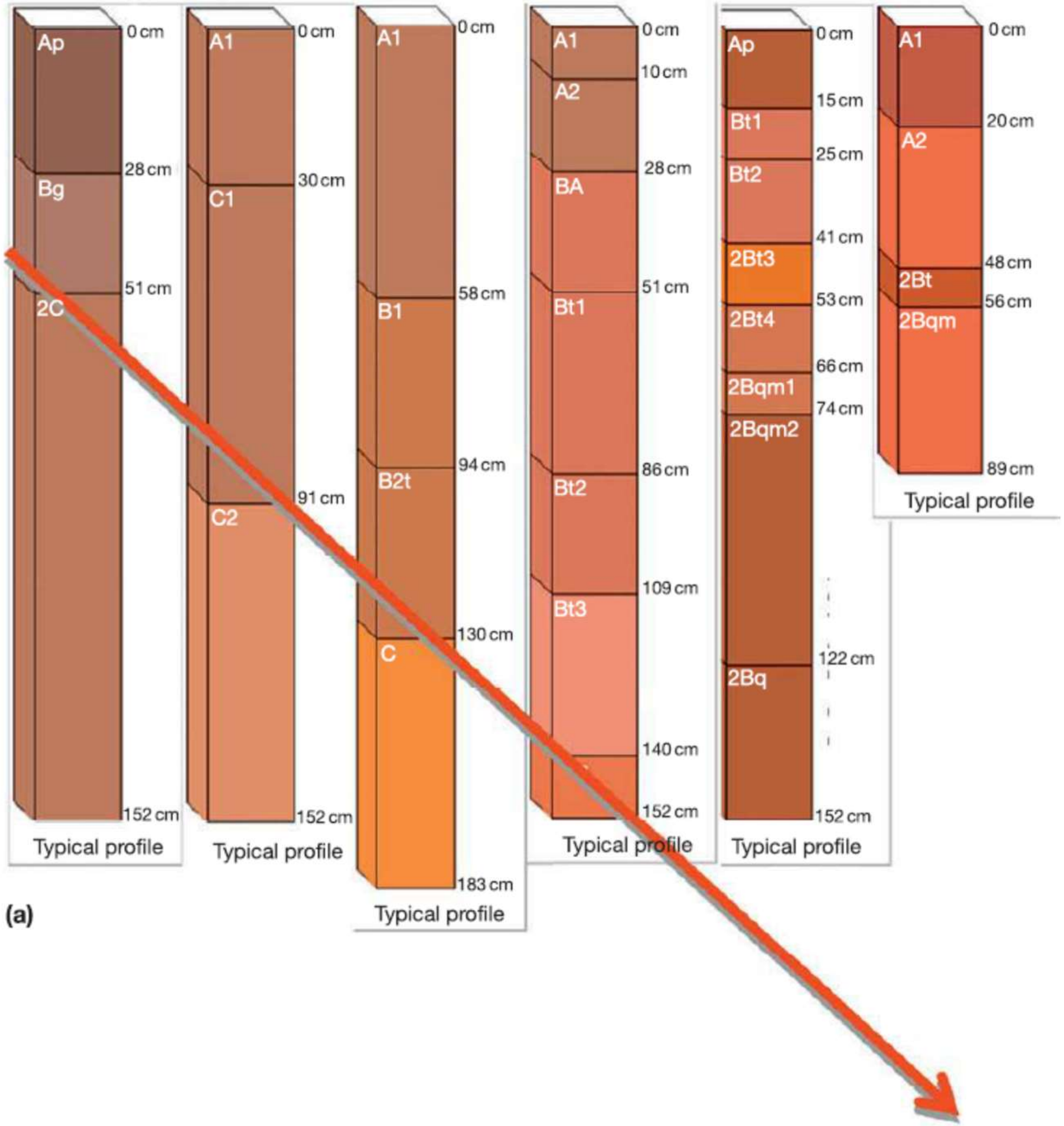
$CO_2$ da fotossíntese é fixado a carbohidratos e $NO_3$ e $NH_4$ são fixados com aminoácidos → solo expande





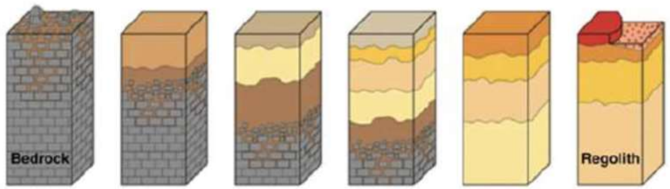

Espessura do solo progride principalmente devido a mecanismos que fisicamente quebram a estrutura sedimentar

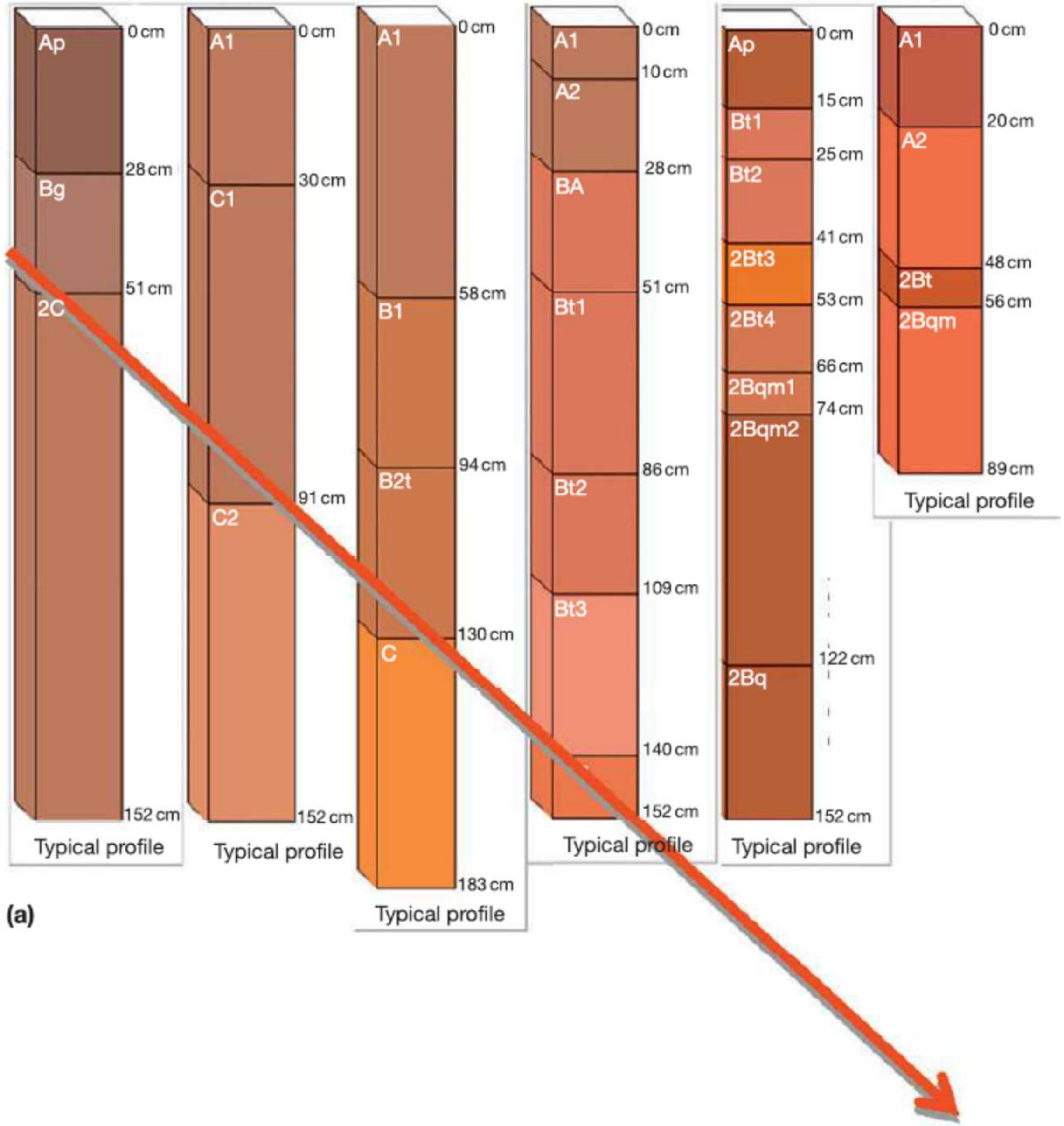





Acúmulo de argilominerais no horizonte B, produtos do intemperismo dos minerais primários.

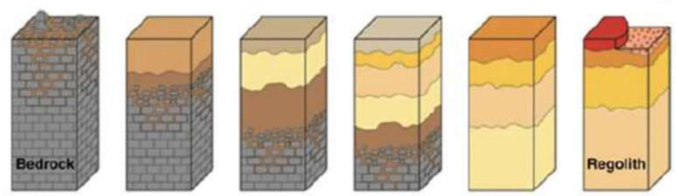
Espessura do solo aumenta com o tempo.



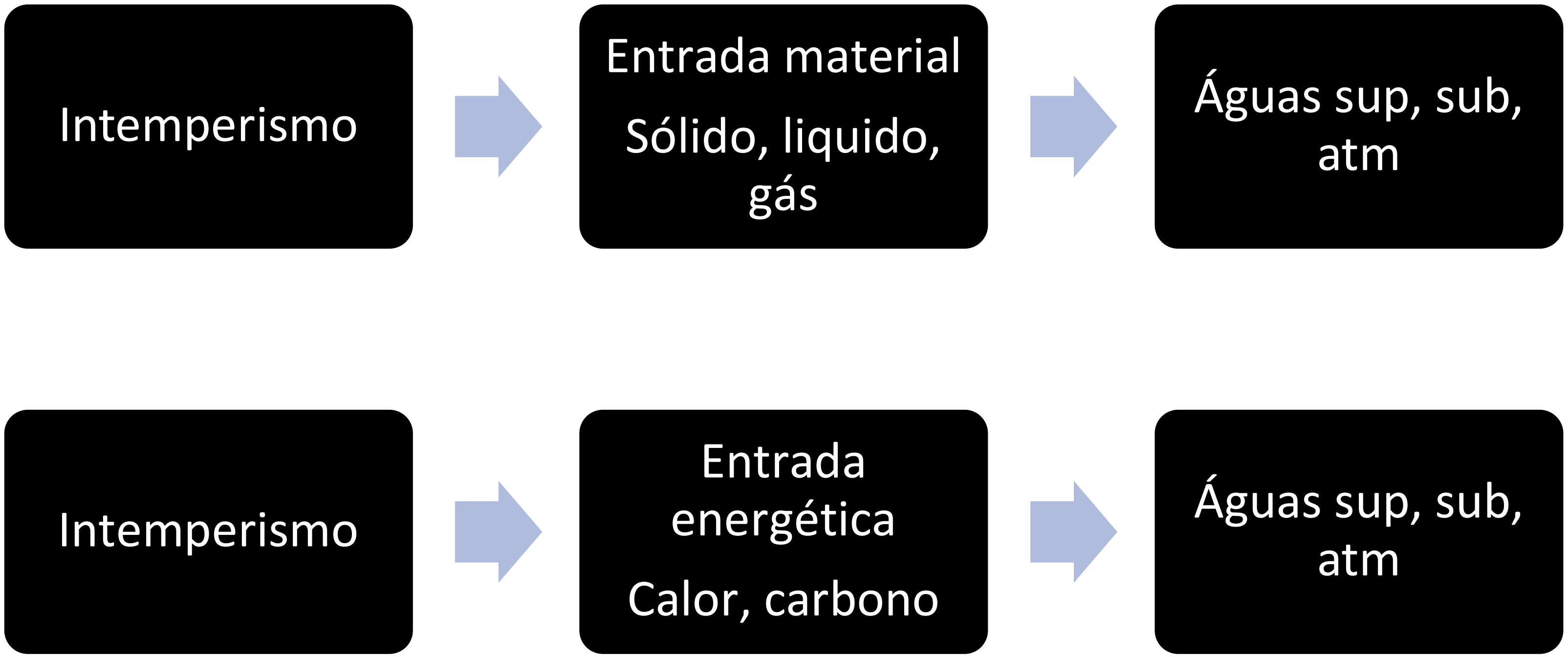


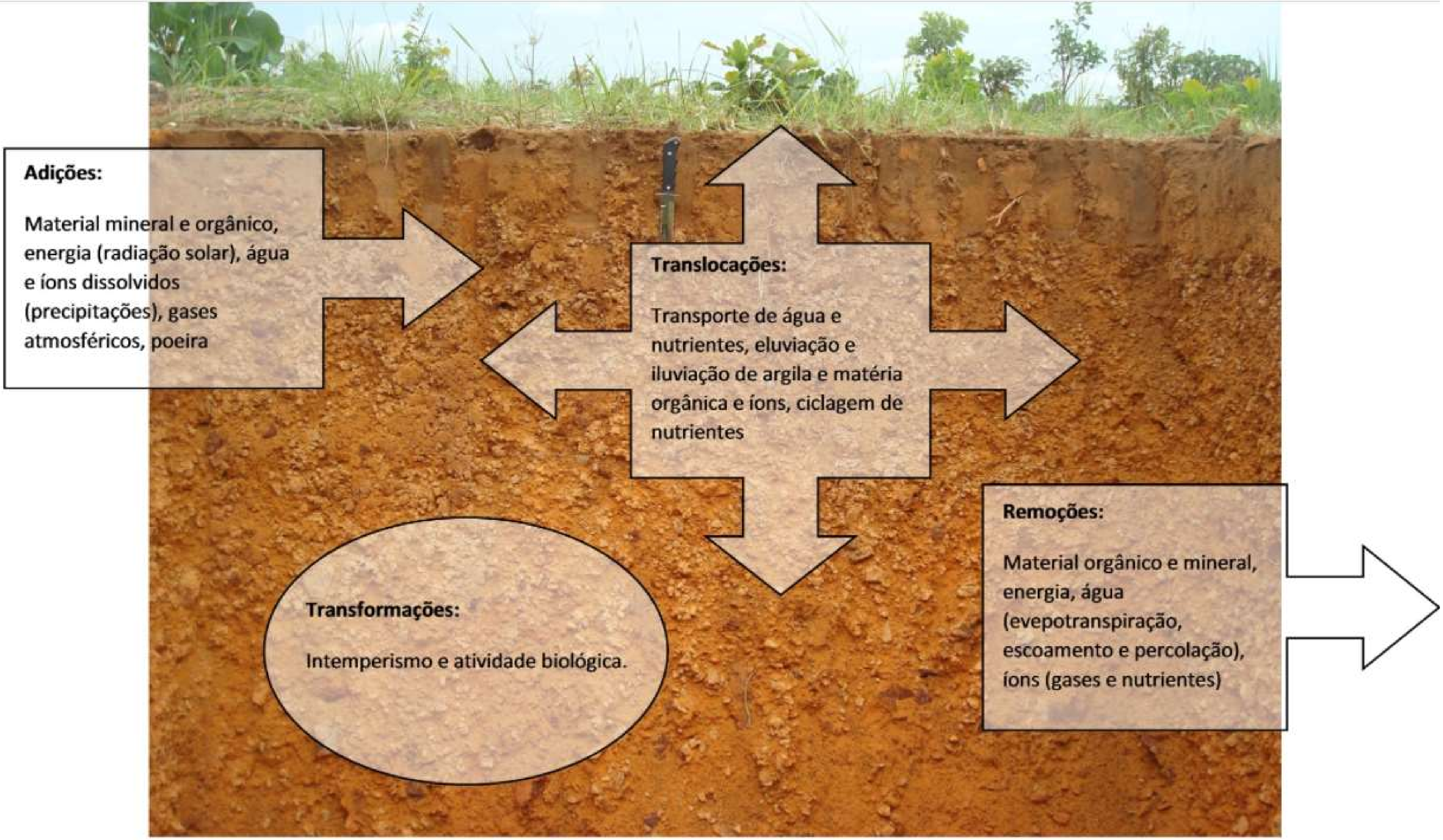

Acúmulo de argilominerais e aumento da espessura do solo aumentam com o tempo.

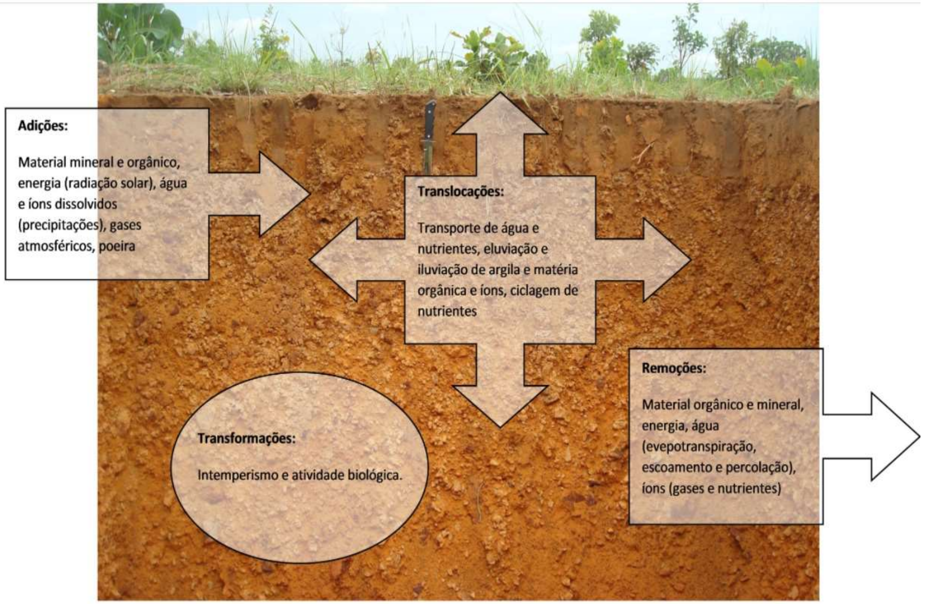
Argilas preenchem os poros → densidade aumenta → volume diminui



# Solos ~ reator biogeoquímico



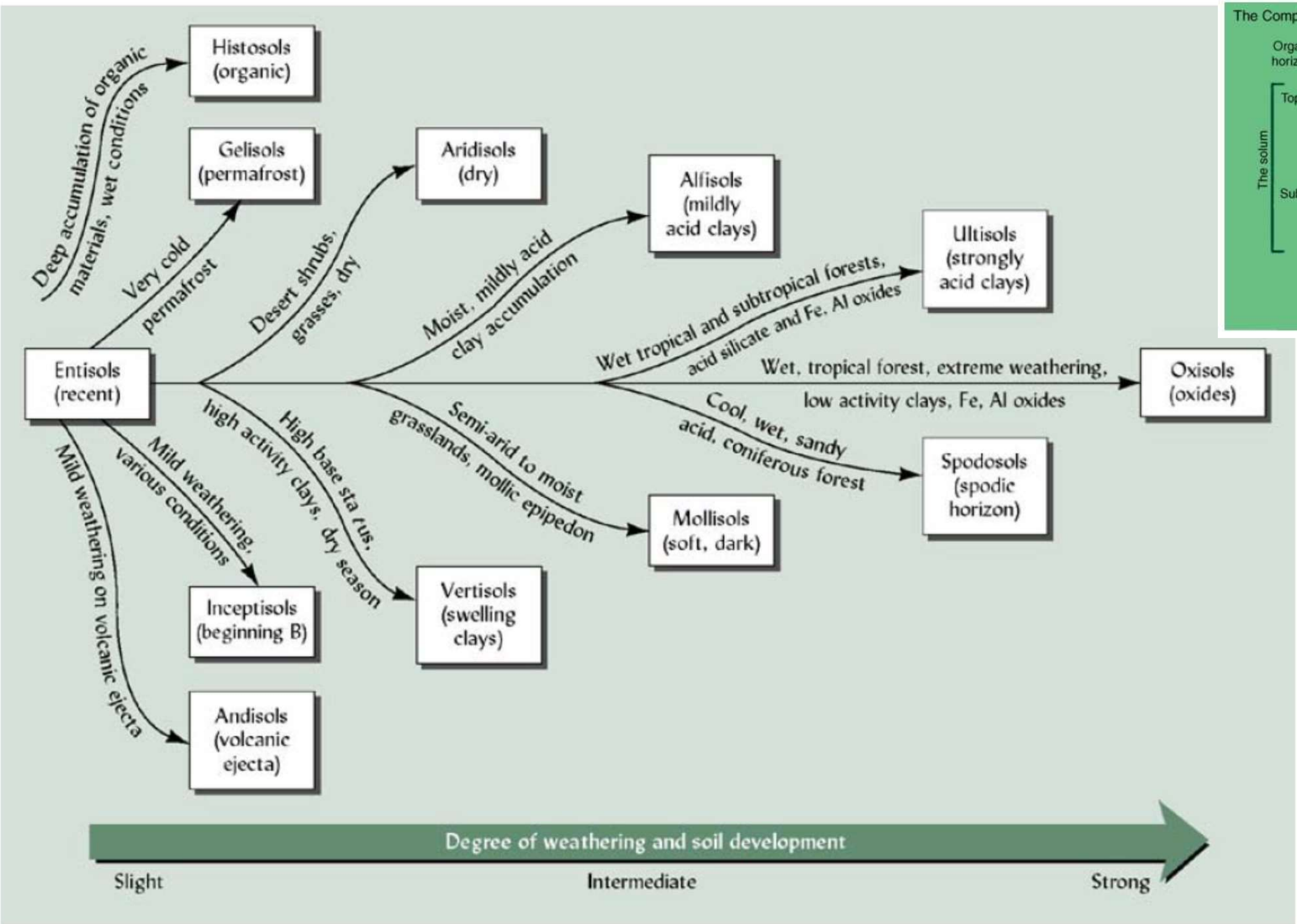

Adições:
Material mineral e orgânico, energia (radiação solar), água e íons dissolvidos (precipitações), gases atmosféricos, poeira
Translocações:
Transporte de água e nutrientes, eluviação e iluviação de argila e matéria orgânica e íons, ciclagem de nutrientes
Remoções:
Material orgânico e mineral, energia, água (evepotranspiração, escoamento e percolação), íons (gases e nutrientes)
Transformações:
Intemperismo e atividade biológica.

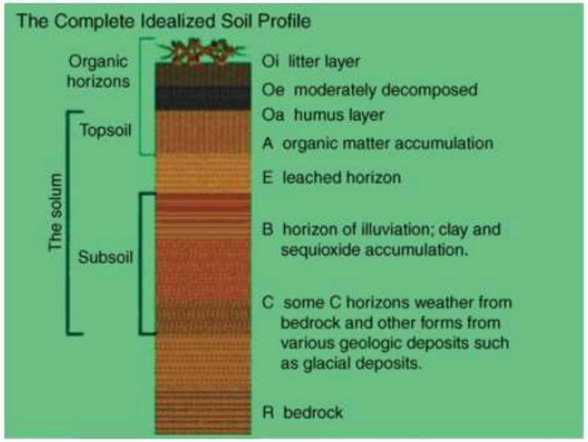


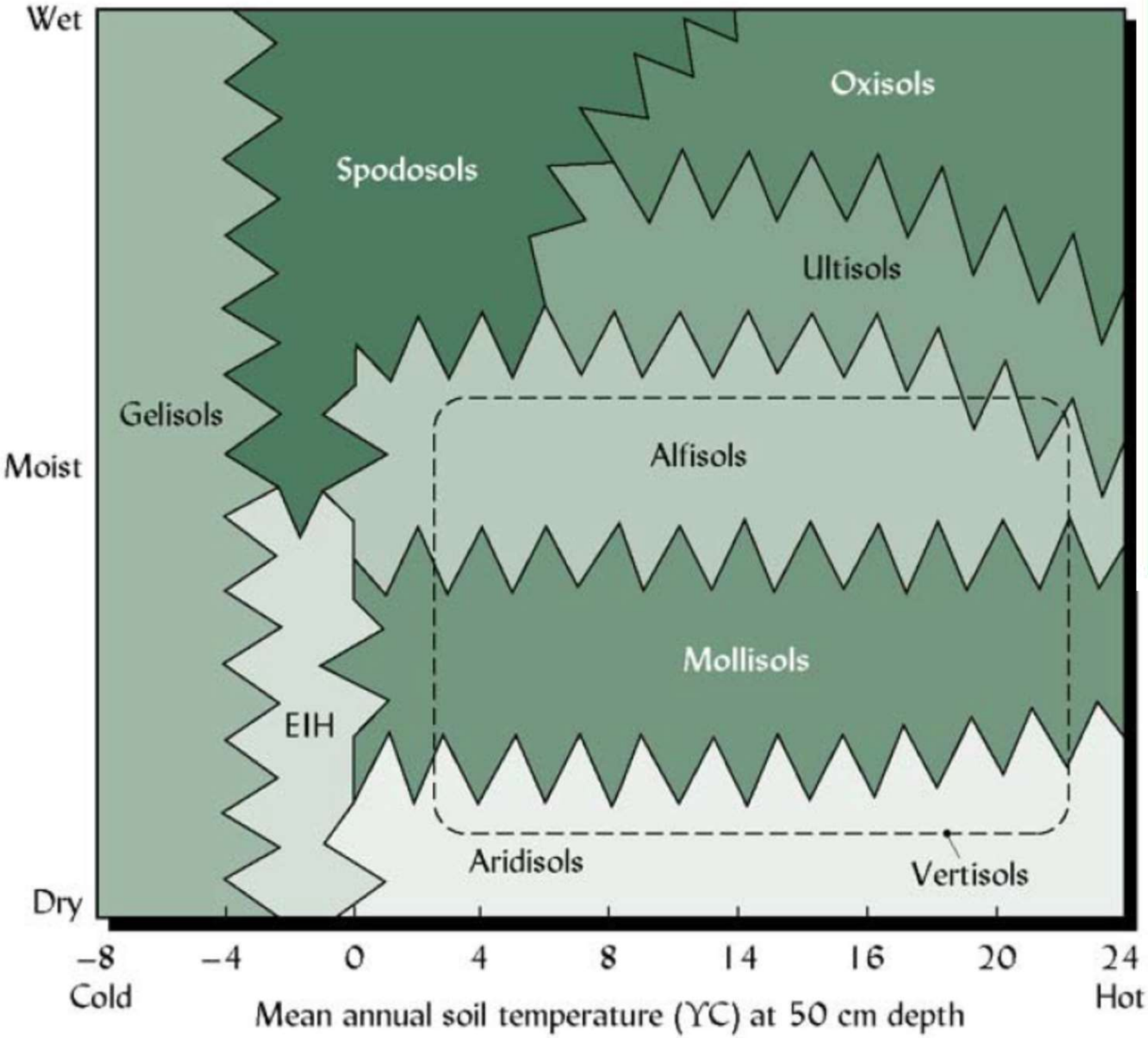

**Processos pedogenéticos**

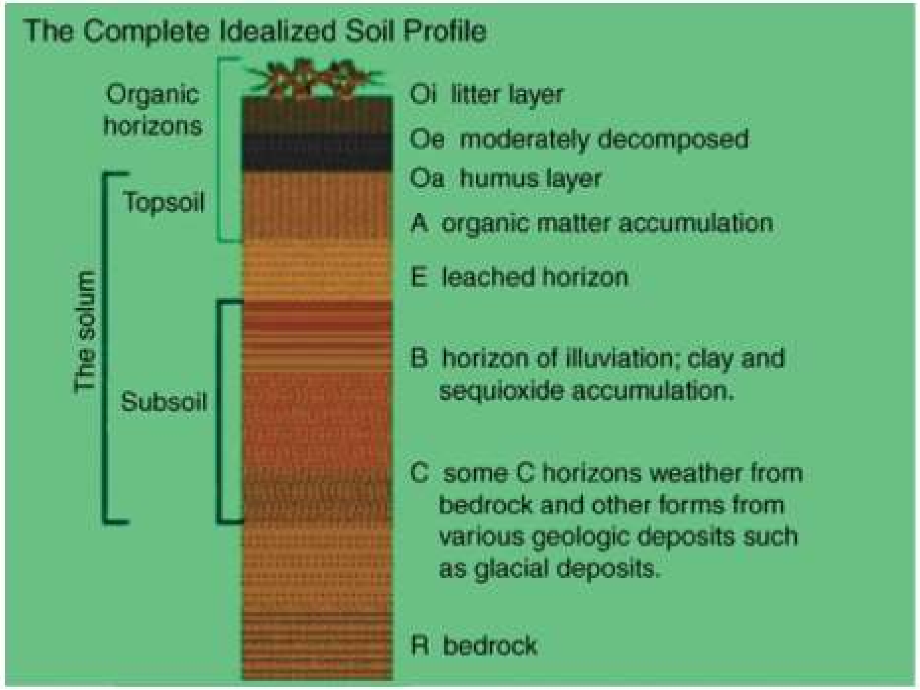
| **Processos pedogenéticos específicos** | **Processos múltiplos** | **Descrição resumida do processo** | **Exemplo de ocorrência** |
|---|---|---|---|
| Ferralitização | Remoção, transformação e translocação | Remoção de sílica e concentração de óxidos de Fe e Al. | Latossolos, Nitossolos, caráter ácrico |
| Silicificação | Transformação e translocação | Migração e acúmulo de sílica cimentando estruturas ou a matriz do solo | Latossolos e Argissolos Amarelos coesos |
| Plintitização e laterização | Transformação e translocação | Redução e translocação de Fe e oxidação e precipitação originando mosqueados, plintita ou petroplintita | Plintossolos |
| Lessivagem ou argiluviação | Translocação | Migração vertical de argila no solo | Argissolos, Luvissolos, horizontes E, lamelas |
| Podzolização | Transformação e translocação | Migração de complexos de Fe, Al e matéria orgânica no solo com acúmulo em horizonte iluvial, com ou sem sílica | Espodossolos, Ortstein |
| Gleização | Remoção, transformação e translocação | Redução de Fe em condições anaeróbias e translocação formando horizontes acinzentados com ou sem mosqueados | Gleissolos, Planossolos |
| Calcificação ou carbonatação | Translocação | Acumulação de $CaCO_3$ com nódulos ou horizonte endurecido | Luvissolos, Chernossolos Rêndzicos |
| Ferrólise | Remoção, transformação e translocação | Destruição de argila com formação de horizonte B textural | Planossolos, Argissolos |
| Salinização | Translocação | Acumulação de sais por evaporação no horizonte superficial ou na superfície do solo | Gleissolos sálicos |
| Sulfurização ou tiomorfismo | Transformação e translocação | Acidificação do solo causada pela oxidação de compostos de enxofre | Gleissolos Tiomórficos |

Adaptado de Kämpf & Curi (2012).


Histosols (organic)
Deep accumulation of organic materials, wet conditions
Gelisols (permafrost)
Very cold permafrost
Aridisols (dry)
Desert shrubs, grasses, dry
Alfisols (mildly acid clays)
Moist, mildly acid clay accumulation
Ultisols (strongly acid clays)
Wet tropical and subtropical forests, acid silicate and Fe, Al oxides
Entisols (recent)
Wet, tropical forest, extreme weathering, low activity clays, Fe, Al oxides
Oxisols (oxides)
Cool, wet, sandy acid, coniferous forest
Spodosols (spodic horizon)
Semi-arid to moist grasslands, mollic epipedon
Mollisols (soft, dark)
High base sta rus, high activity clays, dry season
Vertisols (swelling clays)
Mild weathering, various conditions
Inceptisols (beginning B)
Mild weathering on volcanic ejecta
Andisols (volcanic ejecta)
Degree of weathering and soil development
Slight
Intermediate
Strong


The Complete Idealized Soil Profile
Organic horizons
Topsoil
The solum
Subsoil
Oi litter layer
Oe moderately decomposed
Oa humus layer
A organic matter accumulation
E leached horizon
B horizon of illuviation; clay and sequioxide accumulation.
C some C horizons weather from bedrock and other forms from various geologic deposits such as glacial deposits.
R bedrock

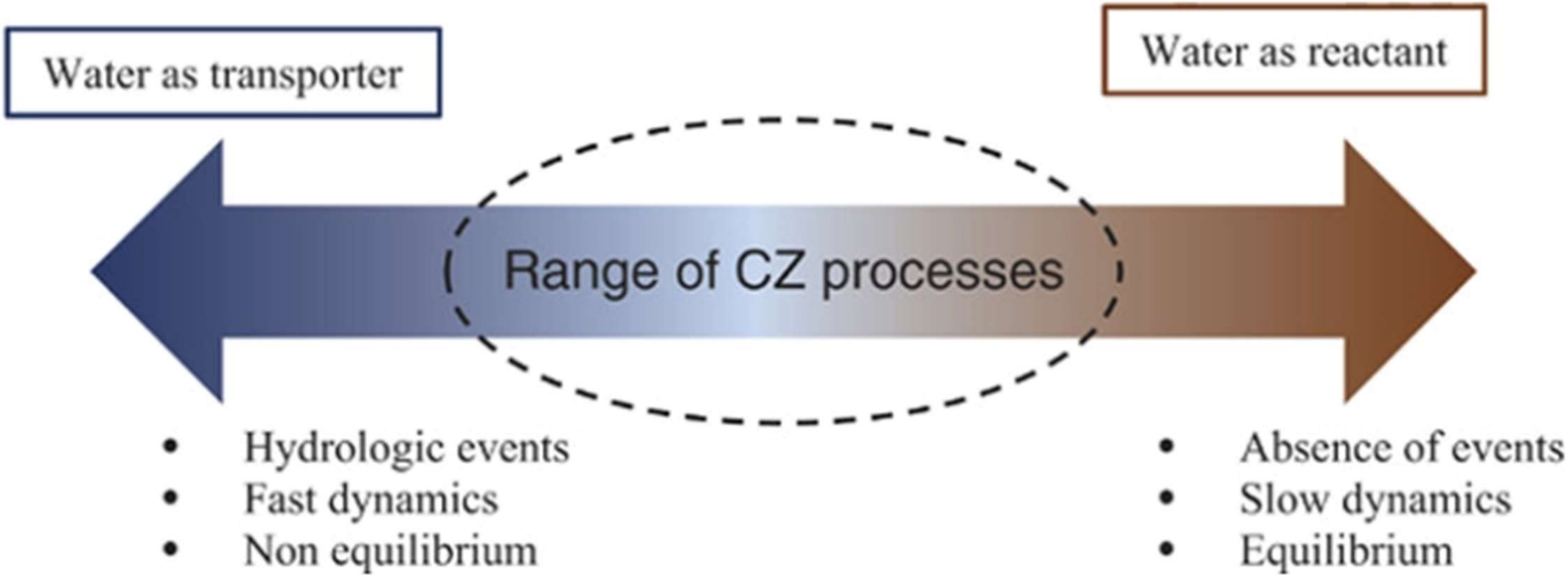

Wet
Moist
Dry
Oxisols
Spodosols
Ultisols
Gelisols
Alfisols
Mollisols
EIH
Aridisols
Vertisols
−8
−4
0
4
8
14
16
20
24
Cold
Hot
Mean annual soil temperature (YC) at 50 cm depth


The Complete Idealized Soil Profile
Organic horizons
Topsoil
The solum
Subsoil
Oi litter layer
Oe moderately decomposed
Oa humus layer
A organic matter accumulation
E leached horizon
B horizon of illuviation; clay and sequioxide accumulation.
C some C horizons weather from bedrock and other forms from various geologic deposits such as glacial deposits.
R bedrock

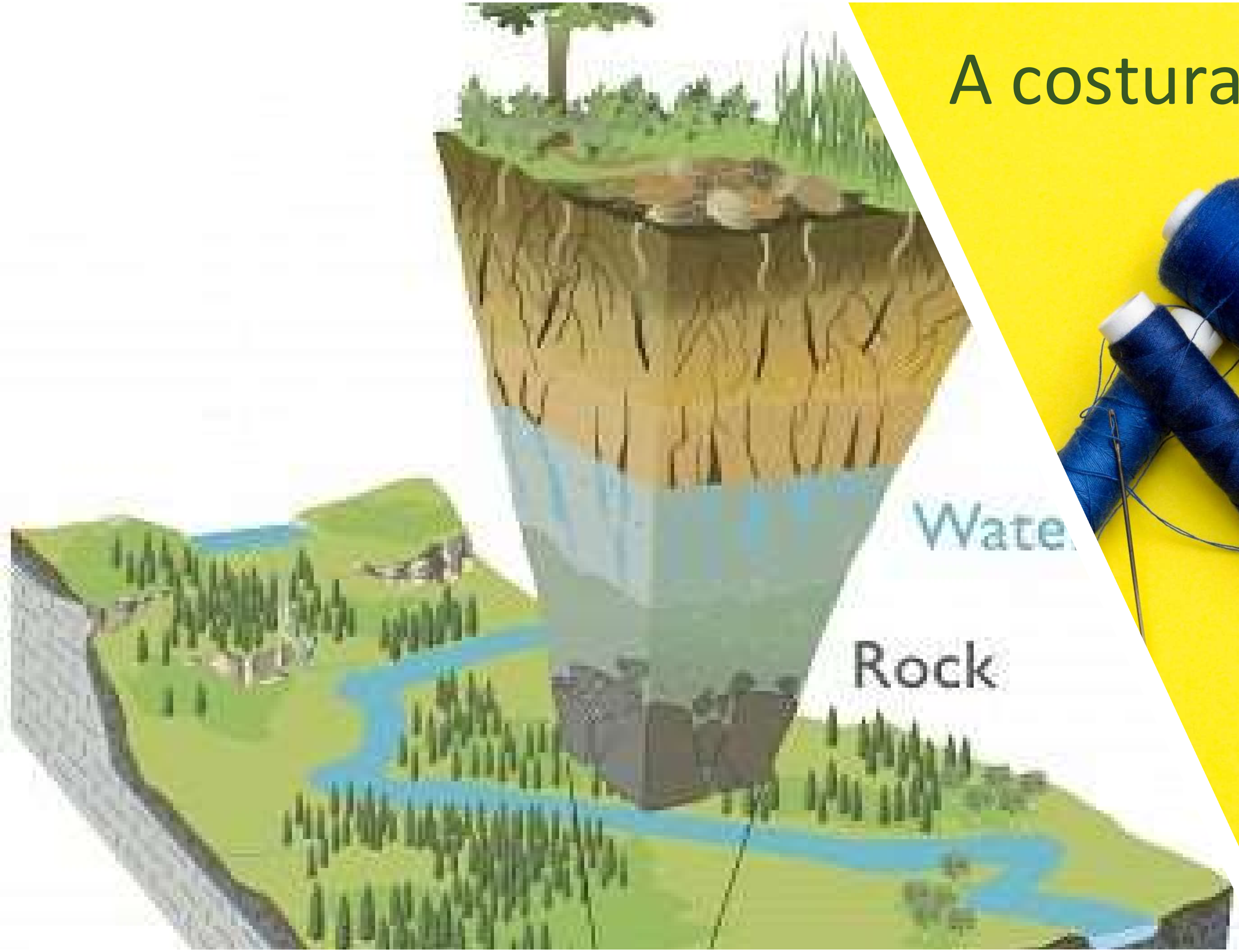
# Solos brasileiros

- Composição mineralógica ~quartzo, caulinita, oxi-hidróxidos de Fe e Al
- Grandes espessuras
- Horizontes amarelo/laranja/vermelho/castanho
- Solos tropicais são mais empobrecidos em relação aos climas temperados (ricos em argilominerais capazes de reter nutrientes)
- Latossolos, vertosolos e outros

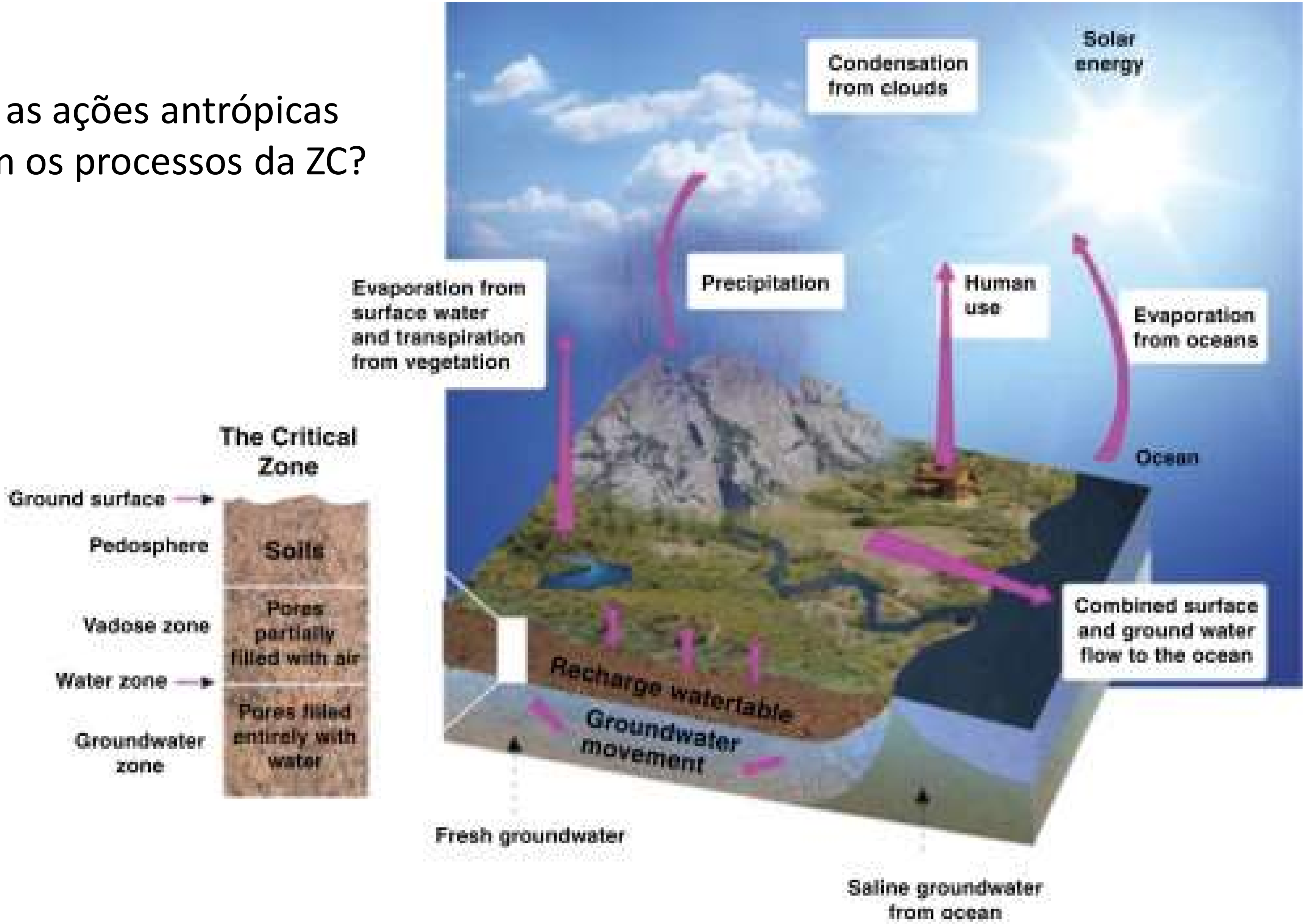
# O papel da água nos processos biogeoquímicos nos solos



# A costura da ZC




Como as ações antrópicas afetam os processos da ZC?

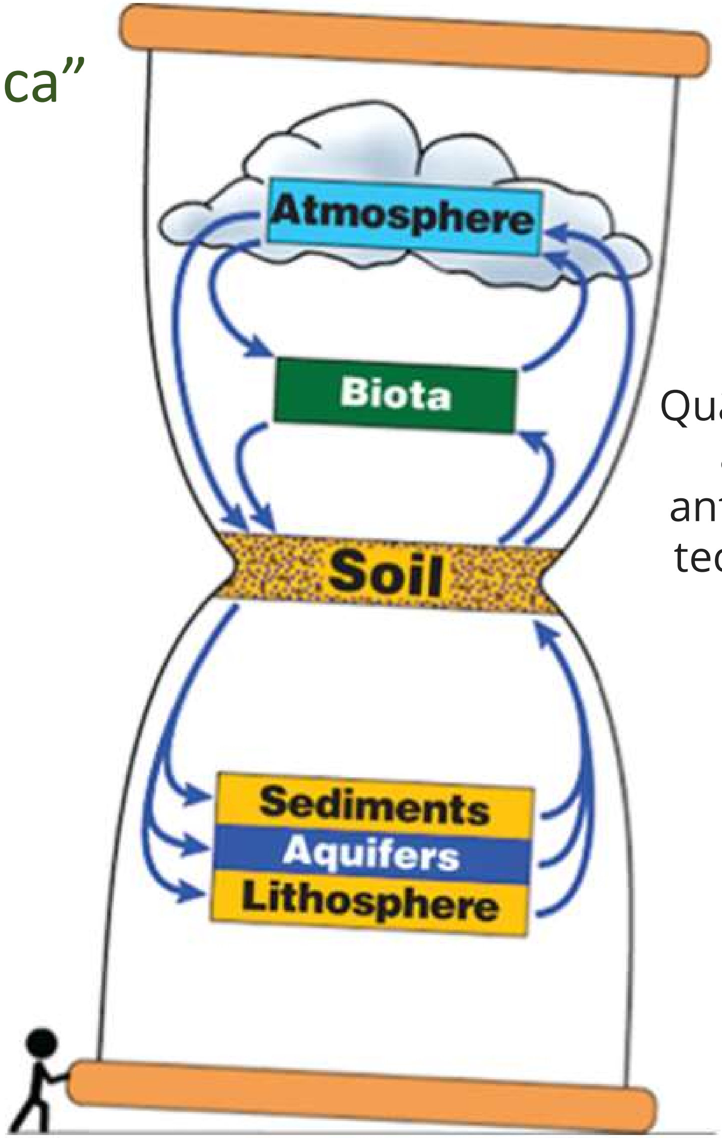


# Somos inclusive uma força "geológica"

Segundos → Milhões de anos

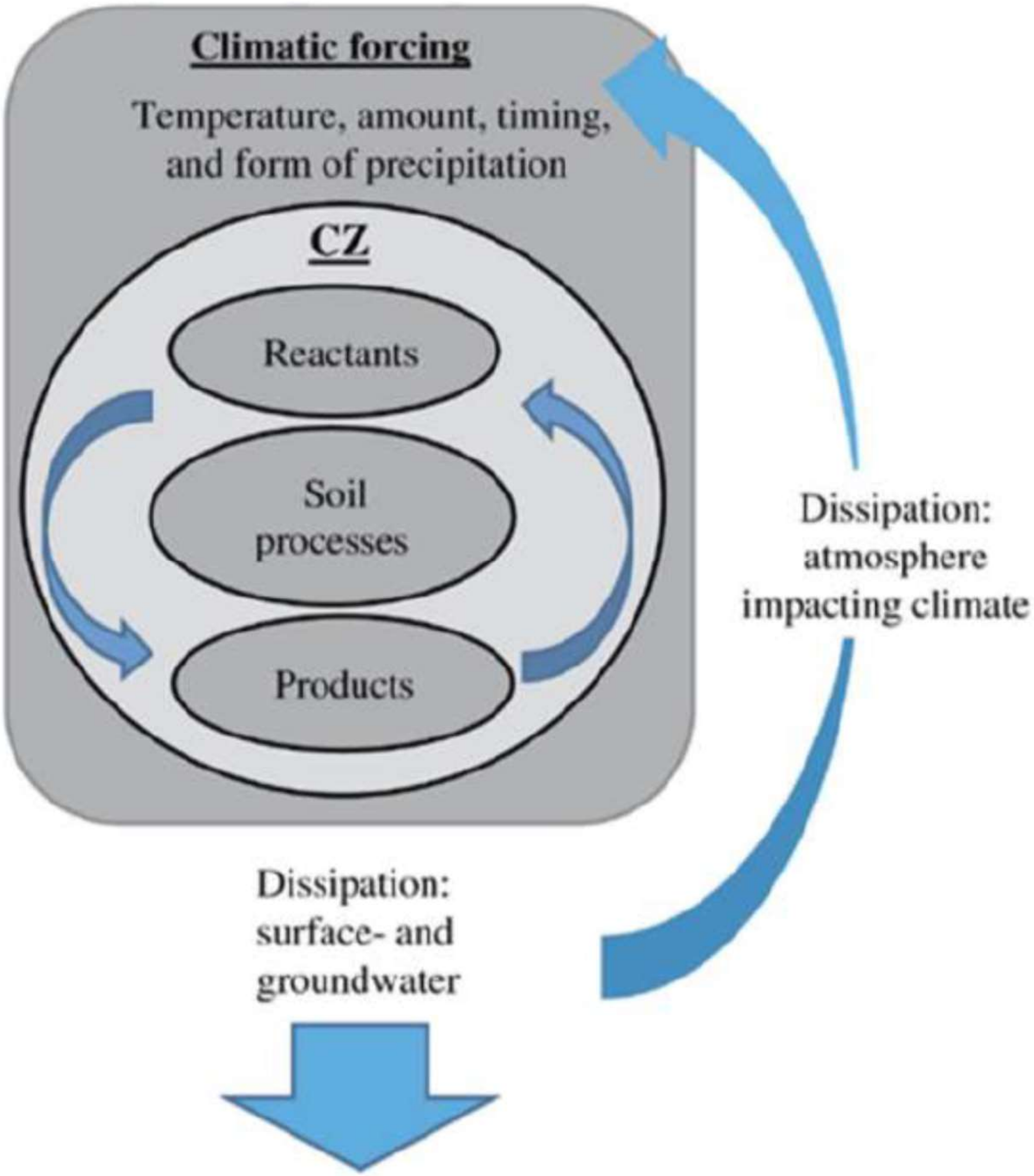
Atividade microbiana

Sequestro de CO2 atmosférico pelo intemperismo da silica




Quão rápido e como responde a forças meteorologicas, antropogênicas, climáticas ou tectônicas, e como as escalas de tempo se ajustam?

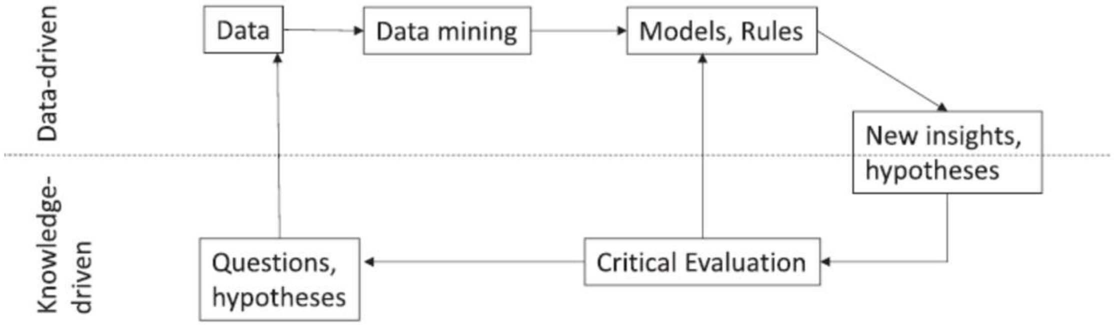
Brantley and Lebedeva, 2011. Annual Review Earth Planetary Science




O clima afeta os processos biogeoquímicos do solo, que por sua vez afetam a composição da atmosfera, águas superficiais e subterrâneas

Mudanças na atmosfera afetam o clima

## Estrutura de coleta de dados



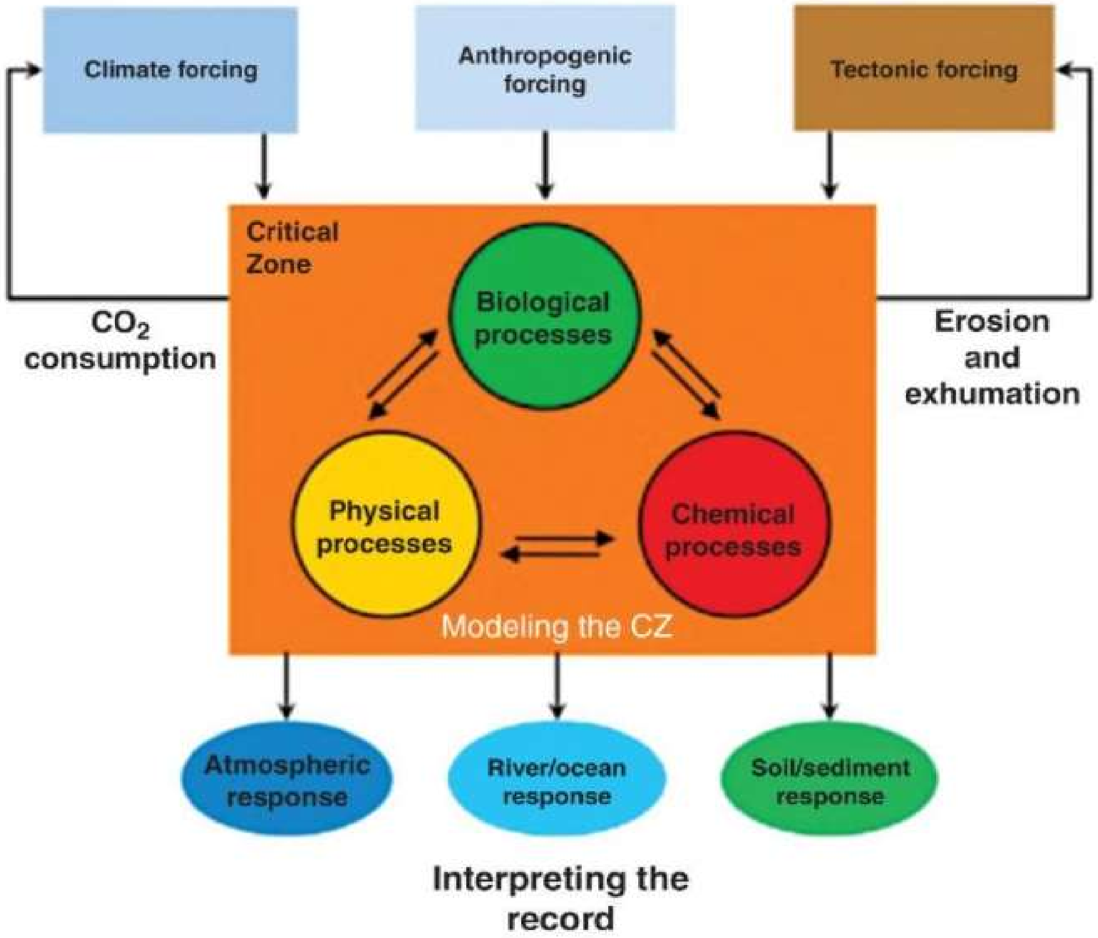




FIGURE 2.1 Physical, chemical, and biological processes in the Critical Zone (CZ) are subjected to climate, tectonic, and anthropogenic forcing that lead to responses in the atmosphere, biosphere, hydrosphere, lithosphere, and pedosphere. The challenge of CZ science is to interpret CZ processes over both short and long timescales: for example, CZ scientists attempt to understand sediment and soil records for comparison to changes in the CZ associated with ongoing climate and land-use change. *(From Brantley et al. (2007).)*

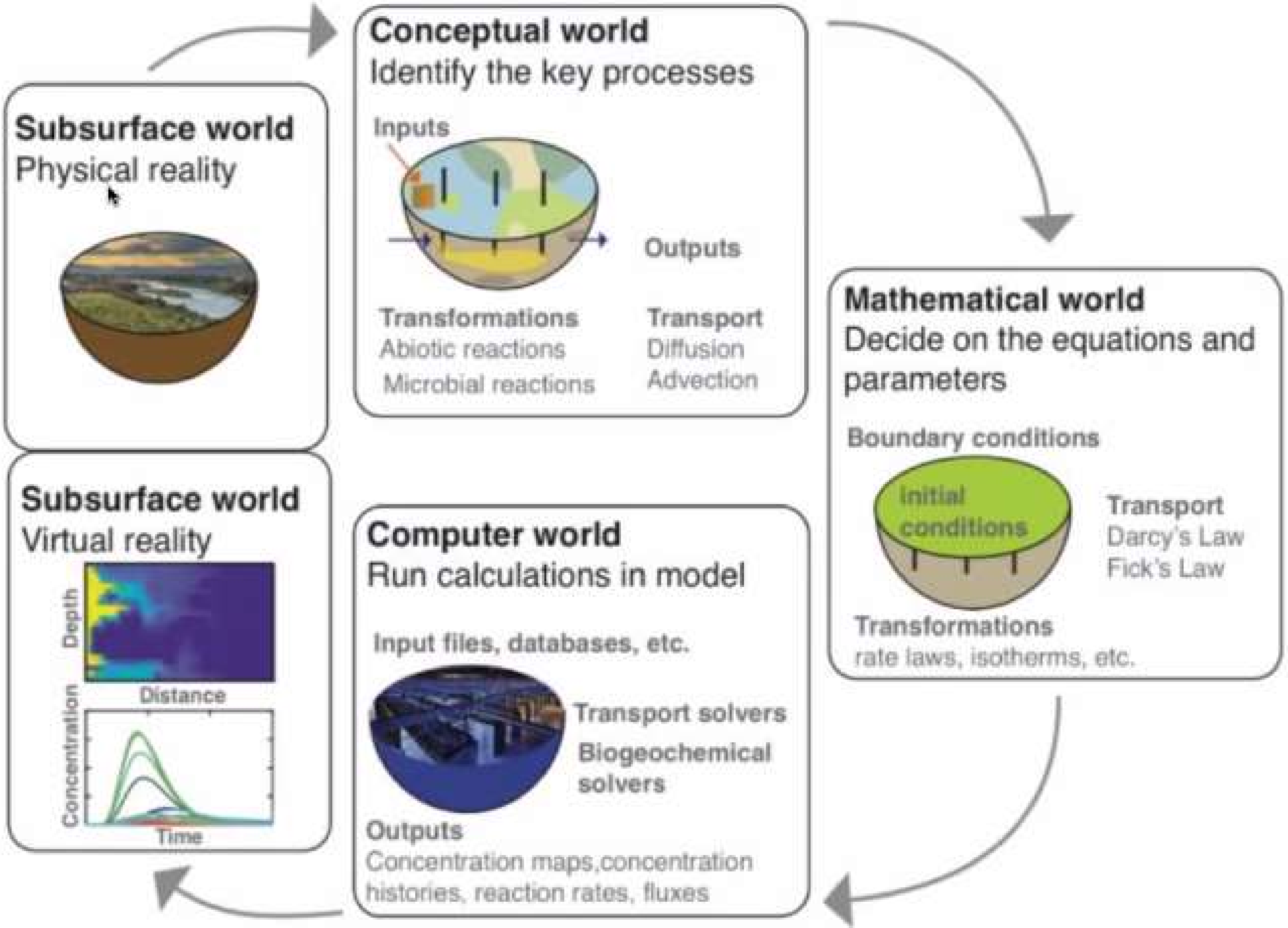
Embora os diversos observatórios de ZC estudem questões específicas mais importantes para cada ambiente específico (montanhas, ambiente árido, florestas, etc)

Algumas grandes perguntas da ZC podem requerer justamente essas particularidades, estudadas de forma integrada

Como os processos que sustentam os ecossistemas mudam na escala de tempo humana e geológica?

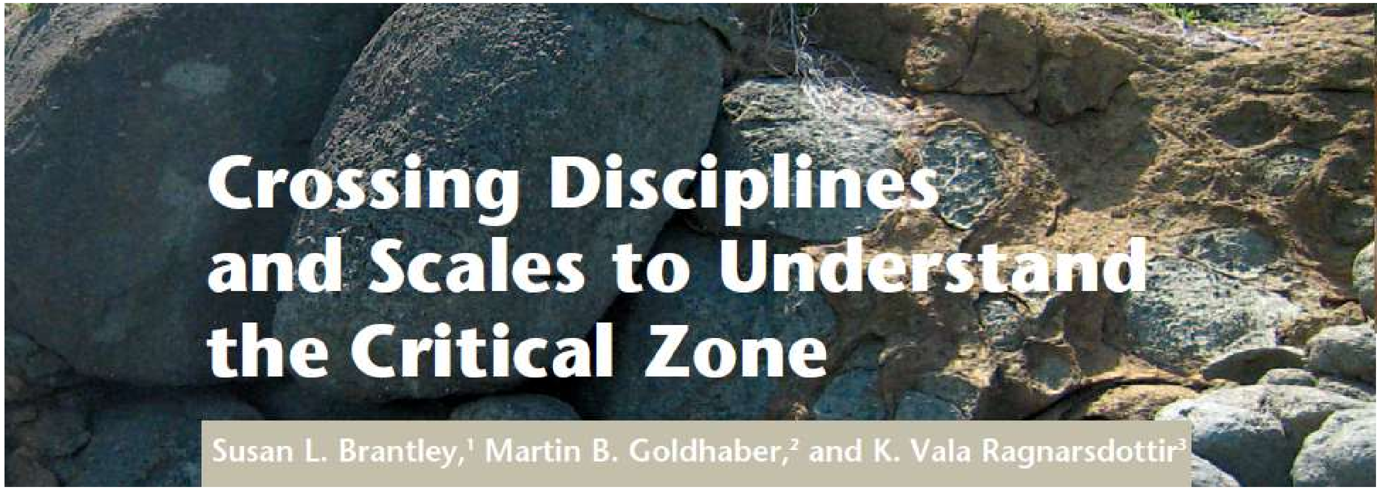
Como os processos biogeoquímicos (biológicos, químicos e geológicos) influenciam os recursos hídricos e de solo?

Será possível usar todas essas observações para desenvolver modelos e explorar como a ZC vai responder as forças antropogênicas, climáticas e tectônicas?




Desafio: os diferentes processos ocorrem em diferentes escalas espaciais e temporais

# Discussão em grupos 2



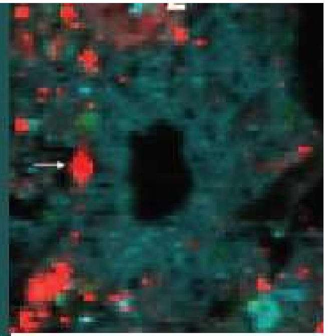

A soil profile developed in Quaternary volcaniclastic debris in Basse Terre Island, Guadeloupe. PHOTO BY P. SAK (DICKINSON COLLEGE)

The challenge to cross disciplines and scales in understanding the CZ is a growing focus for scientists from geology, soil science, hydrology, environmental engineering, chemistry, and ecology.

By way of introduction to the CZ, we discuss in this paper the geochemical story written in the regolith, defined here as the weathered rock material overlying pristine bedrock, as documented by chemical gradients at the pedon scale.

We then describe the flux of materials through the CZ, and we conclude with a discussion of issues that transect disciplines and scales of time and space, as we think about CZ sustainability.

# Soil Biogeochemical Processes within the Critical Zone



Jon Chorover,[1] Ruben Kretzschmar,[2] Ferran Garcia-Pichel,[3] and Donald L. Sparks[4]

In this paper, we emphasize the importance of soil *biogeochemical interfaces to internal CZ function* and focus on their effect on environmental pollutants.

Reactions that occur at the boundary between multicomponent solid, liquid, and gas phases in weathering systems are indeed critical to the capacity of the Earth's surface to sustain water and soil quality.

Removal of pollutants, sustainable provision of clean water, and support of productive ecosystems are all inextricably linked to the diversity and reactivity of natural interfaces formed by interaction of biota and water with lithogenic materials in the CZ.

Soil is central to food production, the regulation of greenhouse gases, recreational areas such as parks and sports fields and the creation of an environment pleasing to the eye. But soil is fragile and easily damaged by uninformed management or accidents.

One type of damage is contamination by chemicals that provide the lifestyles to which the developed world has become accustomed.

Traditional soil “clean-up” has entailed either simple disposal or isolation of contaminated soil. Clearly this is not sustainable.

Modern remedial techniques apply mineralogical and geochemical knowledge to clean up contaminated soil and make it good for reuse, rather than simply discarding this precious and finite resource.

# Organic Amendments for Remediation: Putting Waste to Good Use

David L. Jones and John R. Healey*

Using organic wastes as a sustainable remediation option not only helps divert another waste stream from landfill but also provides a simple remediation technology that has the potential for widespread adoption.

We review the main types of organic waste currently available, the range of contaminants they can treat and their practicality.

As the long-term success of any remediation strategy depends on more than just technical factors, we also assess the environmental,

economic, social and cultural sustainability of organic wastes in land restoration.

Last, we look to the future and speculate on what lies ahead, in particular, the translation of research into industry practice.