Soil System (Pedosphere)

ESO213

Earth Science

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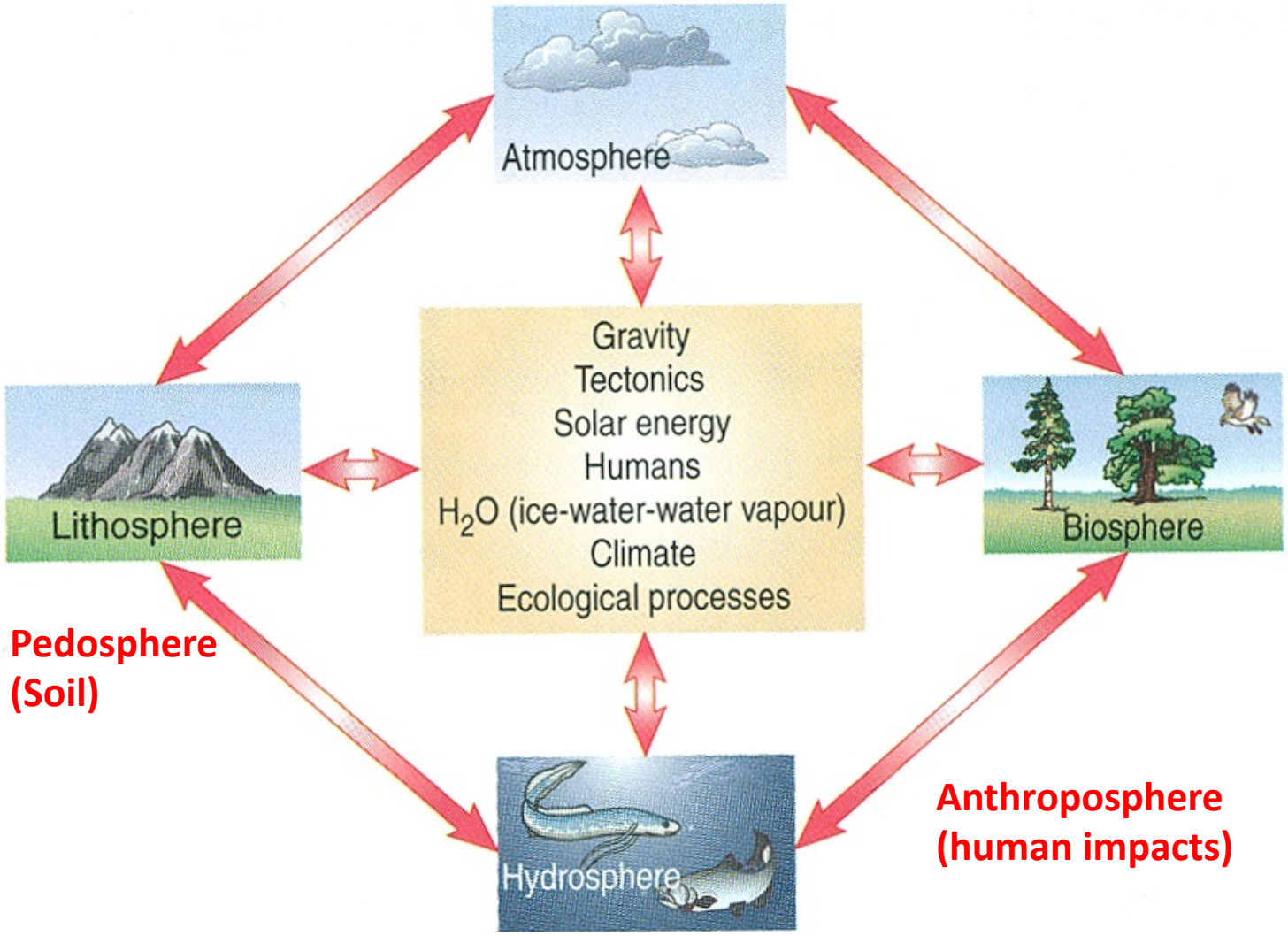
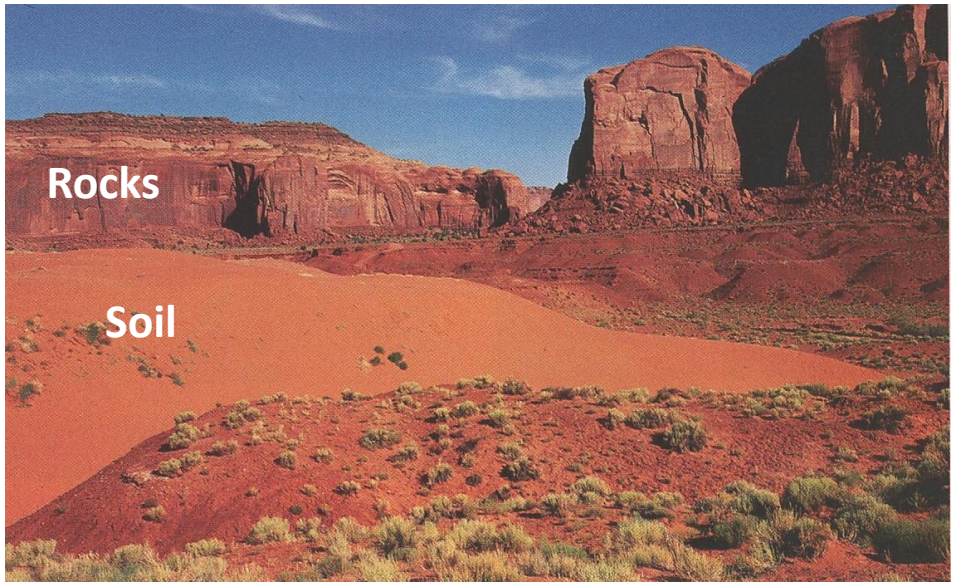
Components of Earth's System



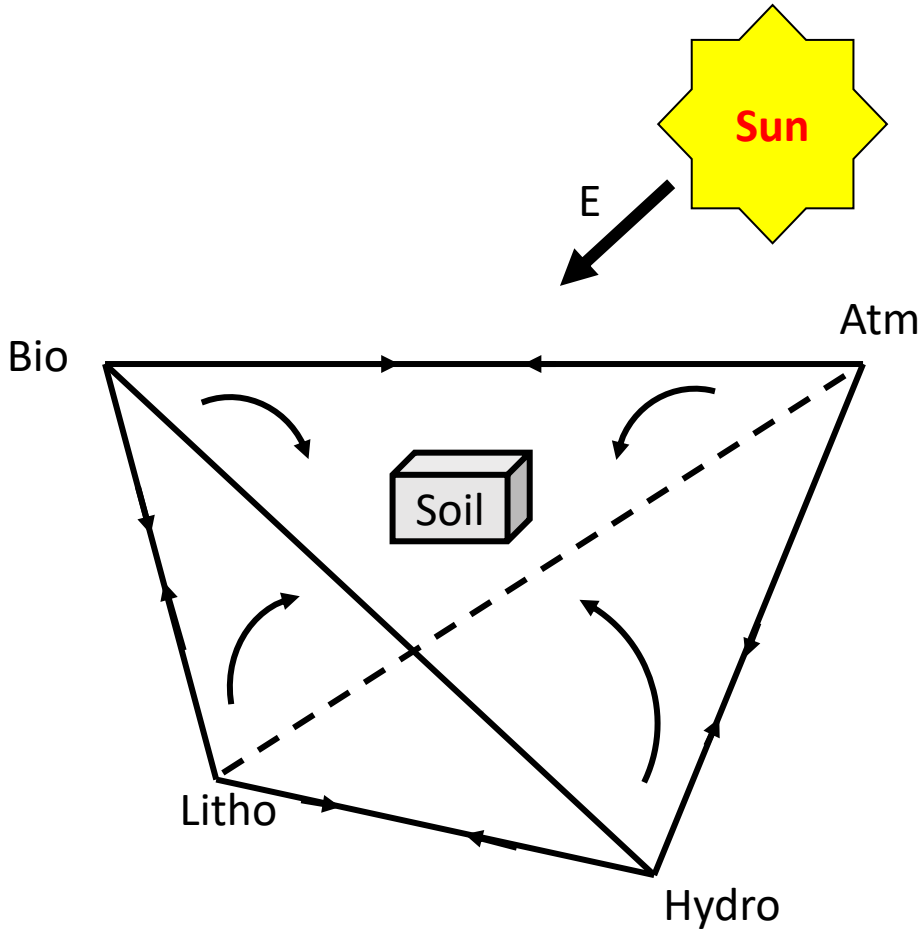
Huddart and Stott, 2010

- Soils – disaggregated and weathered rock debris and organic matter
- 100-200 m thick, supports all terrestrial agricultural activities and food production
- Open system; rate of soil formation depends upon climate, rock type, organic matter, topography and time

How does soil form?



A vertical column of rocks is reduced to a horizontal blanket of loose material!



Soil formation = a +ve feedback process!

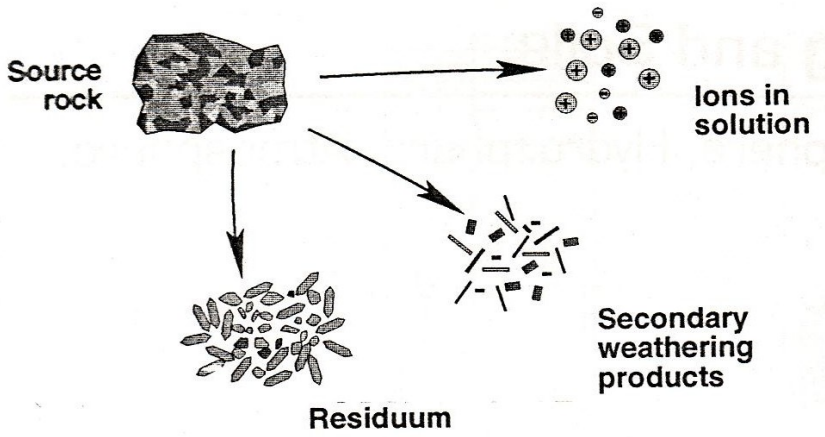
Soil forming factors

(1) *climate*,
(2) *vegetation, fauna, man*
(3) *relief*
(4) *parent material*
(5) *time* span

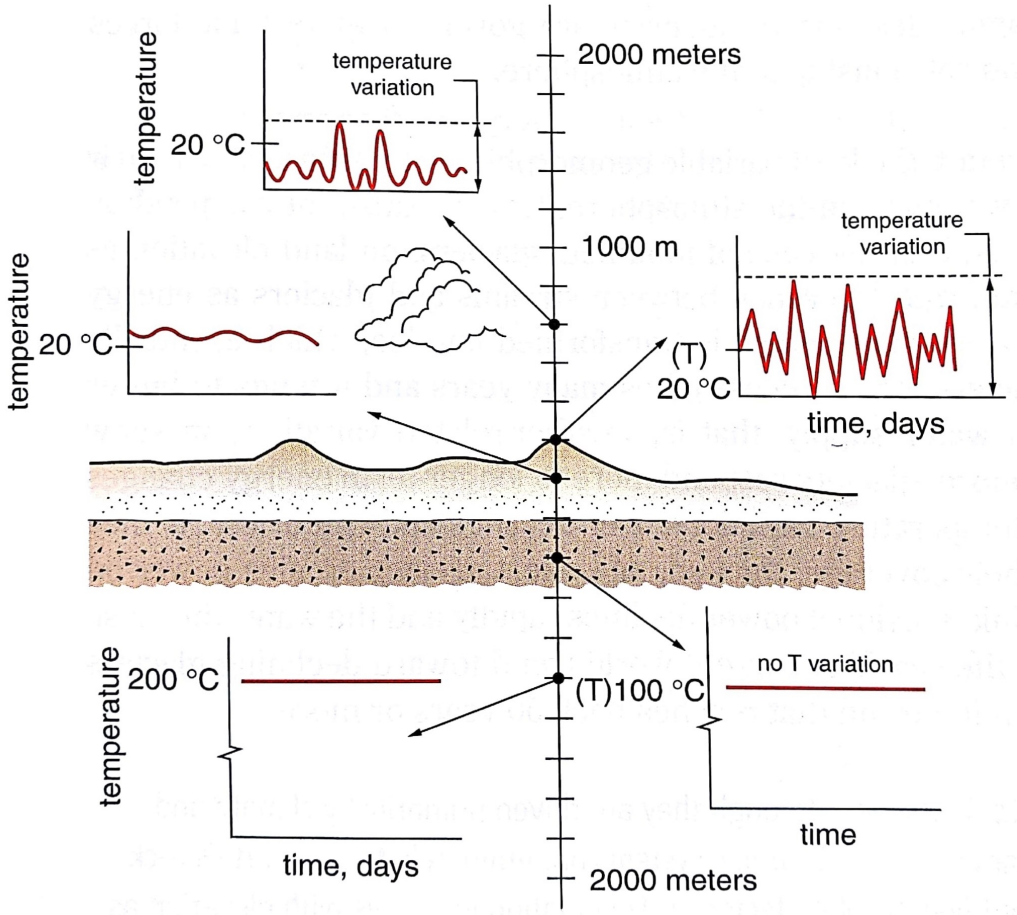
} **Pedogenesis**

Weathering Systems and the Breakdown of Rocks

- Weathering: Normal earth process. Takes place when deep-seated rocks are exposed on the surface of the earth
- Compact and coherent rocks with little porosity get converted into friable and loose material (regolith/soil) with high porosity, and grain size reduction.
- Mineralogical and chemical changes (both loss and gains)



- Water – the solvent
- Surface temperature



Temperature (T) variations over time in the atmosphere, at the Earth's surface, in the soil, and in the crust. Thermal variations are relatively extreme at ground level.

What facilitates weathering ?

Water, air, life, tectonics

(Agents of weathering)

+

Structure in rocks = original planar features (faults, fractures, joints, foliation, bedding planes, lithological boundaries)

+ planar features developed during uplift/unroofing

Types of weathering processes and products

- Chemical
- Mechanical
- Biological

- Loose particles – boulders to fine clays
- Dissolved chemicals – ions of Ca, Mg, Si and others
- Oxides – Fe, Cu etc.
- Clay Minerals

Do different elements behave differently during chemical weathering?

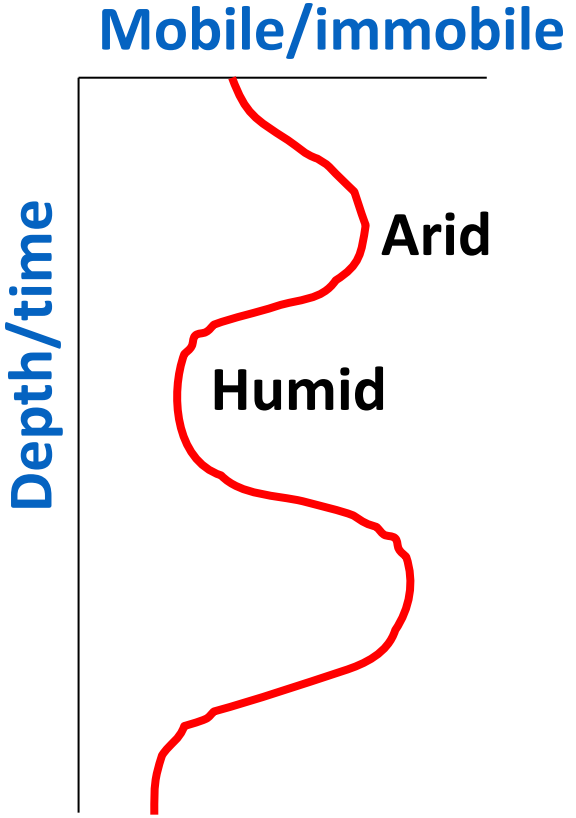
Relative strength

- Si-O 2.4
- Ti-O 1.8
- Al-O 1.65
- Fe^{+3}-O 1.4
- Mg-O 0.9
- Fe^{+2}-O 0.85
- Mn-O 0.8
- Ca-O 0.7
- Na-O 0.35
- K-O 0.25

Ti, Si, Al, Fe – relatively immobile

Na/Al – high in arid condition and low in humid

Mg, Mn, Na, K, Ca – relatively mobile



Chemical Index of Actuation:

$CIA=[Al_2O_3/(Al_2O_3+Na_2O+CaO+K_2O)] \times 100$

UCC = 50 ; Gibbsite/Kaolinite = 100

Weathering reactions – Role of water

$3NaAlSi_3O_8 + H_2CO_3 + \mathbf{3H_2O} + Mg^{2+} = 2Na_{0.5}Al_{1.5}Mg_{.5}Si_4O_{10}(OH)_2 + 2Na^+ + HCO3^- + H_4SiO_4$

(albite) (Smectite) **(Less water, semi humid)**

$4NaAlSi_3O_8 + 4H_2CO_3 + \mathbf{18H_2O} = 4Na^+ + 8H_4SiO_4 + Al_4Si_4O_{10}(OH)_8 + 4HCO3^-$

(albite) (Kaolinite) **(Moderate rainfall)**

$NaAlSi_3O_8 + H_2CO_3 + \mathbf{7H_2O} = Na^+ + HCO_3^- + 3H_4SiO_4 + Al(OH)_3$

(albite) (Gibbsite) **(Intense rainfall)**

- **Na^+ gets dissolved, moves out**
- **Al^{+3} is completely retained in the new clay mineral**
- **Type of clay mineral determined by the amount of water flowing through (climate)**

Weathering reactions

- **Congruent dissolution** – when the mineral goes into solution and dissolved completely with no precipitation of other substances
- **Incongruent dissolution** – when all or some of the ions released by weathering precipitate to form new substances

- $CaSO_4$ (anhydrite) + 2 $H_2O \Leftrightarrow CaSO_4.2H_2O$ (Gypsum)

  Hydration - absorption of water

- $KAlSi_3O_8 + HOH \Rightarrow HAlSi_3O8 + KOH$

  Hydrolysis - formation of hydroxyl ions

- $H_2O + CO_2 \Leftrightarrow \ H_2CO_3$

  $2KOH + H_2CO_3 \Rightarrow K_2CO_3 + 2\ HOH$

  Carbonation - formation of carbonate

- $MgFeSiO_4 + 2HOH \ \Rightarrow \ Mg(OH)_2 \ + H_2SiO_3 \ + FeO$

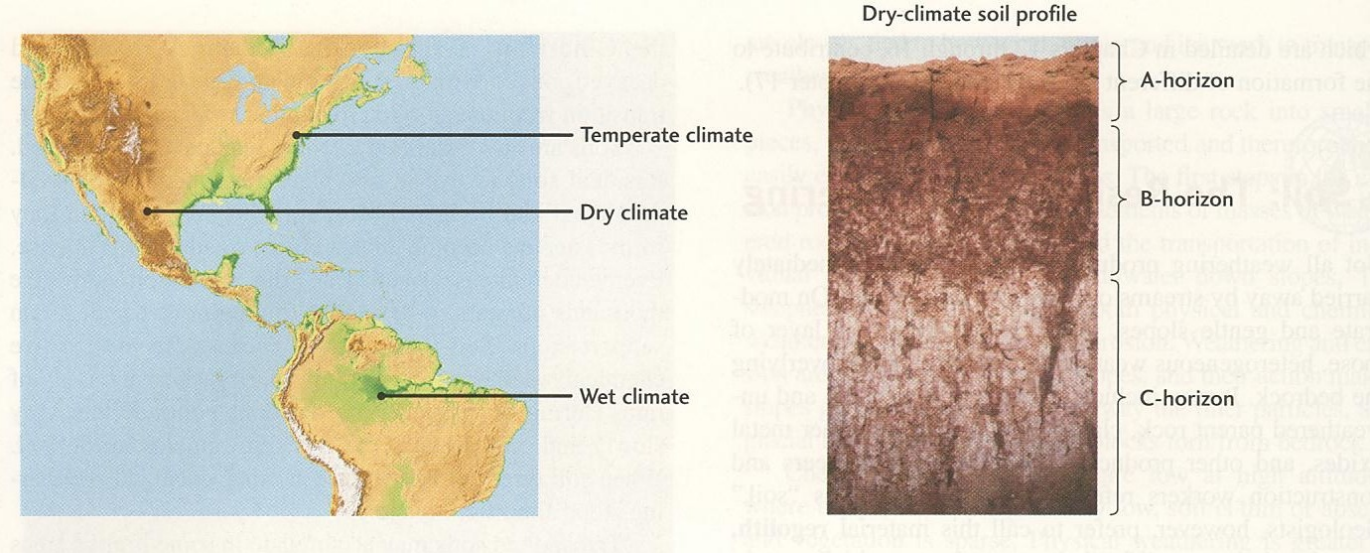
  $4FeO \ \ + 2H_2O \ + \ O_2 \Rightarrow \ 2Fe_2O_3.3H_2O$

  Oxidation - normally preceded by hydrolysis

- $CaCO_3 + \ H_2O + CO_2 \Rightarrow Ca(HCO_3)_2$

  Solution - dissolution

The Soil System- Pedosphere



Interface between geosphere, biosphere, atmosphere & hydrosphere

Engineer- all unconsolidated material

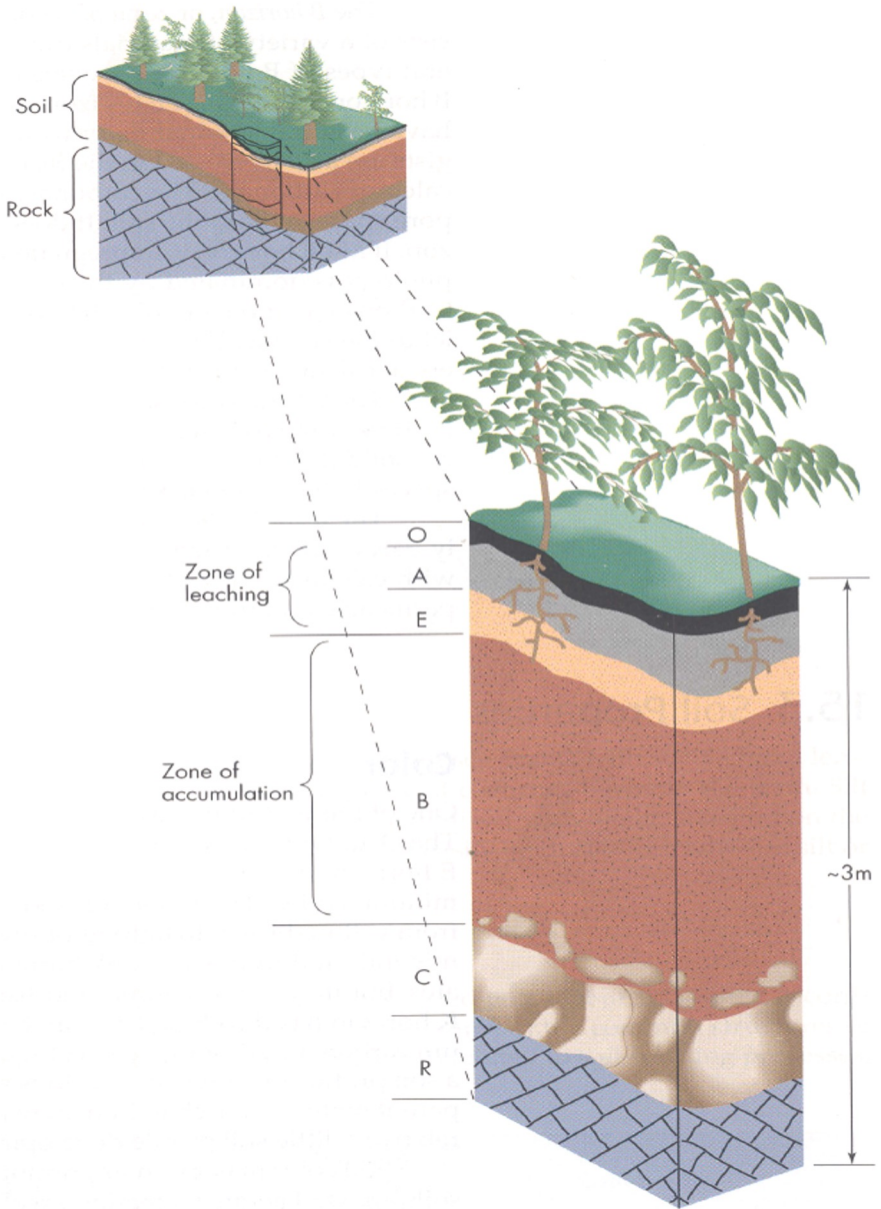
Agriculturist – material on which crops are grown

Geologist – physical substance covering bedrock

Soil scientist – differentiation into different horizons through a complex suit of processes

Mineral weathering
Organic matter transformation

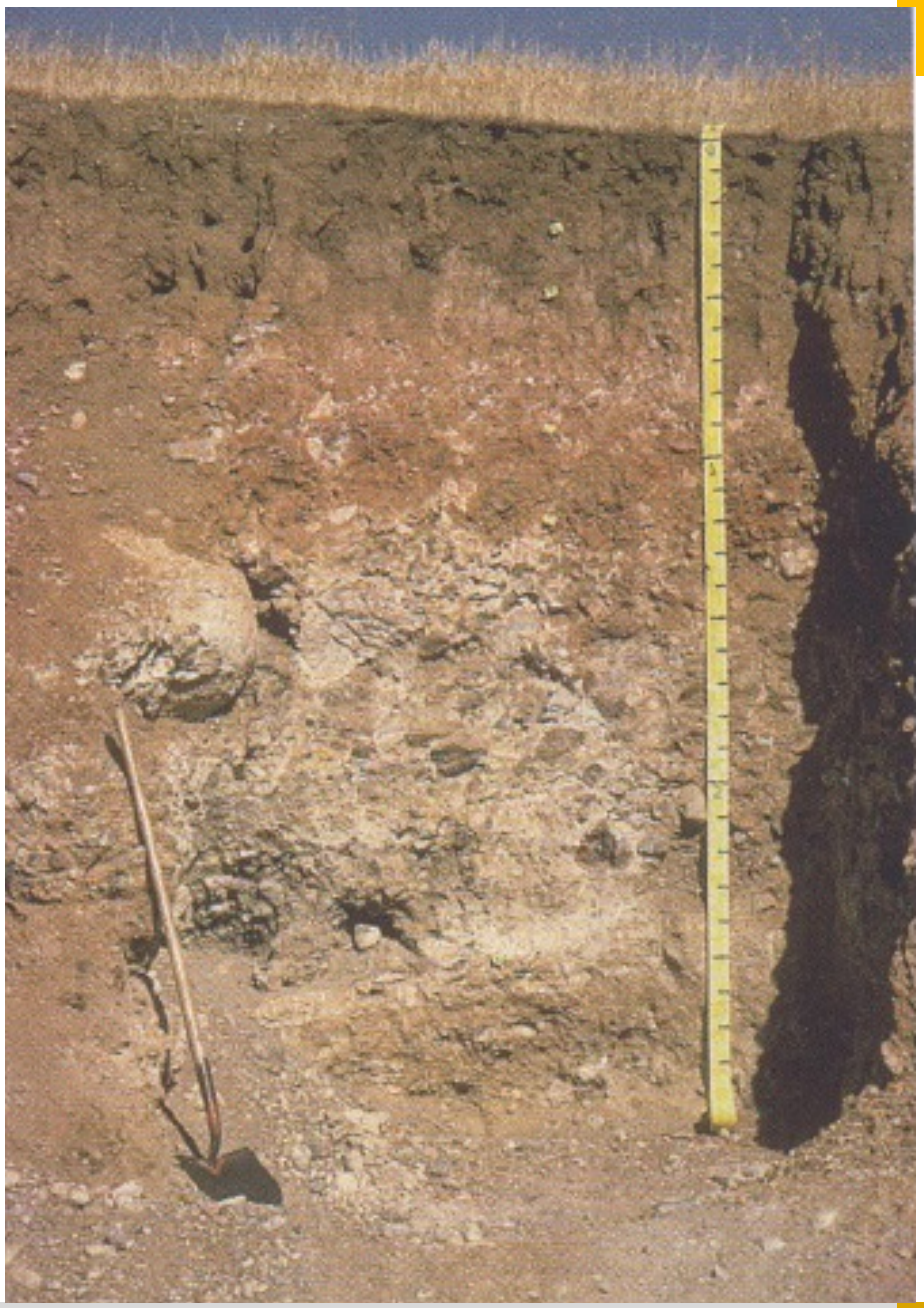
Soil profile



HORIZON	CHARACTERISTICS
O	Organic-rich, decomposed leaves etc.
A	Mineral and organic matter, leaching removes the clay, Fe and Ca to B horizon
E	Similar to A, less in organic matter
B	Rich in clay, Fe-oxides, silica, carbonates etc. leached from A horizon
C	Partially altered parent material
R	Unweathered parent material

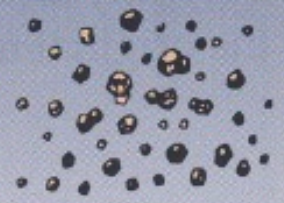
Soil Properties

- Color
  - Variable within the profile – indication of composition and processes
  - Indicates how well a soil drains – important for environmental problems
- Texture
  - Function of grain size distribution
  - Field estimation
  - Laboratory measurements



Soil Properties

- Structure
  - Peds – aggregates of soil particles
  - Shape and organization of peds results into soil structure
  - Indicative of soil-forming processes

Types of peds	Typical size range	Horizon usually found in
Granular 	1–10 mm	*A*
Blocky 	5–50 mm	B_t
Prismatic 	10–100 mm	B_t
Platy 	1–10 mm	*E*

Soils: Interaction of Earth Systems

Processes:

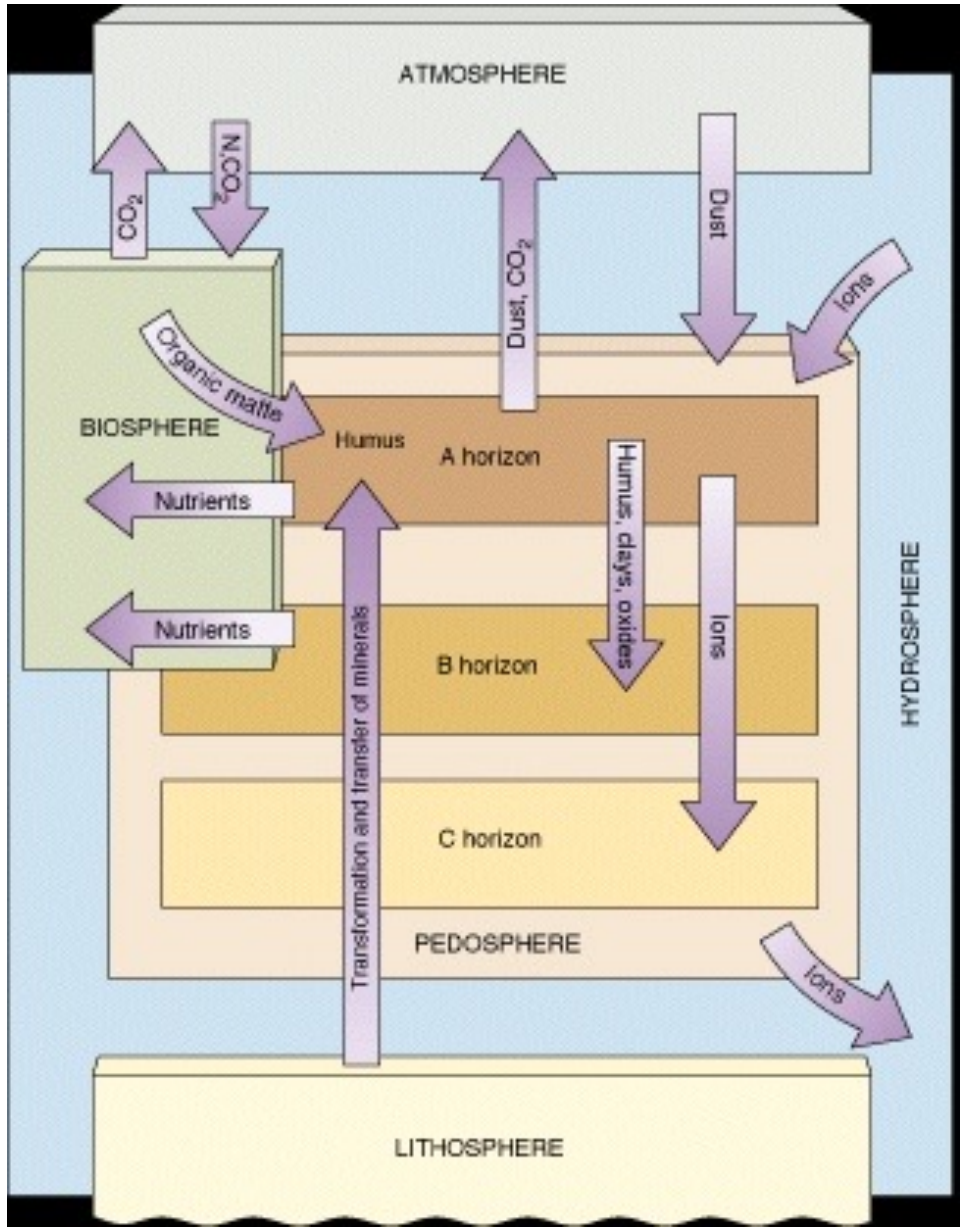
- Additions
- Chemical transformations
- Transfers
- Removals

Lithosphere:
Provides parent material

Hydrosphere:
Transfer of solid and dissolved substances
Removal of ions

Biosphere:
Adds organic matter
Chemical transformations (humus)

Atmosphere:
Adds ions and dust and CO_2, Nitrogen



Soil Processes and Types

Leaching and acidification: Downward movement in solution

Translocation: Downward movement of clays in suspension (Alfisols or Ultisols)

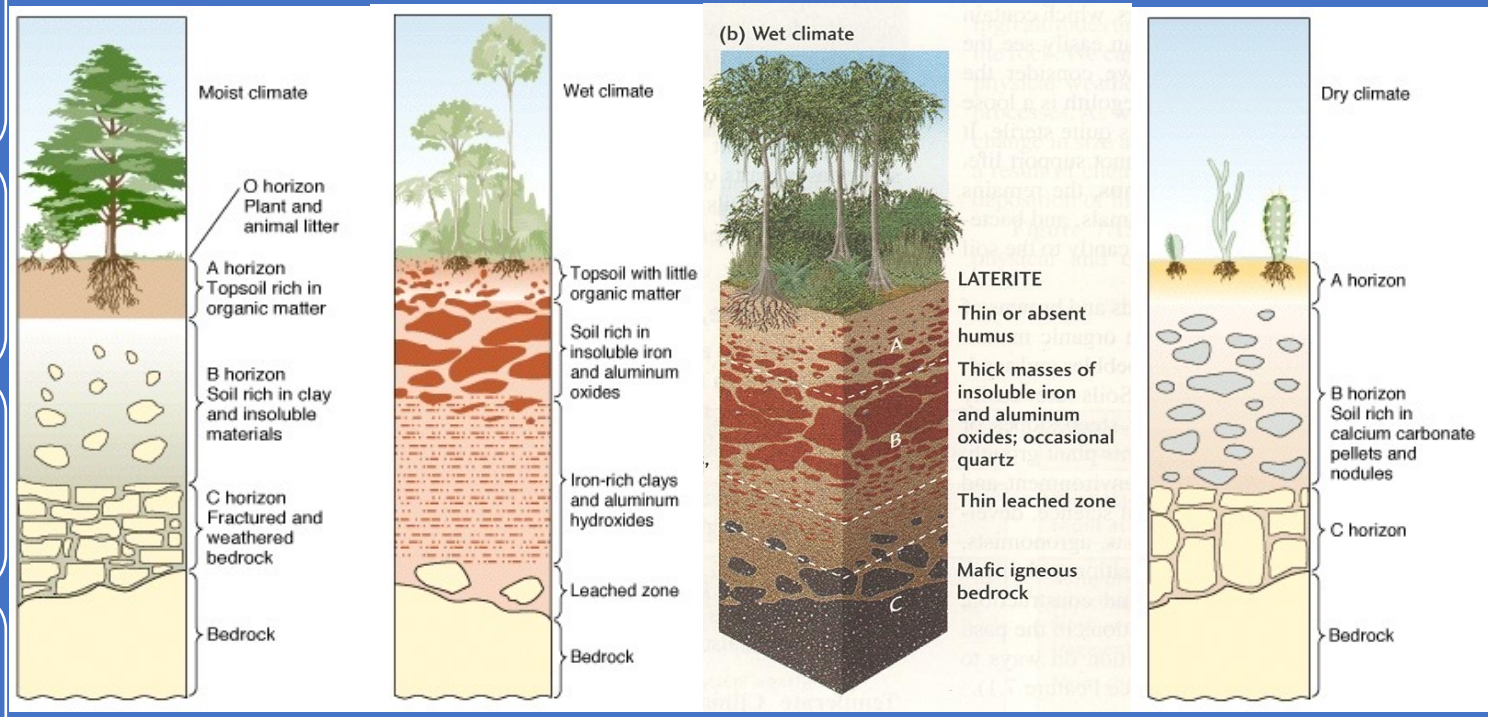
Podzolization: Intense leaching in acidic environment, mobilization in solution (Podosols)

Desilicification: Leaching of SiO_2 and alkali ions from 'A' horizon and accumulation as oxides and hydroxides (Oxisols, laterites)

Gleying: Mobilization of Fe in reducing environment (Gleyed soils)

Calcification: Evaporation and precipitation of carbonates through capillary action in arid regions (Caliche)

Alfisols **Podsols** **Oxisols** **Caliche**



Each of these soil types indicate specific process under different climatic settings – soils as a paleoclimate indicator.

Humans and Soils

- Soils take hundreds to thousands of years to form
- Human activities at a much faster rate
  - Soil erosion and loss of vegetation – agriculture, overgrazing, urbanization
  - Leaching of important nutrients by overuse
  - Build up of toxic elements – fertilizers, industrial wastes
- Impacts
  - Loss of soil cover – affects water resources
  - Loss of fertility – affects food production
  - Soil contamination – goes to food chain
  - Damage to soil ecosystem

Environmental problems and Soil Conservation Practices

- Soil erosion: a major global problem
  - Worldwide, 20 – 30 Gt/y soil eroded by fluvial soil erosion
  - India loses 5334 Mt/y (or 16.4 t/ha/y) of soil due to fluvial soil erosion
- Landuse planning
  - Land capability – a function of soil properties; determines land suitability for urbanization, timber management and agriculture
- Waste disposal problems:
  - Interaction between waste, water and soil
- Evaluation of natural hazards
  - Floods – delineation of floodplains
  - Landslides – relative age of soils – frequency of landslides
  - Earthquakes – age and frequency of earthquakes
- Soil as a paleoclimatic indicator
- Soil as an ecosystem

Soil erosion by water

- Rainsplash
- Sheet wash
- Rill and gully erosion

Headward gully erosion

Desertification

- Exposure and excessive stress dry out the soil
- Native plant species decline - less organic matter production
- Soil fertility reduced; soil hardens – positive feedback to drying
- Increased runoff, scouring, gullying and widespread erosion

- Classification
  - Moderate: 10-50% reduction in crop yield
  - Severe: > 50% reduction in crop yield
  - Very severe: > 90% reduction in crop yield; all vegetation gone

Agriculture

- Traditional agriculture involving plowing in straight lines or furrows – very damaging
- Contour plowing
  - Terracing
- Preservation of remnant woodland (wind barriers)
- Planting vegetation barriers along waterways
- Structures to trap water and sediments

Urbanization

- Soils scraped off and lost; sensitive soils removed and soil strength decreases
- Soils brought from other areas
- Draining of soils – causes desiccation
- Soil pollution due to addition of chemicals
- Filling of streams during construction phase and flooding
- Increased runoff due to urbanisation and flooding

Off Road Vehicles (ORV)

- Soil erosion
- Changes in hydrology
- Damage to plants & animals

Vehicle tracks


Mountain walks/biking


Recreation?

Soils: Take Home Points

- Soils form because of interaction of multiple factors including *climate*, *vegetation, relief and parent material over a time* span
- Specific soil processes such as leaching, gleying, translocation, podsolization, and calcification result in different types of soils.
- Typical soil formation rates : 0.02-0.11 mm/year
- In undisturbed natural system:
  - Soil formation = Soil erosion (steady state)
- Human activity: Rates of erosion = 18-100 x soil renewal
- Environmental impacts
  - Slopes and fields
  - Streams choked up and loss of aquatic life
  - Reduction of soil productivity, less agricultural yield, degraded soils