Metamorphic Rocks

Metamorphism= change of form

- Any rock that undergoes conditions unlike those of its formation becomes metamorphosed
  - These new conditions are due to deformation of rocks during plate movements and/or because of proximity with magma sources
- Metamorphic is a gradual progression
  - from low-grade to high-grade
- The rock remains ~solid (essentially)
- The temperature ranges between ~250°C (top temperature for diagenesis) 650°C (lowest temperature for magmas)

Metamorphism agents and environments

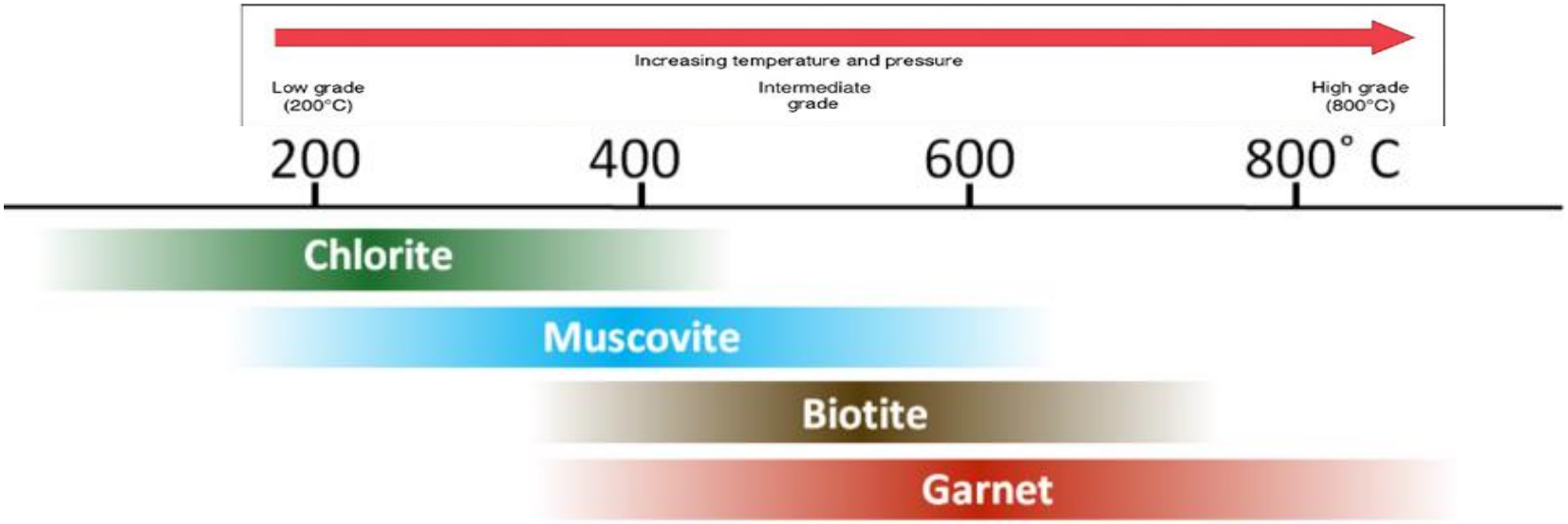
metamorphic agents = can change a rock. They are:

- Heat
- Pressure
- Presence of volatiles

- **The metamorphic environments =** sections of the lithosphere where the changes happen. They are:
  - Contact
  - Regional
  - *Additional metamorphic environments can be generated by presence of fluids (Hydrothermal); pressure from impact of meteorites on the Earth's surface and even from significant dept of sediment accumulation.*

“index” minerals of metamorphism

- Chemical elements can re-combine in the metamorphic rock, forming new minerals under a certain range of conditions of Pressure and Temperature.
- Metamorphic rocks of different degree can have different minerals. Here some important ones:

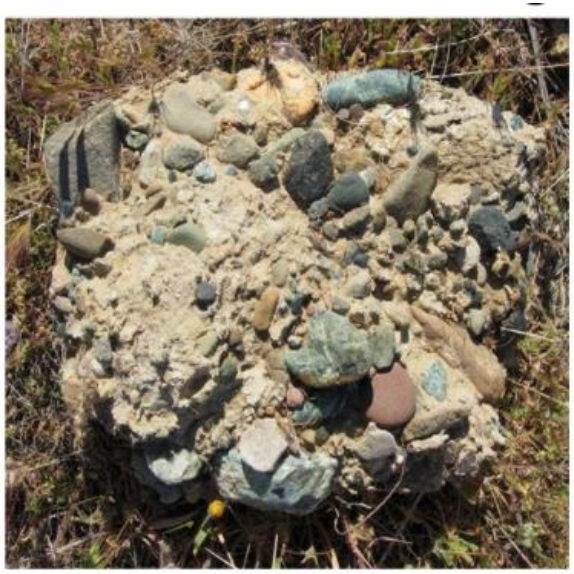


Metamorphic index minerals: garnet

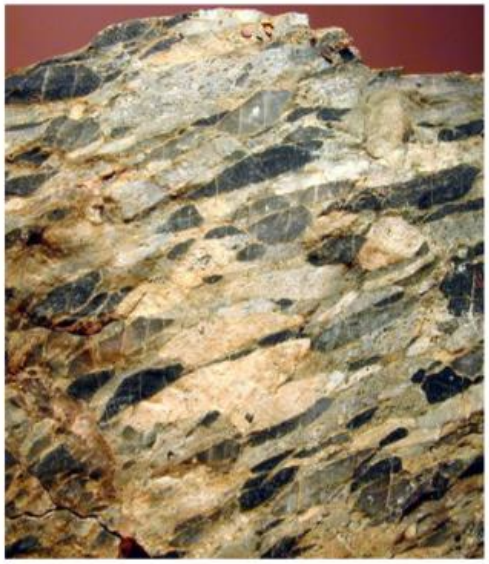
- ***Garnet*** *a 3D framework silicate* – forms at intermediate to high metamorphic conditions

Metamorphic rocks characteristics

- parent rock or protolith is the rock BEFORE metamorphism
- During metamorphism, the overall chemical composition of the rock remains the same: If the rock is made of calcite to start with (=limestone) after metamorphism it will still be made of calcite!
- The rock texture might change depending on the environment



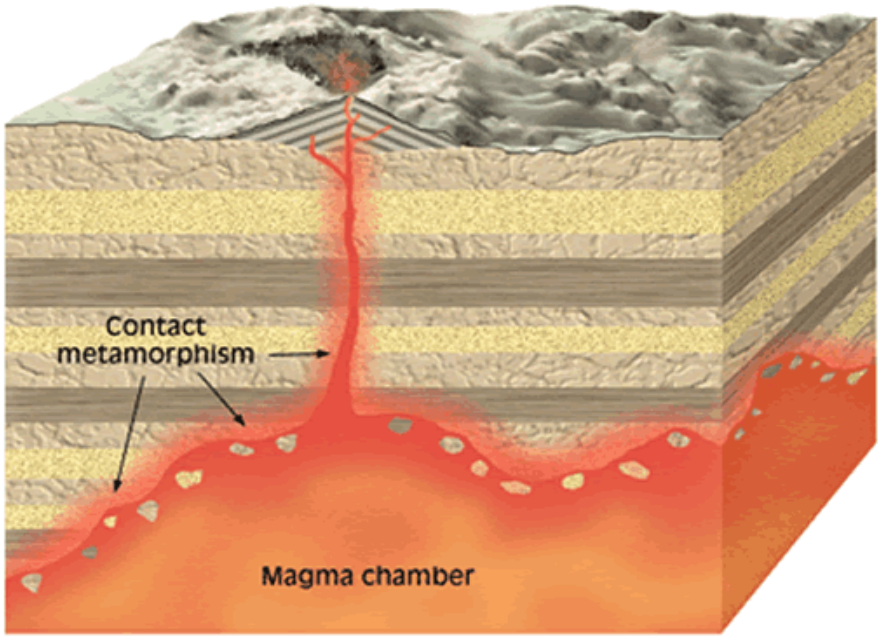
Protolith conglomerate



Foliated Metaconglomerate

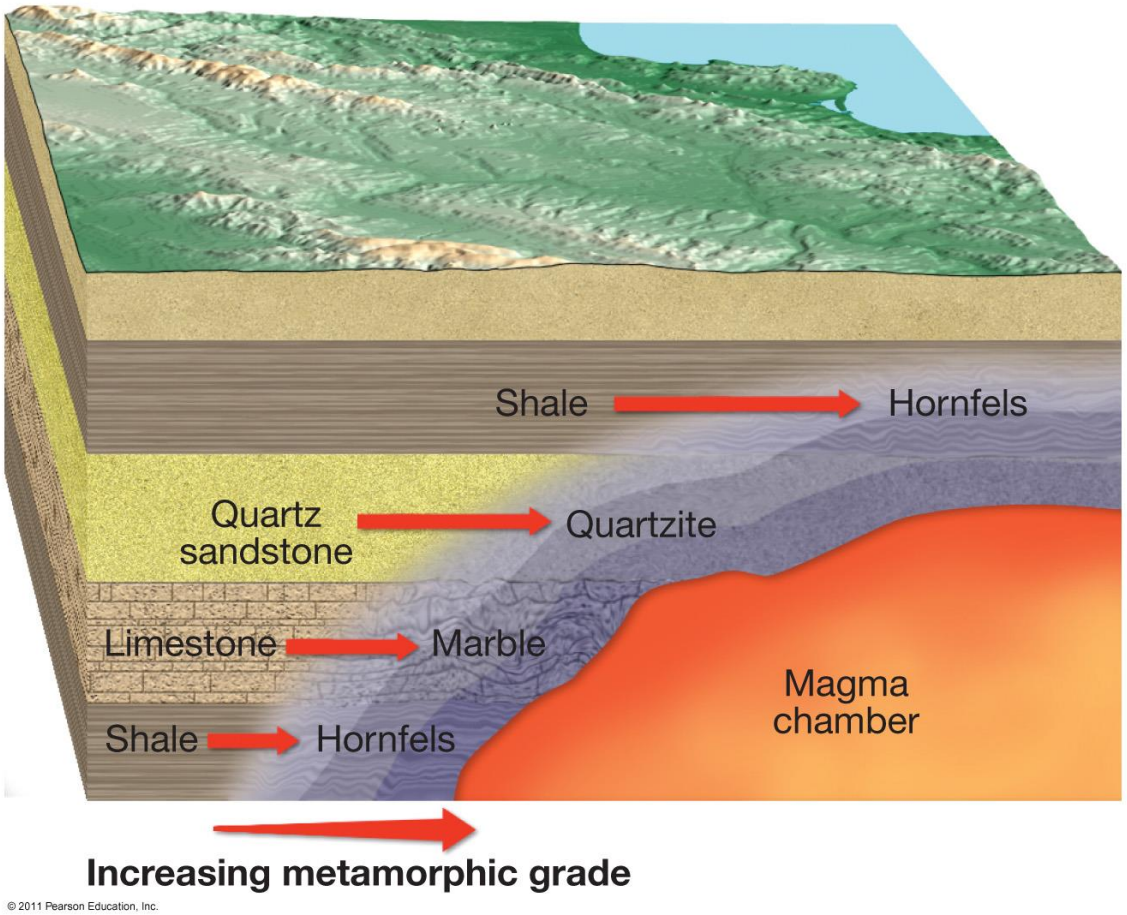
Agents of metamorphism **1- Heat**

- Heat is energy; heat drives the chemical reactions that change minerals' crystalline structure
- Most common source of Heat is Magma
- The rocks surrounding the magma become metamorphosed by the heat



Heat →Contact (thermal) environment

The degree of change (=metamorphic grade) will be greater near the source of heat



Example of contact metamorphism: the mafic dike “baked” the surrounding rocks

Photo by A. Herrold

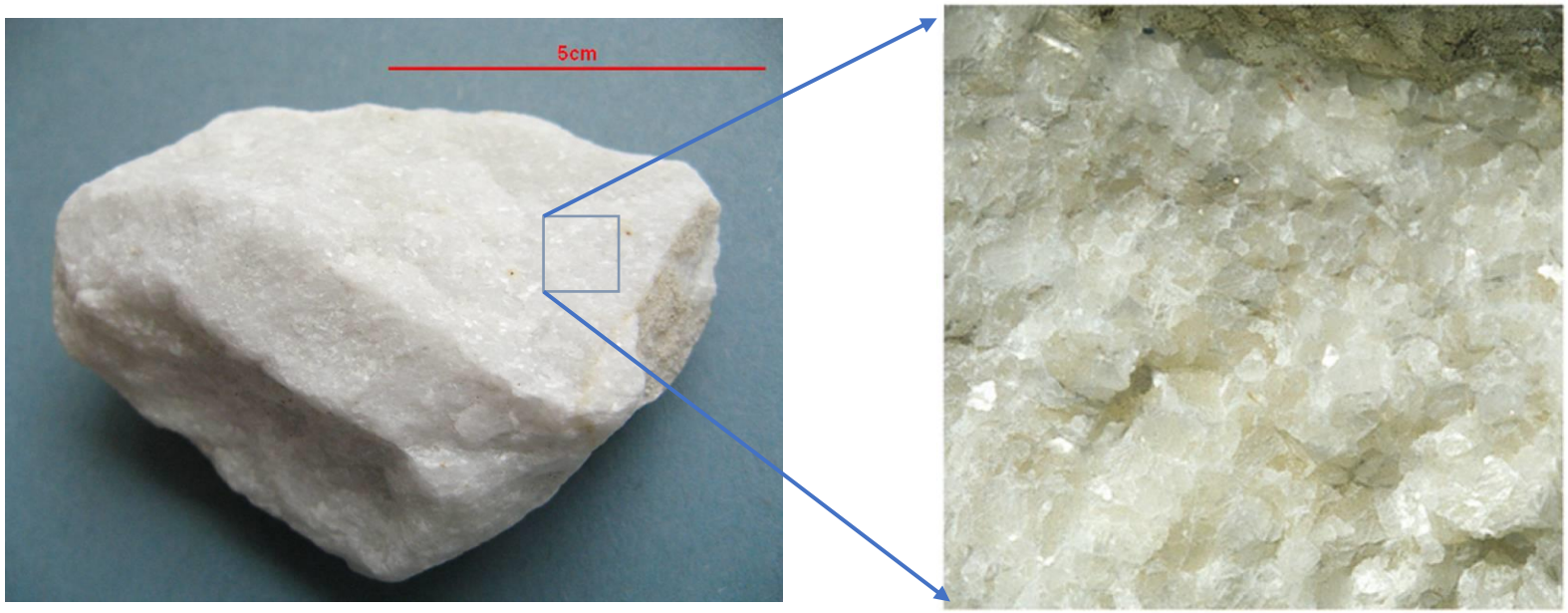
metamorphic textures by contact metamorphism

- The heat induces recrystallization of the minerals
  - The newly crystallized calcite form a compact fabric of crystals, all of ~ the same size

Marble

Protolith: limestone

Like calcite that can have any color, marble can also be of many different colors



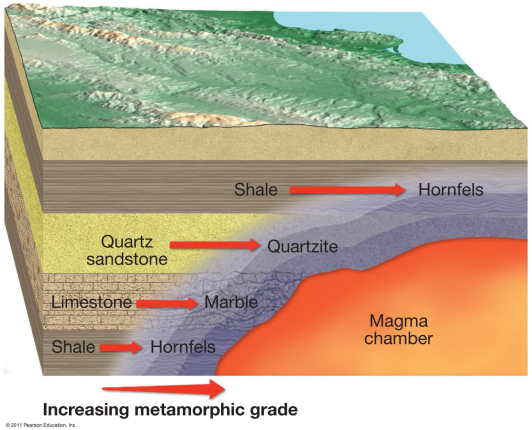

Carrara Marble quarry, Italy

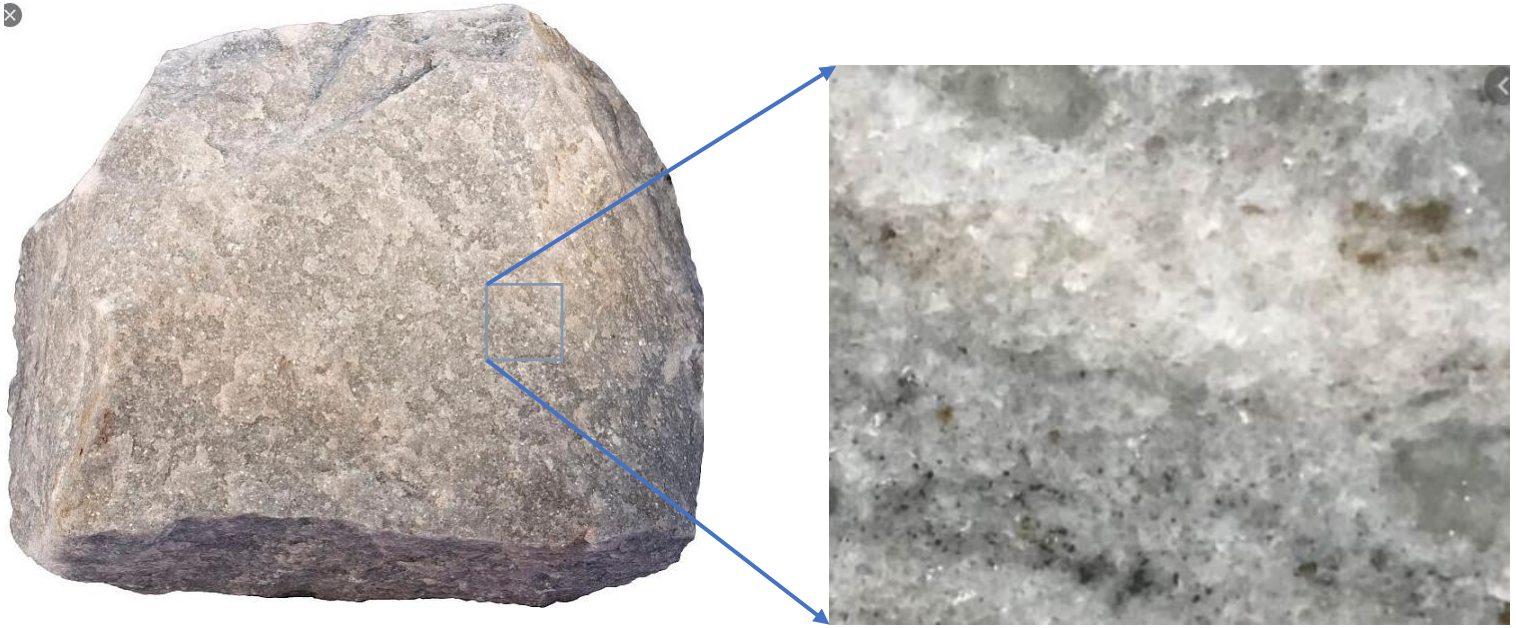
Quartzite

Protolith: quartz sandstone

Quartzite is made of densely packed recrystallized quartz

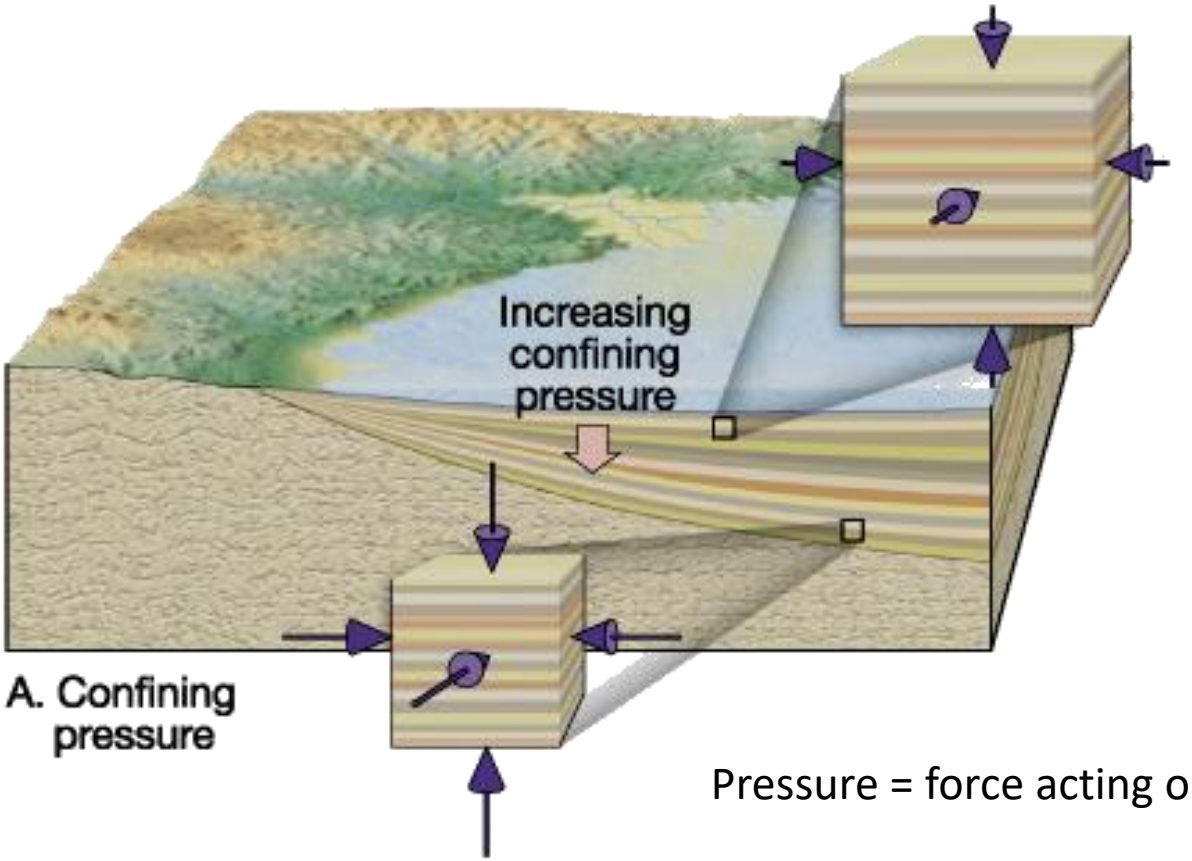
because it is made of quartz that can have any color, quartzite too can also be found in many different colors





Agents of Metamorphism: 2 - pressure

- Confining Pressure
  - Increases with depth in the lithosphere
  - It is equal in all directions (example, like the hydrostatic pressure).

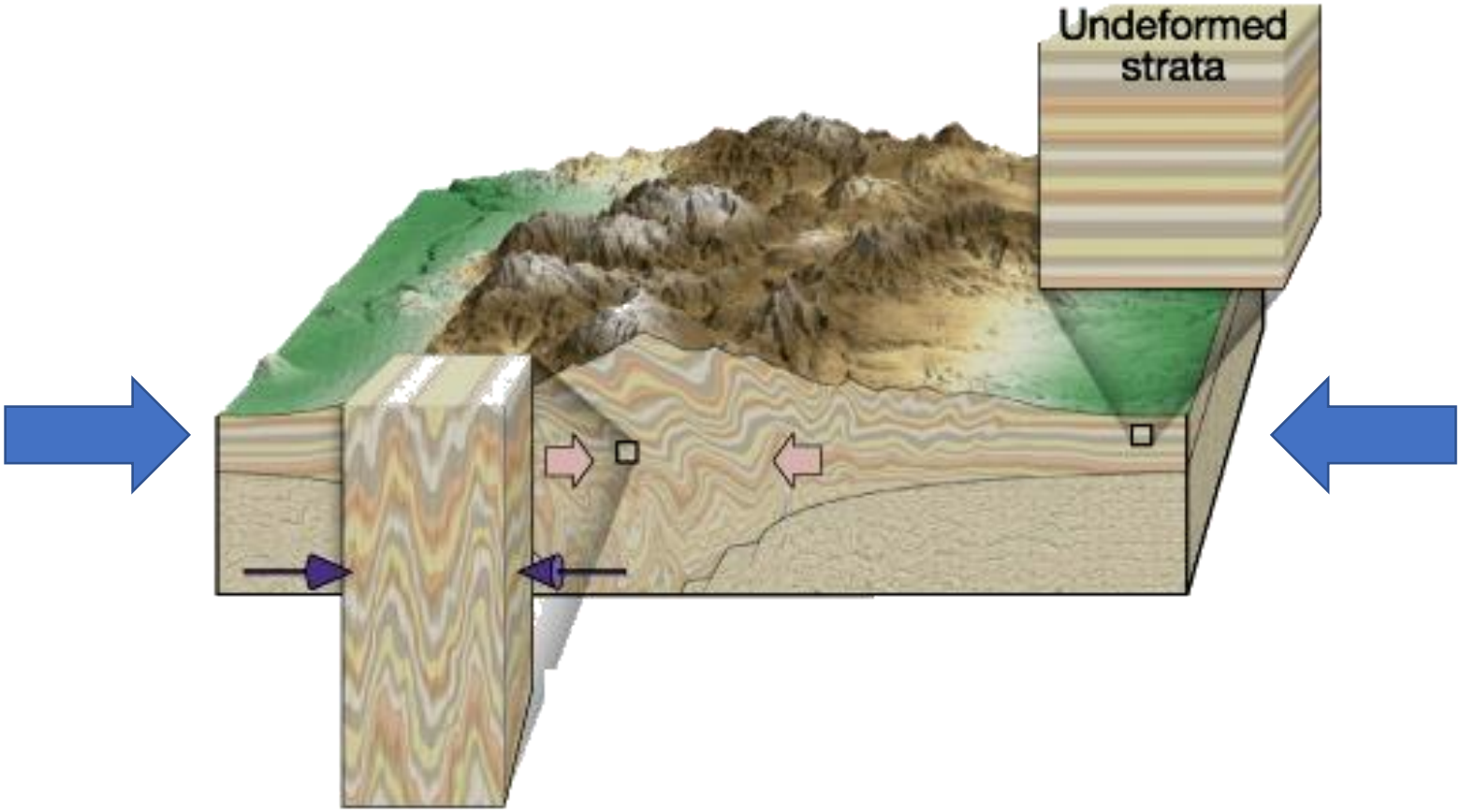


Pressure = force acting on a surface

Differential Pressure

Unequal in different directions – Caused mostly by movements of the plates

Also referred to as stress



Regional metamorphic environment

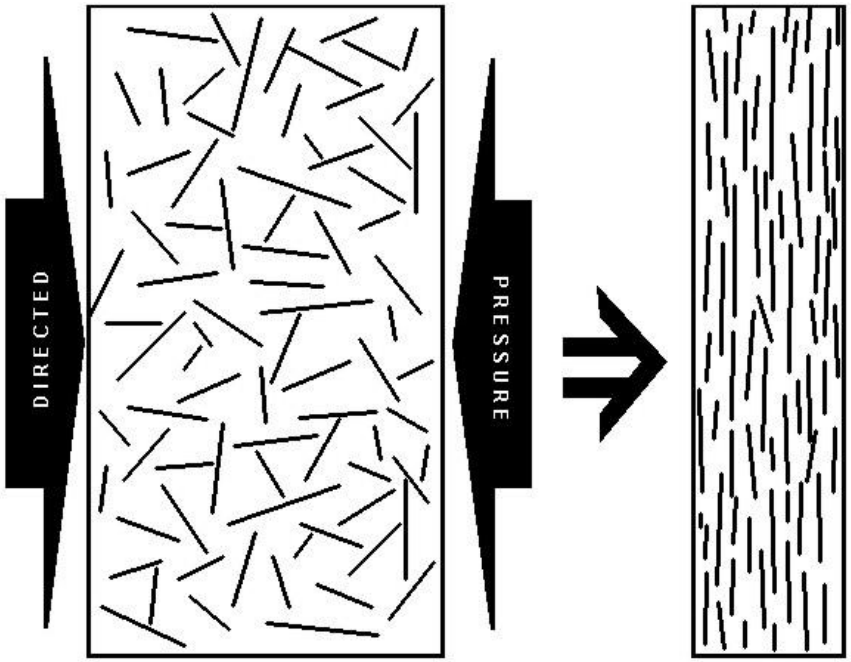
- Occurs when lithospheric plates collide to form mountains ranges (it's plate tectonics at work!)
- Differential pressure deforms rocks
- Regional metamorphism generates the greatest volume of metamorphic rock

Zagros Mts. SE Turkey/Iran

Alps of Switzerland

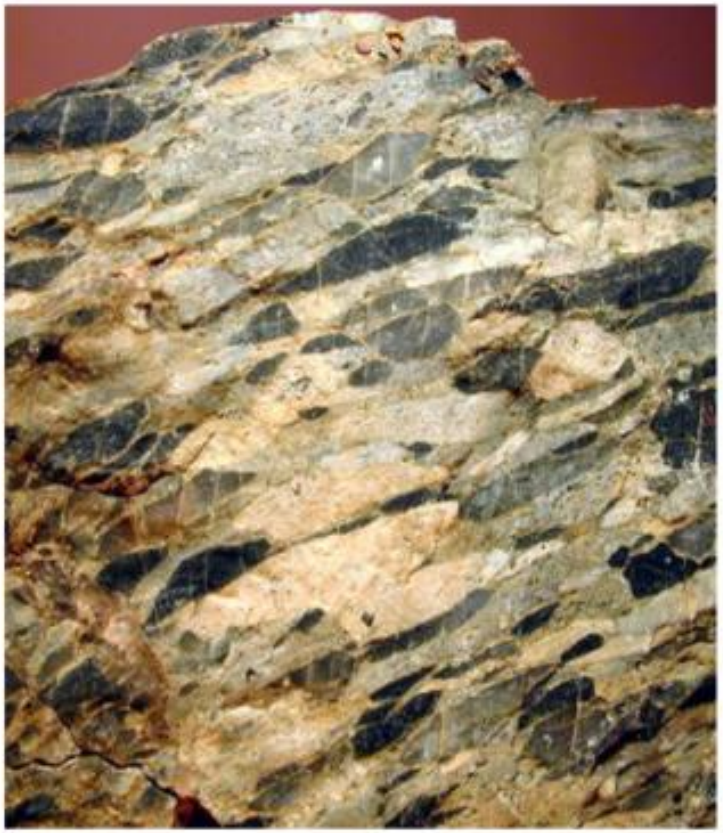
Texture changes by differential pressure: Foliation by rotation(mechanical)

- ✓ Rotation of platy and/or elongated minerals
- ✓ Produces rock cleavage, the rock can split in flat pieces
- ✓ Foliation is typical of differential pressure that develpops at convergent plate boundaries



Example of a conglomerate that experienced foliation

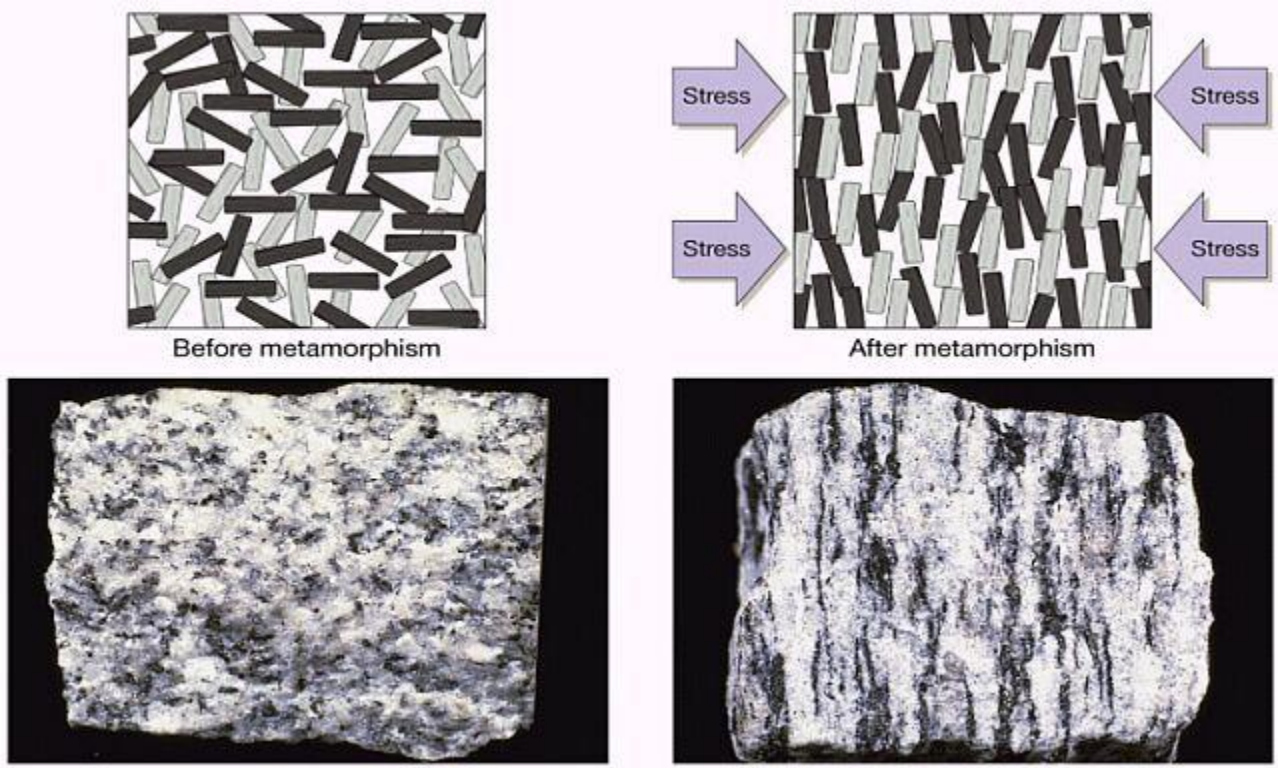
Conglomerate



Metaconglomerate

Foliation by recrystallization

- ✓ For this type of foliation, the crystals “rebuild” themselves in the direction perpendicular to the stress



Common metamorphic foliated rocks: SLATE

- From low-grade metamorphism of mudstone (shale or siltstone) = very fine-grained made of clay minerals
- Mechanical foliation produces rock cleavage = Surface along which the rock splits easily

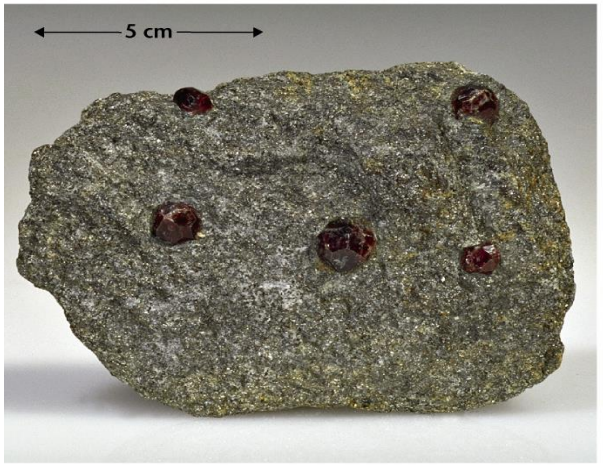
PHYLLITE

- If the metamorphic grade increases → Intermediate grade
  - Slate protolith turns into a phyllite
- Composed mainly of fine crystals of micas + clay
  - Exhibits rock cleavage
  - Glossy sheen and wavy surfaces

SCHIST

If the metamorphic grade increases → intermediate to high grade

- Phyllite protolith turns into a schist
  - Platy minerals – like mica – predominate
  - May contain index minerals like garnet



Fairfax campus is built on this type of rock!

GNEISS

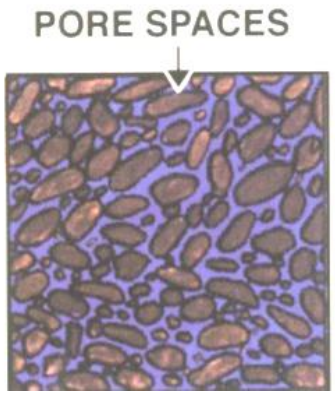
If the metamorphic grade increases → high grade

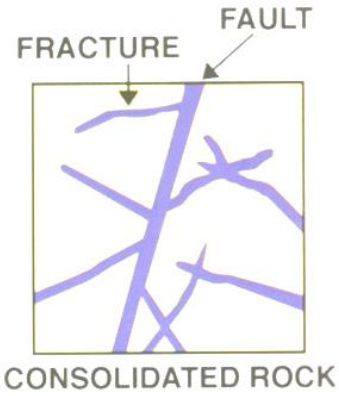
- Protolith sandstone or almost any igneous rock

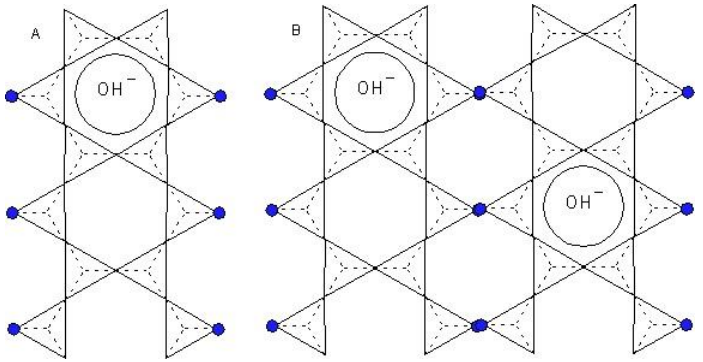
- Silicate minerals ricrystallize: the migrating ions produce the irregular bands of foliation

Agents of metamorphism: **3 - fluids**

- Rocks do contain fluids
- Fluids can be stored in the pore spaces of sedimentary rocks, in rock fractures and even in the crystalline structures



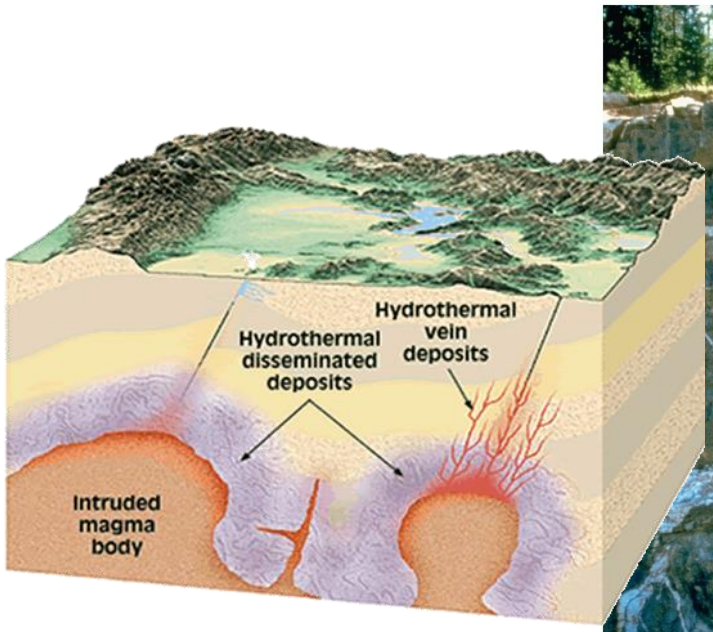




- When rock conditions change, fluids enhance migration of ions → help existing minerals recrystallize

Hydrothermal metamorphic environments

- NEAR a body of magma, the volatiles that do not escape nor find a way to make a pegmatite flush the “country rock with hot ion-rich fluids
- These fluids form networks of fractures in the rocks
- The fractures fill up with the fluids interacting with the surrounding rocks and forming veins of new minerals



Impact (shock) metamorphism

- Impact metamorphism indicates the effects produced by the collision of a meteorite with Earth's surface.
- The collision can produce fractures, fragmentation, deformation, recrystallization of the rocks, at times even melting of rocks/soil at the contact point.

ABOVE: A variety of tektites from the Indochinese Peninsula, the Philippines, the Czech Republic, Texas, USA and Georgia, USA.

Fossil fuels

Technically speaking, these are Not rocks, but they undergo the same processes that form sedimentary and metamorphic rocks

COAL

- Technically not a rock, formed mostly from land plants : NOT MINERALS
  - Step 1: the right environment of formation: wet swamp with trees and calm water.

Step 2: Peat

Peat forms in wetlands, from the accumulation of partially decayed vegetation.

Step 3: Lignite

Forms when peat is subjected to increased vertical pressure from accumulating sediments during diagenesis

Step 4: Bituminous Coal

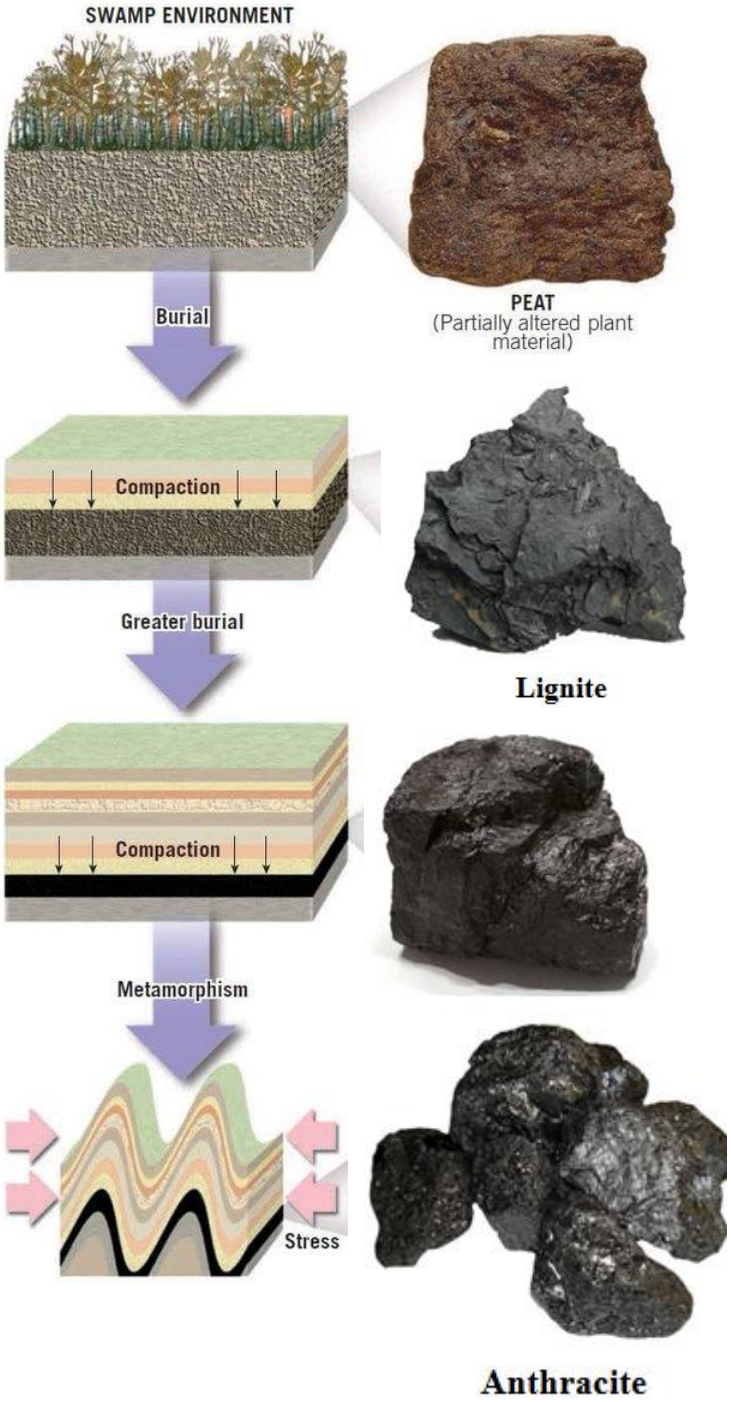
Additional pressure over time compact further the coal.

Bituminous coal contains a mix of 60-80% carbon, oxygen, hydrogen and nitrogen, plus impurities like sulfur

Step 5: Anthracite

formed during orogeny, when the rocks that contain it become part of mountain building, when the pressure are the highest.

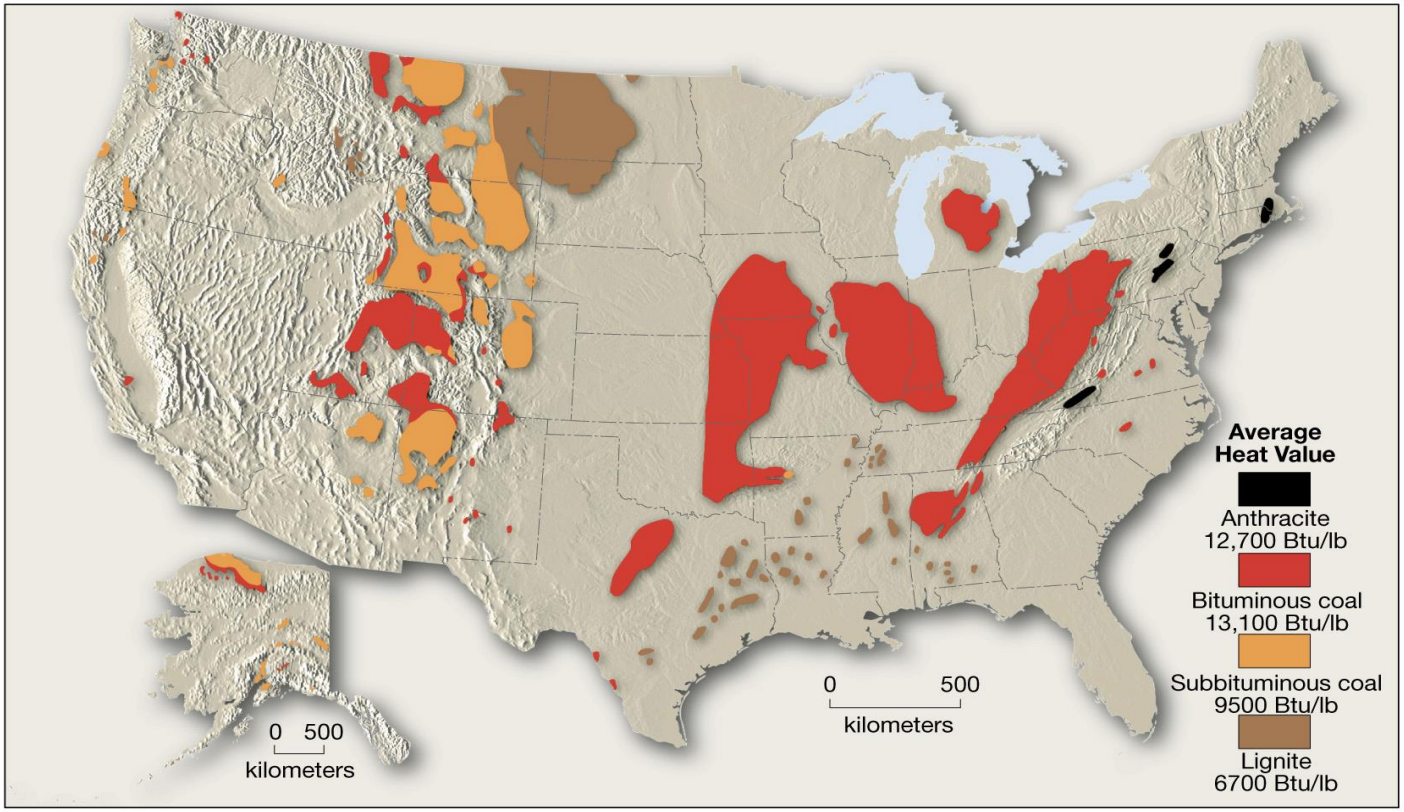
It has a carbon content of 92-98%, it burns most efficiently



Types of coal from increasing pressure and temperature

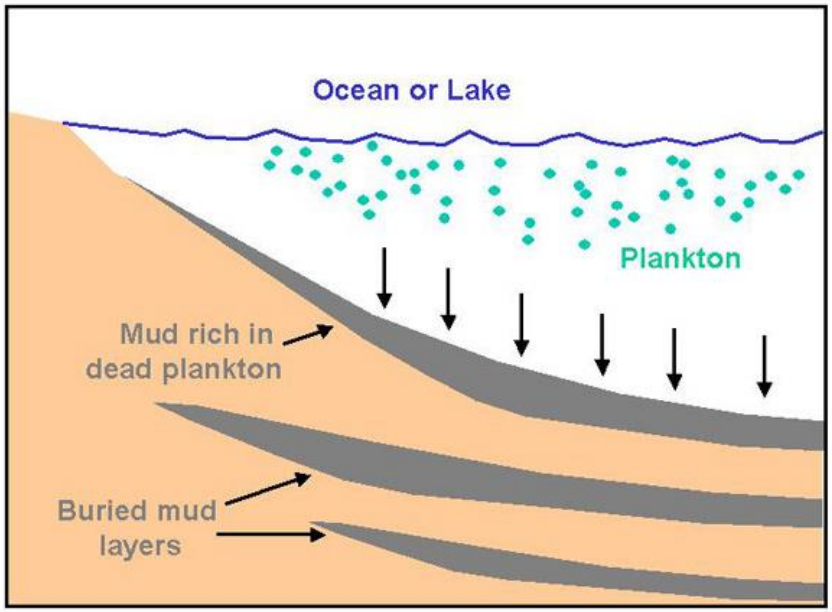
Coal resources - USA

- Areas that have experienced the highest metamorphic deformation have the highest quality anthracite



Oil and natural gas formation

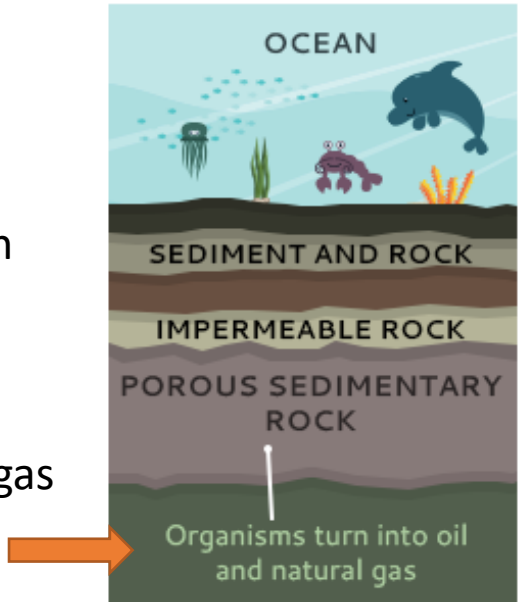
- Derived from the remains of marine plants and animals, mostly plankton, deposited in oxygen poor bays of depressions of shallow marine environments (the shelf)
- Diagenesis transforms the microscopic organisms into oil and gas
- The sedimentary rock in which oil and gas form is called Source rock

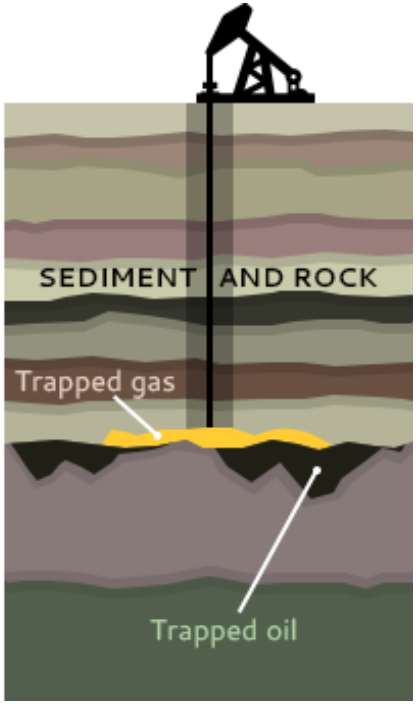


Oil and Natural gas formation: source rocks

- The source rock is a fine-grained sedimentary rock, shale or micrite limestone, rich in organic matter, which can generate and release enough hydrocarbons to form an accumulation of oil or gas
- During diagenesis, the remains of algae can transform into oil and, at higher temperatures, into natural gas.

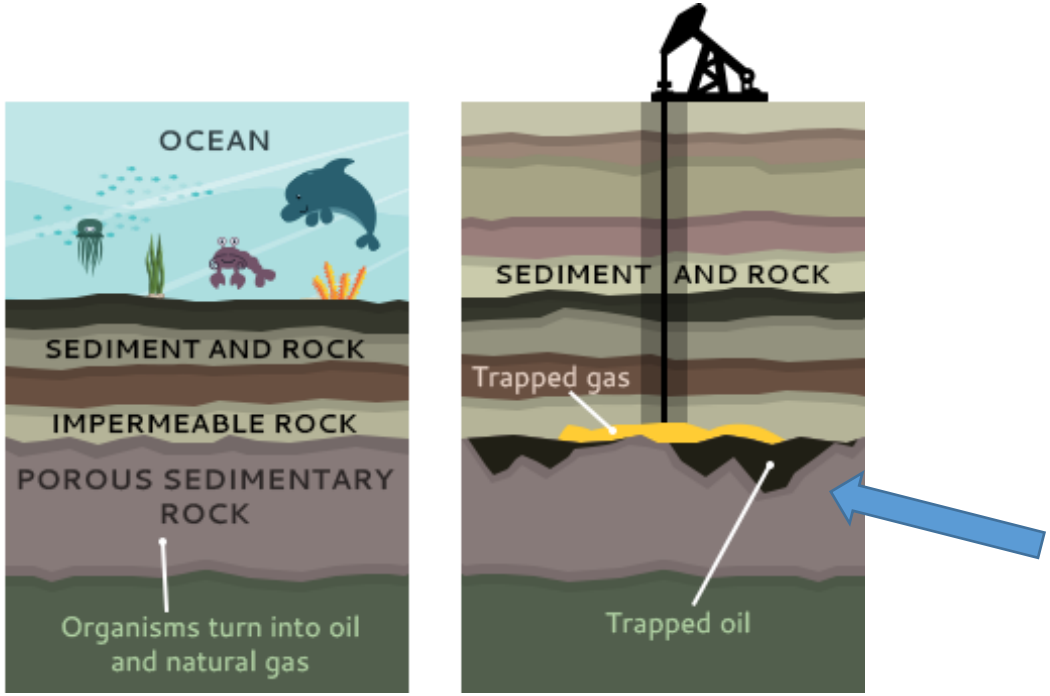
Source rock
The transformation happens at depth greater than 2 km, and temperature over 65C, at 150C gas forms





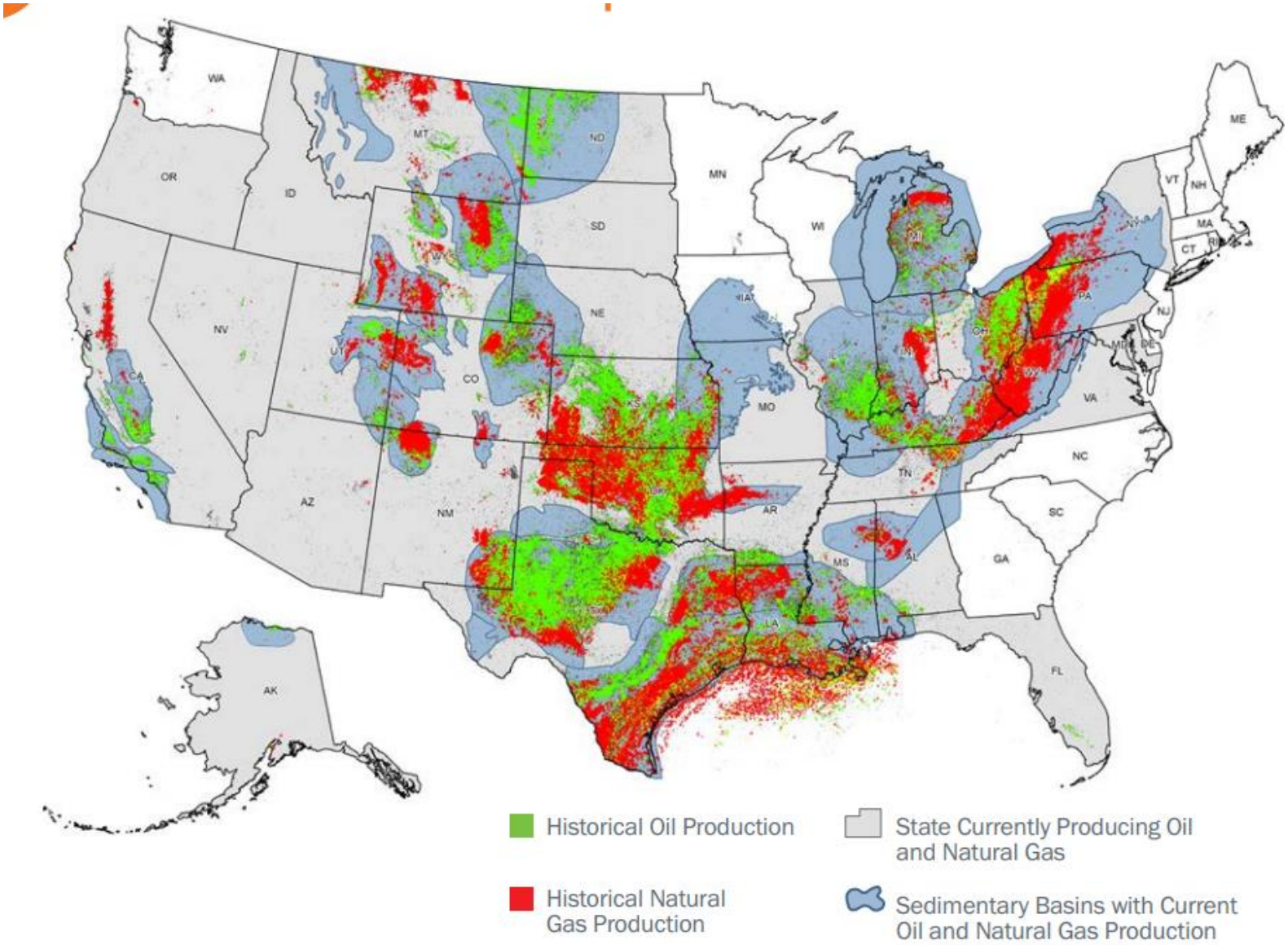
Oil and gas migration: Reservoir Rock

- Once formed, being less dense than the source rock, oil and gas migrate upward into overlaying sedimentary rocks that are both porous and permeable (they can let fluid flow through them) until they encounter either an impermeable rock or a geologic structure that traps oil and gas at depth.
- The rocks that trap oil and gas are called Reservoir Rock examples of reservoir rocks are sandstone and limestone



Reservoir Rock
To reach the oil and gas, the impermeable cap rock needs to be drilled

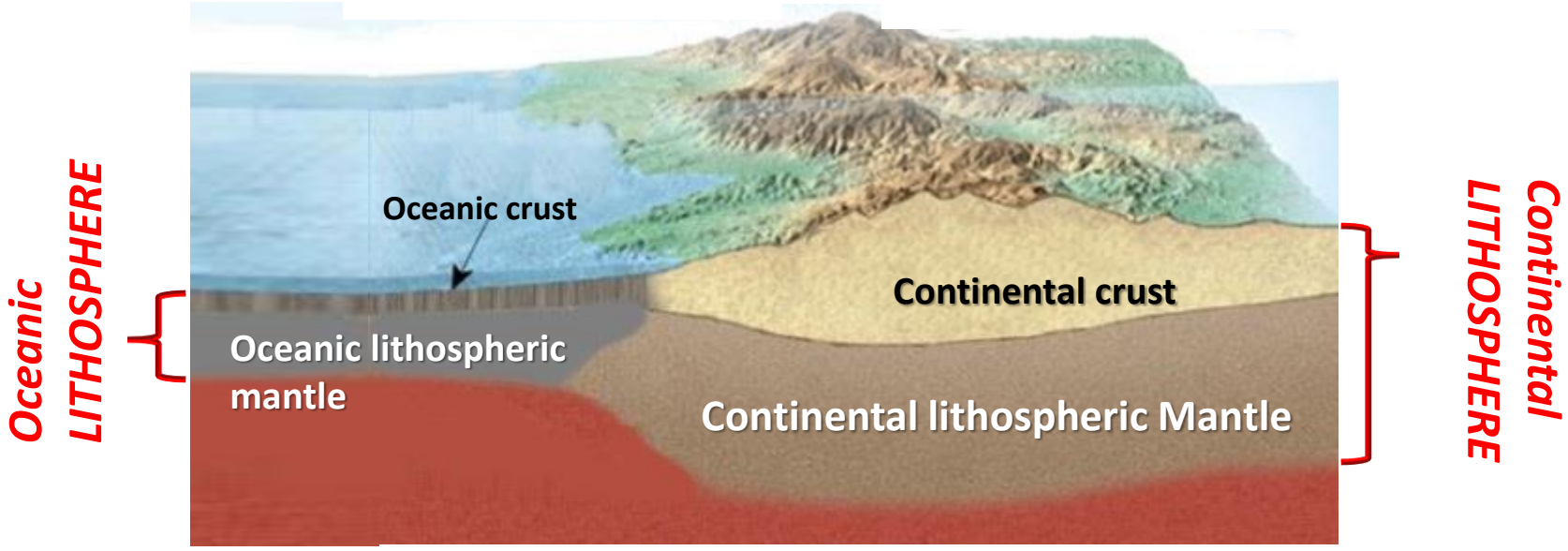
Map of oil and gas fields in the USA



Lithosphere

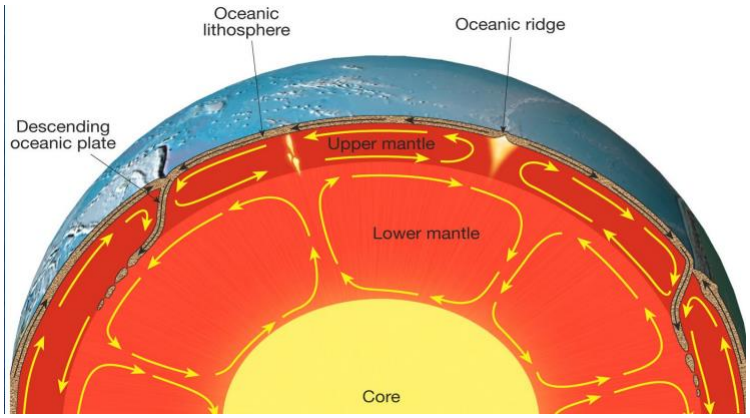
The constant motion of the lithospheric plates generates

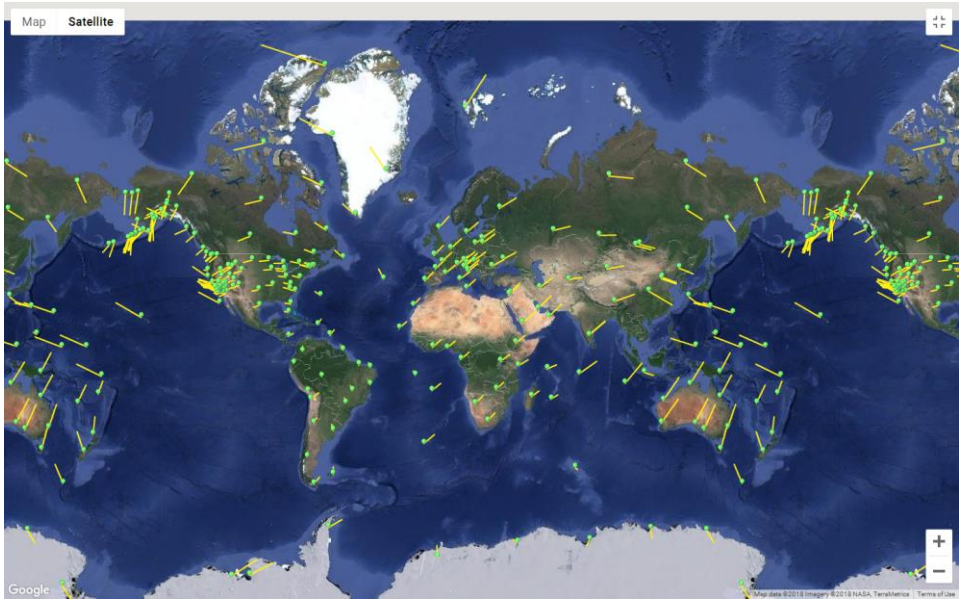
- internal forces (confining and differential pressure)
- the condition for the formation of magma
- the adjustments of the lithosphere (isostasy)
- Surface processes (erosion, transport and deposition) continuously recycle surface rocks, generating material for new sedimentary rocks and adjusting the weight balance on the lithosphere.



Tectonic Plates on the move

- As long as the mantle does the convection
- the plates move
  - Since the semester started, we moved ~1.1 mm westward
- new rocks form from older rocks through the processes of the rock cycle

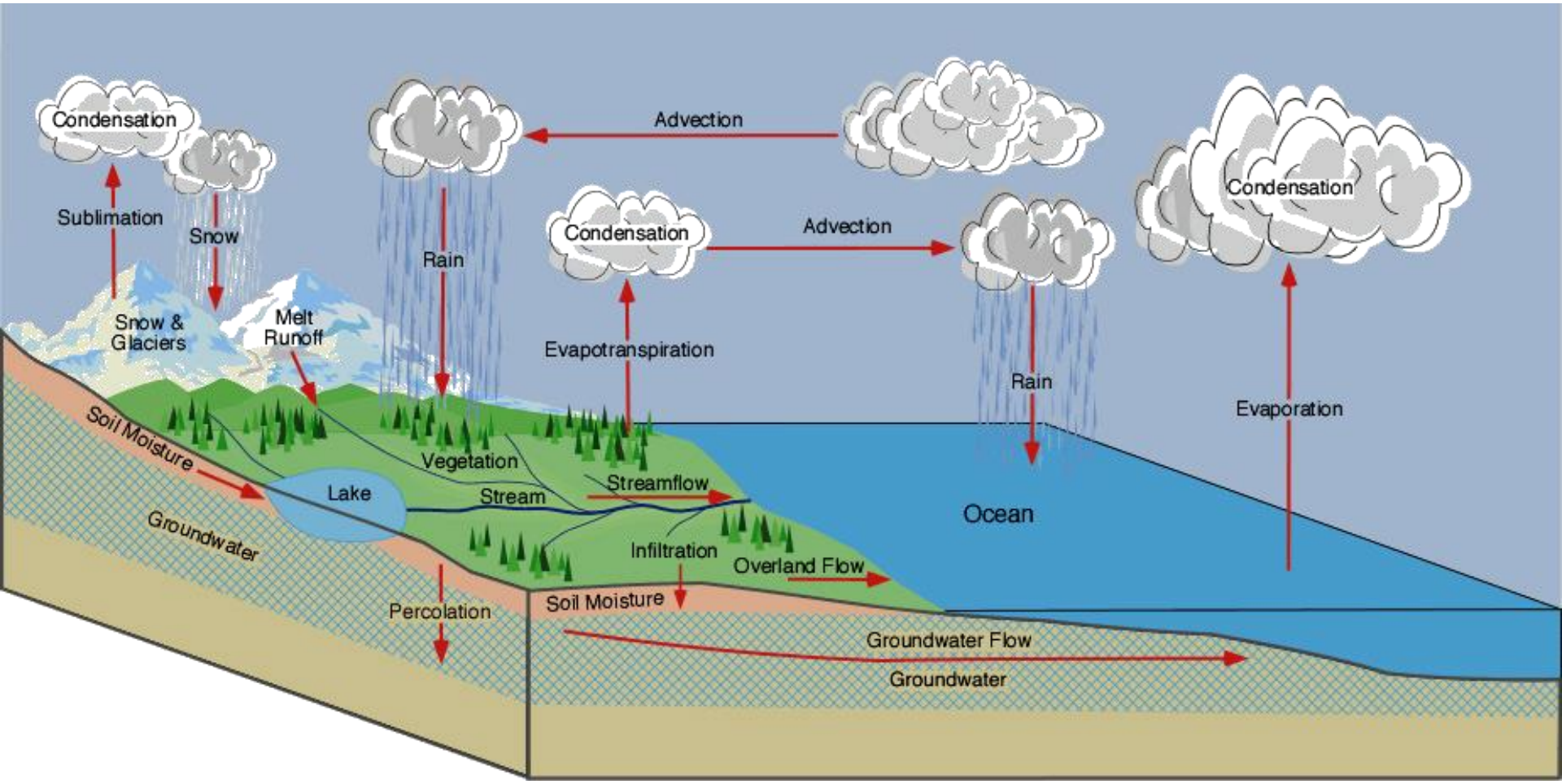




Cycles in the earth System

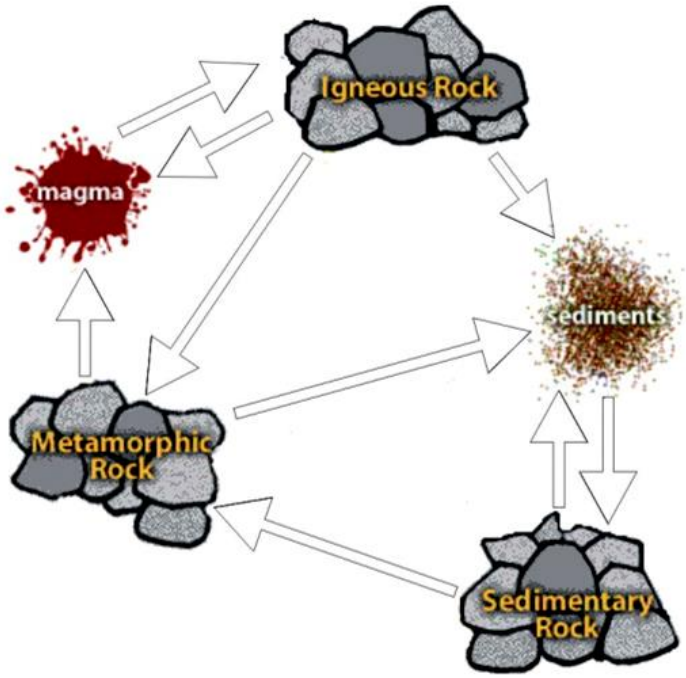
- Recall that Earth system is composed of 4 subsystems:
  - Solid Earth
  - Hydrosphere
  - Atmosphere
  - Biosphere
- The systems are connected and mass and energy flow from one system to another
- This flow can be represented by chemical and physical cycles

Example: the water cycle

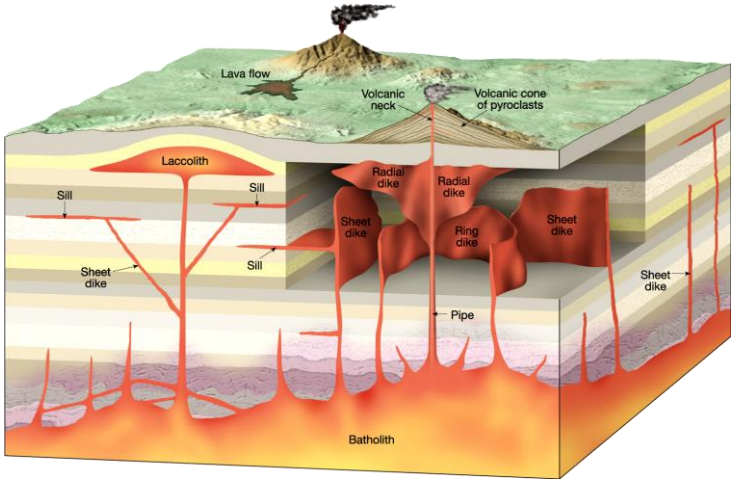


The Rock Cycle

- It represents the relationships between the three major rock types
- The rock cycle is powered by energy from external (surface) process and internal processes

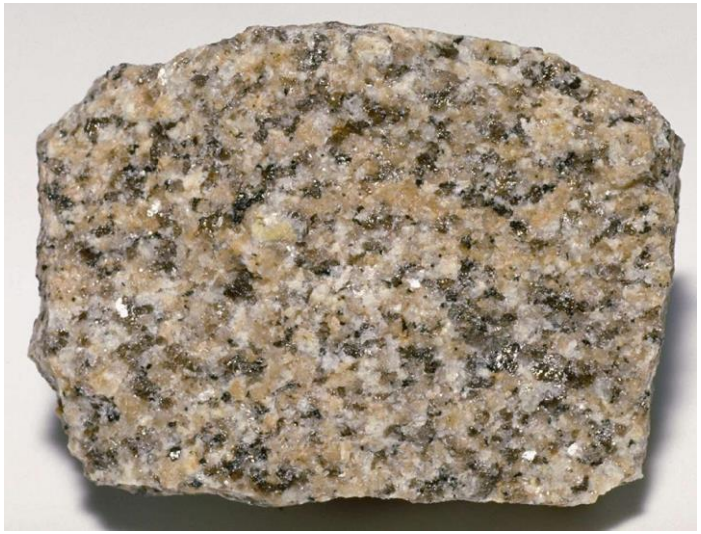


IGNEOUS



Crystallization

IGNEOUS
Plutonic- intrusive



Crystallization

Volcanic
IGNEOUS
Plutonic

Crystallization

Weathering

Erosion

Volcanic

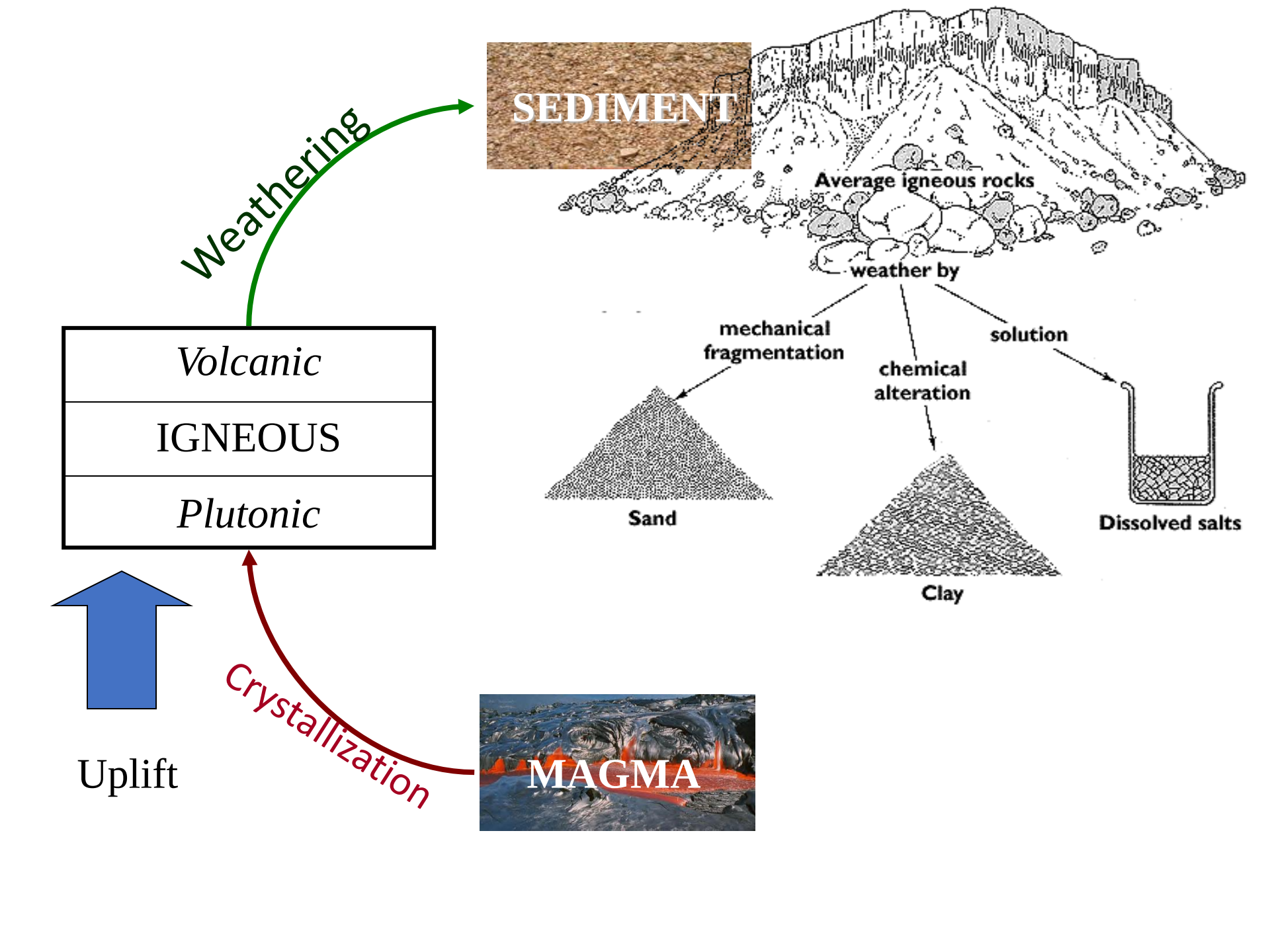
IGNEOUS

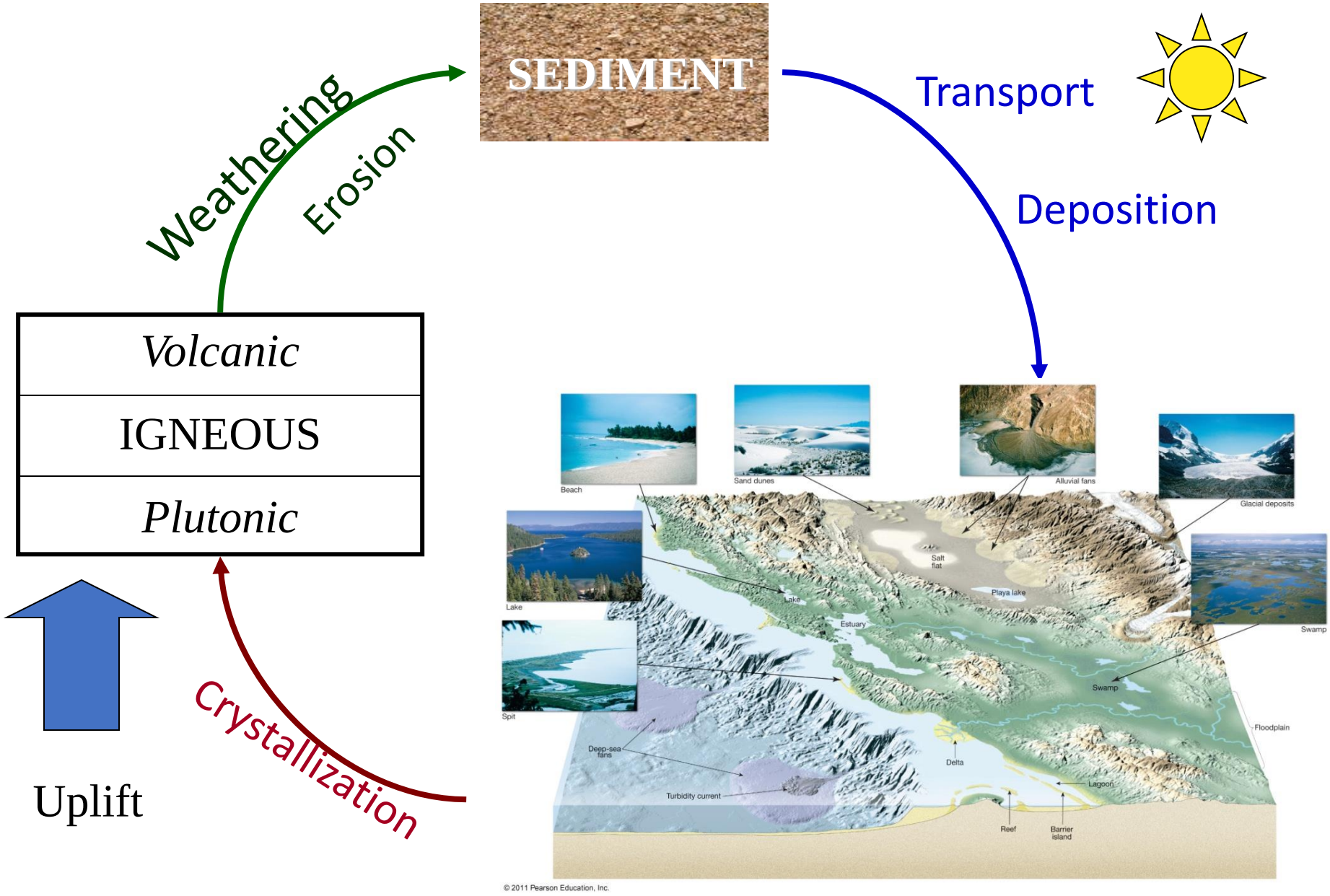
Plutonic

Uplift/

isostasy

Crystallization


SEDIMENT
Weathering
Average igneous rocks
weather by
mechanical fragmentation
chemical alteration
solution
Sand
Clay
Dissolved salts
Volcanic
IGNEOUS
Plutonic
Uplift
Crystallization
MAGMA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Weathering
Erosion
Transport
Deposition
Volcanic
IGNEOUS
Plutonic
Uplift
Crystallization
Beach
Sand dunes
Alluvial fans
Glacial deposits
Lake
Lake
Salt flat
Playa lake
Swamp
Estuary
Spit
Swamp
Floodplain
Deep-sea fans
Delta
Lagoon
Turbidity current
Reef
Barrier island
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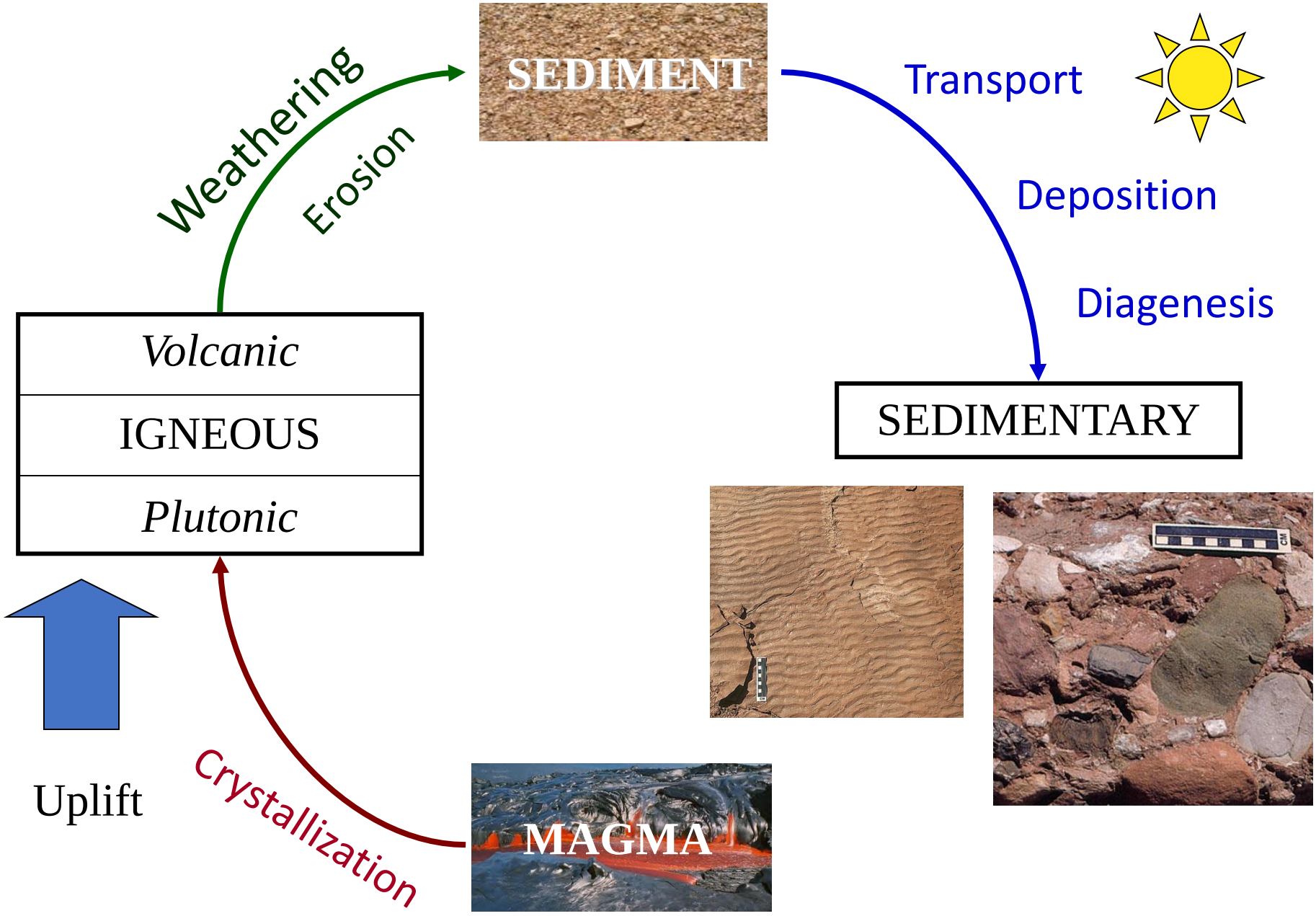
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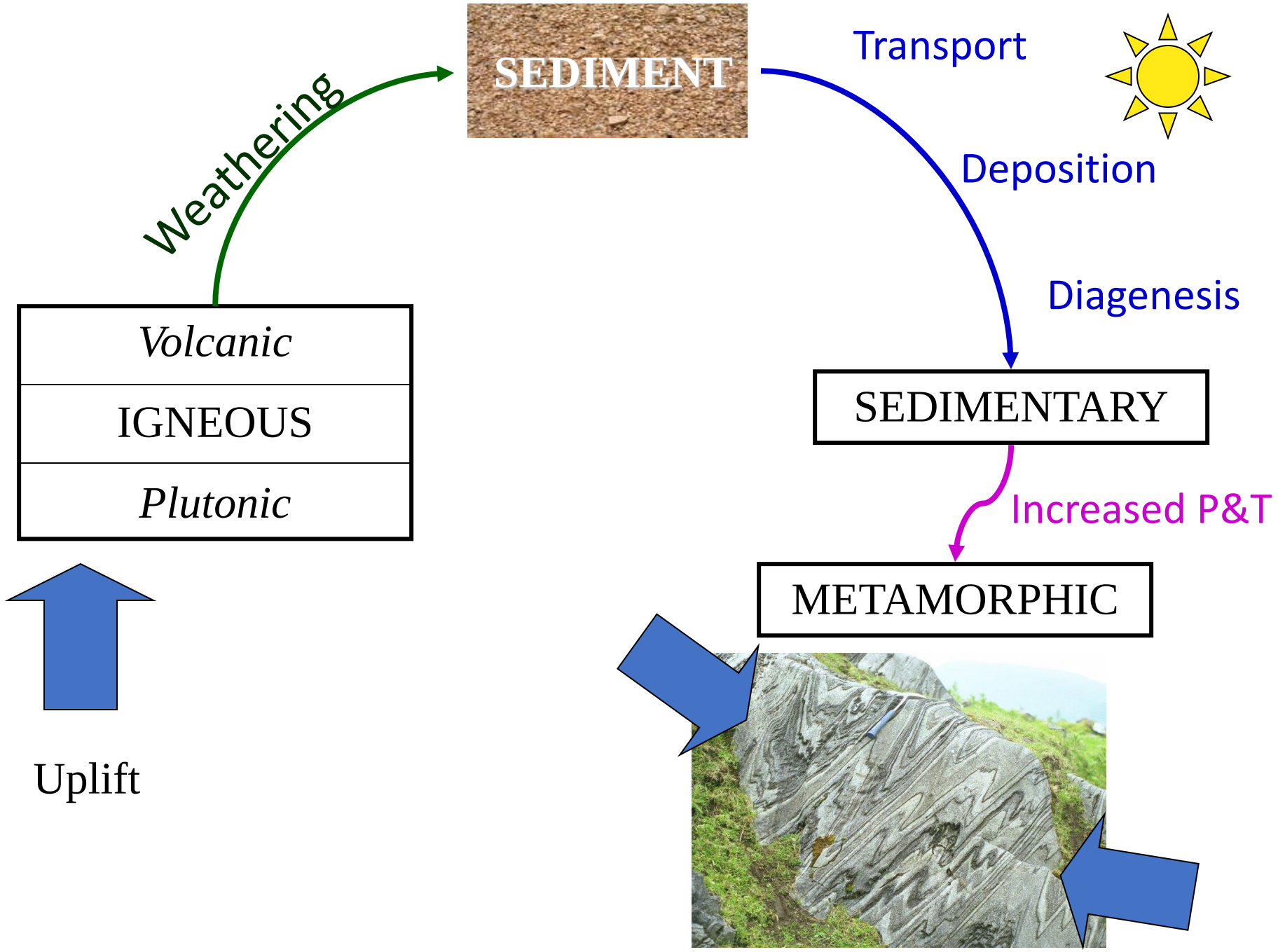
Deposition
Diagenesis
Volcanic
IGNEOUS
Plutonic
SEDIMENTARY
Uplift
Crystallization
MAGMA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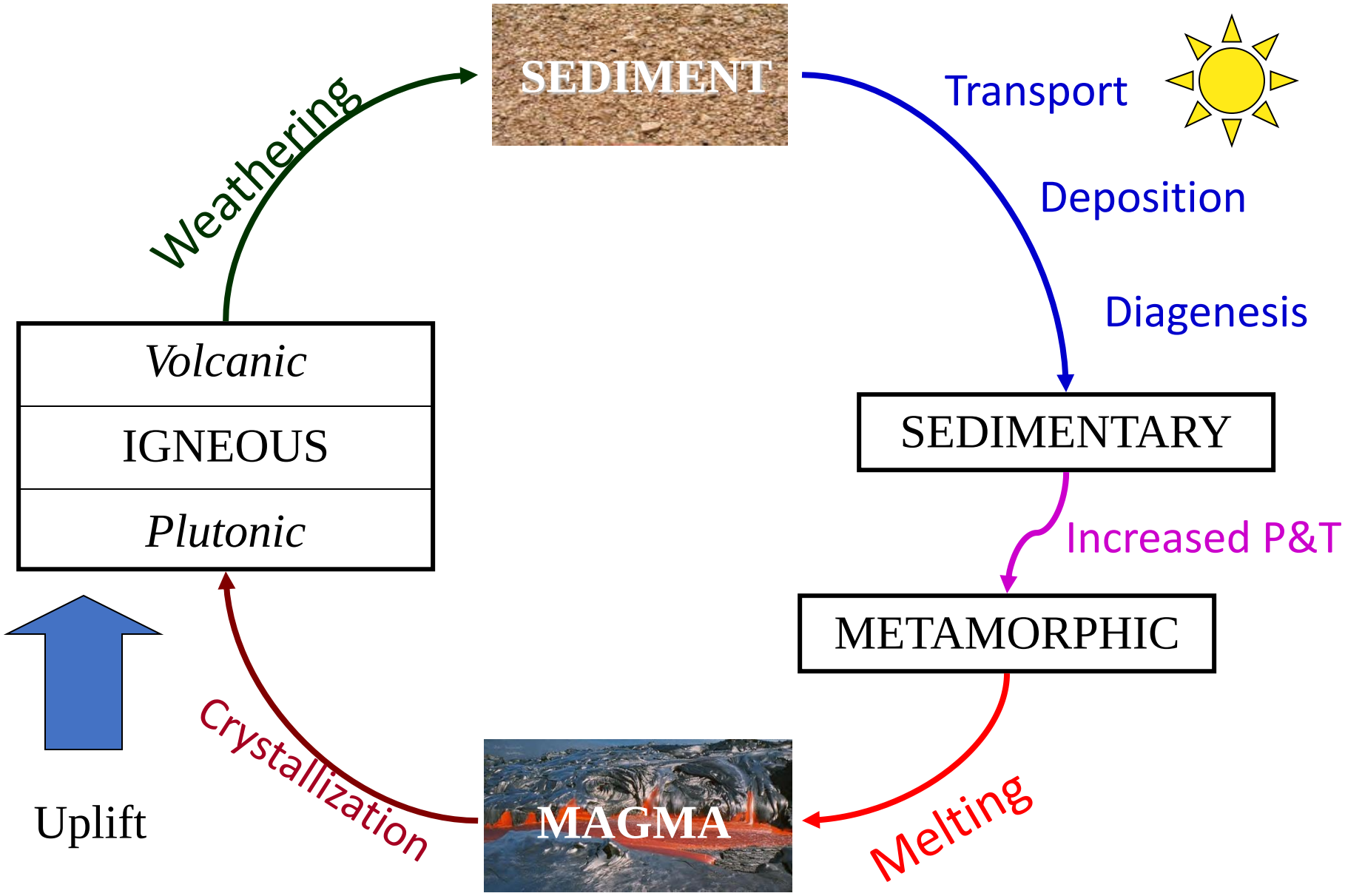
Transport
Deposition
Diagenesis
Weathering
Volcanic
IGNEOUS
Plutonic
SEDIMENTARY
Increased P&T
METAMORPHIC
Uplift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Deposition
Diagenesis
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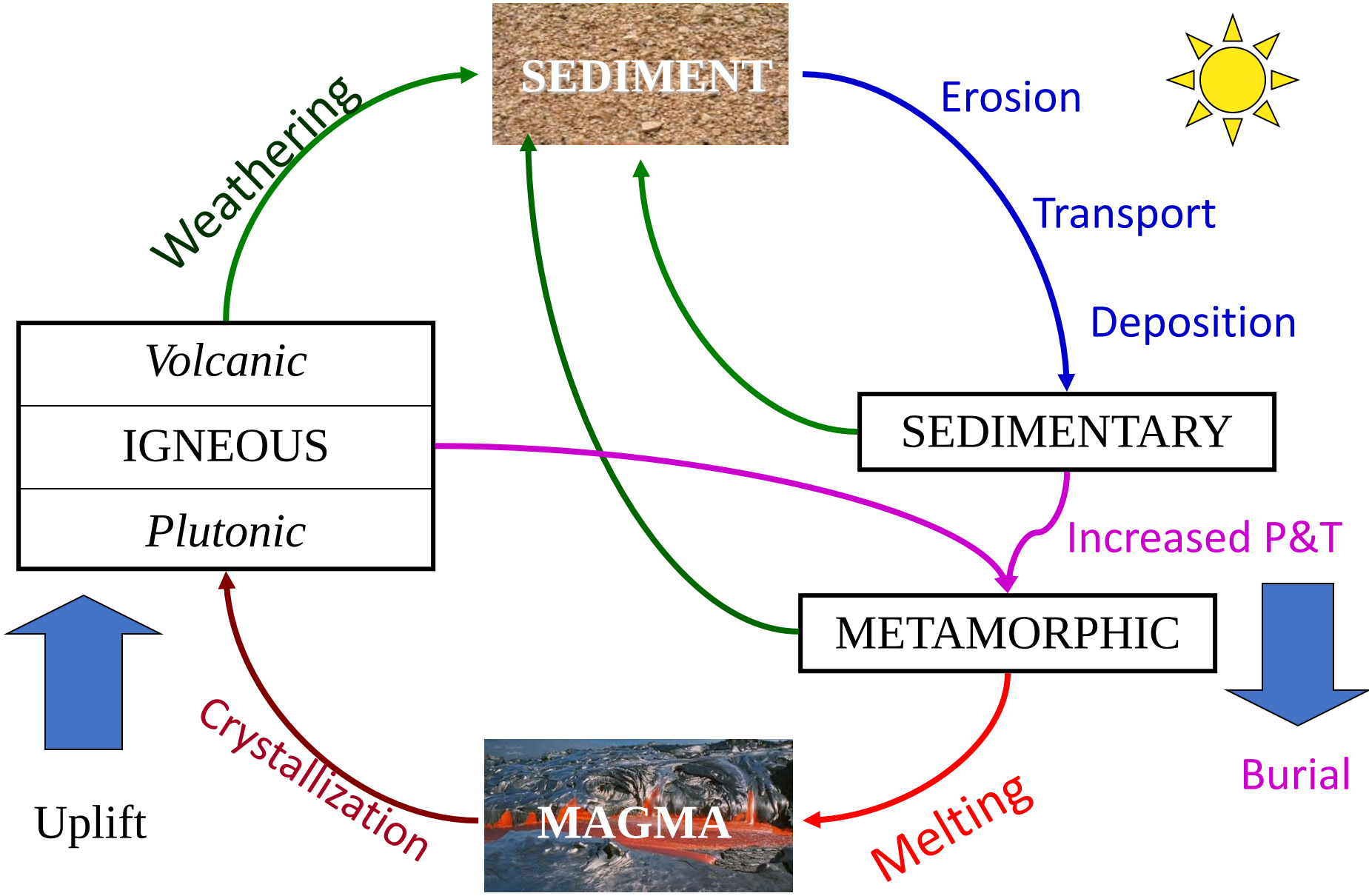
Increased P&T
METAMORPHIC
Melting
MAGMA
Crystallization
Volcanic
IGNEOUS
Plutonic
Uplift
Weathering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Erosion
Transport
Deposition
Weathering
Volcanic
IGNEOUS
Plutonic
SEDIMENTARY
Increased P&T
METAMORPHIC
Burial
Uplift
Crystallization
MAGMA
Melting