Sedimentary Geology

Sedimentology *vs*. Stratigraphy

- **Sedimentology** is the study of the origin and classification of sediments and sedimentary rocks
  - Mostly the physical and chemical properties, and the *processes* by which they formed
- **Stratigraphy** is the science of layered rocks
  - Mostly the interpretation of rock sequences, their age, and correlation
- The interpretation of **depositional environments** relies on both sedimentology and stratigraphy!

Applications

- The ultimate goal of stratigraphy and sedimentology is to develop a *deeper understanding of Earth history*, via:
  - Paleogeography
  - Paleoecology
  - Paleoclimatology
- Strat and Sed have practical applications in
  - Mineral extraction industries (oil & gas; mining)
  - Hydrogeology
  - Environmental geology

Chapter 1—Key points

- Know the main kinds of **chemical weathering** processes and what kinds of minerals are affected by each process (be able to give examples).
- Know the **by-products** of each subaerial weathering process.
- Know the **relative stability** of common minerals under weathering conditions
- What is the **significance** of weathering to stratigraphy and sedimentology?
- Be able to discuss the criteria by which **paleosols** can be recognized.

Weathering vs. Erosion & Landscape Stability

Weathering and soils

- Weathering is the **disintegration** (physical) and/or **decomposition** (chemical) of rocks
- The products of weathering are residual particles, secondary minerals, and dissolved compounds
- Weathering products are the source materials for sediments and soils

Physical weathering

- Physical weathering is the mechanical disintegration of rocks into smaller fragments or individual grains
  - **Frost wedging** (freeze/thaw cycles)
  - **Sheeting** (release of overburden pressure)
  - Break-up of rocks by **plant and animal activity**
- Physical weathering is relatively less important than chemical weathering, and it **operates in concert with chemical weathering**

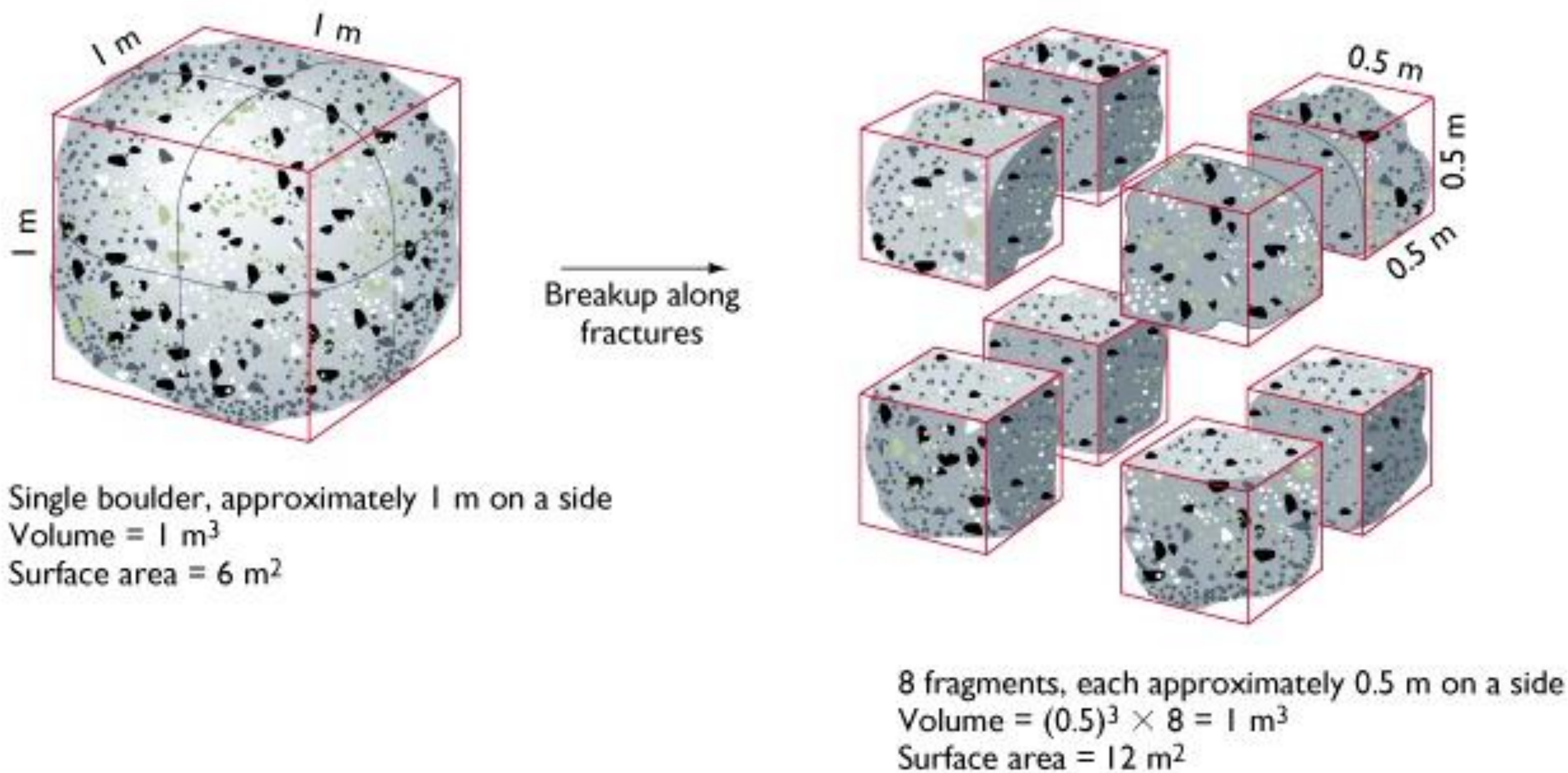
Physical weathering enhanced by natural joints in igneous rock

Physical weathering enhanced by tree roots

Physical weathering: **frost action**

Physical weathering:
exfoliation (sheeting)

Interaction of physical weathering and chemical weathering



Chemical weathering

- Chemical weathering is the decomposition of rocks by water and atmospheric gases dissolved in water (O_2, CO_2)
  - Minerals of the parent rock are dissolved and removed in solution
  - New, secondary minerals may form
  - The fabric of the parent rock is disrupted, leaving behind a residue of more resistant mineral grains and secondary minerals

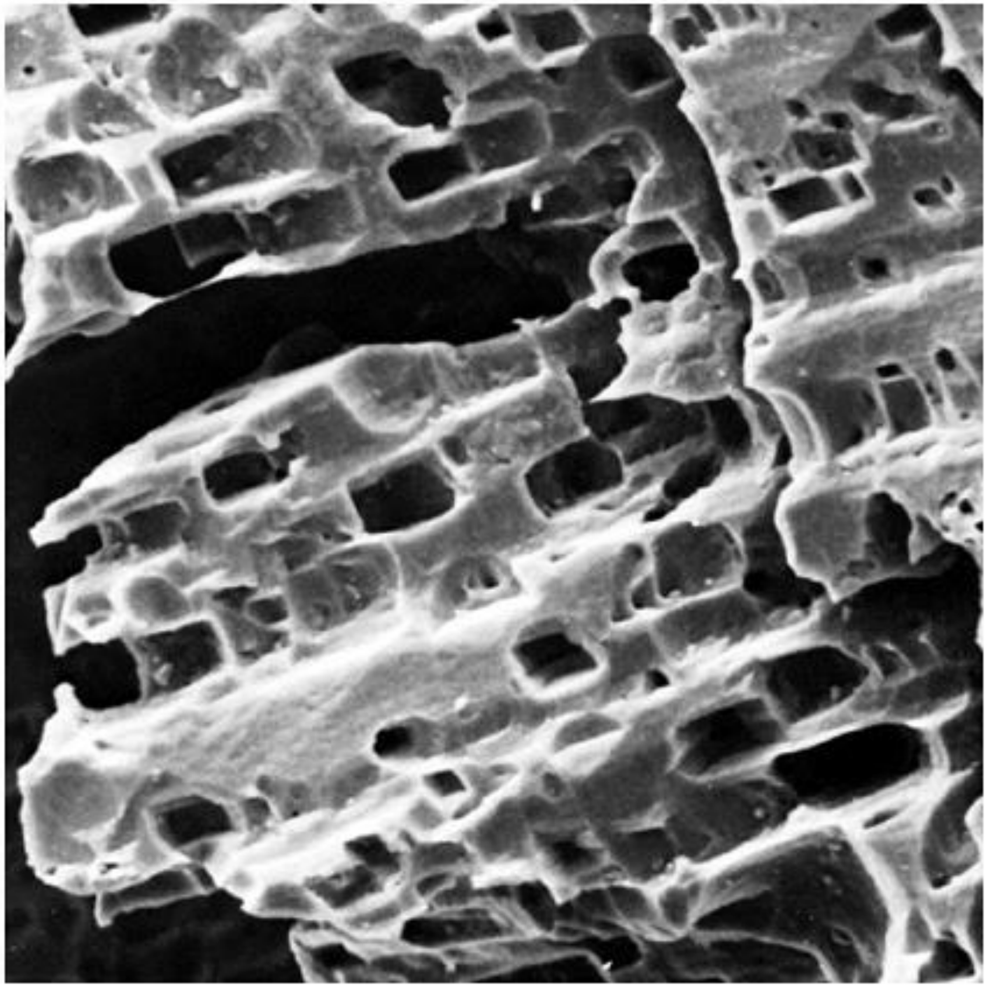
Chemical weathering (continued)

- The **<u>major</u>** types of chemical weathering are
  – Hydrolysis
  – Hydration
  – Oxidation
  – Solution

Hydrolysis

- **<u>Hydrolysis</u>** is the reaction between silicate minerals and acid (H^+) that leads to the breakdown of the minerals and the release of metal cations and silica
- Source of acids is CO_2 dissolved in water
  - $CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$
  - Acids also originate from plants
- Feldspars that undergo hydrolysis typically <u>produce secondary clay minerals</u>
  - Orthoclase (K) feldspar ➔ kaolinite or illite + silicic acid
  - Plagioclase (Na) feldspar ➔ kaolinite or smectite + silicic acid

SEM micrograph of feldspar etched by hydrolysis



Hydration

- **Hydration** is the process by which water is added to a mineral to form a new mineral

anhydrite + water ⇔ gypsum

$$CaSO_4 + 2H_2O \Leftrightarrow CaSO_4 \times 2H_2O$$

  - Hydration generally does not produce secondary products, but it does result in a volume increase, and therefore the potential for mechanical disintegration

Oxidation

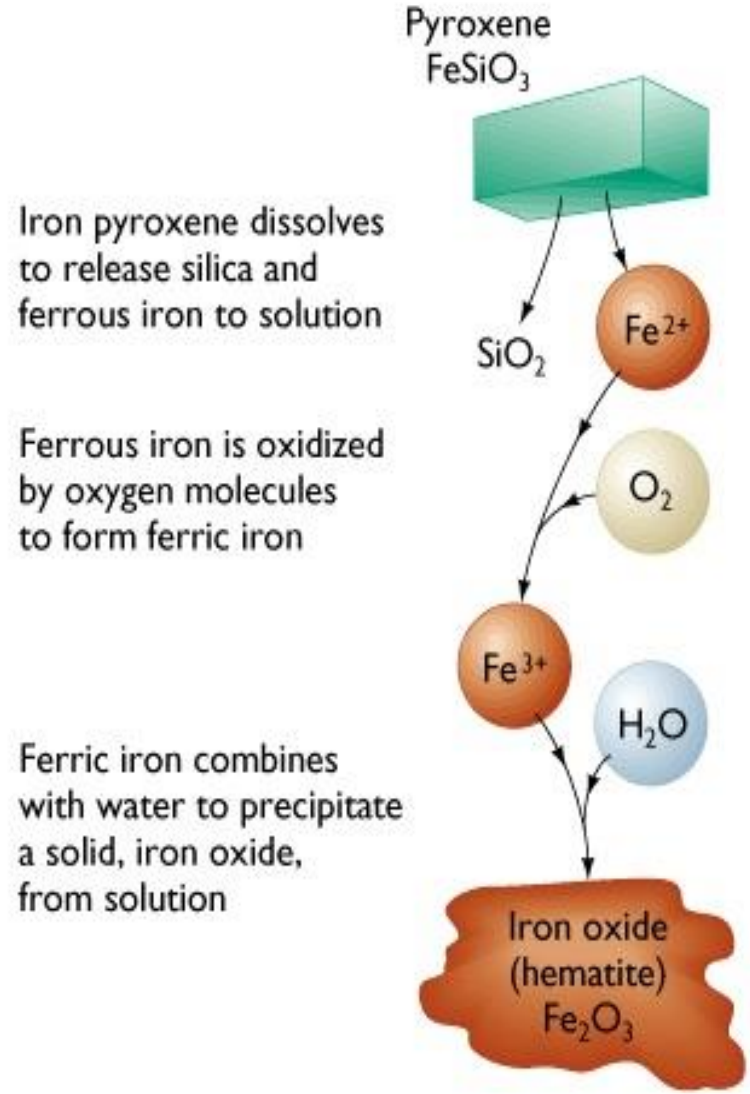
- **Oxidation** is the decomposition of iron- and manganese-bearing silicates by oxygen dissolved in water

$Fe^{2+} \rightarrow Fe^{3+} + e^-$, where the loss of the electron leads to the loss of other cations, such as Si^{4+}, in order to maintain electrical neutrality. This leads to collapse of the crystal lattice

$$4Fe^{2+}SiO_3 + O_2 \rightarrow 2Fe^{3+}{}_2O_3 + 4SiO_2$$

pyroxene hematite quartz

Oxidation



Pyroxene
$FeSiO_3$
Iron pyroxene dissolves to release silica and ferrous iron to solution
SiO_2
Fe^{2+}
Ferrous iron is oxidized by oxygen molecules to form ferric iron
O_2
Fe^{3+}
H_2O
Ferric iron combines with water to precipitate a solid, iron oxide, from solution
Iron oxide (hematite) Fe_2O_3

Solution

- **Simple solution** is the dissolution of soluble minerals upon contact with water
- Highly soluble minerals include
  - Evaporites (gypsum, halite)
  - Calcite
  - Dolomite

$$H_2O + CO_2 + CaCO_3 \rightarrow Ca^{2+} + 2HCO_3^-$$

calcite bicarbonate


Chemical weathering (continued)

- ***Rates*** of chemical weathering vary with climate and mineral composition and grain size of the parent rock
  - Chemical weathering is faster in wet climates
  - Chemical weathering rates increase with increasing temperature
  - Fine grained rocks of a given composition weather more slowly than their coarser grained equivalents

By-products of chemical weathering

Table 6.2 Stability of Common Minerals Under Weathering

Stability of Minerals	Rate of Weathering
Most stable	**Slowest**
Iron oxides (hematite)	
Aluminum hydroxides (gibbsite)	
Quartz	
Clay minerals	
Muscovite mica	
Potassium feldspar (orthoclase)	
Biotite mica	
Sodium-rich feldspar (albite)	
Amphiboles	
Pyroxene	
Calcium-rich feldspar (anorthite)	
Olivine	
Calcite	
Halite	
Least stable	**Fastest**

Chemical weathering (continued)

- Relative stability of sand- and silt-sized common minerals under weathering conditions (note relationship to Bowen's Reaction Series):

increasing stability ↓

Mafic minerals	**Felsic minerals**
olivine	
	Ca plagioclase
pyroxene	
	Ca-Na plagioclase
amphibole	Na-Ca plagioclase
	Na plagioclase
biotite	
	orthoclase, muscovite, quartz

Products of weathering

- New sedimentary particles:
  - Parent rock **residues**, composed of resistant minerals and rock fragments
  - **Secondary minerals**, largely the result of hydrolysis and oxidation
- Raw material for chemical sedimentary rocks:
  - **Soluble compounds**, largely the result of hydrolysis and simple solution
- *Until they are removed by erosion, particulate residues and secondary minerals remain* in situ *to form a* ***soil***

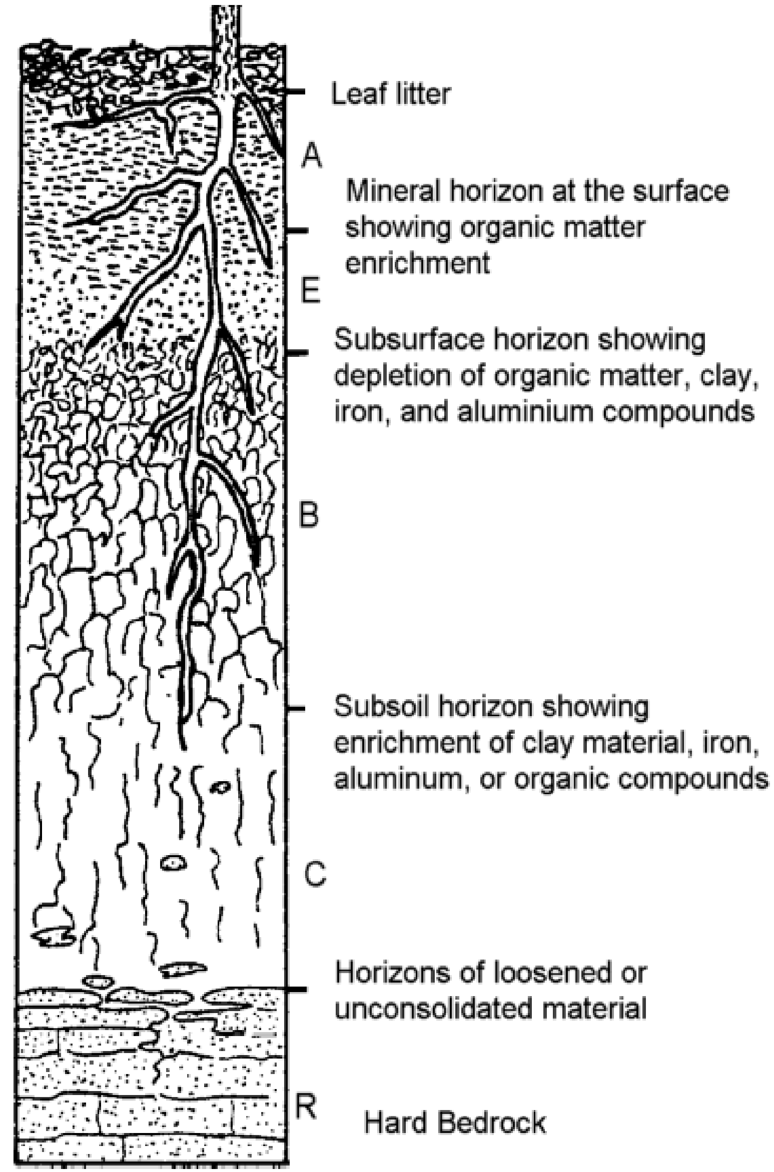
Products of weathering (continued)

- Weathering of **igneous and metamorphic** rocks produces immature soils rich in unstable minerals. As the soil matures, it retains only the more resistant minerals. Clays, iron oxides or hydroxides, and aluminum hydroxides are present as secondary minerals
- Weathering of **siliciclastic sedimentary** rocks produces soils that are depleted in unstable minerals (because the unstable minerals were eliminated in a previous weathering cycle)
- Weathering of **limestones** produces thin soils with insoluble silicates and iron-oxide residues

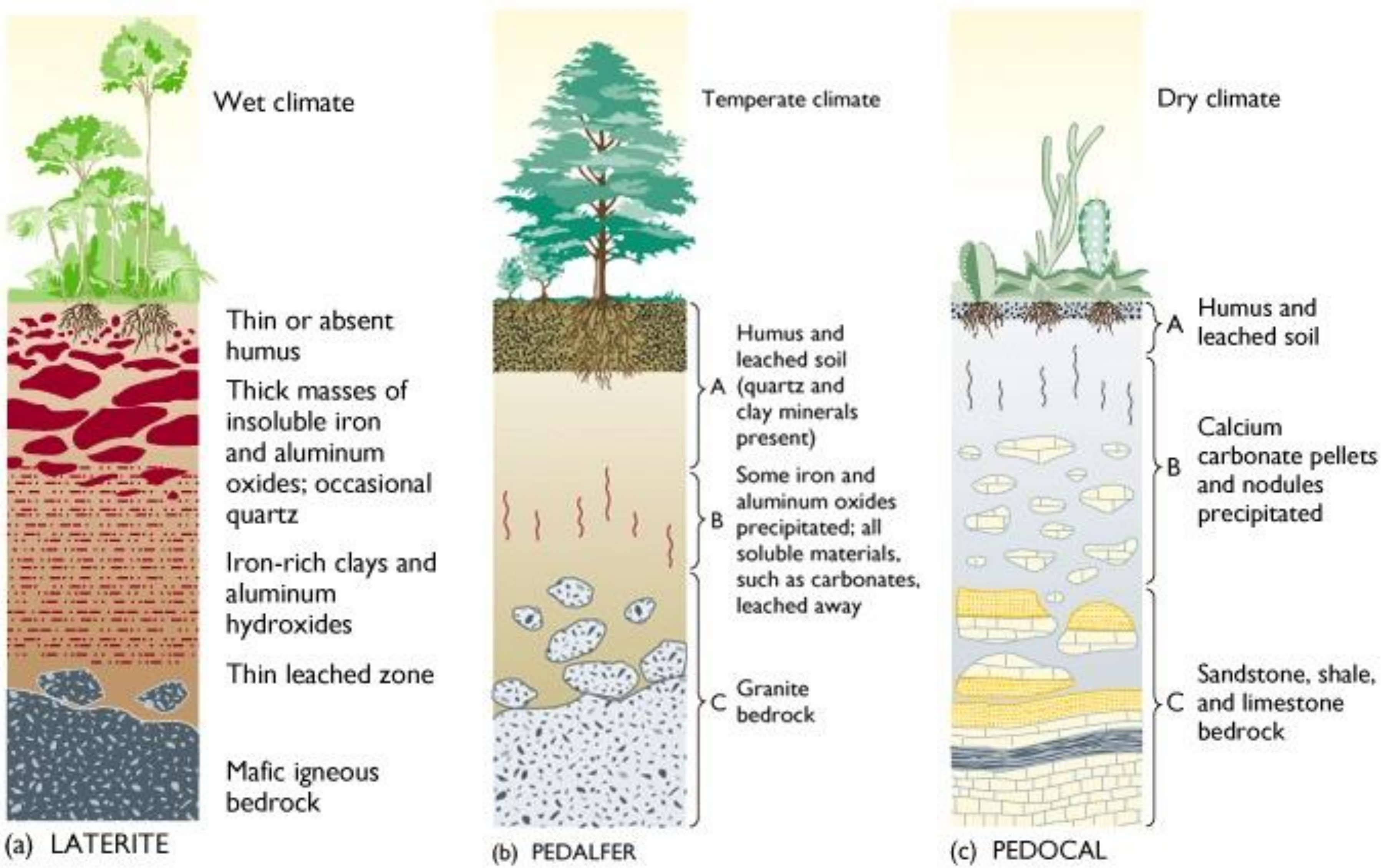
Soils

- Soil above bedrock is made up of:
  - Weathering by-products
    - Residual grains (chemically stable minerals)
    - Secondary minerals (clays, iron oxides, aluminum hydroxides)
  - Organic matter
- Soil type is determined by:
  - Bedrock lithology/Parent material
  - Climate

Generalized soil profile



Soils and climate



Paleosols

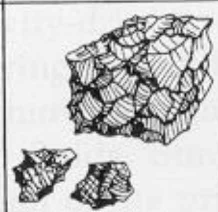
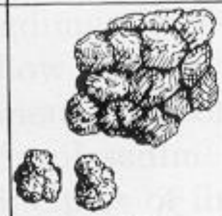
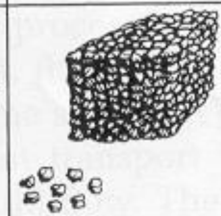
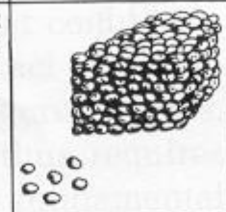
- Paleosols are <u>ancient</u> or <u>fossil soils</u> preserved in the stratigraphic record
- Paleosols generally occur beneath <u>unconformities</u>
- Paleosols provide good clues for the interpretation of <u>paleoenvironments and paleoclimates</u>

Paleosols

<u>Criteria for recognizing paleosols</u>:

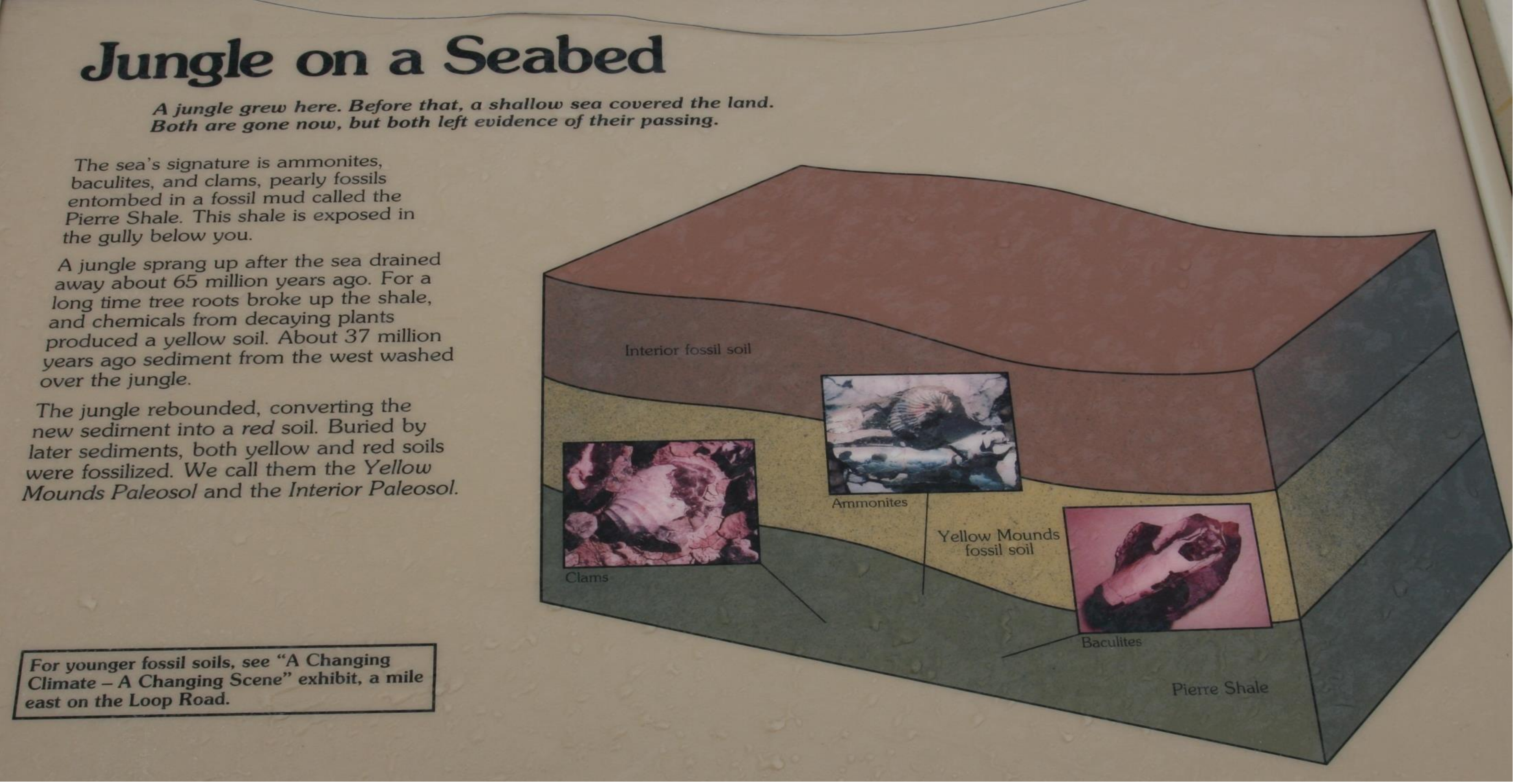
1. Presence of recognizable soil horizons
   - Organic upper horizon
   - Subhorizons exhibbing increasing clay and/or reddish color
   - Uppermost surface sharply truncated
   - Chemically different than parent material including gradational mineral content, with unstable minerals decreasing in abundance up-section
2. Presence of soil structures (e.g. peds)
3. Laterally extensive
4. Root traces, or other disruption of original sedimentary structures by organic activity

Soil structures: *peds*

TYPE	PLATY	PRISMATIC	COLUMNAR	ANGULAR BLOCKY	SUBANGULAR BLOCKY	GRANULAR	CRUMB
SKETCH							
DESCRIPTION	tabular and horizontal to land surface	elongate with flat top and vertical to land surface	elongate with domed top and vertical to surface	equant with sharp interlocking edges	equant with dull interlocking edges	spheroidal with slightly interlocking edges	rounded and spheroidal but not interlocking
USUAL HORIZON	E,Bs,K,C	Bt	Bn	Bt	Bt	A	A
MAIN LIKELY CAUSES	initial disruption of relict bedding; accretion of cementing material	swelling and shrinking on wetting and drying	as for prismatic, but with greater erosion by percolating water, and greater swelling of clay	cracking around roots and burrows; swelling and shrinking on wetting and drying	as for angular blocky, but with more erosion and deposition of material in cracks	active bioturbation and coating of soil with films of clay, sesquioxides and organic matter	as for granular; including fecal pellets and relict soil clasts
SIZE CLASS	very thin < 1 mm	very fine < 1 cm	very fine < 1 cm	very fine < 0.5 cm	very fine < 0.5 cm	very fine < 1 mm	very fine < 1 mm
	thin 1 to 2 mm	fine 1 to 2 cm	fine 1 to 2 cm	fine 0.5 to 1 cm	fine 0.5 to 1 cm	fine 1 to 2 mm	fine 1 to 2 mm
	medium 2 to 5 mm	medium 2 to 5 cm	medium 2 to 5 cm	medium 1 to 2 cm	medium 1 to 2 cm	medium 2 to 5 mm	medium 2 to 5 mm
	thick 5 to 10 mm	coarse 5 to 10 cm	coarse 5 to 10 cm	coarse 2 to 5 cm	coarse 2 to 5 cm	coarse 5 to 10 mm	not found
	very thick > 10 mm	very coarse > 10 cm	very coarse > 10 cm	very coarse > 5 cm	very coarse > 5 cm	very coarse > 10 mm	not found

Soil structures:
Root traces

Paleosols in Badlands


Jungle on a Seabed
A jungle grew here. Before that, a shallow sea covered the land. Both are gone now, but both left evidence of their passing.
The sea's signature is ammonites, baculites, and clams, pearly fossils entombed in a fossil mud called the Pierre Shale. This shale is exposed in the gully below you.
A jungle sprang up after the sea drained away about 65 million years ago. For a long time tree roots broke up the shale, and chemicals from decaying plants produced a yellow soil. About 37 million years ago sediment from the west washed over the jungle.
The jungle rebounded, converting the new sediment into a red soil. Buried by later sediments, both yellow and red soils were fossilized. We call them the Yellow Mounds Paleosol and the Interior Paleosol.
For younger fossil soils, see "A Changing Climate – A Changing Scene" exhibit, a mile east on the Loop Road.
Interior fossil soil
Ammonites
Yellow Mounds fossil soil
Clams
Baculites
Pierre Shale

Paleosol overlain by river channel deposit

Paleosol with root traces

Triassic paleosol with vertebrate animal burrow

Triassic paleosol with vertebrate animal burrow

Paleoclimates

- Clues to the reconstruction of ancient climates are preserved in sedimentary rocks and paleosols
  1. Sedimentary facies (climate-sensitive rock types)
  2. Fossil plants and animals

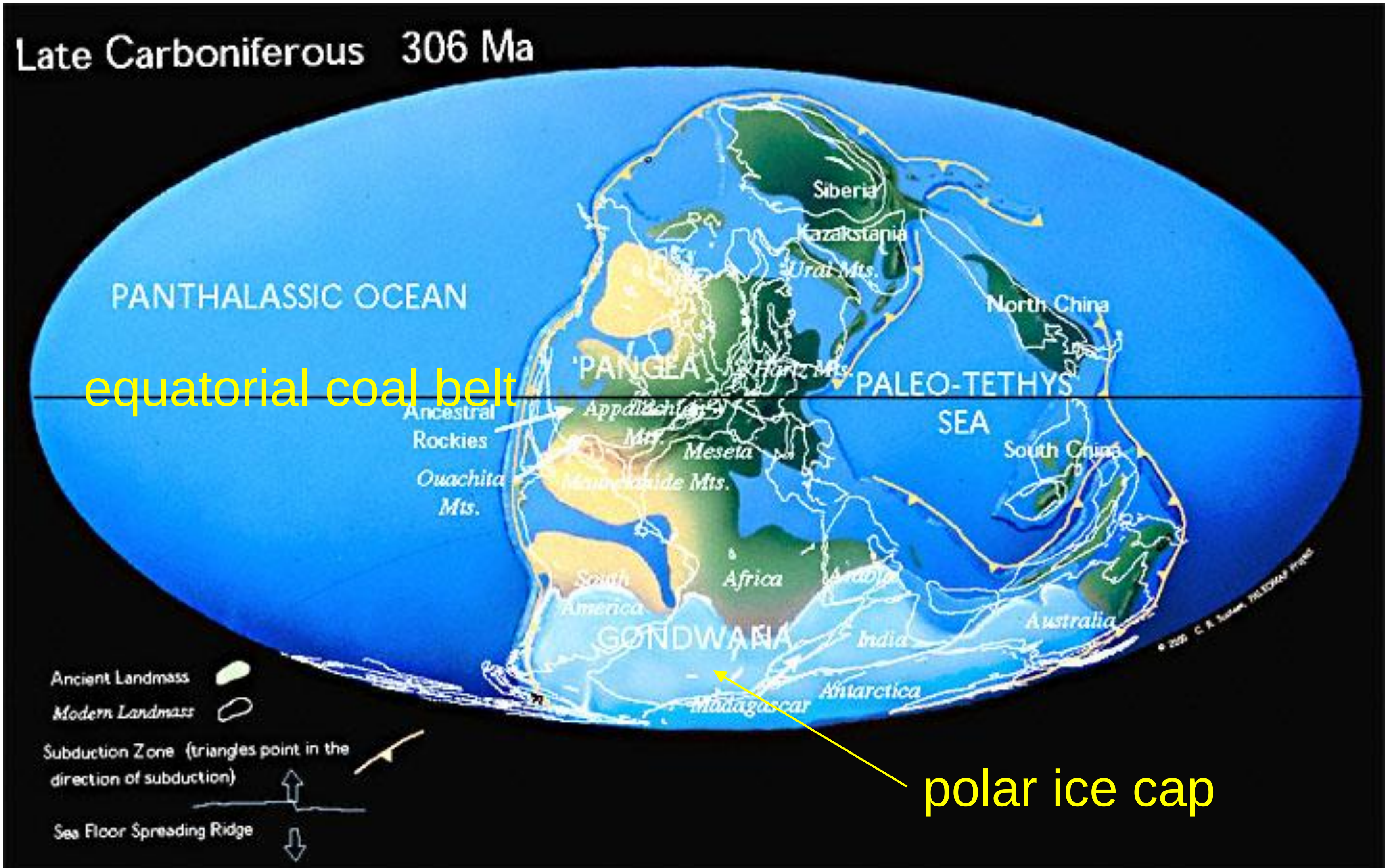
Climate-sensitive rock types

- Marine carbonates and reefs
  - Oxygen isotope ratios in carbonates can be used to infer paleotemperatures
- Evaporites
- Glacial deposits
- Coals
- Eolian deposits

Climate-sensitive biota

- Land plants
  - Tree rings
  - Pollen and spore assemblages
- Land animals
  - Reptiles, amphibians, mammals
  - Must use with analogy to nearest living relatives
- Marine invertebrates and protists
  - Must be able to recognize warm-water vs. cool-water assemblages of species

Pennsylvanian climate reconstruction



Permian climate reconstruction