Chapter 5: Weathering and soils

Monument Valley, Utah
weathering, erosion, and transportation

rocks on Earth’s surface are *constantly changed* by water, air, temperature changes and other factors

*weathering* is the group of destructive processes that change the physical and chemical character of rocks at or near Earth’s surface

*erosion* is physical collection of rock particles by water, ice, or wind

*transportation* is the movement of eroded particles by water, ice, or wind
rock cycle

weathering: slow and steady  erosion: may be more dramatic
weathering ->

results in both positive and negative effects

positive: generates soils

negative: causes deterioration of buildings
if you want to be remembered, what will you choose?
weathering is divided into two classes:

• mechanical weathering
  -- breaks rock into smaller pieces
  -- does not change chemical makeup
  -- causes physical disintegration only

• chemical weathering
  -- changes chemical composition of minerals/rocks
    (exposure to atmospheric gases)
    -- alters rocks that are unstable at Earth’s surface to more stable substances
    (new chemical compounds -- minerals -- form)

both go on continuously and usually together
mechanical weathering

more resistant sandstone cap rock

less resistant shale

Photo by David McGeary
chemical weathering

marble statue

loss of detail
weathering and Earth’s systems

atmosphere
  oxygen and carbon dioxide critical to chemical weathering
  water cycled through atmosphere essential to mechanical weathering

hydrosphere
  chemical weathering
    oxygen dissolved in water oxidizes iron in rocks
    carbon dioxide dissolved in water creates carbonic acid
  mechanical weathering
    running water loosens and abrades particles
weathering and Earth’s systems

cryosphere

*mechanical weathering*

- glacial ice removes and abrades particles
- freeze/thaw cycling breaks rocks apart

biosphere

*mechanical weathering*

- plant root growth widens cracks
- animal movement and human activity break rocks

*chemical weathering*

- decaying organic matter in soils yields acids
mechanical weathering: processes

frost action: mechanic effect of freezing (and expanding) water on rocks

- upper surface freezes first (contact with atmosphere)
- water below freezes later and cannot expand upward
- ice expands and fractures rock

where?

water expands about 9% when it freezes
pressure release: removal of mass of overlying rocks, allows for expansion of buried rock and fracturing

- mass presses down on buried rock
- removal releases pressure
- rock expands
classic example: Half-Dome in Yosemite National Park
plant growth: growing roots widen fractures

burrowing animals: activity breaks down rock
thermal cycling: large temperature variations fracture rocks from expansion and contraction

- different minerals will expand different amounts as $T$ increases (e.g. quartz expands much more than feldspar)

- important where days are hot and nights are cool

- water likely is necessary

*similar to frost action, but freezing is not required*
what happens during mechanical weathering?

*rock breaks down into smaller pieces...*

for a cube that is 1 m on each side...mechanical weathering breaks it down into smaller pieces, exposing more surfaces

**surface area to volume ratio increases**

(volume remains constant at 1 m³)
over time, can make rectangular pieces “spheroidal”

spheroidal weathering
granite that has undergone spheroidal weathering
chemical weathering: processes

oxidation: chemically active oxygen from atmosphere reacts with Fe and oxidizes (“rusts”) it

\[ 4 \text{Fe} + 3 \text{O}_2 = 2 \text{Fe}_2\text{O}_3 \]

Iron       Oxygen       Hematite

rust is very stable at the Earth’s surface; remember “Rust Never Sleeps...”
acid dissolution: atmospheric gas dissolved in water yields acid

- atmospheric carbon dioxide forms carbonic acid
- sulfur and fluorine from volcanic eruptions form sulfuric and hydrofluoric acid
- some minerals, e.g. calcite, will completely dissolve
- human activity from burning fossil fuels, mining, etc. can also produce acids in atmosphere -- "acid rain"

caves in limestone in Saudi Arabia etched by carbonic acid
acid leaching from mining
industrial pollution -- generating acid rain
what is acid rain?

**pH -- concentration of H⁺ ions**

\[ \text{pH} = - \log [\text{H}^+] \]

larger number is greater concentration - acid
Hydrogen ion concentration as pH from measurements made at the field laboratories, 1995

Sites not pictured:
AK01 5.1
AK03 5.1
PR20 5.2

National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu
Hydrogen ion concentration as pH from measurements made at the Central Analytical Laboratory, 2006

Sites not pictured:
- AK01 5.2
- AK03 5.3
- PR20 4.9
- VI01 4.8

National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu
alteration of feldspars: feldspars easily broken down by acidic rain water

- feldspars are most common minerals in crust
- alteration of feldspars forms clay minerals
- K, Na, Ca ions released into water
- SiO₂ also released into water and carried away

pathway on right is for calcite -- calcite dissolves completely --
what happens to feldspars as they alter?

Water molecule
($H_2O$)

Clay mineral

water is added to crystal structure of feldspar to yield clay
carbonic acid essential for weathering (carbon cycle)

- Carbon dioxide in atmosphere combines with water to make carbonic acid.
- Carbonic acid weathers rocks.
- Limestone (calcium carbonate) forms in bodies of water.
- Plate tectonics returns limestone to deeper in Earth.
- Volcanic eruptions send carbon dioxide back to atmosphere.
an example of both mechanical and chemical weathering

crystals growing in cracks put pressure on walls

example is Cleopatra’s Needle
...survived Egypt for > 3,000 years
...removed for transport to New York City
...stored at site where salty groundwater penetrated column
another famous example: Mesa Verde, Colorado

process builds ledges that cliff dwellers preferred for habitation

**Mesa Verde Geologic Setting**

The bedrock geology is largely sandstone. Water falling on the plateau surface percolates downward to a perched water table above a less permeable bed. Where the water table intersects the canyon wall, water slowly seeps onto the rock surface and evaporates in the semiarid climate. Dissolved minerals in the seeping groundwater crystallize as the water evaporates and these crystals pry the rock grains apart. The notches are excavated, grain by grain, over geologic time.

Mesa Verde is but one of many canyons in the Colorado Plateaus region that exhibits these features. Other cliff dweller sites include Walnut Creek Canyon and Montezuma's Castle in Arizona.
weathering does not occur at same rate everywhere

factors:

**climate:** heat, humidity increase chemical weathering
...warmer water, increased plant growth...

**living organisms:** surface exposure increases from breakdown
...average earthworm colony brings 7-18 tons
of soil per acre to surface each year

**time:** rock must be exposed; if not, more time required

**mineral composition:** stability of minerals at Earth’s surface
...minerals formed at high temperatures/pressures
are not stable at Earth’s surface
  e.g. olivine, pyroxene
soils

sedimentary rocks
what happens to rock after it weathers?

chemical and mechanical weathering of sediment and bedrock (pre-existing hard, rock)
breaks rock into regolith (fragmented rock)

upper few meters of regolith is soil
soil – a layer of weathered, unconsolidated material on top of bedrock contains:

- clay minerals
- quartz
- water
- organic material
idealized soil profile

not all horizons will be present everywhere

O Organic matter

A Organic matter mixed with mineral material

B Accumulation of clay minerals, Fe oxides, and calcite "leached" from above

C Fragments mechanically weathered from bedrock and some partially decomposed

E Leaching by downward-percolating water

*downward motion of water*
O: (organic horizon) uppermost portion of soil
  plant matter; 2 trillion bacteria, 400 million fungi,
  50 million algae, thousands of insects in kilogram

A: inorganic mixed with organic derived from O horizon)
  thickness depends on amount of decomposed vegetation
  ...in tropical regions may be thick...

E: light-colored with little or no organic material
  color from dissolution and removal of Fe and Al

B: variety of types: depends on organic and oxide content
  where dissolved materials from upper levels collect
example of a soil profile
influences on soil formation

- parent material
- climate
- topography
- vegetation
- time
**parent material:** bedrock from which soil develops

minerals in parent material determine:

- *nutrient richness of soil*
- *amount of soil produced*

**differences in soils among Indonesian islands reflect parent materials**

**Java:** parent materials are volcanic ashes
--nutrient rich, thick soils
...population density is 460/square km

**Borneo:** parent materials are granites, gabbros, and andesites
--soils depleted of nutrients (lack of fresh ash)
...population density is 2/square km
climate: controls precipitation/chemical weathering

moderately wet climates:
- more chemical weathering and thicker soils
- significant clay-rich layers -- may be solid enough to form hardpan

arid climates:
- less chemical weathering and thinner soils
- subsurface evaporation leads to build-up of salts
- calcite-rich accumulation zones may form -- solid enough for hardpan

extremely wet climates (tropical rain forests):
- highly leached and unproductive soils -- laterites
- most nutrients come from thick O/A horizons
hardpan (hard surface) forms at depth where annual rainfall penetrates

arid climate:
calcite horizon forms “caliche”

moderately wet climate:
clay that hardens

“soil” is now “rock” hard
spectacular example of caliche formation in Kansas
laterite: unproductive, tropical soils contain lots of \( \text{Fe}_2\text{O}_3 \) and \( \text{Al}_2\text{O}_3 \) -- what remains after rest is leached away

paradoxical? wet, yet not productive?

very red; very oxidized (rusted)

homogenized
topography: differences in elevation

- relief (elevation change -- valley bottoms to hill tops)
- steepness of slopes

think about what water does...

water flows quickly down steep slopes -- little soil formation

water accumulates in low-lying areas -- high soil formation
vegetation: source of organic matter in soil

- produces oxygen and carbon dioxide -- chemical weathering
- yields H⁺ for ion exchange in feldspars/clays that gives plants Ca, Na, K

time: dependent on other factors per se

- warm, moist climate -- soils develop quickly
- arid, dry climate -- soils form very slowly

thicker soil is not necessarily older
soil classification

• *residual soil* – “what is left” -- weathering of bedrock

• *transported soil* – soil from “elsewhere”
  - flood plain deposits (soils) from rivers.
  - wind-transported deposits (soils) are called *loess*

• *soil composition*
  - parent rock is deciding factor
  - chemical weathering through time determines composition

• *soil thickness*
  - time increases soil thickness
  - wet climate increases soil thickness
  - low slopes also increase thickness
US Soil map

soft & organic rich
gray-brown & moist

Mollisols
Alfisols
Entisols
Inceptisols
Aridisols
Vertisols
Ultisols
Histosols
Spodosols
Andisols

strongly weathered & clay rich
paleosols: “paleo” -- old; “sols” -- soils

formed in the past and preserved in rock record
--implies that rocks formed on surface in the past--

tells us when paleosol was exposed at Earth’s surface