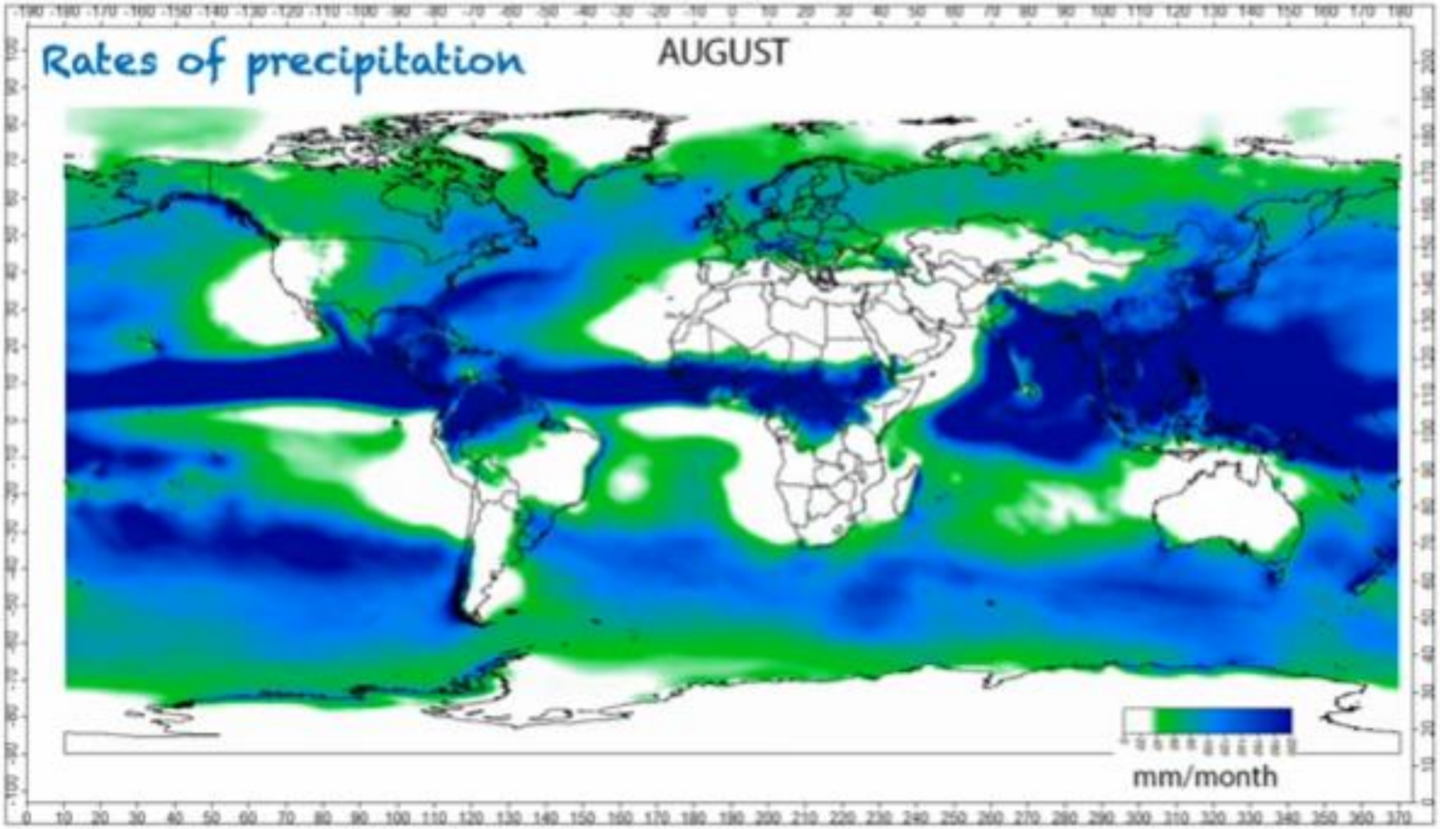
Geoinformatics in Desert Geotechnology

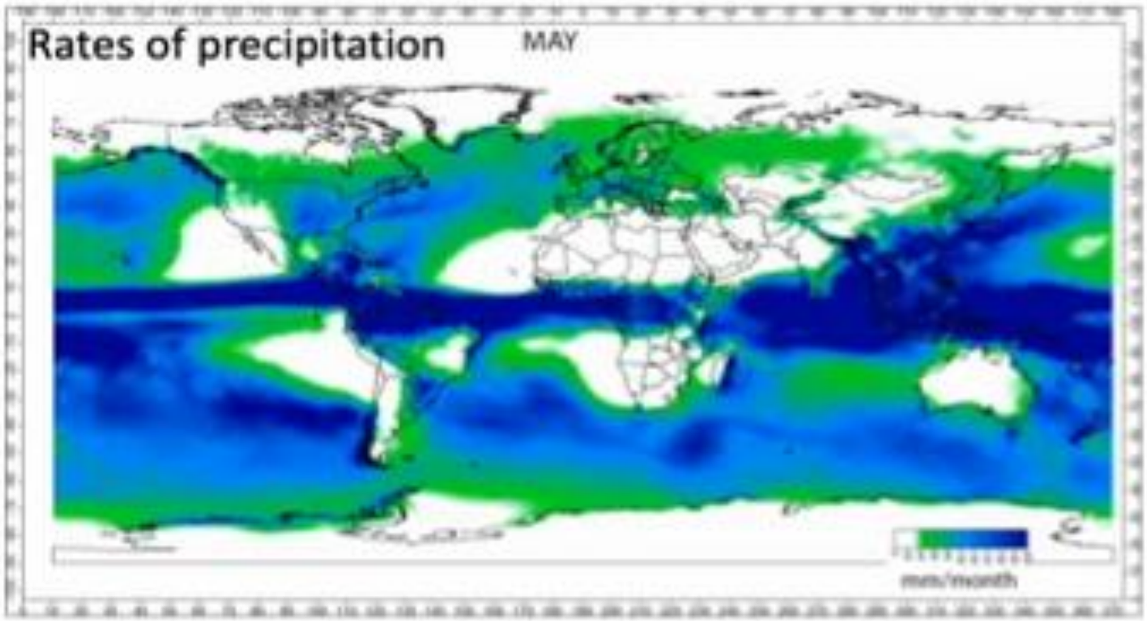
Definition and distribution of Desert:

- Desert are areas of aridity and they are usually defined scientifically in terms of some measure of water shortage. Such measures, indices of aridity, are commonly based on the relation between water gained from precipitation and water lost by evaporation or transpiration.
- A **desert** is a landscape or region of land that is very dry because of low rainfall amounts (precipitation), often has little coverage by plants, and in which streams dry up unless they are supplied by water from outside areas.
- Deserts generally receive less than 250 mm of rain each year. ***Semideserts or steppes*** are regions which receive the rain fall between 250 mm and 400 to 500 mm.
- There are five major regions of aridity: North and South America, North-Africa-Eurasia, Southern Africa and Australia. They cover a third of the Earth's land surface

What are deserts? → Areas in which: potential rates of evaporation >>> rates of precipitation

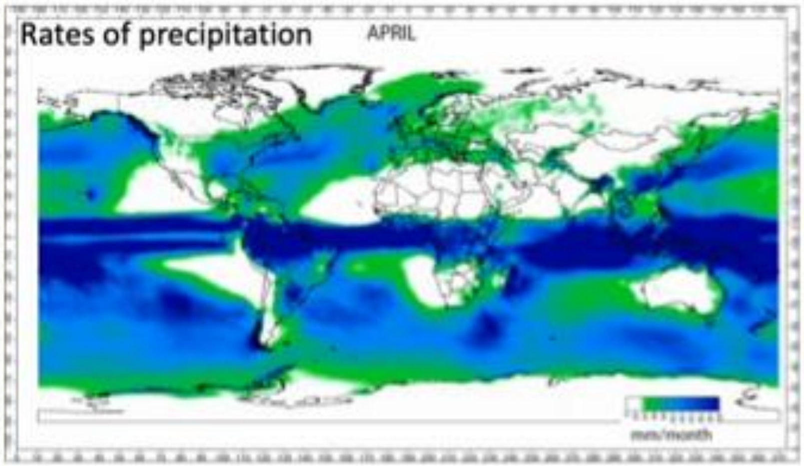


Where do deserts form?

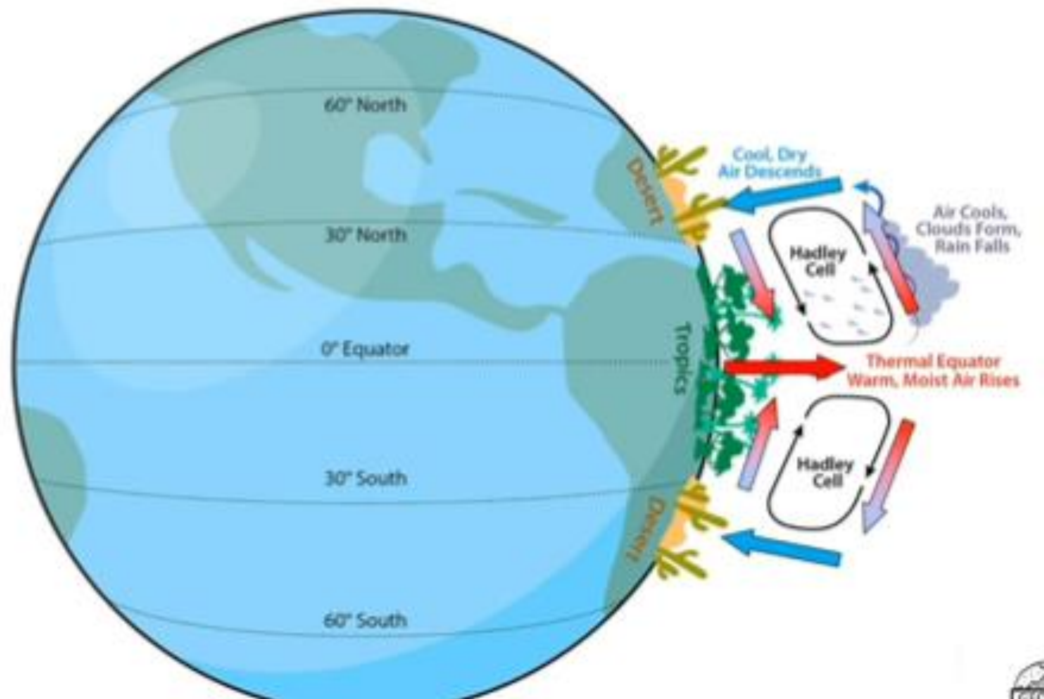


Where do deserts form?

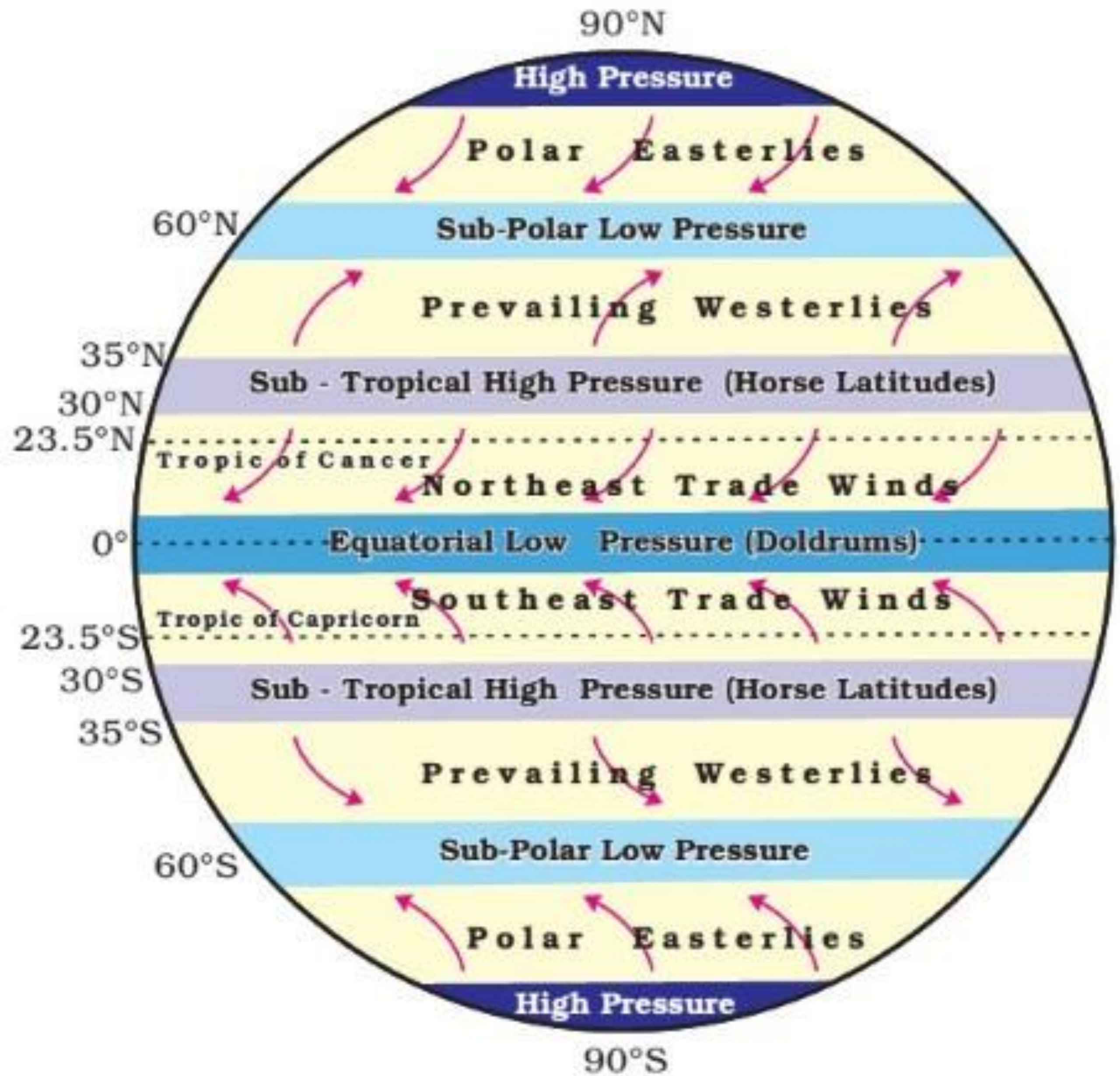
- Around 30° North and South of the Equator;
- Interior of continents;
- Rain shadows of large mountain belts.



WHY IS THAT?



https://askabiologist.asu.edu/explore/desert



Major Pressure Belts and Wind System

Distribution of Desert:
There are five major regions of aridity; the deserts of North and South America, North-Africa-Eurasia, Southern Africa and Australia. They cover a third of the Earth's land surface

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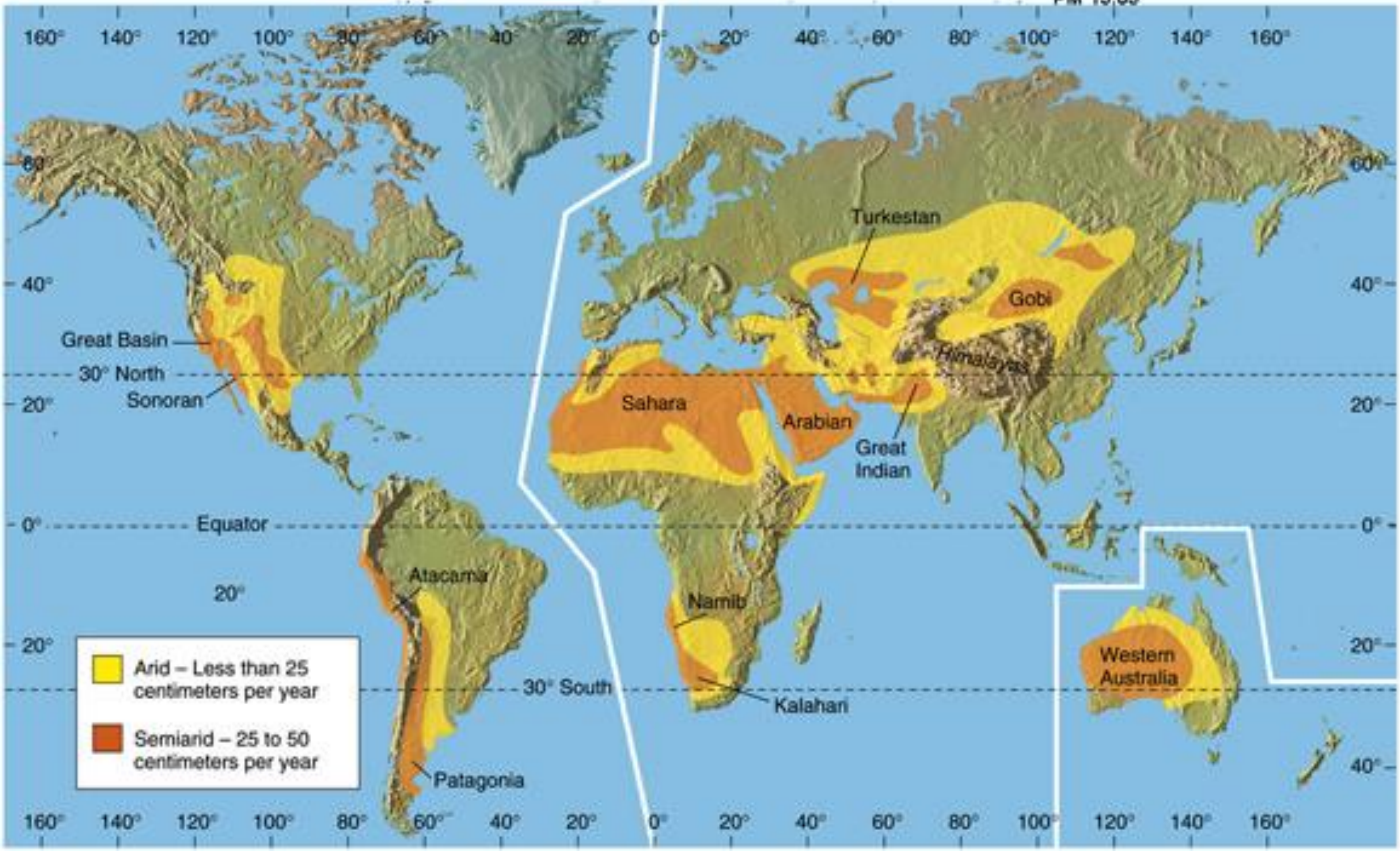
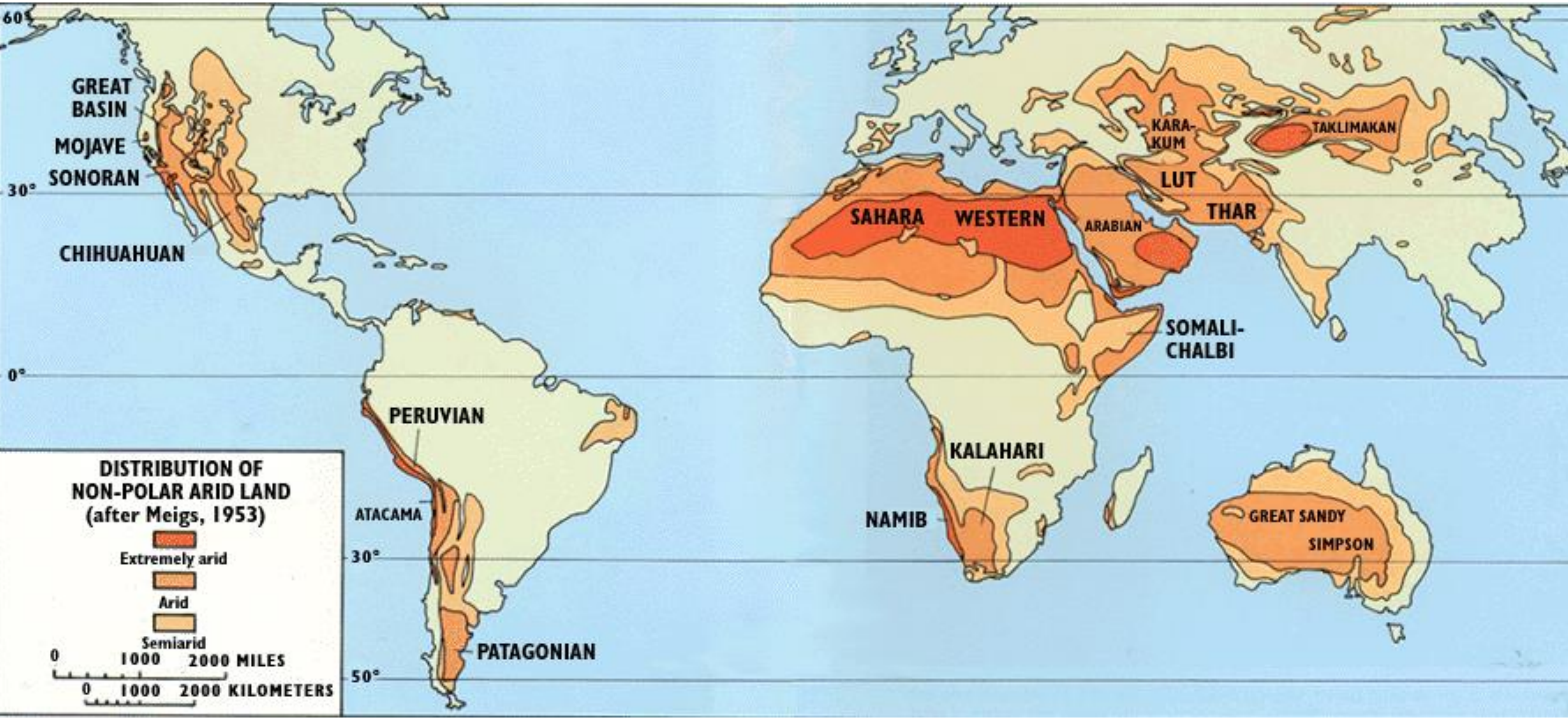
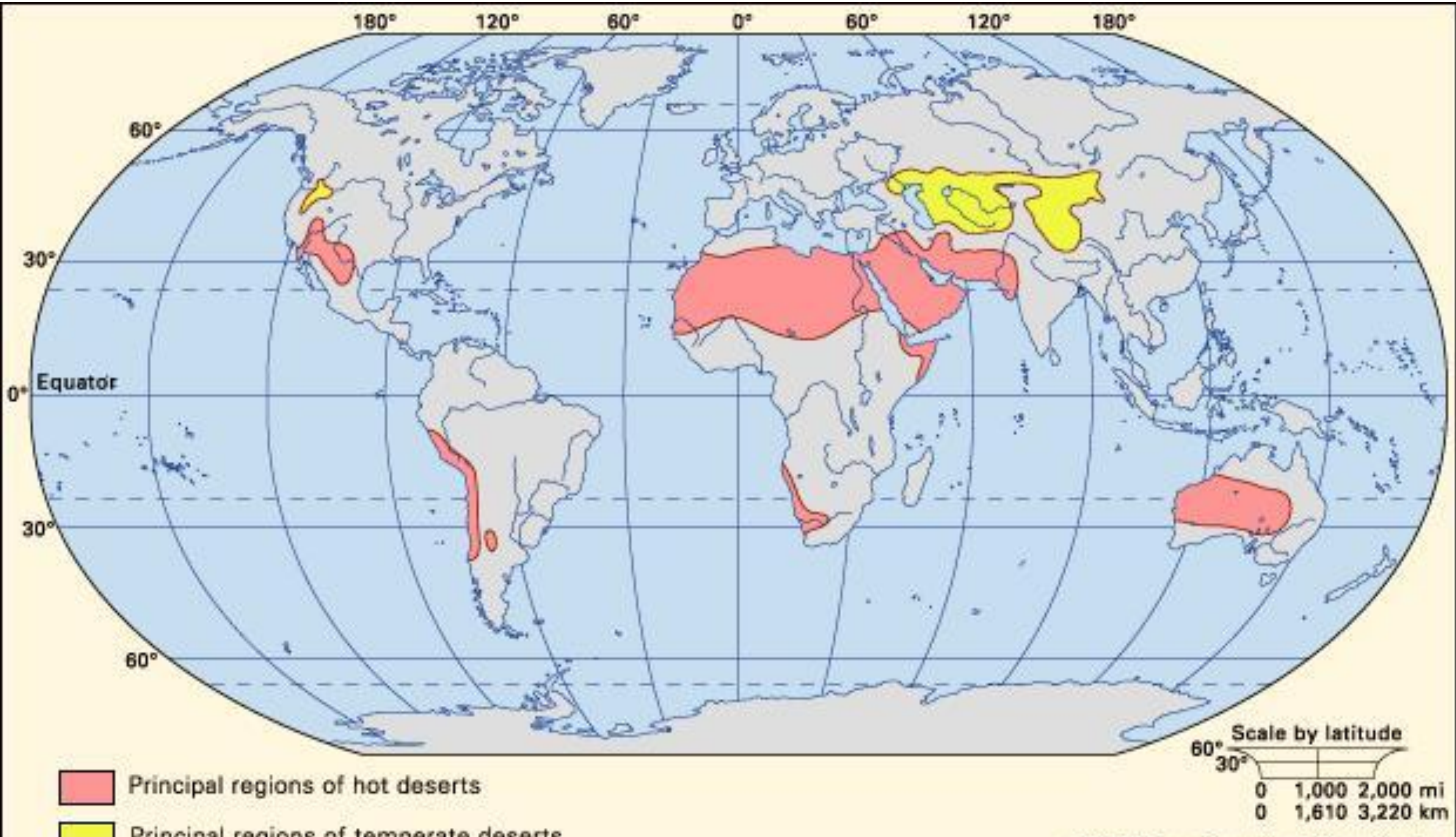


Turkestan
Gobi
Himalayas
Great Basin
30° North
Sonoran
Sahara
Arabian
Great Indian
Equator
Atacama
Namib
Kalahari
30° South
Patagonia
Western Australia
Arid – Less than 25 centimeters per year
Semiarid – 25 to 50 centimeters per year


60°
GREAT BASIN
MOJAVE
SONORAN
30°
CHIHUAHUAN
0°
PERUVIAN
ATACAMA
30°
PATAGONIAN
50°
SAHARA
WESTERN
ARABIAN
KARA-KUM
LUT
THAR
TAKLIMAKAN
SOMALI-CHALBI
KALAHARI
NAMIB
GREAT SANDY
SIMPSON
DISTRIBUTION OF NON-POLAR ARID LAND (after Meigs, 1953)
Extremely arid
Arid
Semiarid
0 1000 2000 MILES
0 1000 2000 KILOMETERS


180°
120°
60°
0°
60°
120°
180°
60°
30°
0°
Equator
30°
60°
Principal regions of hot deserts
Principal regions of temperate deserts
Scale by latitude
60°
30°
0 1,000 2,000 mi
0 1,610 3,220 km

Causes of Aridity

1. **Atmospheric high pressure zones (Hadley Cells)**

- Earth's atmosphere moves somewhat predictable patterns that are largely driven by the sun's rays and the earth's rotation.
- At the Equator, the sun's rays are perpendicular with the Earth's surface and solar heating is intense.
- Air is heated at the equator, rises, and is replaced by inrushing air.
- As the heated air moves upward, it is gradually cooled.
- Cool air, with a lower saturation point, is capable of holding less moisture within than warm air.
- As the air cools, it releases the excess moisture it contains, helping to produce the moist tropics.

Causes of Aridity

- As the air rises, it cools and the water condenses and precipitation occurs. Water returns to the surface as rain.
- After, dry air rises and moves away from the equator.
- At about 30 degree latitudes in both hemispheres (north and south), the air descends, as it does, it warms.
- As it warms, the air expands, condensation and precipitation are infrequent. (Horse latitudes).
- To the north and south of these desert latitudes, the air once again ascends, producing moisture for the land; finally, over the poles, the air descends again.
-
- Desert formation in these particular latitudes is primarily due to complex global air-circulation patterns caused by the rotation of the earth on its axis.

2. **Continentality or (Distance from oceans)**

- Most water in atmosphere is evaporated from the sea, and this water eventually precipitates on land.
- Land closer to the sea generally receives much of this moisture.
- As air moves inland, it gets depleted of moisture and precipitation drops.
- Areas lying deep within a continent may become desert simply because air currents reaching them have already traversed vast land distances; by the time they arrive over the deserts, these currents have already lost the moisture they once carried.
- This is true of some of the Asian deserts., the Gobi and Takla-Makan Deserts.
- Distance from oceanic moisture sources; and cold ocean currents – are instrumental, sometimes singly, more often in combination, as primary forces producing arid lands.

Causes of Aridity

Coastal Cooling: Deserts may result if air is cooled, and then rewarmed, prior to reaching the region.

a. Cool air holds less moisture than warm air.

b. When warm, moist air is cooled, excess water condenses and falls as precipitation. If it is subsequently re-warmed, it will be drier than it was previously.

1. Air at 30 C (86 F) can hold 30.4 grams of water per cubic meter (m3).
2. If saturated air (100% relative humidity) was cooled from 30 C to 10 C (50 F), 21 grams of water would condense and precipitate because this cold can only hold 9.4 grams of water per cubic meter.
3. If the air were then re-warmed to 30 C, it would have just a fraction (31%) of the moisture it did originally.

Causes of Aridity

4. (31% relative humidity is fairly dry, and further precipitation is unlikely).

5. Winds that blow onshore tend to do so across cold currents produced by movement of water from high latitudes (poles) to low latitudes (equator), and associated with the upwelling of cold waters from the ocean's depth.

6. Cold or cool winds have relatively small moisture-bearing capacity and, when warmed during their passage over the land, they become stable and, thereby, reinforce the stability produced by the global stability of these latitudes. (Subtropical highs).

c. This occurs along coastal areas where there are cold coastal seas (Baja, CA), and in rain shadows (adiabatic heating and cooling).

d. Air moving across the frigid currents is cooled to a low temperature; thus the air holds little moisture when it arrives over land, where it may provide fog or mist, but rarely rain. (Namib and Atacama).

Causes of Aridity

4. **Rain shadow effects**

a. Moisture-laden air encounters a mountain mass and is moved upward.

b. The ascending air is cooled and releases moisture on the windward side of the range.

c. Once over the summit, the air descends the lee side of the range, warming as it does so, and hence increasing its evaporative power.

d. The windward side of a range may support a heavy well-watered forest, while the leeward side and the area far below it, robbed of moisture, is occupied by a desert or steppe plant community.

The rain-shadow effect produced by great mountains can create arid areas in the lee of the mountains even when continentality is not particularly marked, such as in Patagonia where the Western Ghats and the Andes intercede. Rain shadows include adiabatic heating and cooling.

Sahara Desert

1. The Arabic ***sahra***, means “wilderness”, and Arabic speakers apply it to the barren emptiness of the world’s largest desert, also known as the ”Great Desert”.

2. It occupies more than 3.5 million square miles (9.1 sq. kilometers) in North Africa, not far short of the area of the United States (3.7 million sq miles/9.5 million sq. kilometers).

3. The Sahara is bounded:

a. in the west by the Atlantic Ocean

b. in the north by the Atlas Mtns. and the Mediterranean Sea

c. in the east by the Red Sea

d. in the south partly by the Niger River, and eventually the desert gives way to the semiarid lands known as the Sahel.

Sahara Desert

4. Much of the Sahara is a plateau with an elevation varying between 1300-1600′ (395-490m) above sea level. Altho parts of the desert lie below sea level, and the tallest mountains in the Sahara, Mount Touside of the Tibesti Mountains, an extinct volcano, rises to 10,712′ (3,265m).

5. At various times what is now desert lay beneath ancient seas. This led to a deposition of sand and calcareous deposits that now form sandstone and limestone.

6. Sahara is a hot desert, with summer daytime temperatures exceeding 90F for 8 months of the year, and often exceeding 100F.

a. The high temperature record, recorded at Al-Aziziya in northern Libya, reached 1236.4F (58C).

b. At night the temperatures drop sharply, by as much as 50F: nights can be cold and temperatures often fall below freezing in winter.

c. Precipitation – rainfall is sparse, <2″ per year.

There are 3 types of lands surfaces in the Sahara: erg, reg, and hammada.

a. **Erg** – "sand seas", composed of dunes that have formed basins and depressions from the sand carried into them by rivers of earlier times.

i. The large area of dunes are in the northern Sahara, extending across the Libyan Desert and into Egypt.

ii. Surface temperatures can reach 180 F (85C) Air heated by contact with the surface expands and rises. This produces an area of low pressure near ground level. Denser air rushes in to compensate and its movement causes strong, gusty winds. These are called thermal winds because they are caused by temperature differences.

b. **Reg** – name given to ground covered by boulders and gravel.

The reg is fairly level, and the areas are generally bleak, windswept, and monotonous.

i. Reg is formed by wind action. Small particles are blown from around and between the larger, heavier stones, in a process called “deflation”.

ii. The wind keeps the surface clean, and the finest particles are carried very long distances: Saharan dust has been identified in the United States.

c. **Hammada** – is the rocky desert.

i. No sand or small particles on the surface – just rock, either as large boulders or bedrock.

ii. Hammadas are found in northern Libya, and there resembles a vast and uneven parking lot. Probably the most inhospitable type of desert surface. Very little can live on it.

Arabian Desert – includes the whole peninsula of Arabia (Jordan, Iraq, Israel, Syria, and part of Iran);

a. An empty quarter in the southern part of the desert is too hot and dry even for desert nomads (similar to the Sahara).

i. Includes the largest sand desert in the world (south of Najd), called the Rub' al-Khali (the empty quarter), covering 230,000 square miles (595,700 sq kilometers).

ii. Despite its name, it includes many watering holes and, is therefore, "crossable" to those familiar with the desert.

b. Arid or extremely arid, < 4" per year.

1. Hot desert, averaging between 100-107 F from May-Sept.
2. Most of the plants are annuals; most of the perennials are halophytes.

Gobi Desert : China, Mongolia, Mountain and basin desert, Northwest of Takla-Makan, Sand dunes and gravels (gobi), shrubs and semi-shrubs.

1. There are no towns in the Gobi Desert, but the capital of Mongolia, Ulan Bator, lies not far from its northern margin.
2. Precipitation falls mainly in the summer, the center of the desert receiving 1-2" per year. Ulan Bator ahs an annual precip of 8"/year.
3. Vegetation is sparse, consisting of grass, shrubs, and thornbushes.

Takla Makan –

1.**Rain shadow desert and continentality** from Tien Shan and Kunlun Shan Mountains in northwestern China, and the Tibetan plateau (12,000′).

2. West of the Gobi.

3. Much more barren than the Gobi.

4. Climate is extremely dry because air must cross high mountains to reach the desert and in so doing loses much of the moisture it carries.

5. There is some vegetation on the borders of the desert, where there are permanent rivers, but no vegetation in the interior.

Namib Desert – Coastal cooling

1. Coastal strip desert along the west coast of Africa, from southern Angola to South Africa.
2. Very dry but not too hot because of coastal fog.
3. High humidity and fog (like Atacama), with less than 2″ (51 mm) annual precipitation.
4. Very little vegetation: Lichens on the leeward side of rocks, leafless, stem-succulent plants, and halophytes.
5. The Benguela Current, is a cold current that flows northward along the coast. It flows from the edge of the Antarctic Ocean as a stream of water blown in an easterly direction by the West Wind Drift and turning north just south of the southern African continent.
6. Despite having crossed the ocean, winds and air bring no rain because it was chilled as it crossed the cold water of the Benguela Current and its water condensed. It condenses as low clouds and fog, rather than rain and fog.

Kalahari Desert – covers an area of about 275,000 sq. miles (712,250 sq. kilometers).

1. Inland desert from the Namib; southwestern Botswana.
2. Notable for its deep subsurface sands.
3. Landscape dominated by gentle dunes.
4. Precipitation in the northern Kalahari reaches 25" annually; precipitation in the southern Kalahari, 10" annually.
5. The rate of evaporation is high enough to remove much of the surface water before it can be absorbed by the ground.
6. Temperatures range from 90F (32C) in summer to 70 F (21C) in winter, but frosts are common in winter nights.

Atacama Desert – 140,000 sq miles (363,000 sq kilometers) in northern Chile. The Tropic of Capricorn passes thru its center.

1. Narrow strip, 600 miles along (parallel to) coast of Chile.
2. World's driest coastal desert; 0.04" (10 mm) precipitation; most of it from coastal condensation (fog). Rain can be expected no more than 2-4 times per century.
3. **Coastal cooling**: Air reaching the coast from the ocean loses most of its moisture at sea, where it is chilled. It is dry when arrives on land. Any remaining moisture is lost as the air rises to cross the coastal ranges, forming clouds that rarely bring rain, although may be low enough to be called fog.
4. Air from the southwest crosses South American continent, then loses the moisture it carries during its ascent over the Andes Mountains. The combination of coastal cooling from the west, and **rainshadow** from the southwest accounts for the extreme aridity of the Atacama.
5. Average elevation is about 2,000'; its height contributing to its moderate temperature.

6. A cool (little seasonal variation – about 65 F), very dry climate in a coastal region suggests the presence of a cool ocean current. South America has its equivalent of Africa's Benguela Current, called the Peru Current.

i. Both the Benguela and Peru Currents originate in the Antarctic Ocean, and bring cold water thru a series of upwellings that carry cold water to the surface.

7. Almost no vegetation save for lichen.

8. Very little vegetation, except along streams.

9. On slopes moistened by mist or drizzle during the winter a sparse stand of Tillandsia may exist with a few lichens in association.

10. Despite its bleakness, in the last century Chile and Bolivia fought over part of the Atacama Desert. The War of the pacific lasted from 1879-1884, and ended with Chile in control of the area, and made Bolivia into a landlocked nation.

i. The desert has rich deposits of sodium nitrate and copper.

ii. Sodium nitrate is the raw material for commercial fertilizer and explosive manufacture.

Patagonia – occupying the whole of Argentina; 300,000 sq miles (770,000 sq kilomteres)

1. Cold, rainshadow desert, average annual temperature is 7C.
2. Average rainfall < 10" annually.
3. There is no other desert in the world lying on the eastern side of the continent in a latitude north of 40d S.
4. Highest precipitation in the winter, April - Aug.
5. Bleak desert, but in the north there are tough grasses and shrubs; the grasses providing pasture for sheep.
6. Little vegetation farther south, where climate is colder and drier.

Australian Desert

1. The Tropic of Capricorn passes thru the center of Australia. This means the country lies close enough to trade wind latitudes for the prevailing winds to be from the southeast. These bring maritime conditions, with abundant rain, to the coast of New South Wales and Queensland.
2. Inland lies the Great Dividing Range, a mountain range running the length of the country parallel to the east coast.
3. Lands to the west of the mountains lie in a rain shadow.
4. 40% of Australia's land mass is classified as desert (3.4 million square miles). Of all the continents, Australia is the driest. (Australia is alarge island with a continental climate).
5. No succulents, very few spiny plants. Prevalent desert plants are the perenial evergreen tussock grasses (spinifex) and small trees or shrubs belonging to the genus Acacia.

6. Australia has 5 deserts: 4 on the west side, one in the center.

a. Simpson Desert – southeast corner of the Northern Territories;
< 500′ asl; stony desert

b. Great Sandy – north part of western Australia; < 600′ above sea level.

c. Great Victoria – western Australia

d. Gibson Desert –

e. Nullarbor Plain – south of the Great Victoria Desert.

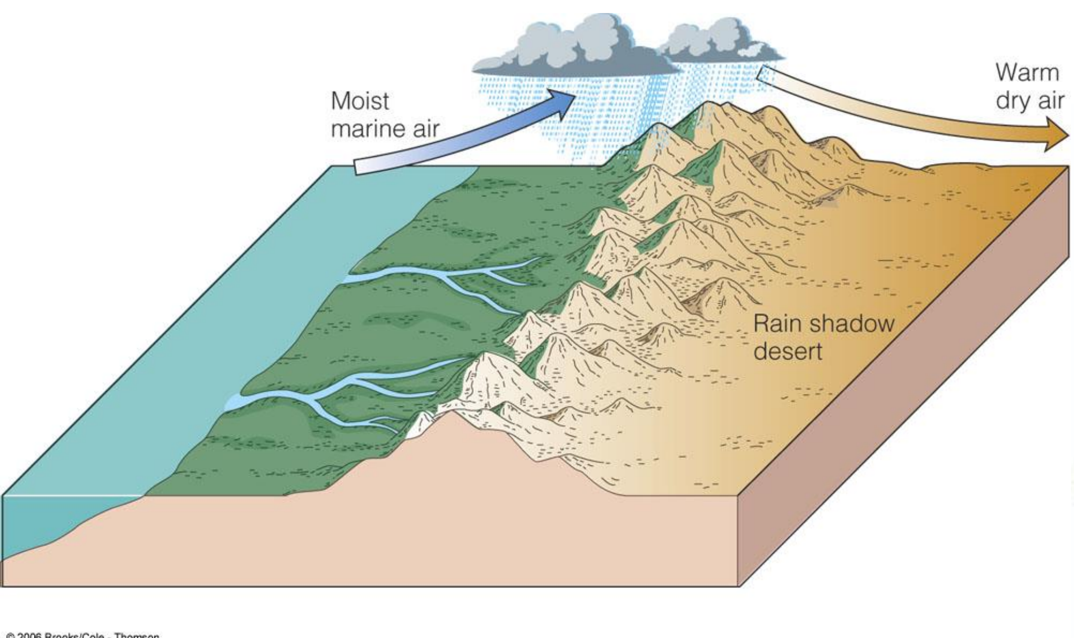
North America

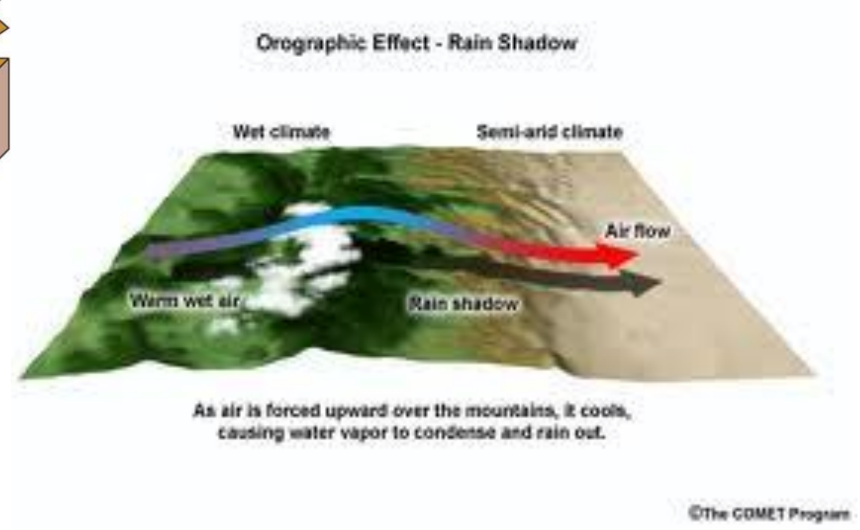
1. **Great Basin Desert** - rainshadow desert
2. **Mojave Desert** - rainshadow desert
3. **Sonoran Desert** - rainshadow desert
4. **Chihuahuan Desert**- No. Mexico; precipitation restricted by anticyclonic conditions rather than topography (rainshadow).

The causes and distribution of deserts

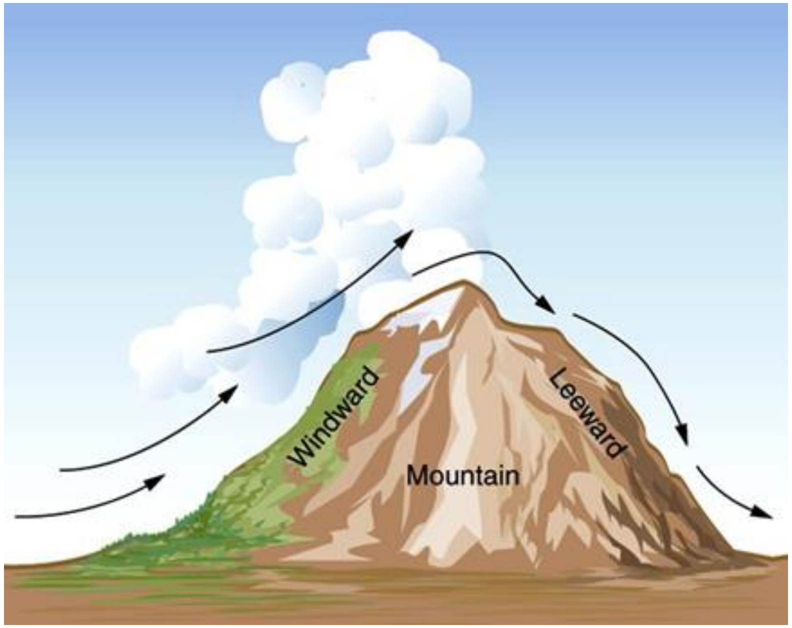
Causes of aridity:

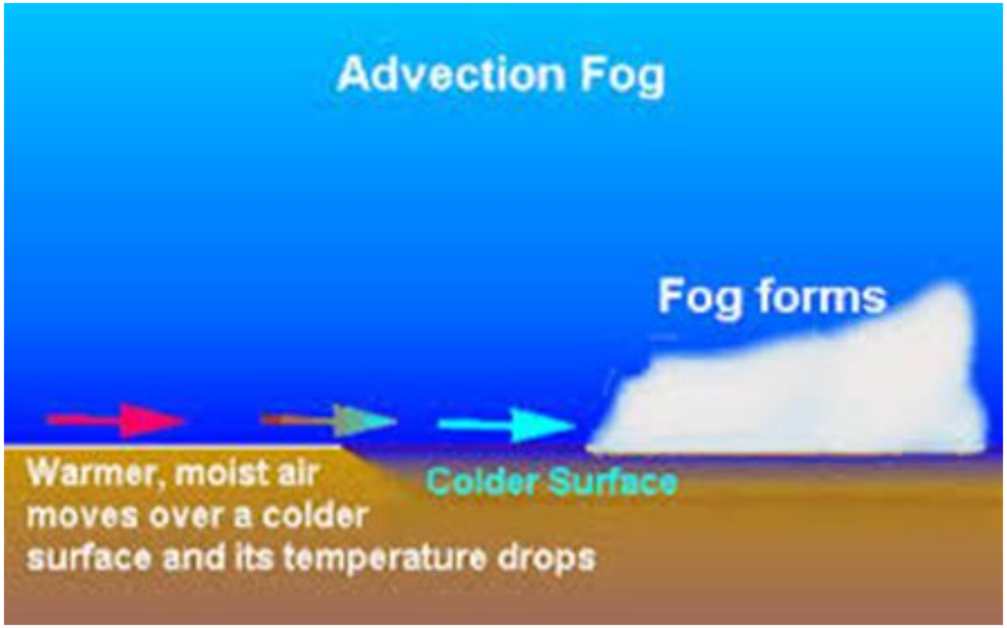
- Distance from marine or other moisture sources, which means the largest desert are near to the centers of the largest landmasses
- Aridity is a lack of water and generally it can be classified by mean annual rainfall.
- Temperature also has an effect as it can determine evapotranspiration.
- **Orographic** influences are another major control





- Aridity is also reinforced on the dry western littorals of continents by coastal upwelling of cold water associated with cold, equator ward-flowing offshore currents creating advection fogs and accentuating atmospheric stability.
- The aridity also due to high reflectivity of the desert surface themselves causes net loss of radiative heat. It creates horizontal atmospheric temperature gradient along the desert margin, and induces circulation system that further induces reinforce prevailing subsidence.



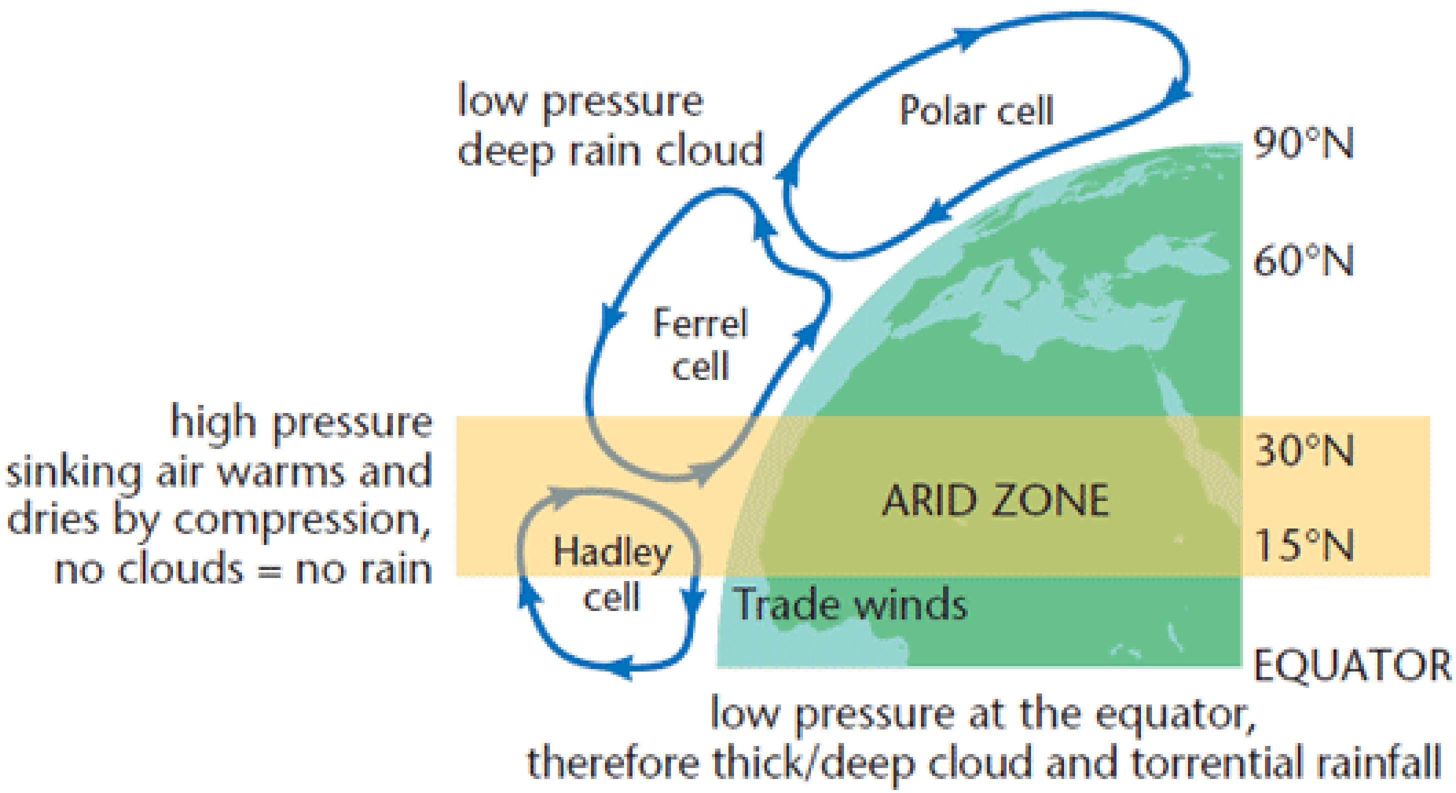


The causes of aridity

Pressure

Deserts are found in 60+ countries of the world between 10° and 30° N and S. About one-third of the land surface of the world is classified as arid, semi-arid and/or dry.

Sand covers 20% of the Earth's surface. Over 50% of this area is deflated desert pavements.



The ‘rainfall definition’ of aridity:

1. 250–500 Semi-Arid Sparse vegetation (grassland, few trees grow)
2. 25 – 250 Arid Plants only appear along river courses
3. < 25 **Cm/yr** - Extremely Arid Plant growth only after rainfall

These classifications cover one-third of the world

Origin of Desert:

Desert classified in to three groups on the basis of origin; polar, middle latitude and tropical deserts.

Polar Desert:

It is not concern us at present at least. It has sufficient moisture present in the ice sheets but it is not available because it is frozen.

Middle Latitude Desert:

It may be described as topographic desert.

It is located either deep interior of large continental masses or to the presence of high mountain across the path of prevailing winds.

Tropical Desert:

Tropical desert some time called Low Latitude desert. These deserts around the latitudes of20 to 25 degrees and may extend approximately 15 to 30 degrees

There are several types of deserts:

1. Subtropical: Those associated with the circum-global belts of dry, subtropical air (Sahara, Kalahari, Great Australian)

2. Rainshadow: Lee side of mountain ranges in the rain shadow (Sonoran).

3. Continental interiors: with low rainfall (Gobi, Takla Makan in Asia)

4. Coastal deserts where upwelling cold seawater cools the air, lowering its ability to hold moisture (Peru, Chile, SW Africa)

5. Polar deserts (N. Greenland, ice-free areas in Antarctica)

Weathering: group of destructive processes that change physical/chemical character of rock at/near surface.
Weathering: in situ breakdown of rocks in contact with water, air, or organisms. Forms sediment and soil.

Mechanical Weathering

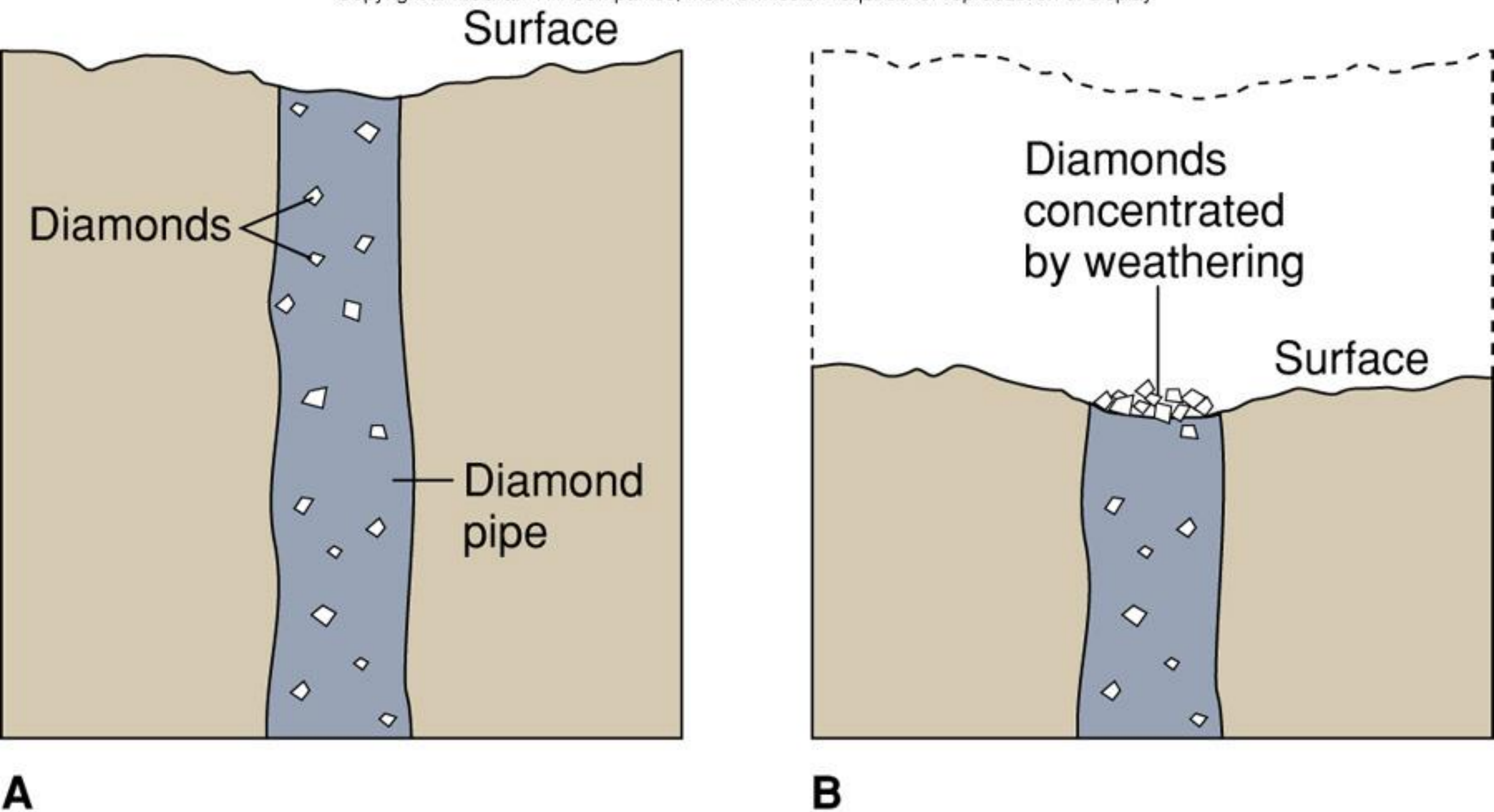
Physical breakdown without a change of the chemical composition – the minerals remain in tact.

Chemical Weathering

Minerals change in composition to come in to equilibrium with surface conditions.

Minerals dissolve.

Residual Concentration by Weathering



Chemical Weathering

B

Photo by David McGeary

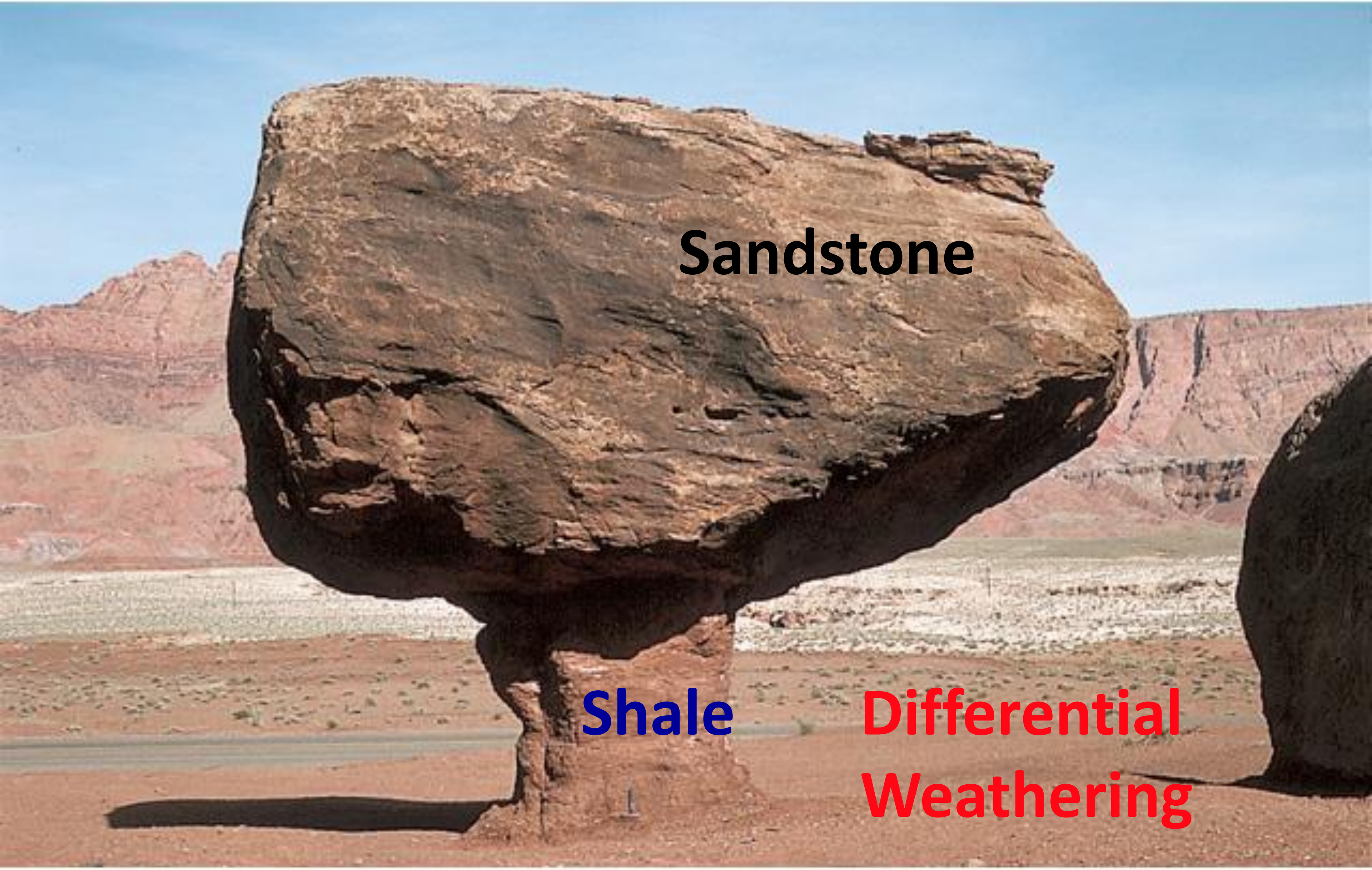


Photo by David McGeary

Differential Weathering

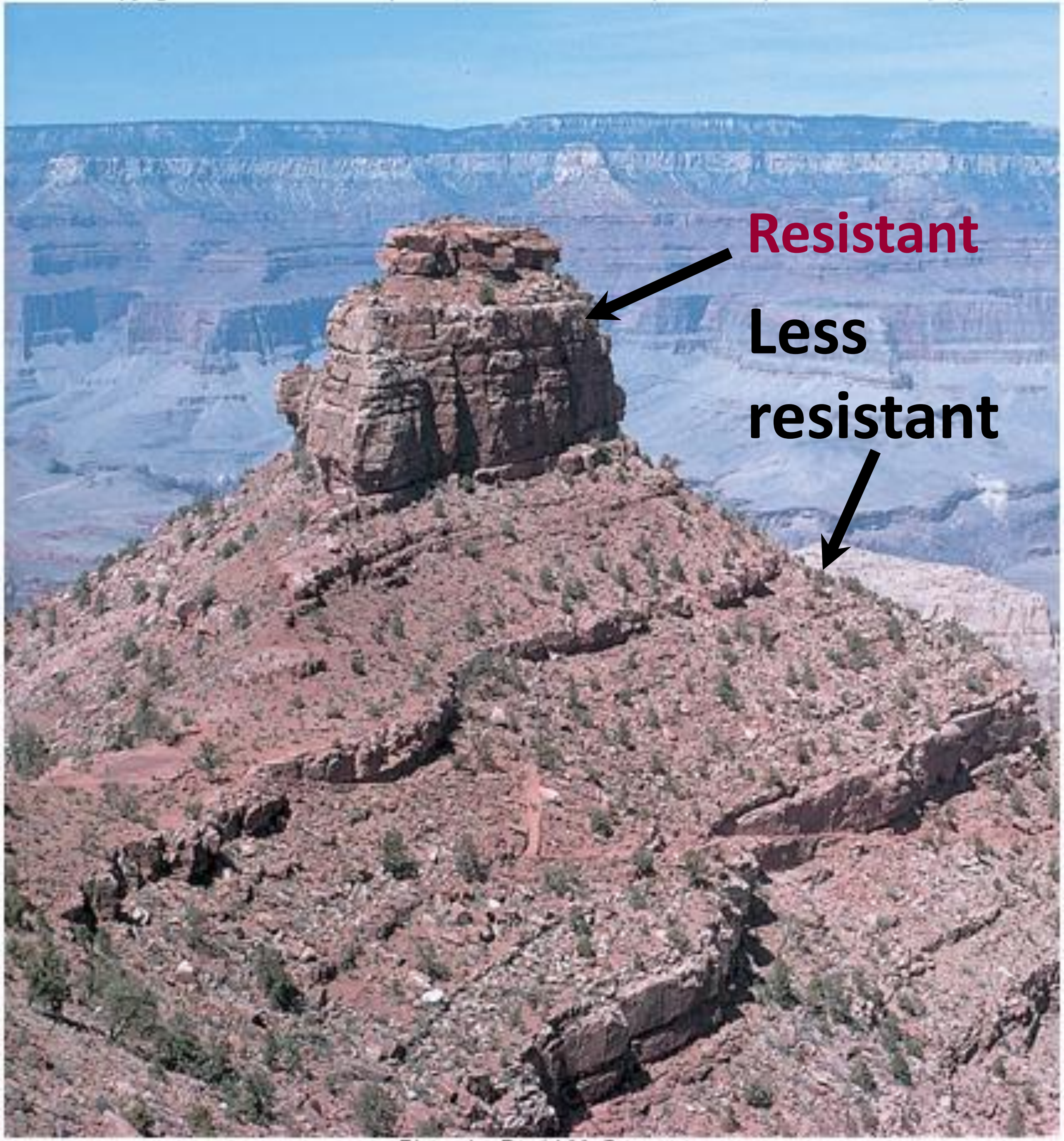
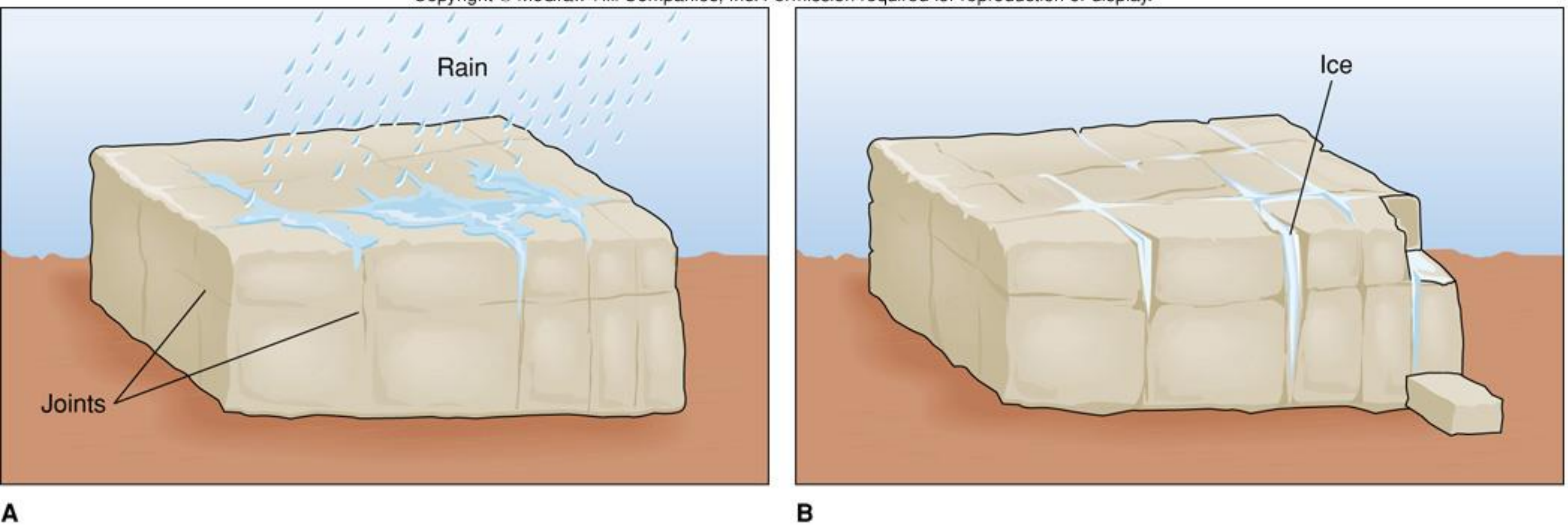


Photo by David McGeary

Mechanical Weathering- Frost Action

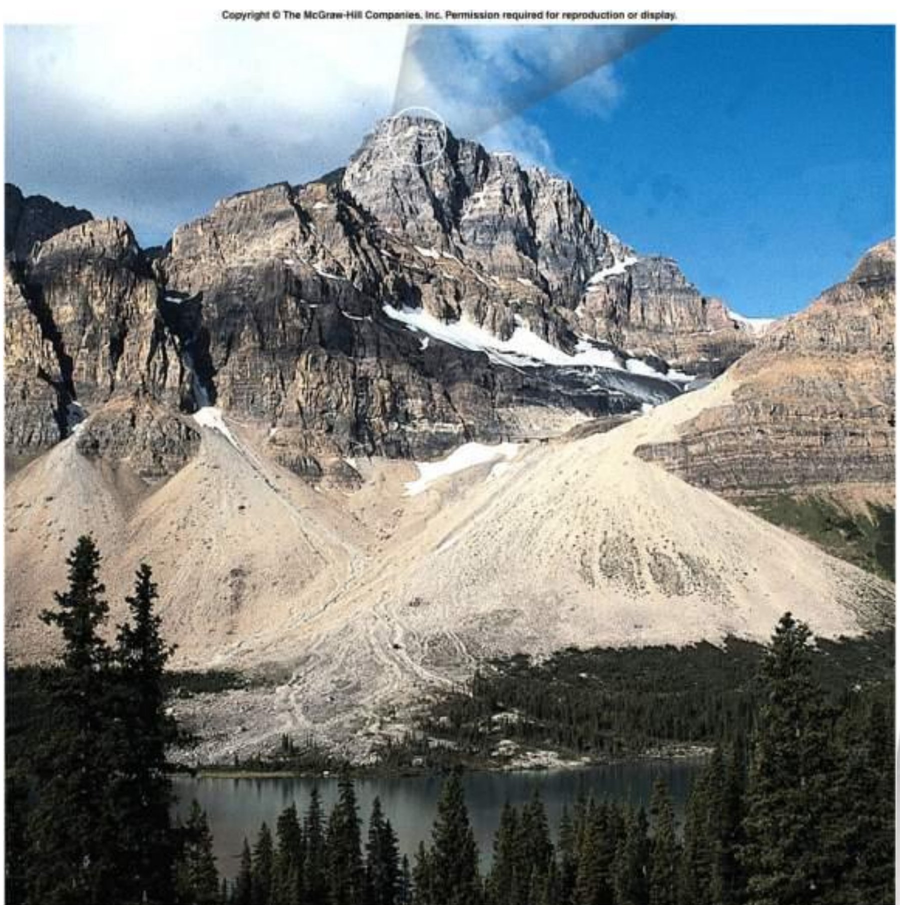
Frost-Wedging: water expands by 9% upon freezing – most significant where freeze-thaw cycle occurs often.



Frost Heaving: cooler under rocks, freezes first, expands and lifts.

Mechanical Weathering

Temperature Changes: differential expansion (deserts, mountains, & forest fires).



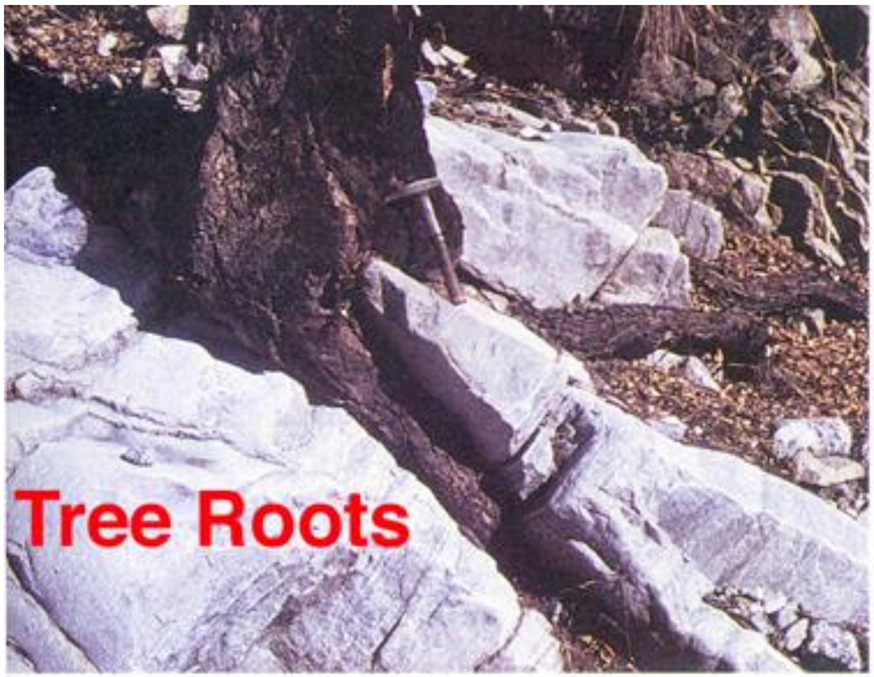
B

Frost action

- **Landforms:**
  - talus, talus cones, scree slopes

Mechanical Weathering-Salt Weathering

Precipitation of Crystals: salts precipitating from water in rock crevices/cracks. Forces the opening wider.



Root Systems: dominant in cold/dry climates.

Salt weathering (physical weathering)

- **salt crystallization: occurs as saline solutions evaporate**
- **salt crystal expansion: occurs when salt crystals get wet**

Honeycomb weathering in graywacke sandstone, Golden Gate National Recreation Area. Photo: National Park Service, http://www.nps.gov/goga/forteachers/graywacke-sandstone-faq.htm

graywacke: a coarse usually dark gray sandstone or fine-grained conglomerate composed of firmly cemented fragments (as of quartz or feldspar)
also called **dirty sandstone**

Salt weathering

- **occurrence:**

- **hot and cold arid and semi-arid environments**

  capillary rise brings saline water toward surface

  limited liquid water (either due to supply or phase) incapable of washing salts away

  hot arid regions: large diurnal changes in temperature and relative humidity promote repeated wetting and drying

  cold regions: cold temperatures encourage salt precipitation from solutions

- **rocky coastal areas**

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Salt weathering

- **rock susceptibility to salt weathering**

… is a function of:

- **proportion of micro pores**
- **water absorption capacity**
- **surface texture**
- **presence of clay minerals**

Salt weathering

- **landforms**

- **tafoni**
  - **Cavernous weathering of granite ("tafoni") near Caldera. Chile. No date.**

- **honeycomb weathering**

- **granular disintegration**

- **spalling**

Photo: K. Segerstrom, USGS Photographic Library image Tafoni sk000626. http://libraryphoto.cr.usgs.gov/

Salt weathering

- **landforms**

- **tafoni**

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granular disintegration

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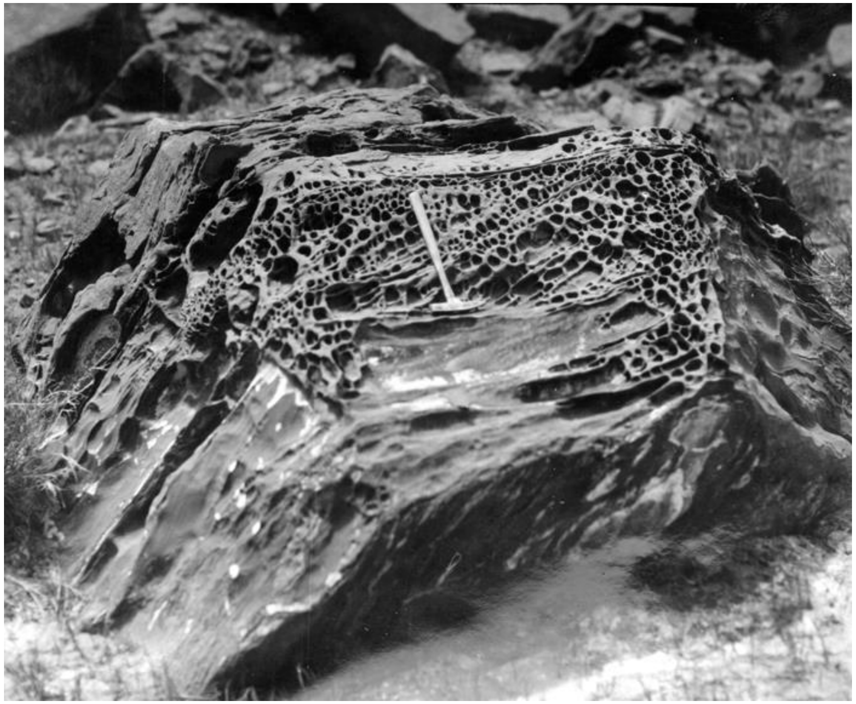

Honeycomb weathering in block of Wingate sandstone Silver Falls canyon. Garfield County, Utah. 1921. Plate 9-B in U.S. Geological Survey. Professional paper 164. 1931. ID. Moore, R.C. 98 mrc00098

Salt weathering

- **landforms**

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- **tafoni**
- **honeycomb weathering**
- **granular disintegration**
- **spalling**

Sequoia National Park, California. Northern edge of the Siberian Outpost. The frost-split blocks of granite might readily be mistaken for glacial boulders, but, having the same composition as the underlying bedrock, they have obviously been formed in place. The granite here is sparsely jointed and breaks up into large blocks. These, in turn, are subject to granular disintegration which at this lower altitude is probably effected not only by frost action, but also by the solvent action of carbon dioxide. The latter, derived from decaying lichens and pine needles, is carried by water into the interstices between individual granules. Eventually the blocks lose their sharp angles and become rounded. 1935.

Photo: Marli Miller, University of Oregion. Earth Science World Image Bank, photo hhrhuz, http://www.earthscienceworld.org/

Salt weathering

- **landforms**

- **tafoni**
- **honeycomb weathering**
- **granular disintegration**

- **spalling**

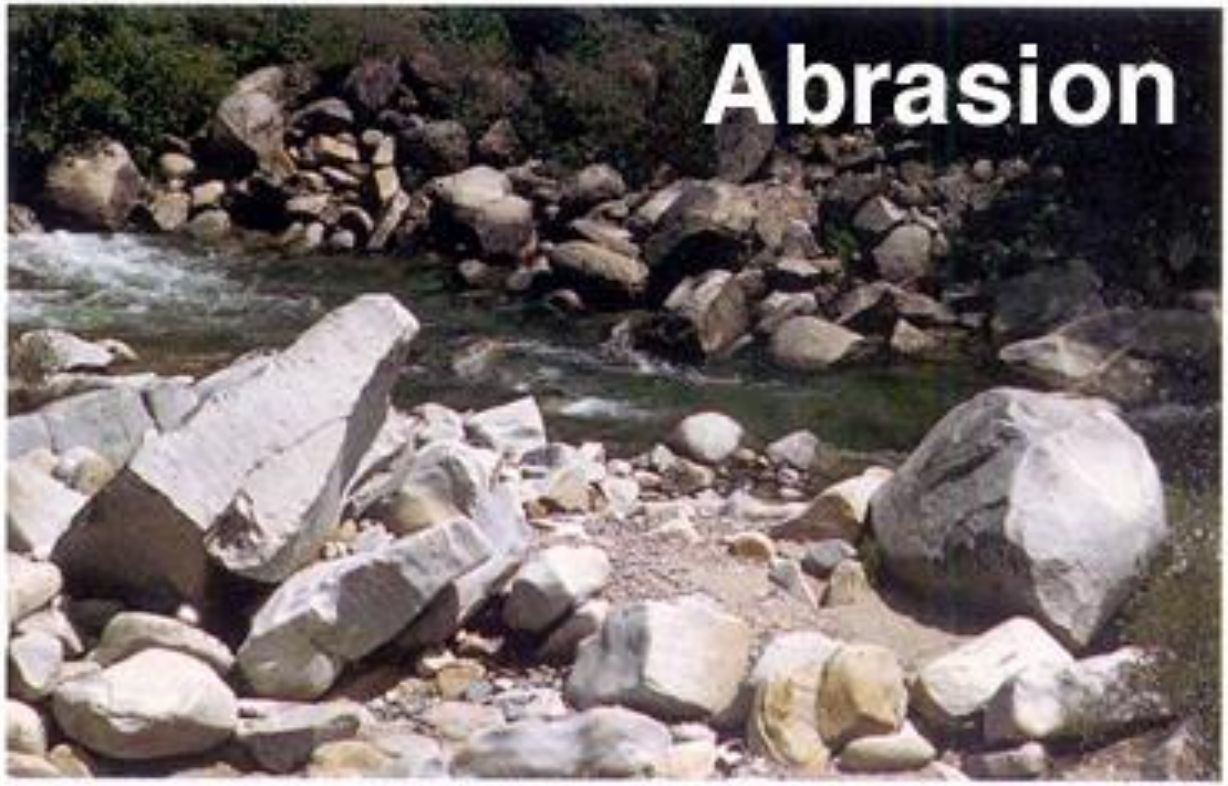
J.R. Stacey, USGS Photographic Library, Image hcb00980.
http://libraryphoto.cr.usgs.gov/

Wetting & drying (physical weathering)

- susceptible soils & rocks:
  - soils with 2:1 layered clays (e.g. montmorillonite)
  - shale, clayey siltstones and sandstones, granite
- result: spalling, granular disintegration

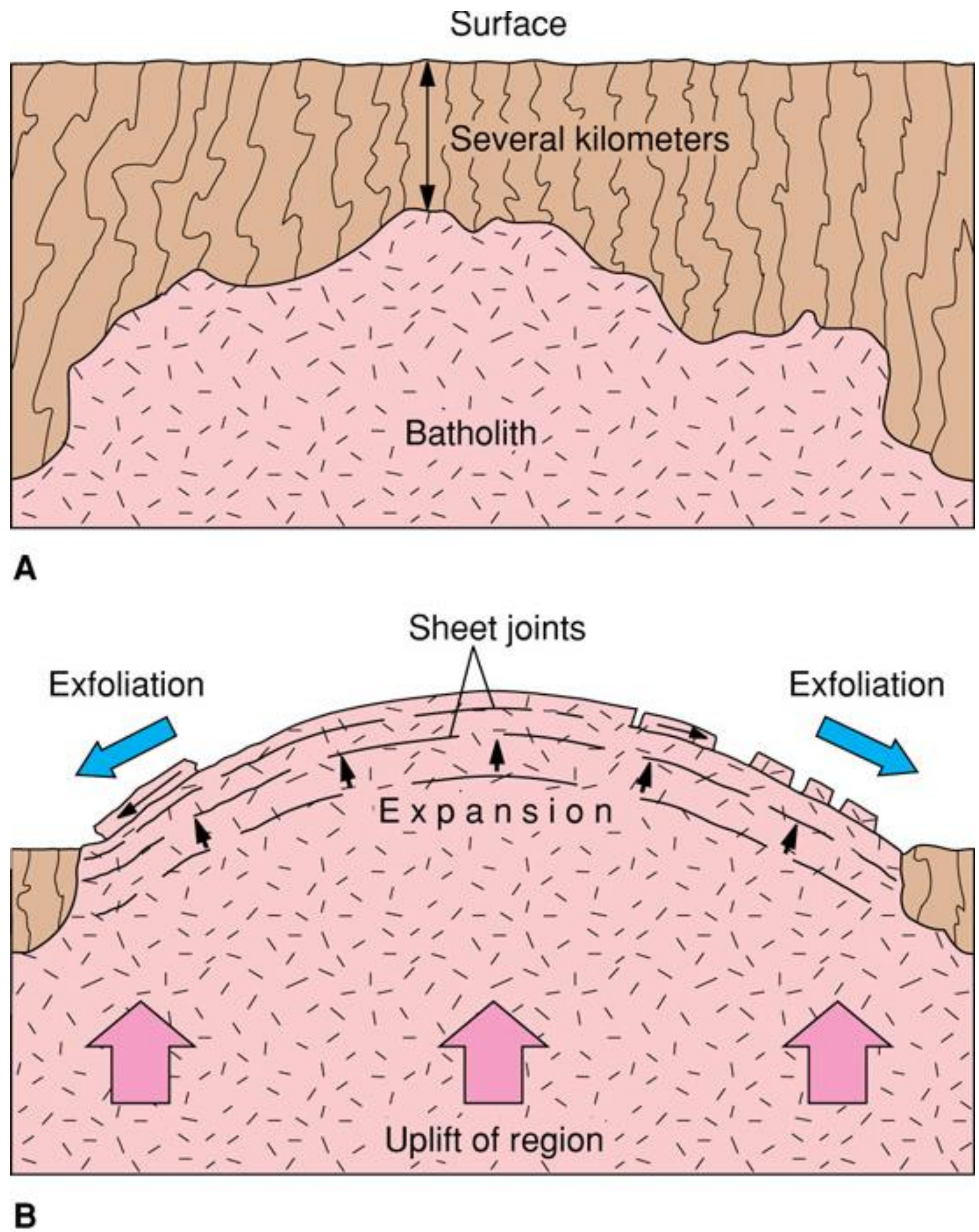
Mechanical Weathering

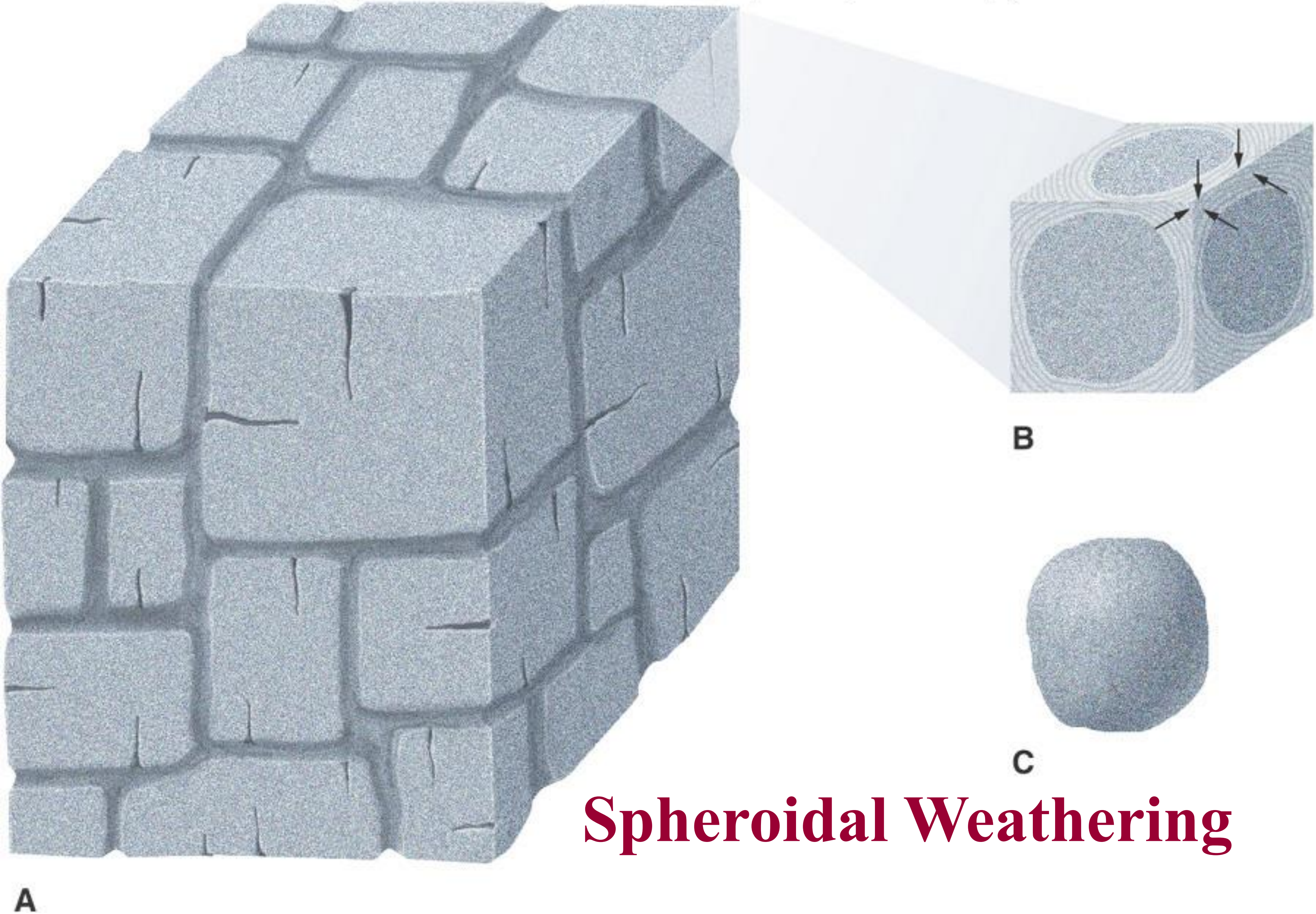
Abrasion: friction/impact during transport.



Mechanical Weathering

Pressure-Release: often called ***exfoliation***. Caused by unroofing of deep-seated rocks by erosion. Sheet joints and joint sets form (joint = break in the rock along which there has been no movement). Exfoliation domes.





Spheroidal Weathering

Spheroidal Weathering

Photo by David McGeary

Weathering:

Exfoliation:

Cold ocean currents

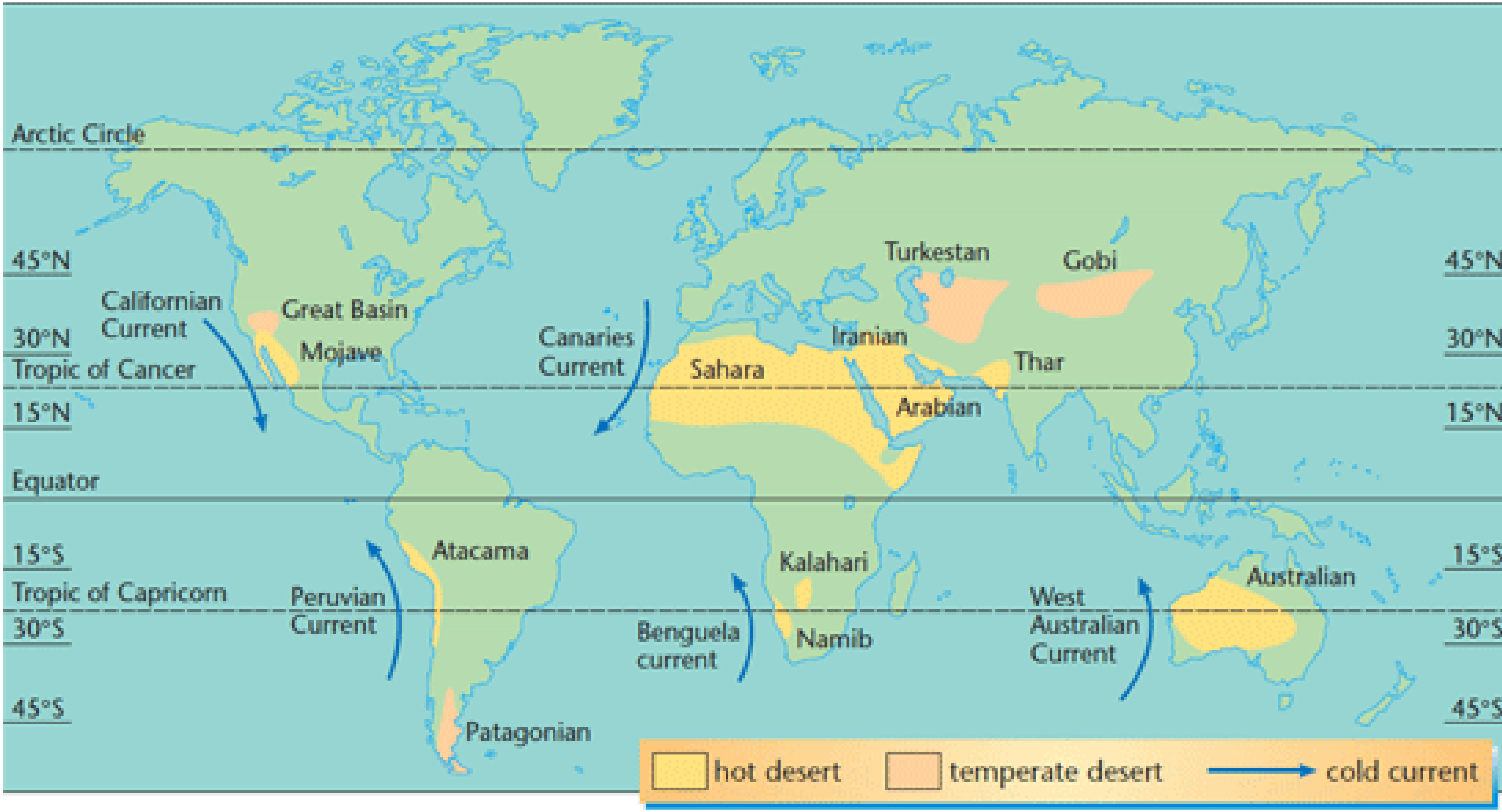
Cold air present above such currents ensures that there is little moisture available to cool and form clouds. The coasts of Western, North and South America and Africa display such conditions. Both continents have west coast deserts just a little inland.

Rainshadow and continentality

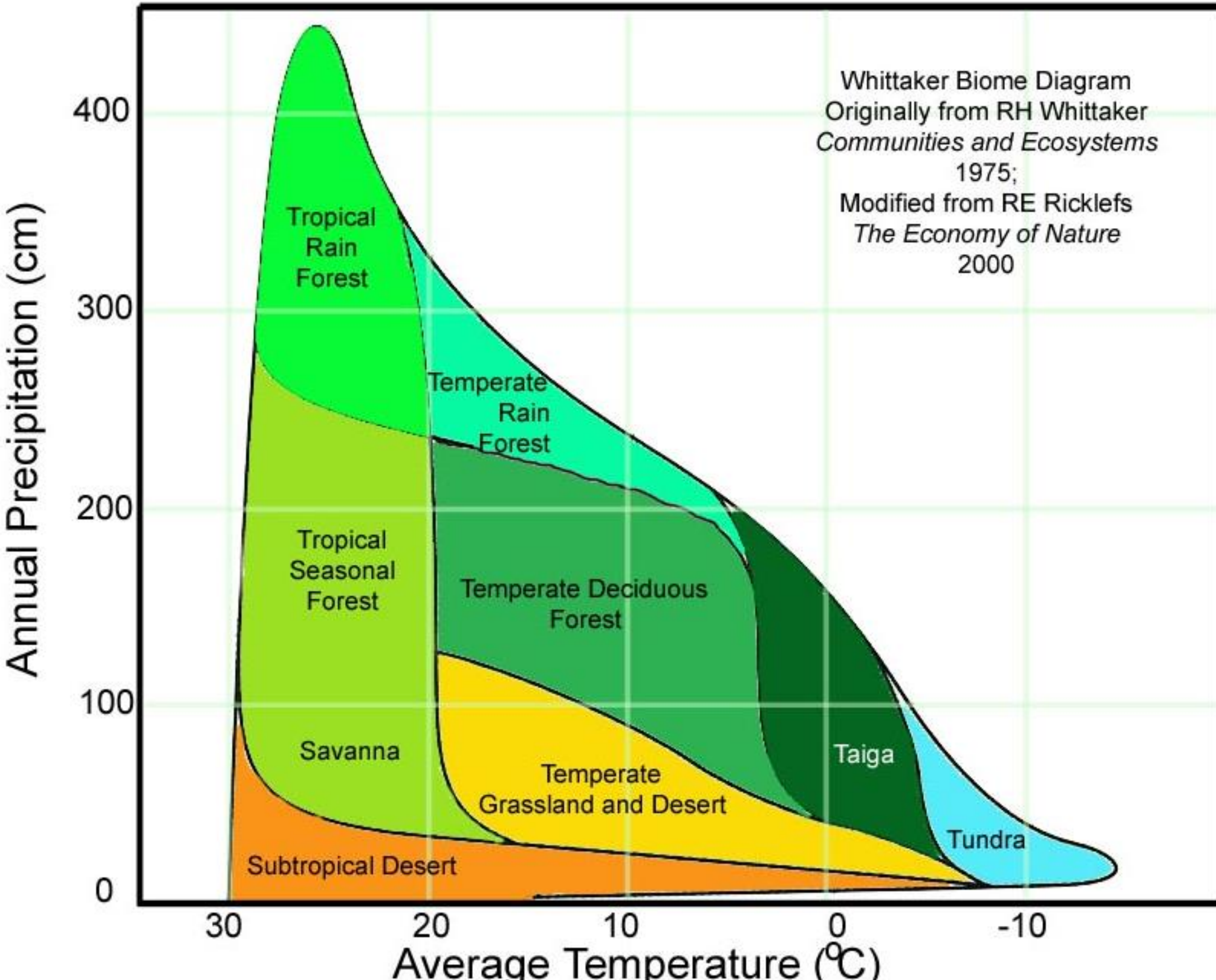
Air descending from mountainous areas warms and dries by compression, little rainfall forms and aridity is the result. Central areas of continents are dry because air moving over landmasses does not absorb large amounts of water vapour. During the last ice age, conversion of water to ice resulted in larger continental areas. This extreme continentality is thought to have facilitated the spread of deserts during the ice age.

World wide distribution of deserts

The majority of the world's most arid areas lie between 15° and 30° North or South of the equator.



Arctic Circle
45°N
30°N
Tropic of Cancer
15°N
Equator
15°S
Tropic of Capricorn
30°S
45°S
45°N
30°N
15°N
15°S
30°S
45°S
Californian Current
Great Basin
Mojave
Canaries Current
Sahara
Turkestan
Gobi
Iranian
Thar
Arabian
Atacama
Peruvian Current
Patagonian
Kalahari
Benguela current
Namib
West Australian Current
Australian
hot desert
temperate desert
cold current



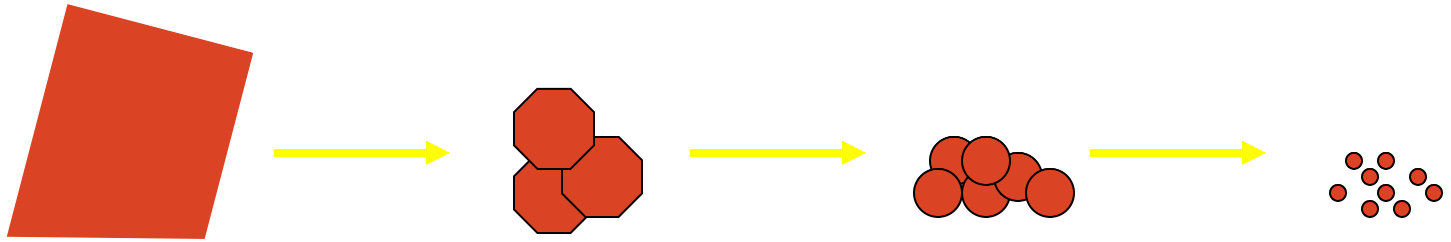
Whittaker Biome Diagram
Originally from RH Whittaker
Communities and Ecosystems
1975;
Modified from RE Ricklefs
The Economy of Nature
2000
Annual Precipitation (cm)
400
300
200
100
0
30
20
10
0
-10
Average Temperature (°C)
Tropical Rain Forest
Temperate Rain Forest
Tropical Seasonal Forest
Temperate Deciduous Forest
Savanna
Temperate Grassland and Desert
Taiga
Tundra
Subtropical Desert

Rank	Desert	Area (km²)	Area (mi²)
1	**Antarctic Desert** (Antarctica)	14,200,000	5,500,000
2	**Arctic Desert** (Arctic)	13,900,000	5,400,000
3	**Sahara Desert** (Africa)	9,100,000	3,500,000
4	**Arabian Desert** (Middle East)	2,600,000	1,000,000
5	**Gobi Desert** (Asia)	1,300,000	500,000
6	**Patagonian Desert** (South America)	670,000	260,000
7	**Great Victoria Desert** (Australia)	647,000	250,000
8	**Kalahari Desert** (Africa)	570,000	220,000
9	**Great Basin Desert** (North America)	490,000	190,000
10	**Thar Desert** (India, Pakistan)	450,000	175,000

Weathering

Weathering: the disintegration, or breakdown of rock material

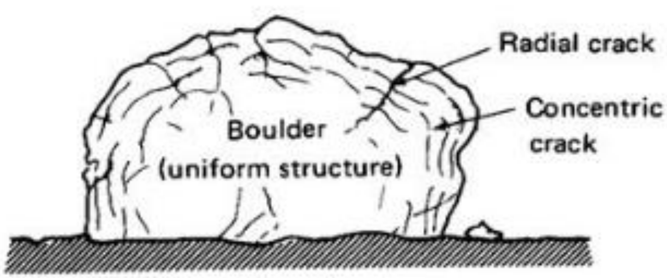
Mechanical Weathering: no change in chemical composition--just disintegration into smaller pieces



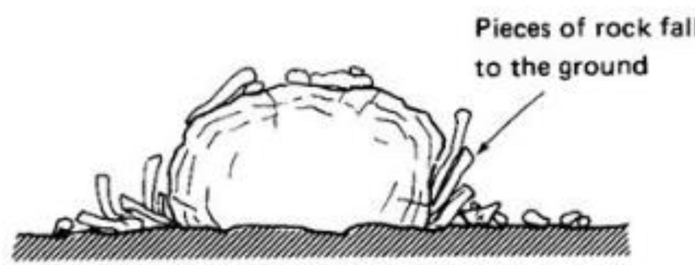
Types of Physical weathering

- Exfoliation / Onion Scaling
  - Rocks with homogeneous structure.
  - Repeated heating and cooling by daily temperature changes.
  - Repeated expansion and contraction create stress in rock and produce radial and concentric cracks.
  - The outer layers eventually peel off to form exfoliation.

(a) Repeated expansion and contraction production radial and concentric cracks

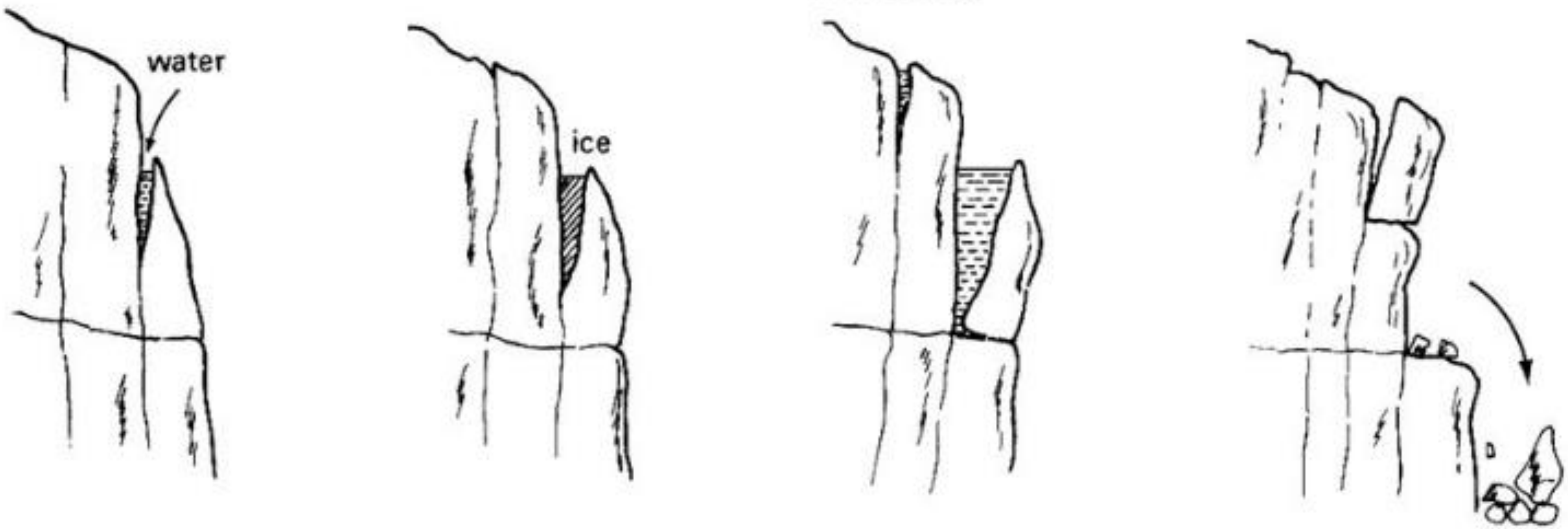


(b) Layers of rock peel off and fall to the ground



Freeze thaw action

Daytime | Night-time | Repeated freeze-thaw action | Eventually



(a) Cracks or joints pre-exist. Water occupies a crack.

(b) Water freezes. Ice expands. Crack is widened.

(c) Crack is further widened.

(d) Rock block is detached and broken into angular blocks or fragments.

Types of Physical weathering

- Block disintegration
  - Well-jointed rock (eg. Granite)
  - Great diurnal range of temperature with more than 10°C between freezing point (0°C)
  - Repeated heating and cooling by temperature changes, which causes alternate expansion and contraction.
  - Cracks and joints are widened or breaks down into small blocks or fragments.
  - It may be accompanied by frost action and chemical weathering.

Block disintegration

Types of Physical weathering

- Frost action / Freeze and Thaw Action
  - Diurnal range of temperature fluctuating above 0°C.
  - During daytime, water seeps into cracks or joints of rocks.
  - Night time, temperature drops to below freezing point, water freezes in joints or cracks, which expands and widen the cracks.
  - Alternate freez and thaw, the rocks break down into smaller, angular fragments

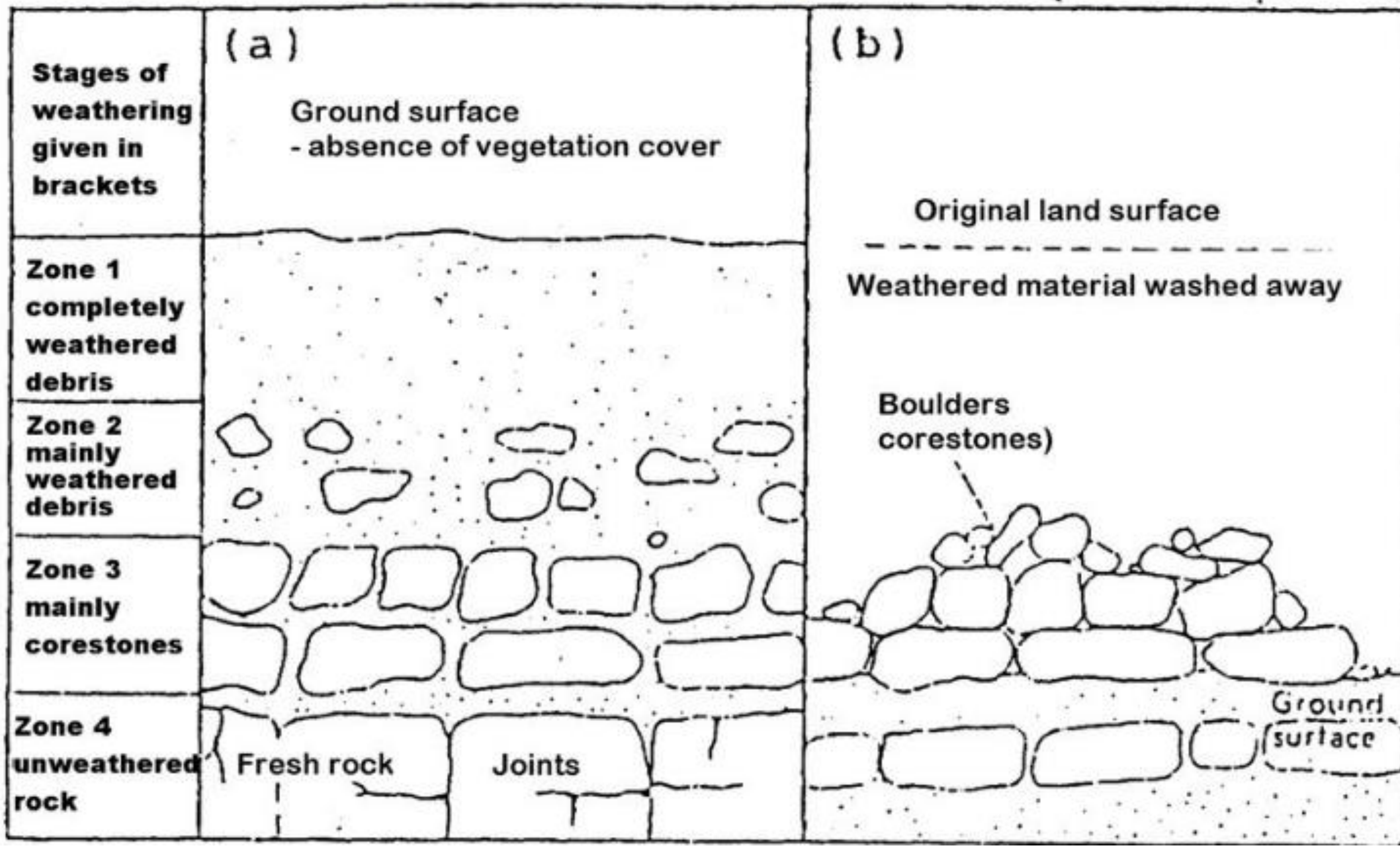
Chemical weathering

- Introduction
  - Chemical weathering is the decomposition or decay of solid rocks as a result of chemical reactions between the rock minerals and moisture, rain water, sea water and organic acids produced by plants and animals,
  - Chemical weathering can be accelerated by high temperature.
  - It also can accelerated by physical weathering which breaks rocks up and increase the surface exposed to possible chemical weathering.

Processes of Chemical weathering

- Oxidation
  - It is the process of the combination of oxygen.
- Hydrolysis
  - Free hydrogen ions in water enter into the mineral structure and create a new compound.
  - Eg. Feldspar in Granite to Kaolinite.
- Hydration
  - The whole water molecule combines with the mineral.
- Carbonation
  - Carbon dioxide (rain water pH=5.7) is capable of reaction with certain minerals
  - It is particularly effective in limestone with humid climate.
- Solution
  - Soluble minerals (rock salt,…)are dissolved directly in water.

Weathering Profile of Granite



Biological / Organic weathering

- Biological weathering is the physical disintegration or chemical decomposition of rocks in situ by organic agents – plants and animals.
- It is effective in regions with a continuous vegetation cover and burrowing animals.
- In desert regions and polar regions, it is insignificant for limited plants and animals.

Biological weathering - Plants

- The growth of plants roots and their penetration into rocks are sufficiently effective to widen cracks and joints.
- Rocks may be weathered by orgranic acids secreted by roots of plants and from decayed plants.

Biological weathering - animals

- Animals
  - Burrowing animals may dig or turn up and loosen the joints of rocks.
  - Earthworms and termites also loosen and expose the surface materials for weathering.
  - Wastes secreted by animals or derived from dead animals (organic acids) help chemical weathering
- Human
  - Human activities often cause large scale disintegration of rocks (mining, quarrying, excavation for building….)
  - Careless removal of vegetation by man exposes large surface area to weathering processes. (deforestation for farming, for lumbering, for firewood; abandon farmland, overgrazing, hill fires,…..)

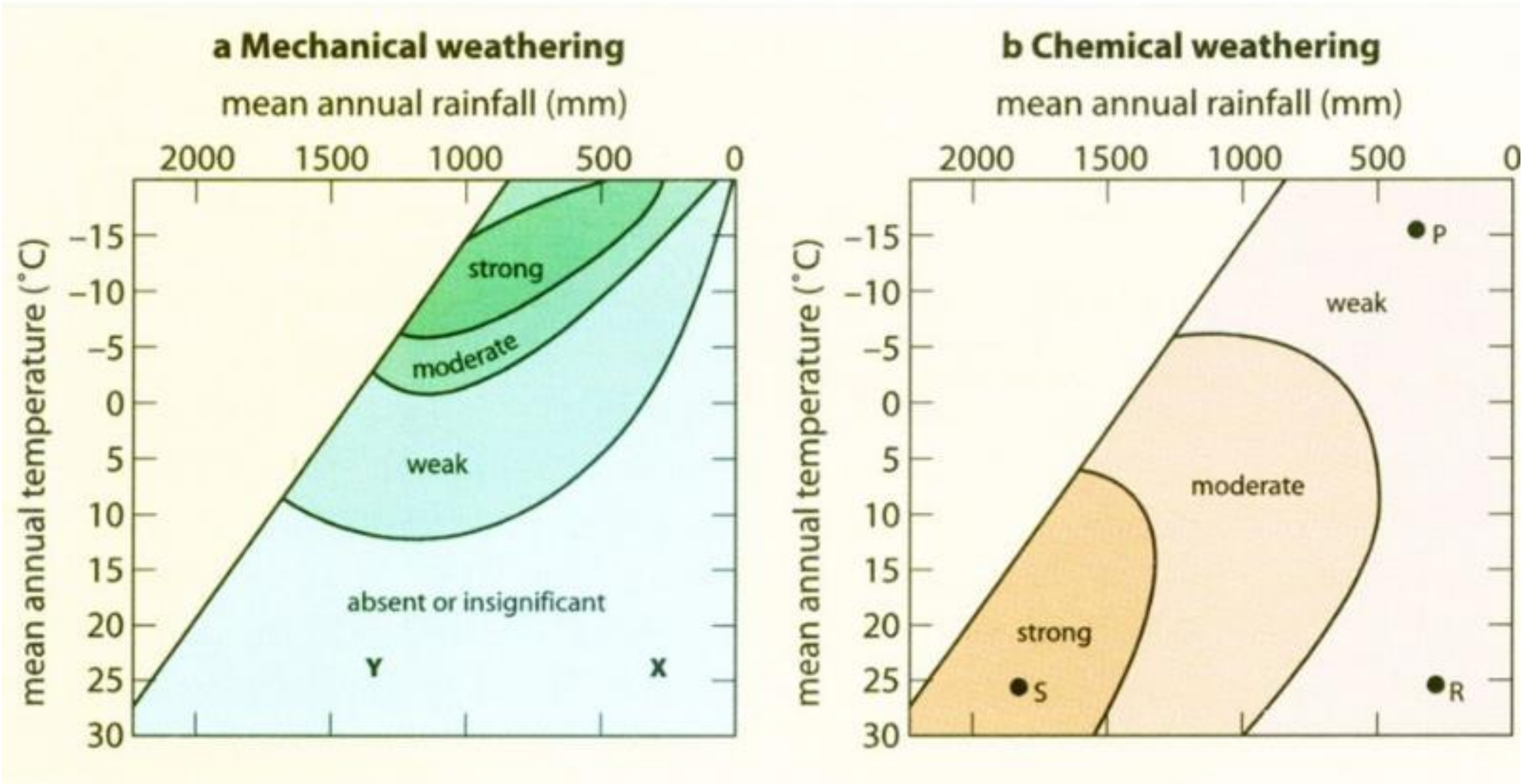
Case study – weathering in desert

- Traditional concept:
  - Little rainfall, strong winds and large daily range of temperature.
  - Mechanical weathering (block disintegration and granular disintegration) is dominant.
  - Exfoliation is very common in deserts.
  - Chemical weathering only takes place by the drawing of strong solutions to the surface by capillary and forms duricrust (a hard compact layer) on the land surface.

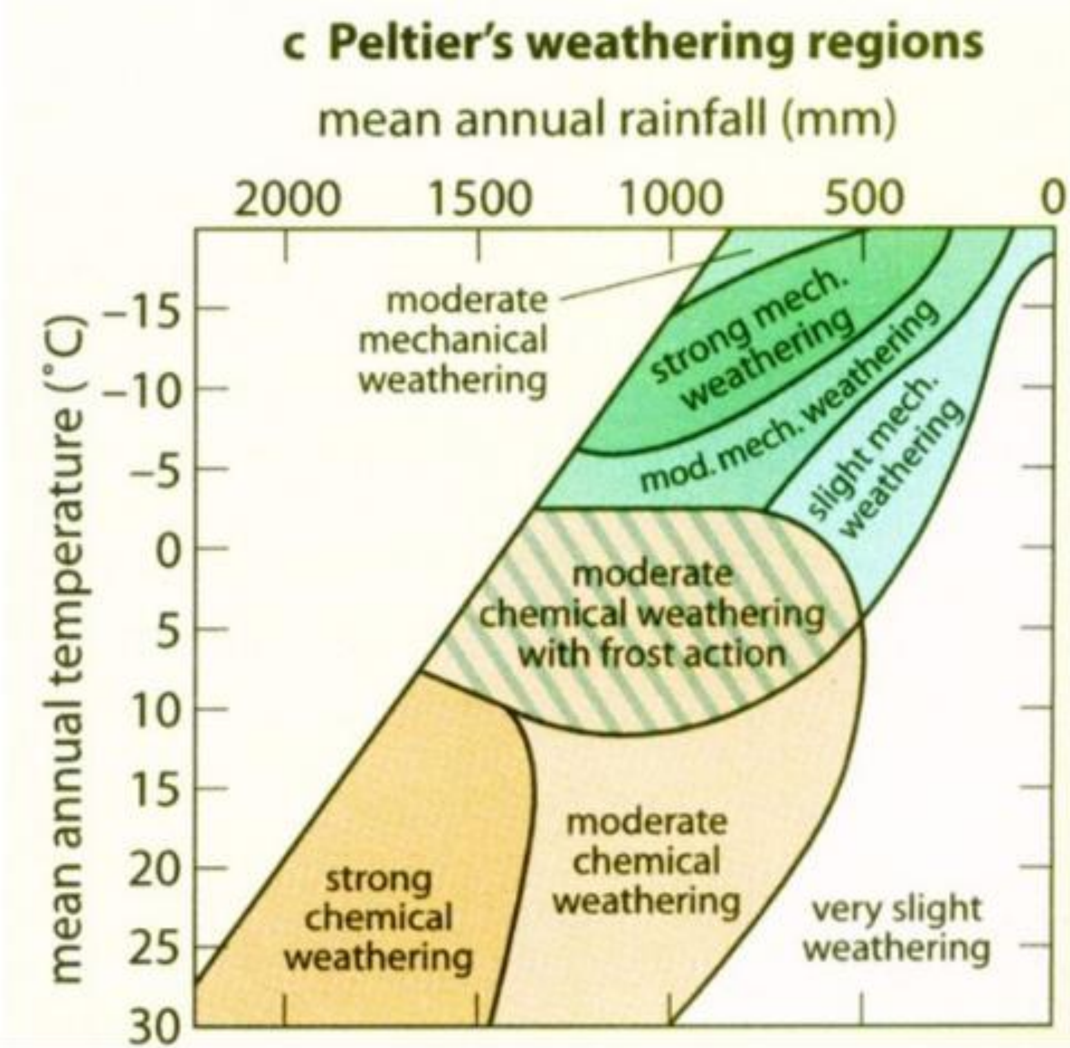
Case study – weathering in desert

- New founding
  - Barton:
    - He found that weathering of the stonework was in general more pronounced in the Delta than higher up the Nile Valley where has the maximum heating and cooling effects.
  - Griggs's experiment:
    - He gave the granite to 90000 fifteen-minutes cycles of alternate heating and cooling over a temperature range of nearly 90°C.
    - He found the rock totally undamaged at the end.
    - When he gave some water in the experiment, the whole block very quickly disintegrated.
  - Chemical weathering involving water was the real destroyer of rocks in the desert regions.

Weathering regions - 1



Weathering regions -2



Chemical Weathering: breakdown as a result of chemical reactions

$$CaCO_3+CO_2+H_2O \text{ ---> } Ca^{2+} + 2HCO^{3-}$$

Mechanical Weathering

Physical breakup

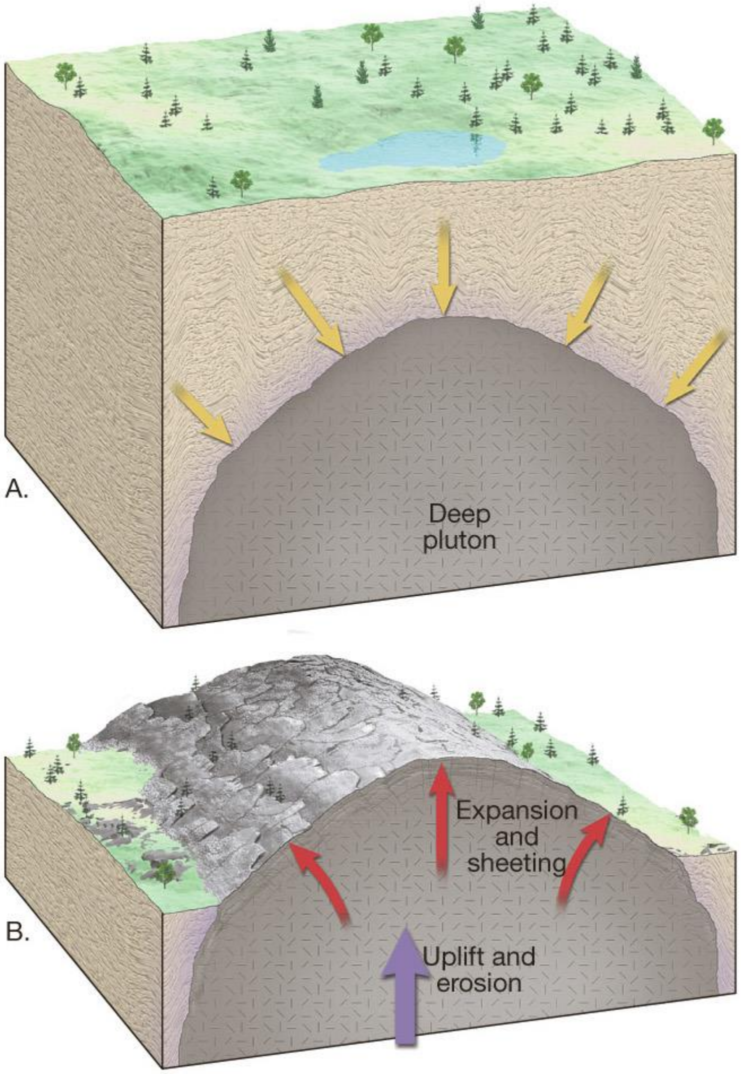
- pressure release
- water: freeze - thaw cycles
- crystallization of salt in cracks
- thermal expansion and contraction

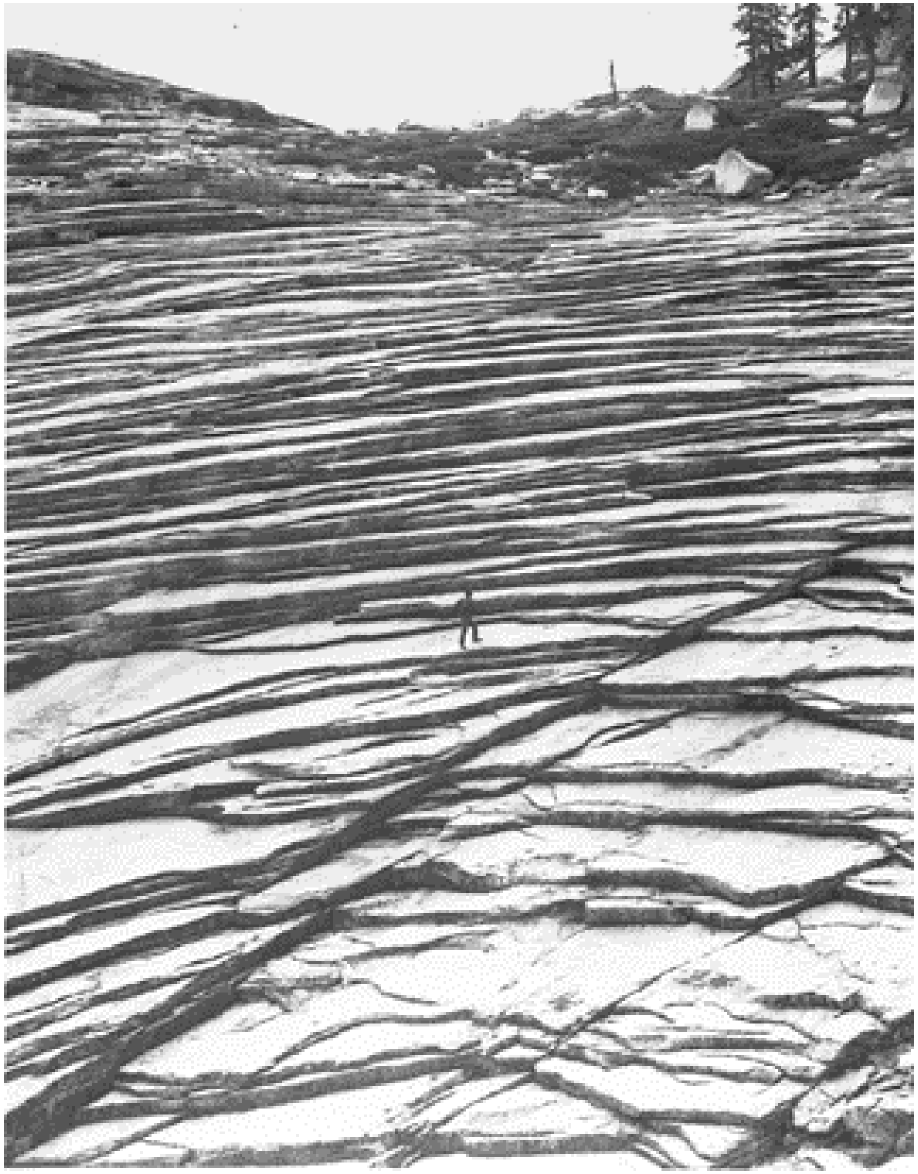
All this increases the total surface area exposed to weathering processes.

Mechanical Weathering

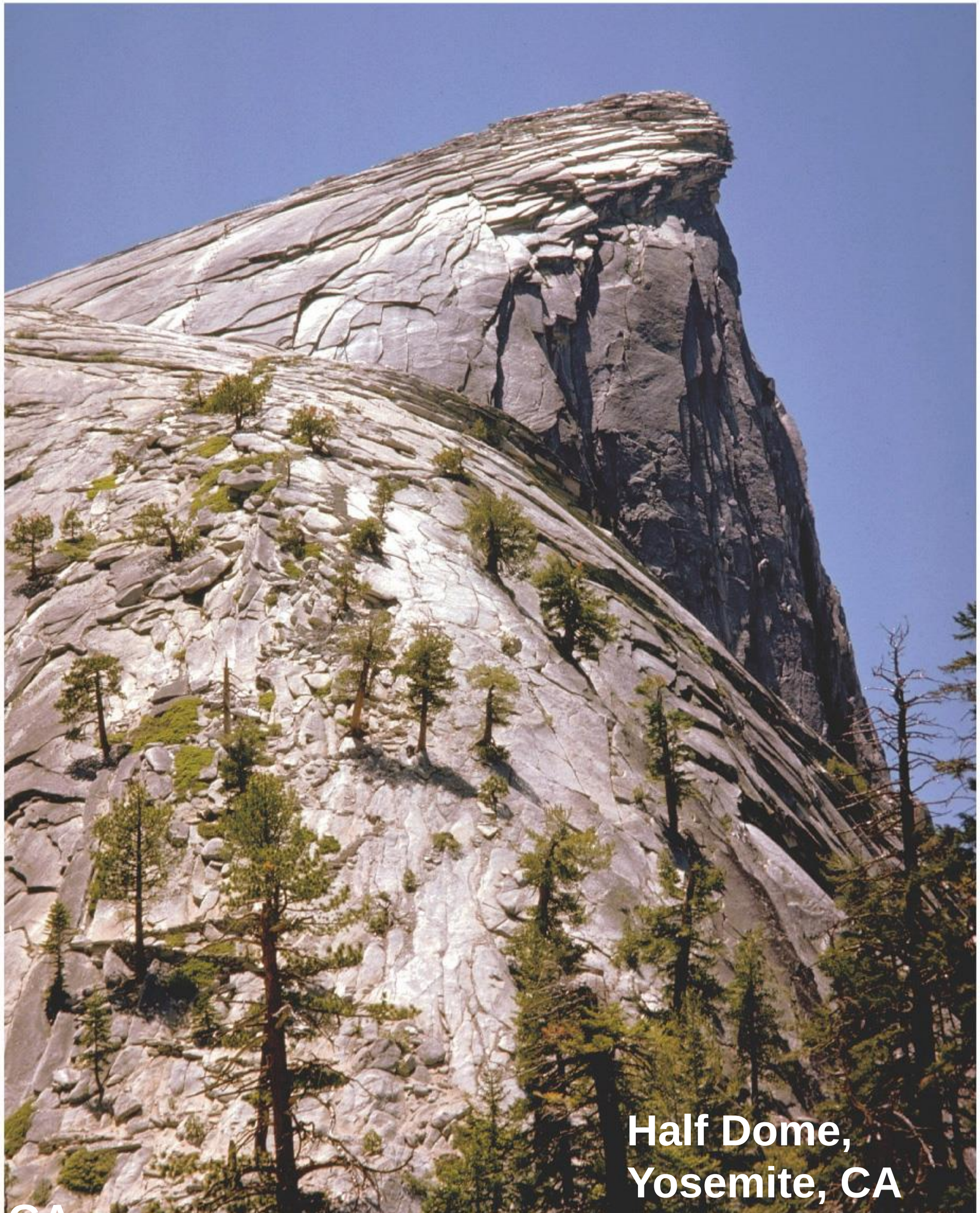
Exfoliation:
Rock breaks apart in layers that are parallel to the earth's surface; as rock is uncovered, it expands (due to the lower confining pressure) resulting in exfoliation.

Mechanical Weathering



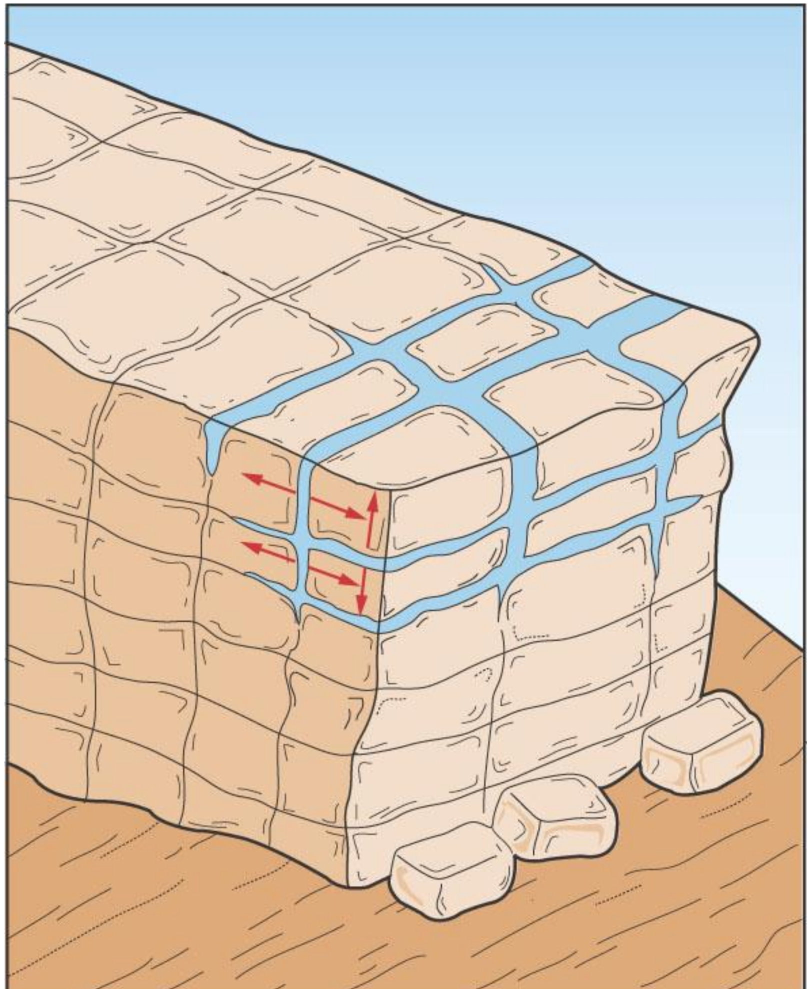


Sheet Joints (Exfoliation)



Half Dome,
Yosemite, CA

Frost Wedging: rock breakdown caused by expansion of ice in cracks and joints



© 2004 Thomson - Brooks/Cole

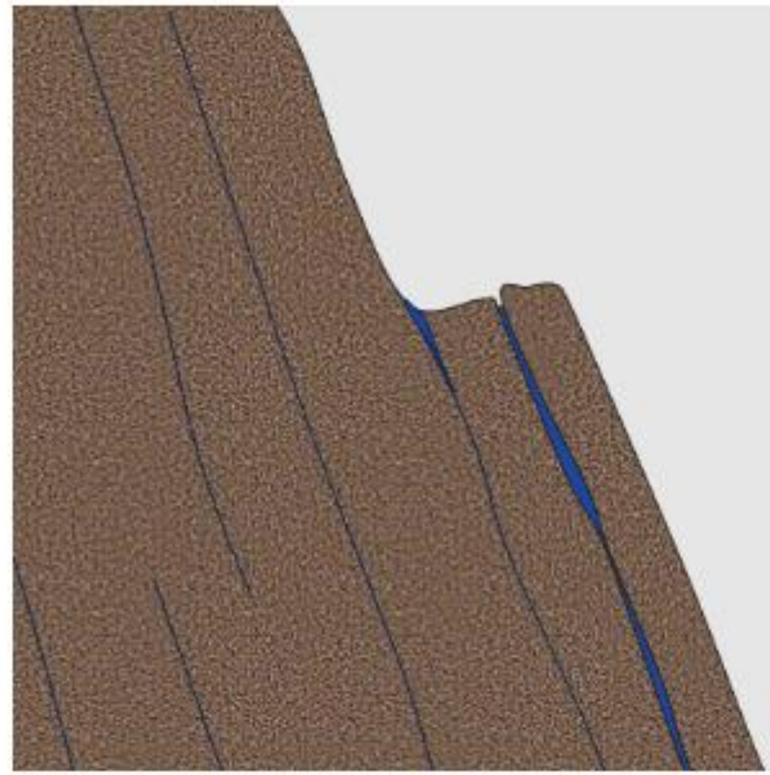


Figure 5.5 The process of frost wedging on a steep slope. Water gets into fractures and then freezes, expanding the fracture a little.

Shattered rocks are common in cold and alpine environments where repeated freeze-thaw cycles gradually pry rocks apart.

Thermal expansion due to the extreme range of temperatures can break rocks in desert environments.

Repeated swelling and shrinking of minerals / rocks with different expansion rates will also shatter rocks.

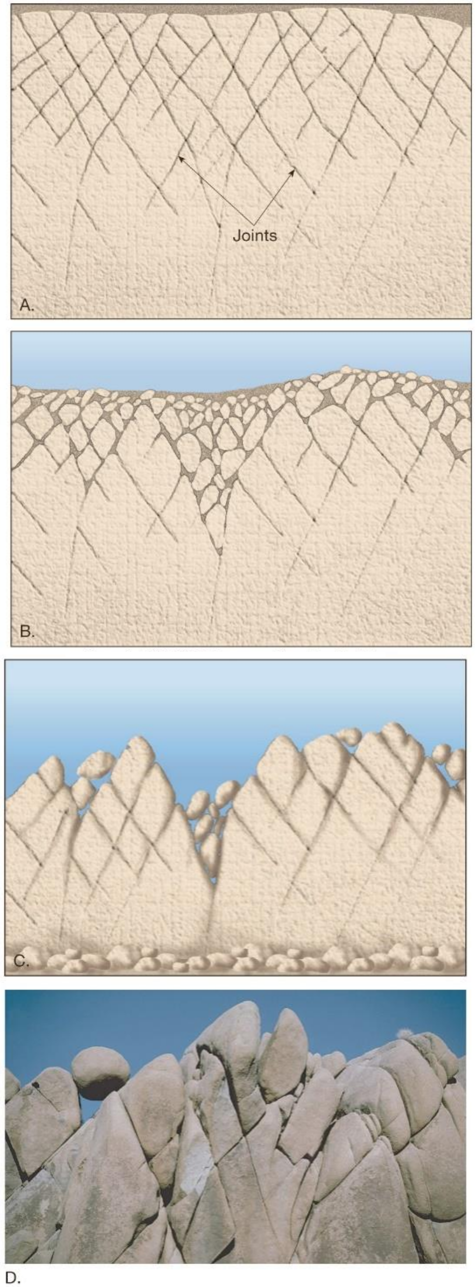
Role of Physical Weathering

1) Reduces rock material to smaller fragments that are easier to transport

2) Increases the exposed surface area of rock, making it more vulnerable to further physical and chemical weathering

Rates of weathering

Joints in a rock are a pathway for water – they can enhance mechanical weathering



Chemical Weathering

<u>Definition</u>: transformation/decomposition of one mineral into another

Mineral breakdown

- carbonate dissolves
- primary minerals --> secondary minerals (mostly clays)

Net loss of elements retained in the soil.

Chemical Weathering

- Water is the main operator:
  - Dissolution
    - Many ionic and organic compounds dissolve in water
      - Silica, K, Na, Mg, Ca, Cl, CO_3, SO_4
  - Acid Reactions
    - Water + carbon dioxide <---> carbonic acid
    - Water + sulfur <---> sulfuric acid
    - H^+ effective at breaking down minerals

Dissolution

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

water + carbon dioxide + calcite dissolve into calcium ion and bicarbonate ion

Biological activity in soils generates substantial CO_2

Bicarbonate is the dominant ion in surface runoff.

Chemical Weathering

- Oxidation
  - Oxygen dissolved in water promotes oxidation of sulfides, ferrous oxides, native metals
- Organic Activity
  - Plant material makes H^+ ions available

Chemical Weathering

- *Hydration*: attachment of water molecules to crystalline structure of a rock, causing expansion and weakness
- *Hydrolysis*: combination of hydrogen and oxygen in water with rock to form new substances

Chemical Weathering

<u>Solution</u>: process by which rock is dissolved in water

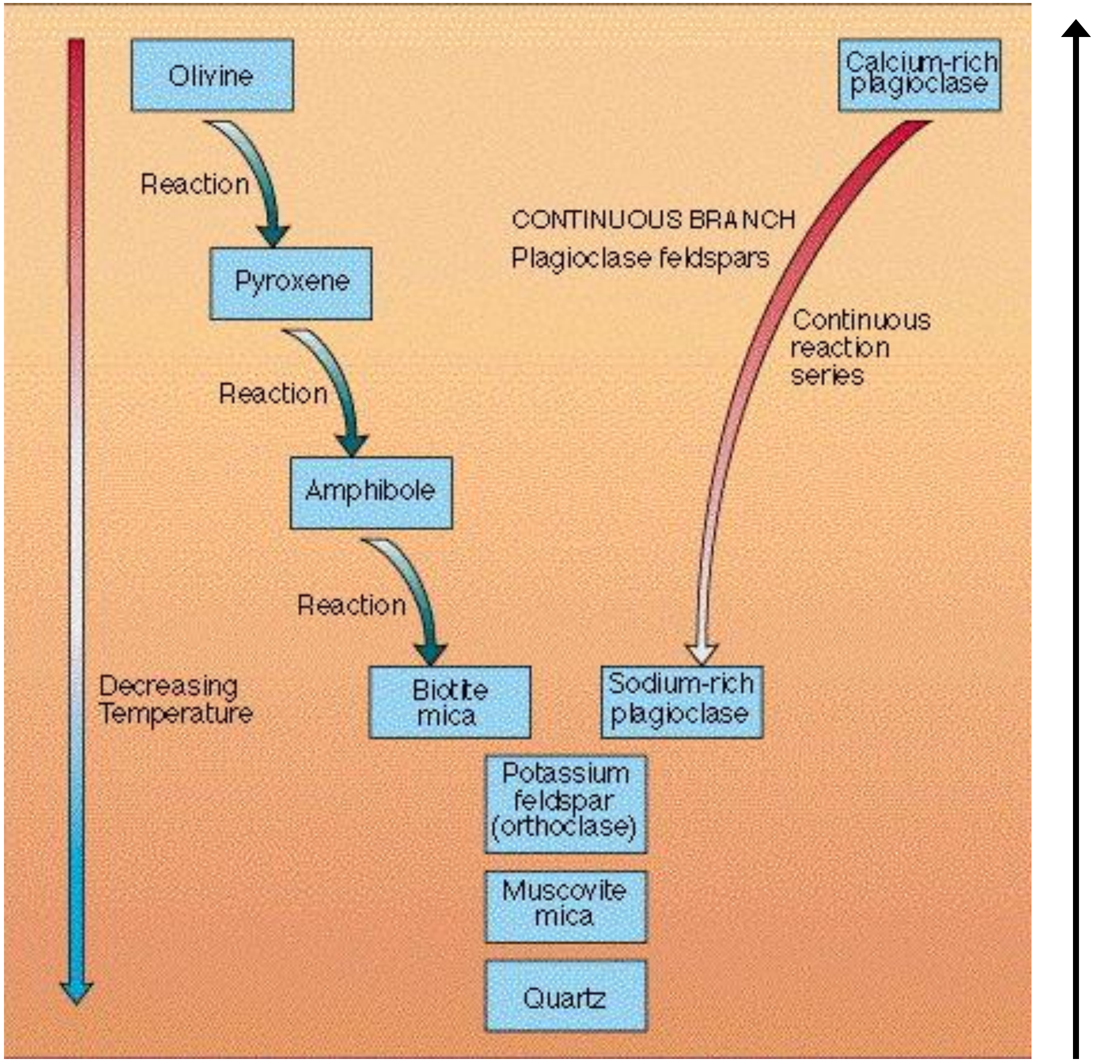
- Is strongly influenced by pH and temperature
- When water becomes saturated, chemicals may precipitate out forming *evaporite* deposits.
- Calcium carbonate (calcite, limestone), sodium chloride (salt), and calcium sulfate (gypsum) are particularly vulnerable to solution weathering.

Resistance to Weathering

First to Crystallize

Bowen's Reaction Series

Last to Crystallize



Fast Weathering

Goldrich Stability Series

Slow Weathering

Olivine/pyroxene to clay

+ H_2CO_3 (acid)

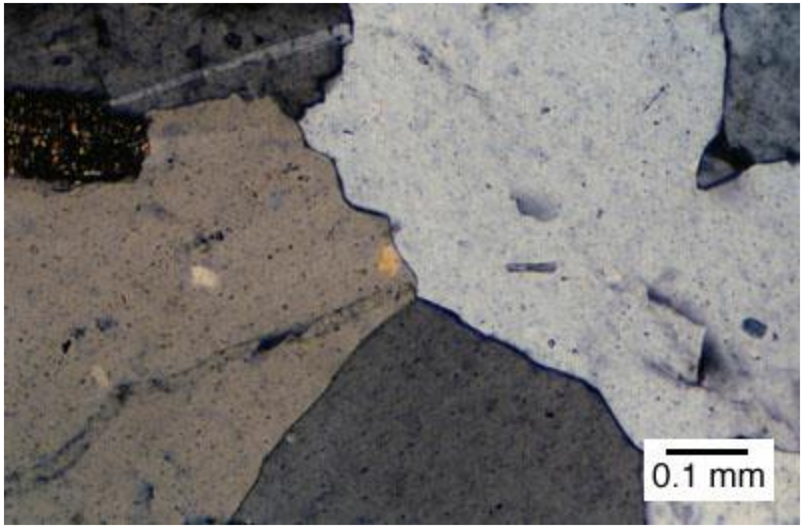
↓

Feldspars to clay

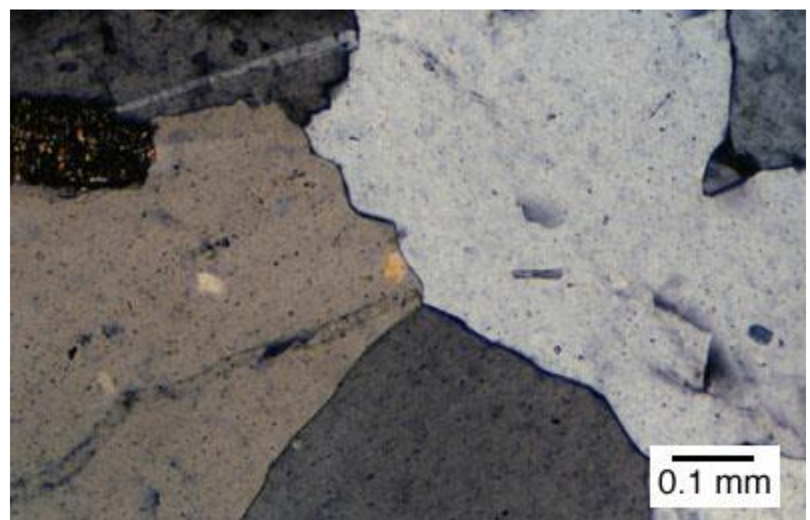
+ H_2CO_3 (acid)

↓

Quartz to quartz (!)



+ anything



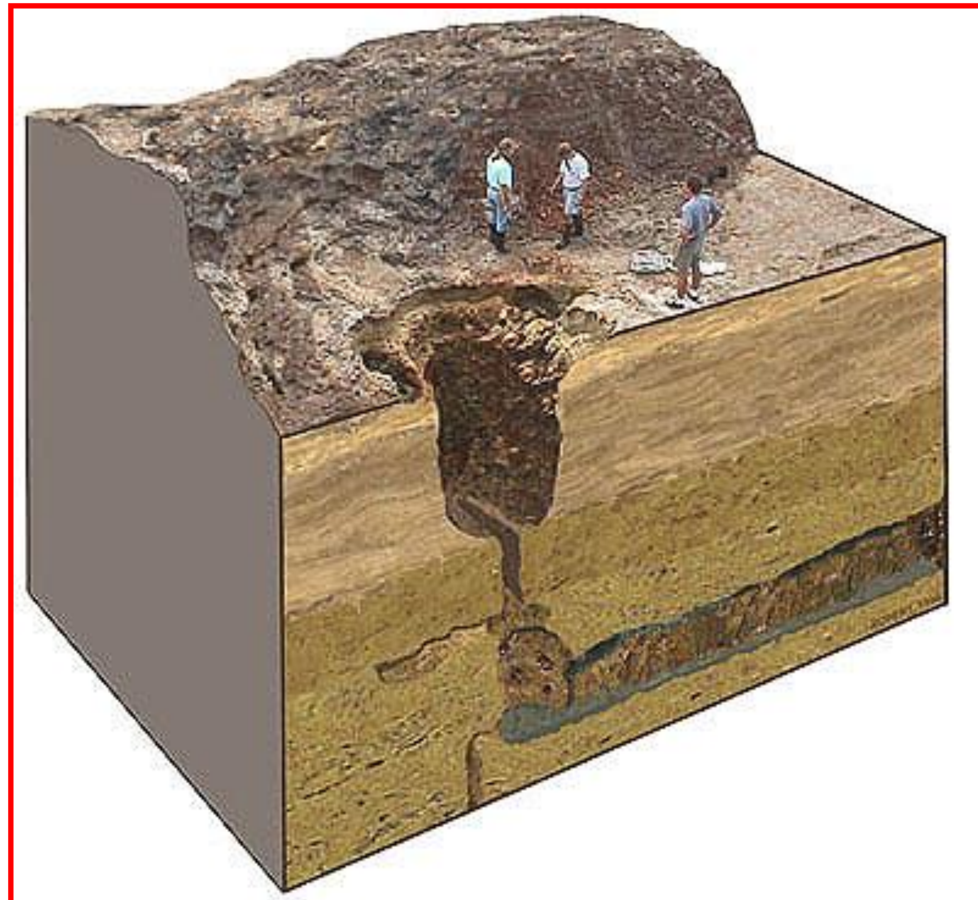
Calcite to …….

+ anything

↓

nothing

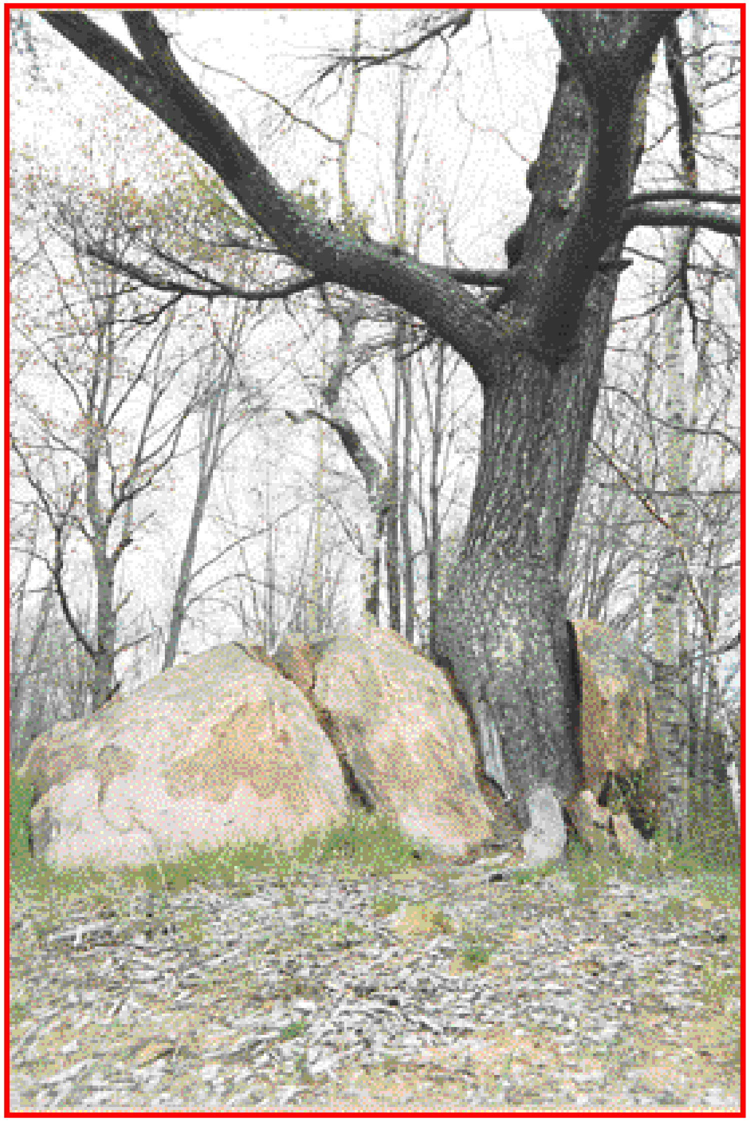
'Karst' landforms develop in areas underlain with limestone



Biological Weathering

Can be both chemical and mechanical in nature.

- roots split rocks apart
- roots produce acids that dissolve rocks.
- tree throw
- burrowing animals



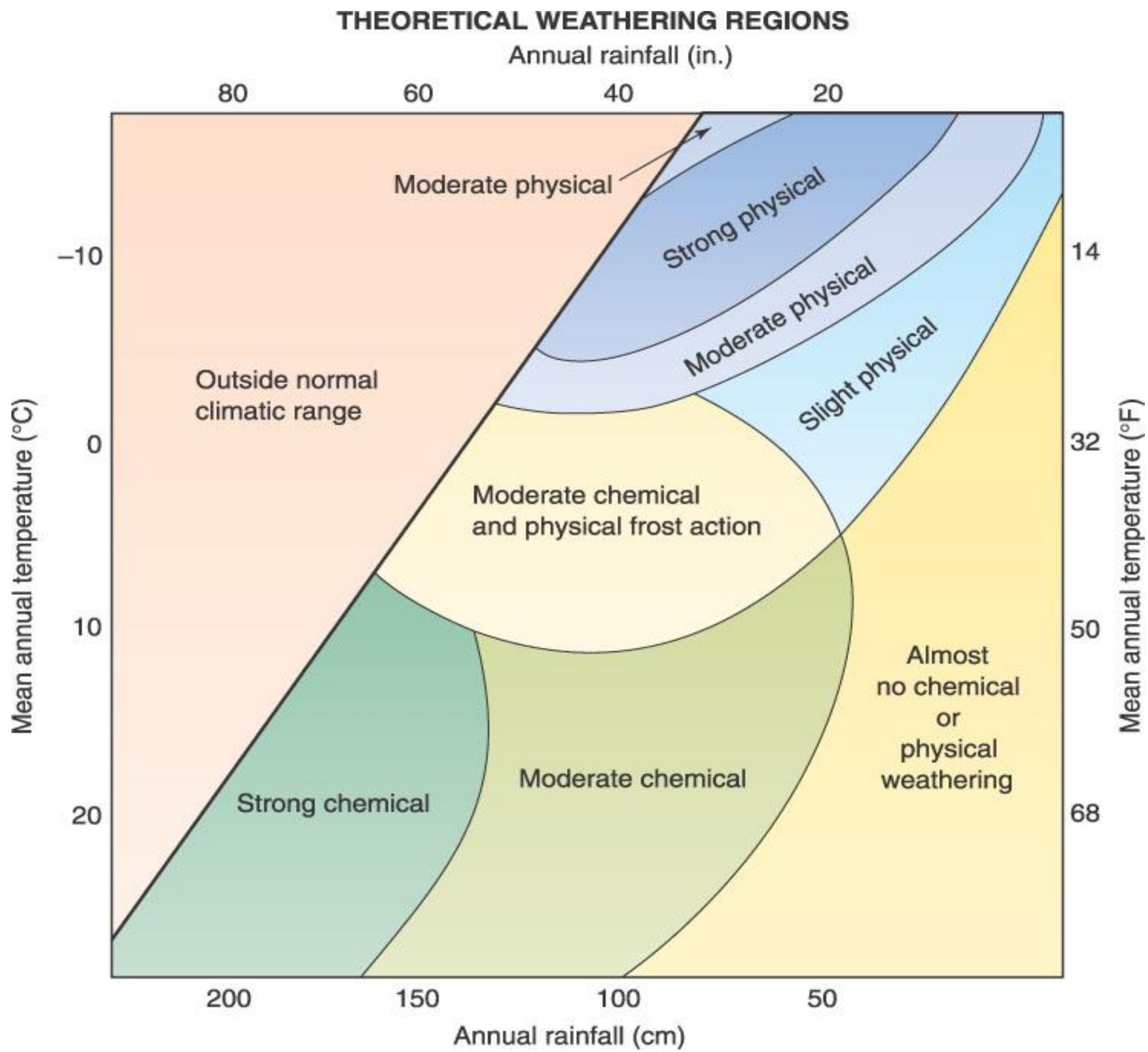
Weathering

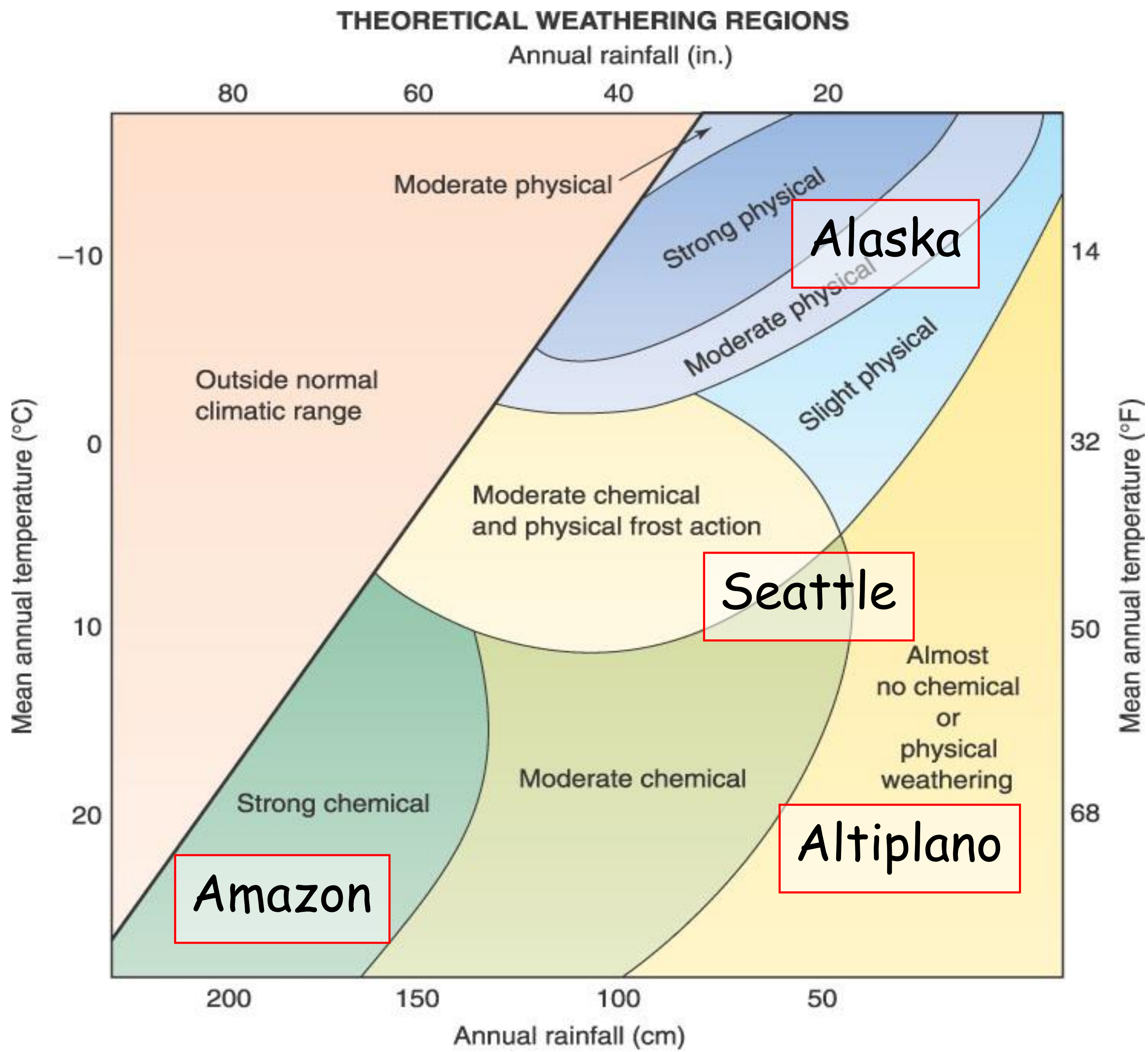
- Climate
  - Temperature and moisture characteristics
  - Chemical weathering
    - Most effective in areas of warm, moist climates – decaying vegetation creates acids that enhance weathering
    - Least effective in polar regions (water is locked up as ice) and arid regions (little water)
  - Mechanical weathering
    - Enhanced where there are frequent freeze-thaw cycles

Mechanical and Chemical Weathering

– Fracturing, disintegration caused by mechanical weathering exposes more surface area.

– Greater surface area, means more places for chemical action to occur.


THEORETICAL WEATHERING REGIONS
Annual rainfall (in.)
80
60
40
20
Moderate physical
Strong physical
Moderate physical
Slight physical
Outside normal
climatic range
Moderate chemical
and physical frost action
Almost
no chemical
or
physical
weathering
Strong chemical
Moderate chemical
−10
0
10
20
Mean annual temperature (°C)
14
32
50
68
Mean annual temperature (°F)
200
150
100
50
Annual rainfall (cm)


THEORETICAL WEATHERING REGIONS
Annual rainfall (in.)
80
60
40
20
Moderate physical
Strong physical
Alaska
Moderate physical
Slight physical
Outside normal climatic range
Moderate chemical and physical frost action
Seattle
Almost no chemical or physical weathering
Moderate chemical
Strong chemical
Altiplano
Amazon
–10
0
10
20
Mean annual temperature (°C)
14
32
50
68
Mean annual temperature (°F)
200
150
100
50
Annual rainfall (cm)