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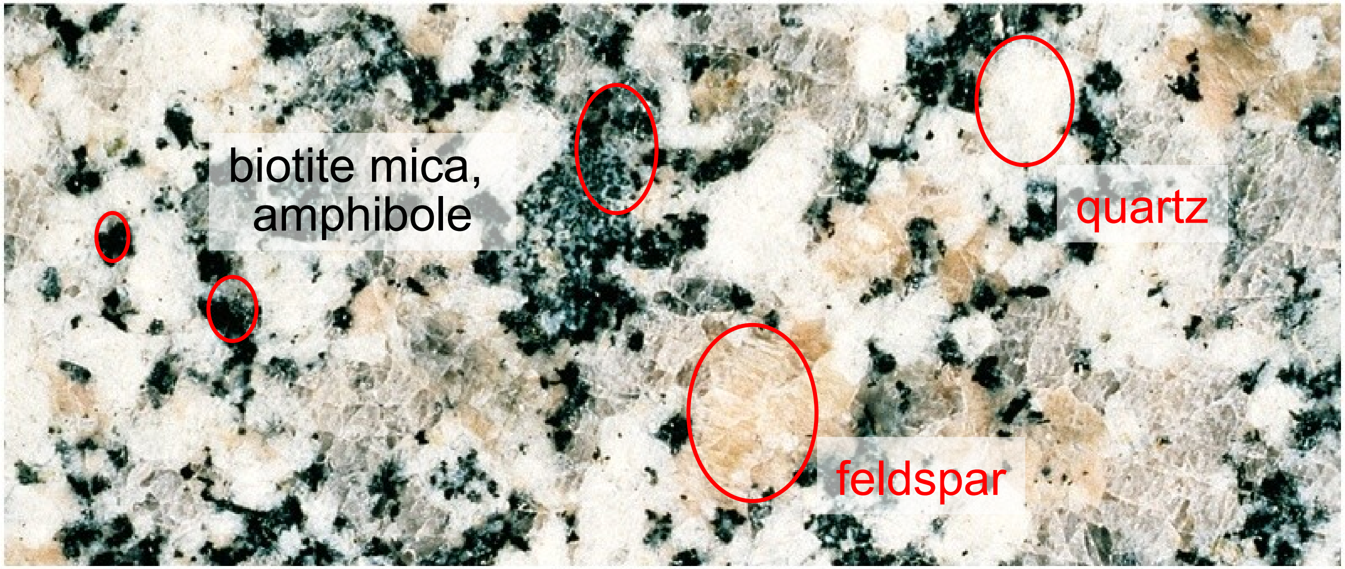
Chapter 7: Rocks and Minerals

1. Minerals, Brief Chemistry
2. The Rock Cycle
3. Igneous Rocks
4. Sedimentary Rocks
5. Metamorphic Rocks

Elements and Atoms: Basic Building Blocks

Rocks are made of minerals

- ~20 common minerals
- Example: The rock **granite** (below) is composed of 4 key minerals - ***feldspar, quartz, mica, amphibole*** - and minor amounts of others.



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Elements and Atoms: Basic Building Blocks

Minerals are made of elements

- 8 common elements compose 98% of continental crust rocks

Table 7.1 Most Common Elements in Continental Crust

Element	Ion	Percent by weight	Also found in
Oxygen (O)	O^{2-}	46.6	Air
Silicon (Si)	Si^{4+}	27.7	Window glass, computer chips
Aluminum (Al)	Al^{3+}	8.1	Cans, aircraft
Iron (Fe)	Fe^{2+}, Fe^{3+}	5.0	Meat, cornflakes, your car
Calcium (Ca)	Ca^{2+}	3.6	Milk, cheese, cement, antacids
Sodium (Na)	Na^{+}	2.8	Salt, bacon, cheese
Potassium (K)	K^{+}	2.6	Fish, fruit, nuts, fertilizer
Magnesium (Mg)	Mg^{2+}	2.1	Bread, nuts, salt
Other	–	1.5	–

Elements and Atoms: Basic Building Blocks

Minerals are made of elements

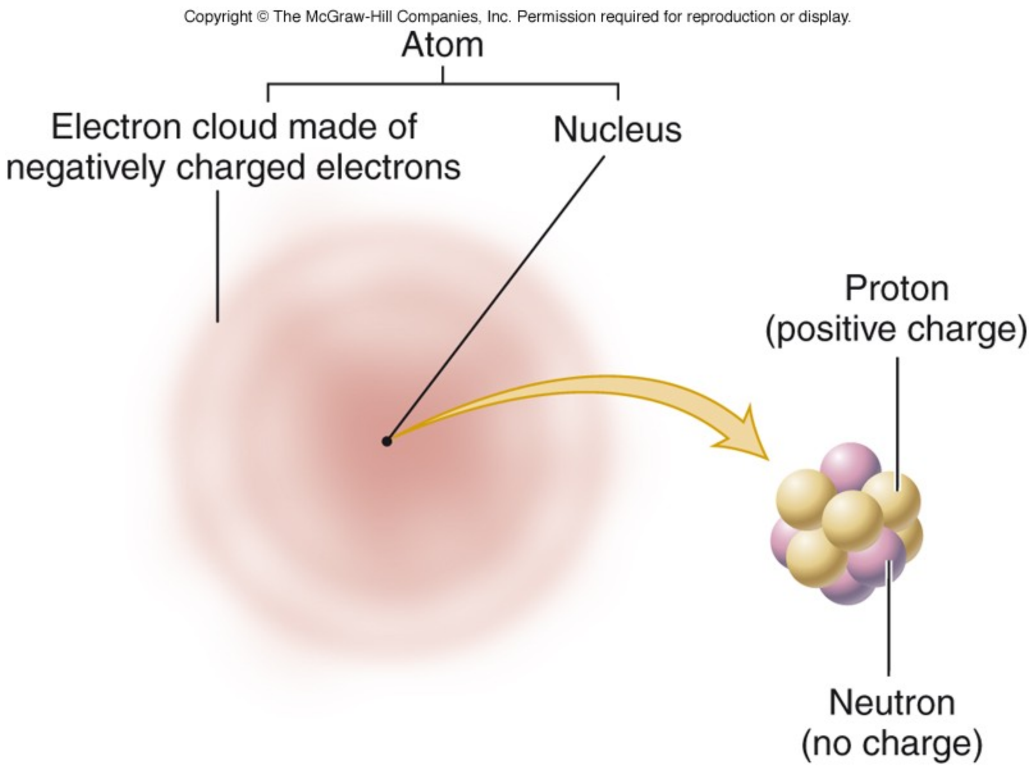
- Some minerals (e.g., quartz) are composed of just two elements
- Others (e.g., amphibole) are made up of several elements
- Some elements occur more frequently than others

Table 7.2 Most Common Elements in Granite Minerals

Mineral	Elements
Quartz	Oxygen, silicon
Feldspar	Oxygen, silicon, aluminum, calcium, sodium, potassium
Mica	Oxygen, silicon, aluminum, iron, potassium, magnesium
Amphibole	Oxygen, silicon, aluminum, iron, calcium, magnesium

Elements and Atoms: Basic Building Blocks

Atom – smallest particle that retains the characteristics of an element



- Atoms are made up of **protons, neutrons,** and **electrons**
- Protons and neutrons in atomic nucleus
- Electrons in surrounding "cloud"

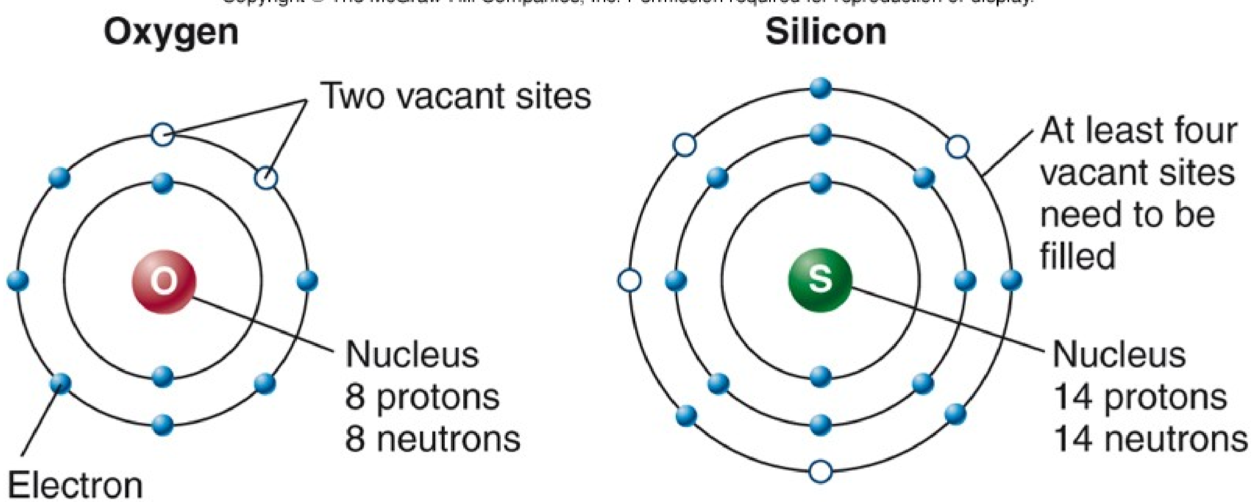
Definition of mineral

- Naturally occuring
- Inorganic compound
- Periodic Structure

Elements and Atoms: Basic Building Blocks

Atoms may have negative or positive charge if they gain or lose electrons

- **Ions** – atoms with different numbers of protons (positive) and electrons (negative)



- Oxygen can gain two electrons to fill vacant sites
- 8 protons, 10 electrons → -2 (negative charge, O^{2-})
- Silicon may lose 4 electrons → +4 (positive charge, Si^{4+})

Elements and Atoms: Basic Building Blocks

Elements bond together to form minerals

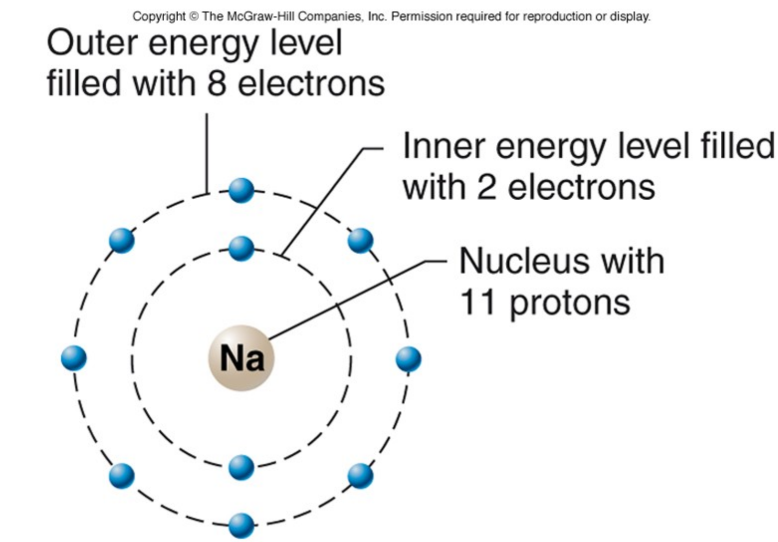
- **Ionic bonds** – Weak, balance of negative and positive charges of different ions (NaCl – Halite or rock salt -- Na donates electron to Cl)
- **Covalent bonds** – Strong, sharing of electrons between elements (e.g., Hydrogen-Oxygen from water H_2O, Silicon-Oxygen form quartz SiO_2 or silica ion SiO_4^{4-}) to achieve a stable atomic structure

Elements and Atoms: Basic Building Blocks

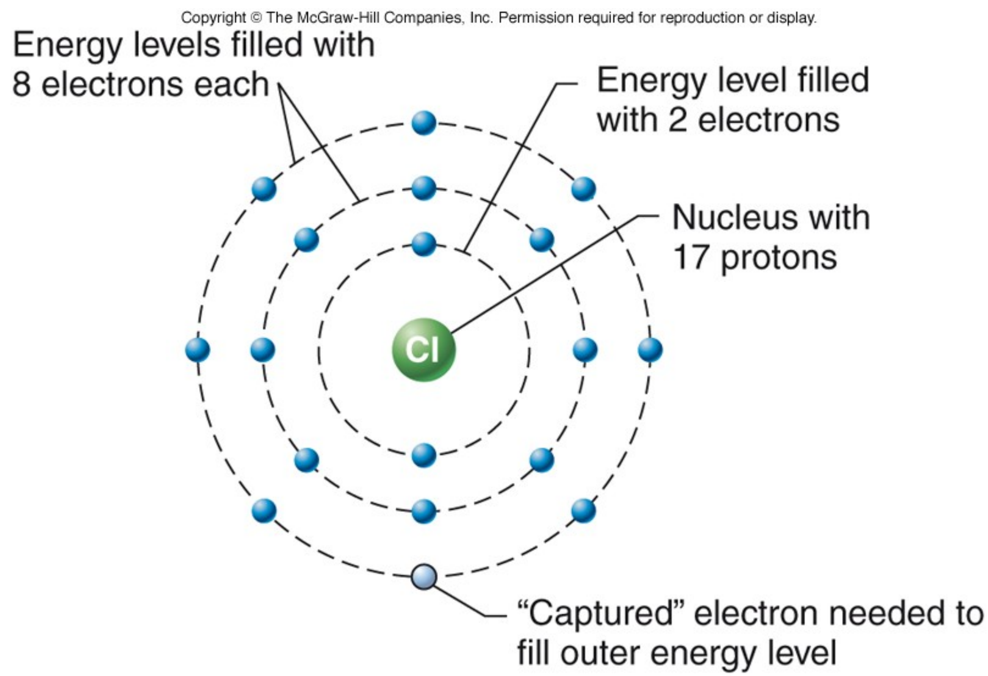
- **Ionic bonds** – balance of negative and positive charges

Sodium atom loses extra electron to yield a positive charge (Na^+)

Chlorine ion gains extra electron to produce a negative charge (Cl^-)



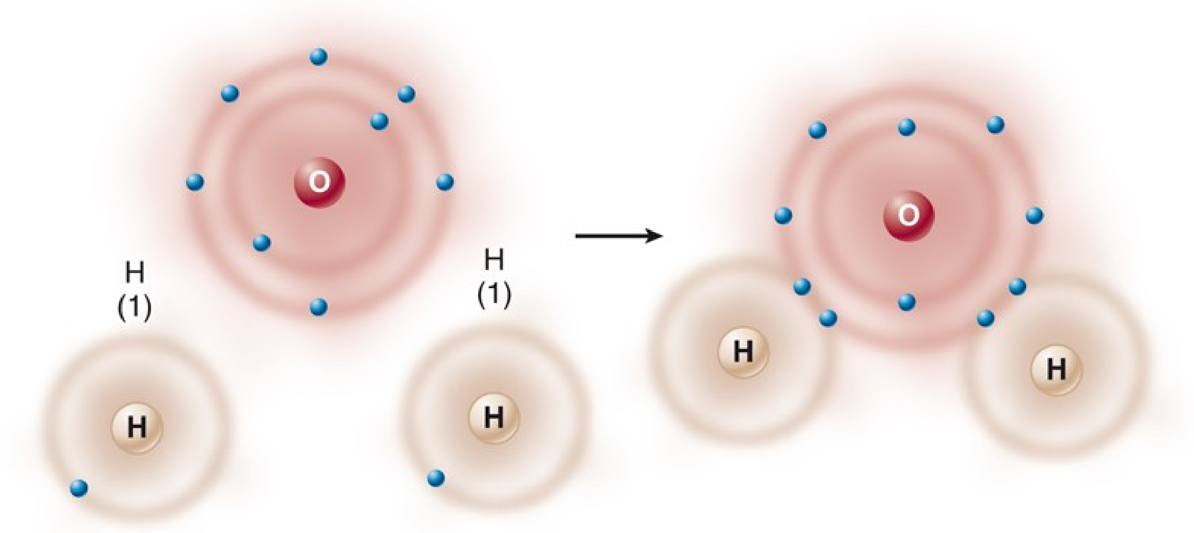
a. Sodium (Na^+)



b. Chlorine (Cl^-)

Elements and Atoms: Basic Building Blocks

Covalent bonds – sharing of electrons between elements



Oxygen is 2 electrons short of 8 electrons in its outer energy level.

The hydrogen and oxygen atoms share electrons to give oxygen an outer energy level of 8, and the hydrogens each have 2.

- Hydrogen and oxygen bond together to form water (H_2O)
  - **Covalent bond** – sharing of electrons between atoms ions

Rocks and Minerals Concept test

The total electrical charges of the ions of the elements in the mineral olivine must balance. From the data in Table 7.1, which is the most reasonable formula for the mineral?

Only Valence electrons contribute to bonding.
Stable molecules must be charge neutral.

Table 7.1 Most Common Elements in Continental Crust

Element	Ion	Percent by weight	Also found in
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Sodium (Na)	Na^{+}	2.8	Salt, bacon, cheese
Potassium (K)	K^{+}	2.6	Fish, fruit, nuts, fertilizer
Magnesium (Mg)	Mg^{2+}	2.1	Bread, nuts, salt
Other	–	1.5	–

A. $MgSiO_2$

B. $MgSiO_4$

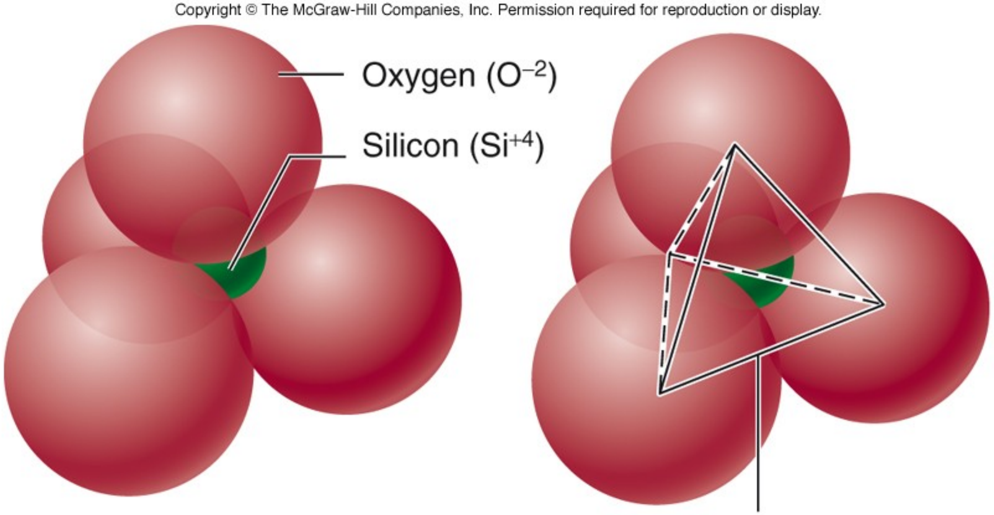
C. $\mathbf{Mg_2SiO_4}$

D. Mg_4SiO_2

Magnesium (Mg) donates two electrons and has charge 2+
Silicate (SiO4) needs 4 electrons and has charge 4-

Elements and Atoms: Basic Building Blocks

Multiple bonds – silicon and oxygen join together by a combination of ionic and covalent bonding



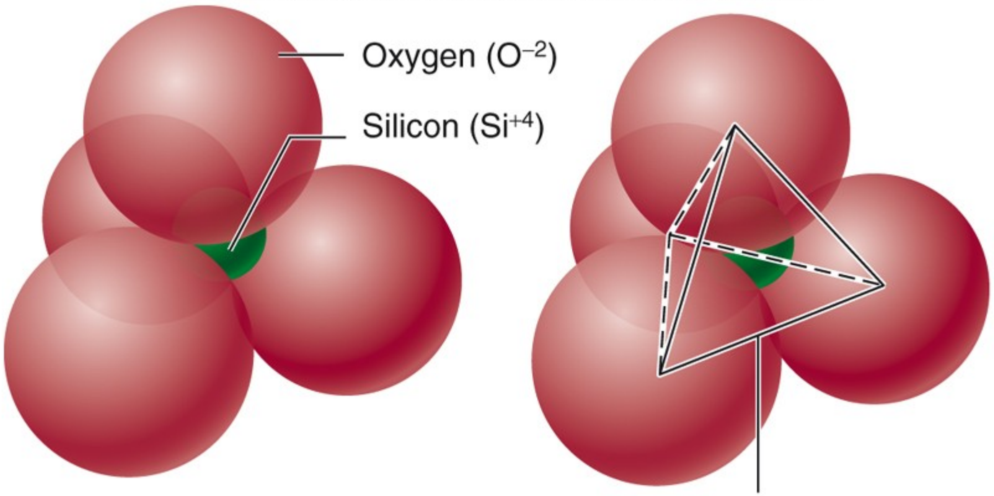
a. Arrangement of atoms in silica tetrahedron

b. Diagrammatic representation of a silica tetrahedron

- 4 oxygen and one silicon atom combine by covalent bonds to form a ***silica tetrahedron (SiO_4)***
  - Tetrahedron has a negative charge ($^{4-}$) and forms ionic bonds with atoms of other elements

Elements and Atoms: Basic Building Blocks

Silicate minerals – contain both silicon and oxygen



a. Arrangement of atoms in silica tetrahedron

b. Diagrammatic representation of a silica tetrahedron

- Silicon and oxygen are most common elements in crust
- Silicates are the most common mineral group
  - Examples: quartz, feldspar, mica, amphibole

Elements and Atoms: Basic Building Blocks

Different types of bonds result in minerals of different strengths

- Type of bonds determine strength of minerals, rocks
  - **Ionic bonds** – Velcro analogy, weaker bonds
  - **Covalent bonds** – Rope analogy, stronger bonds
- Minerals formed with covalent bonds are stronger and more resistant to destructive forces at Earth's surface
  - Silicates form more resistant rocks than most other mineral groups

Minerals

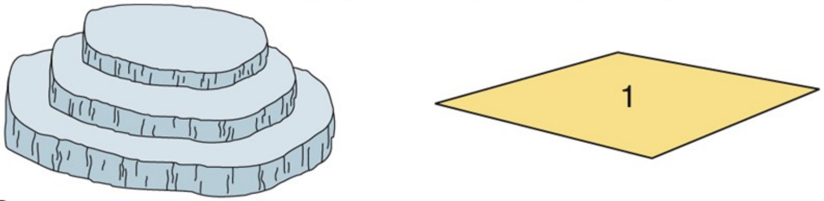
- **Minerals**: Naturally occurring, inorganic solids of one or more elements that have a definite chemical composition with an orderly internal arrangement of atoms

Minerals

Mineral Characteristics

***Cleavage* –** minerals break along planes of weakness defined by atomic structure

- Cleavage planes more likely to occur across weak bonds between ions
- Example: **mica** forms sheets joined by weak ionic bonds (metal ion joining silicate ion)



a.

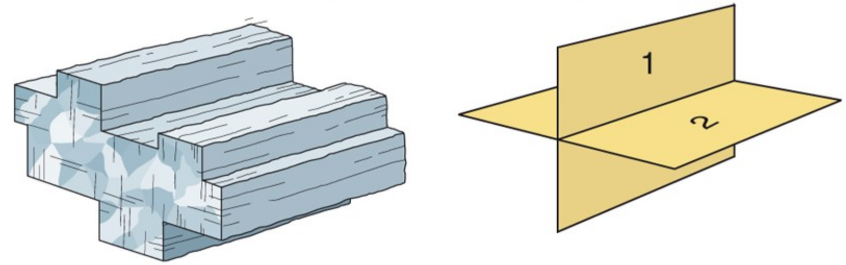
Mica → 1 set of cleavage planes

b.

Minerals

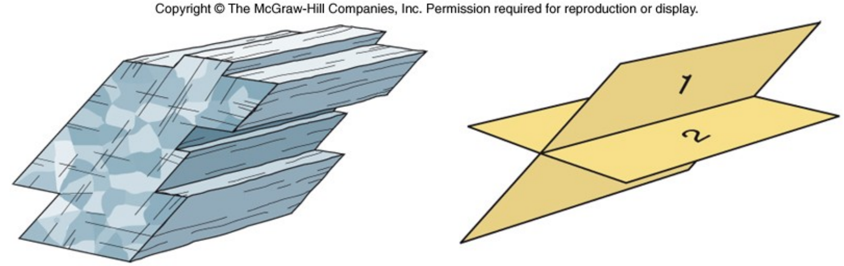
Mineral Characteristics

- ***Cleavage* –** minerals break along planes of weakness defined by atomic structure
  - Example: **feldspar** has 2 cleavage planes that intersect at 90 degrees
  - Example: **amphibole** has 2 cleavage planes that are not at 90 degrees to each other



b.

Feldspar → 2 sets of cleavage planes



c.

Amphibole → 2 sets of cleavage planes

Minerals

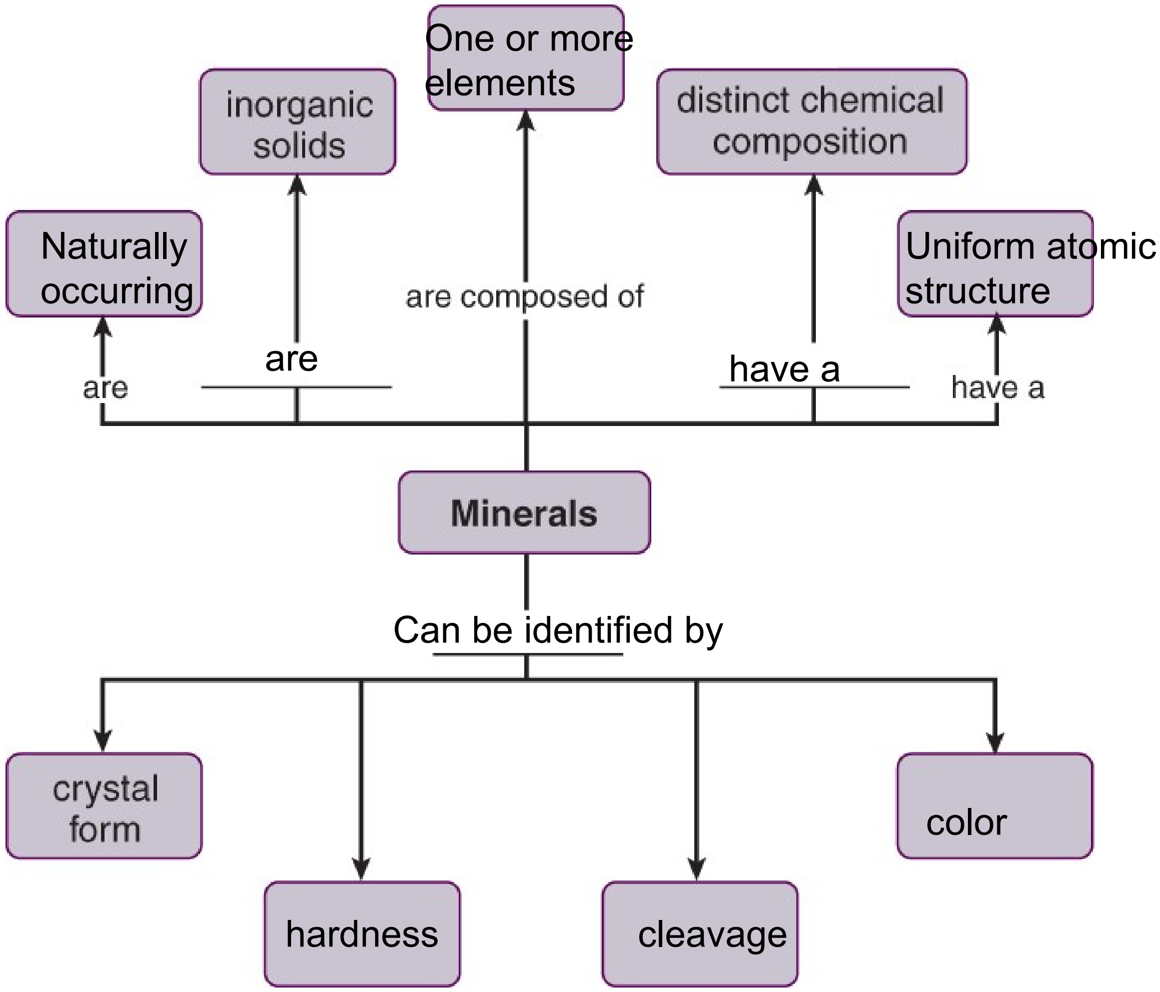
Mineral Characteristics

- ***Hardness* – minerals ranked by their relative hardness using Mohs Hardness Scale**
  - Harder minerals can scratch softer minerals
  - Softer minerals more likely to break down at Earth's surface
  - More resistant minerals more likely to be preserved (e.g., quartz sand on beaches)

Table 7.3 Hardness Scales

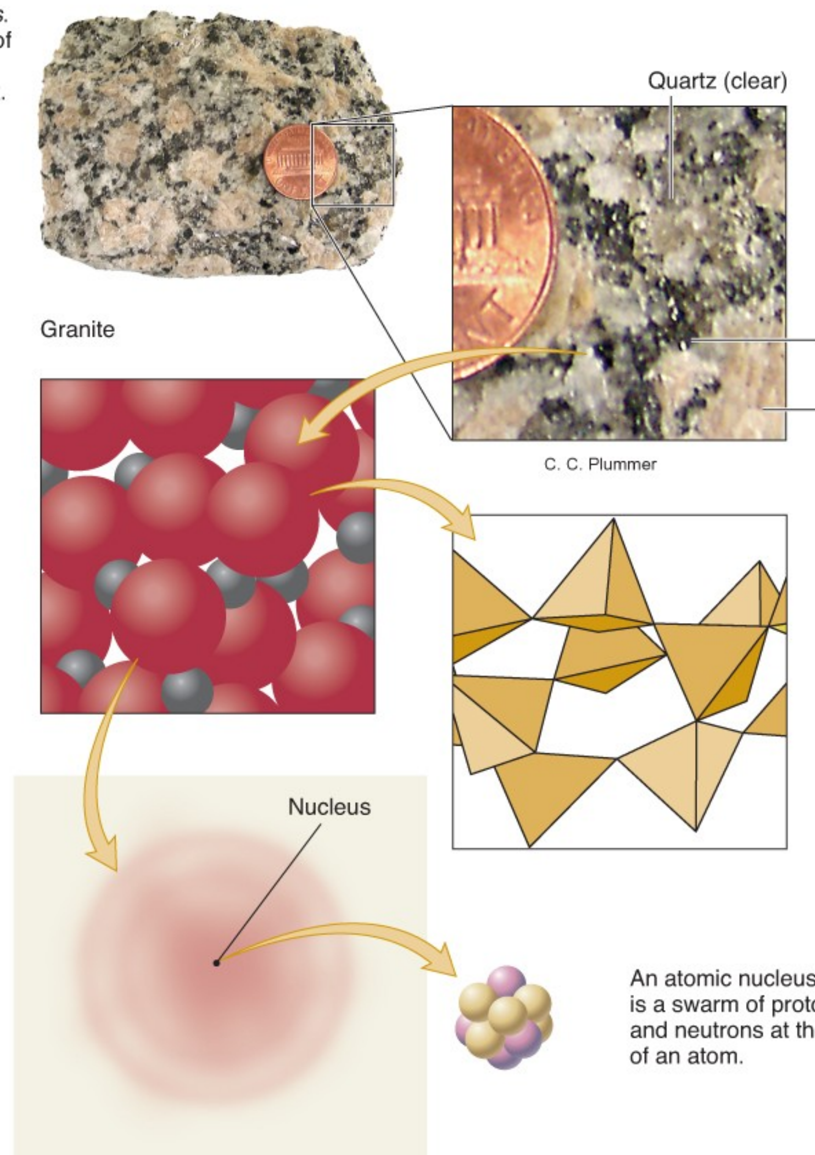
	Mohs hardness scale	Mineral	Absolute hardness scale
Softest	1	Talc	1
	2	Gypsum	2
	3	Calcite	9
	4	Flourite	21
	5	Apatite	48
	6	Feldspar	72
	7	Quartz	100
	8	Topaz	200
	9	Corundum	400
Hardest	10	Diamond	1,500

concept map of minerals



Atoms to rocks: How they fit together

A *rock* is an *aggregate* of *minerals*. The structure, texture, and types of minerals depend upon the conditions of formation of the rock.



A mineral is a physically and chemically distinct part of a rock. It has properties you can see with an unaided eye, such as color and cleavage.

Each type of mineral also has its own orderly internal (crystalline) structure at the atomic level. This explains the physical properties seen at a larger scale.

In this example, showing quartz, large oxygen atoms enclose smaller silicon atoms.

We construct models of some crystal structures linking the centers of oxygen atoms together to form silica tetrahedra. This helps us envision the geometric beauty of a mineral's atomic arrangement.

An atom consists of a cloud of electrons at different energy levels enclosing a tiny nucleus.

An atomic nucleus is a swarm of protons and neutrons at the core of an atom.

Earth Scientists: Rocks in Geosphere

How rocks formed

- Neptunism
  - Rocks formed in a global ocean when material sank to ocean floor or was precipitated from chemical reactions (Example: Biochemical rocks)

- Plutonism
  - Heat from Earth's interior melted rocks or caused them to fuse together (Example: large grain Granite, small grain Basalt)

Minerals at a specific temperature range.
Plutonic rocks form as magma rises towards the surface
Slow cooling below Earth's surface gives silicon rich Granite which solidifies at ~200^{o}C
Rapid cooling at Earth's surface gives silicon poor Basalt.

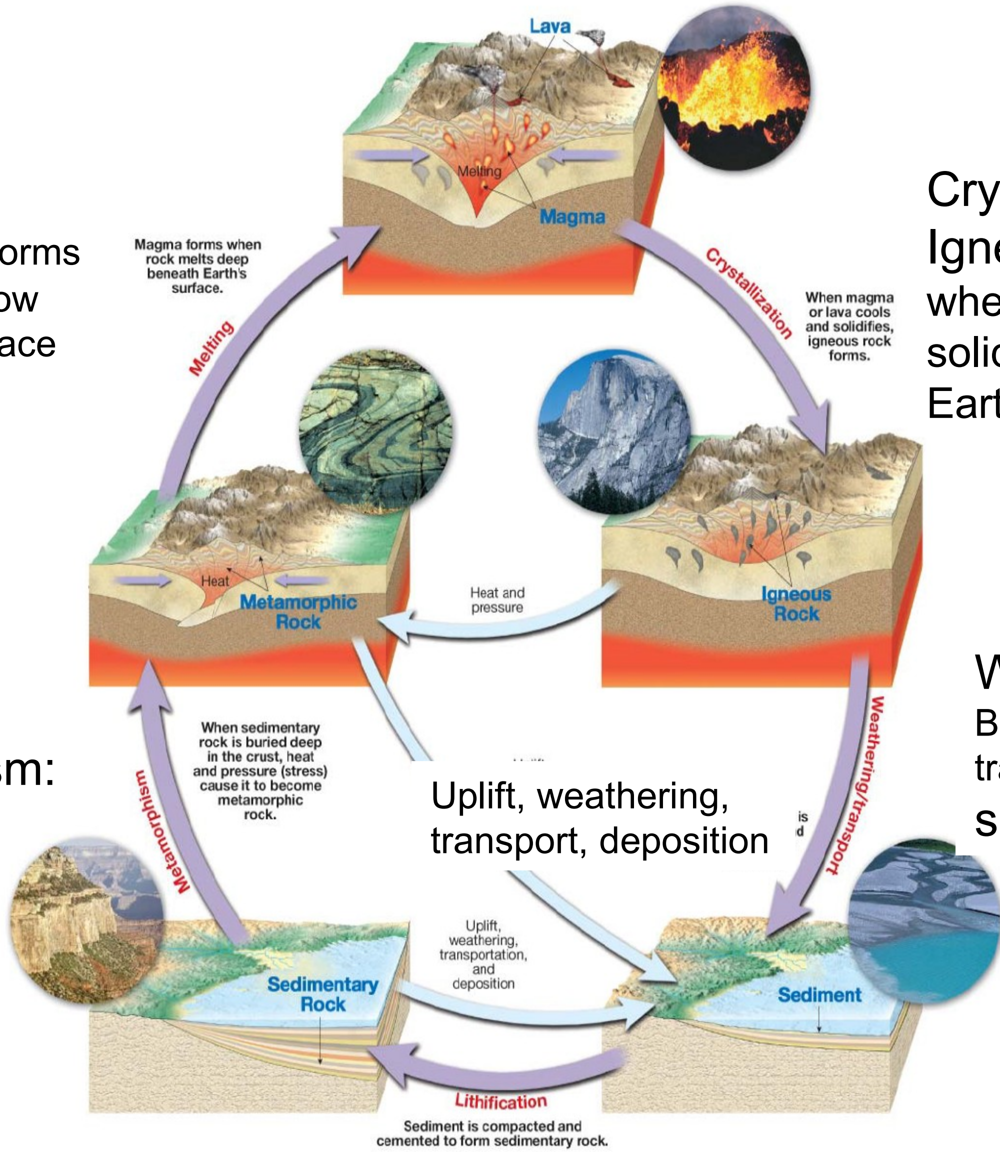
Obsidian is formed from quickly cooled lava, which is the parent material.[13][14][15] Extrusive formation of obsidian may occur when felsic lava cools rapidly at the edges of a felsic lava flow or volcanic dome, or when lava cools during sudden contact with water or air. Intrusive formation of obsidian may occur when felsic lava cools along the edges of a dike.[16][17]

Yellowstone is volcanic – calderas, warm water lakes, geysers. Yellowstone contains OBSIDIAN minerals in the rocks. Implies lava cooled quickly by contacting cooler ocean water – NEPTUNISM. Ocean was at an earlier geologic time, next to Wyoming -- ~900 miles inland.

Rock Cycle

Melting: forms magma below Earth's surface

Crystallization: Igneous rock forms when magma solidifies on or below Earth's surface

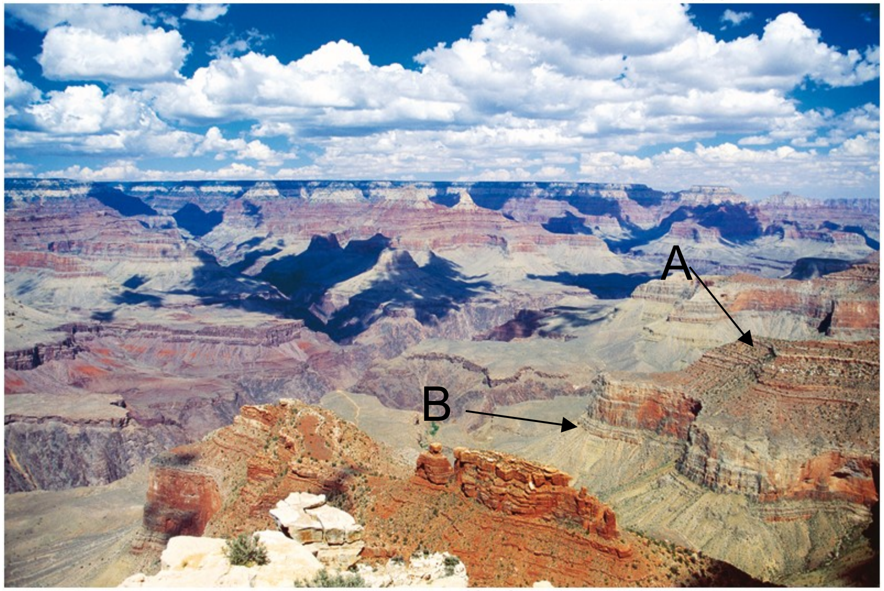


Weathering: Breaks down into transported sediment

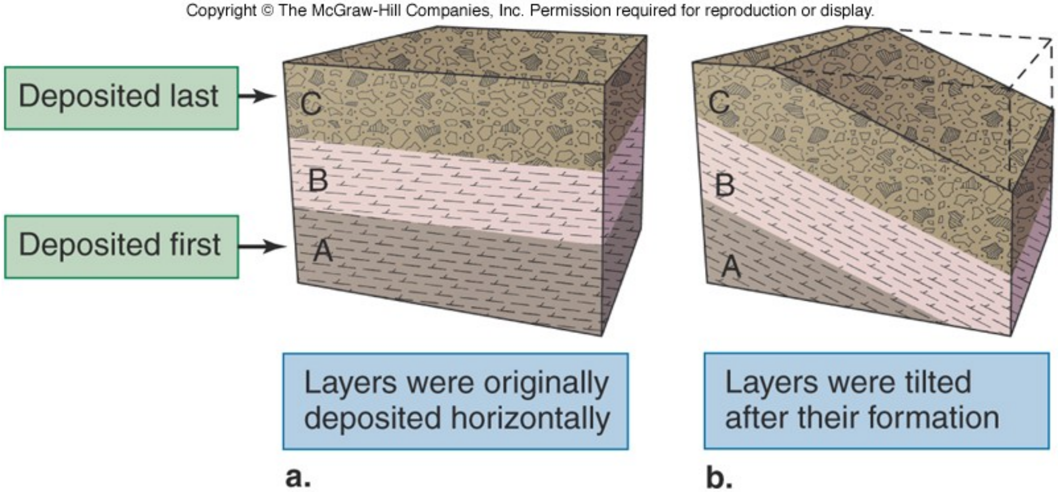
Metamorphism: Heat & Pressure

Lithification: Compaction into Sedimentary Rock

Relative Time



The Grand Canyon – rock layers record thousands of millions of years of geologic history.



- Relative Time = which came first, second…

Sediment is layered. Older sediment below younger sediment

But can get tilting after formation (stress between layers). This is called uplift when the tilted layers are exposed to weather.

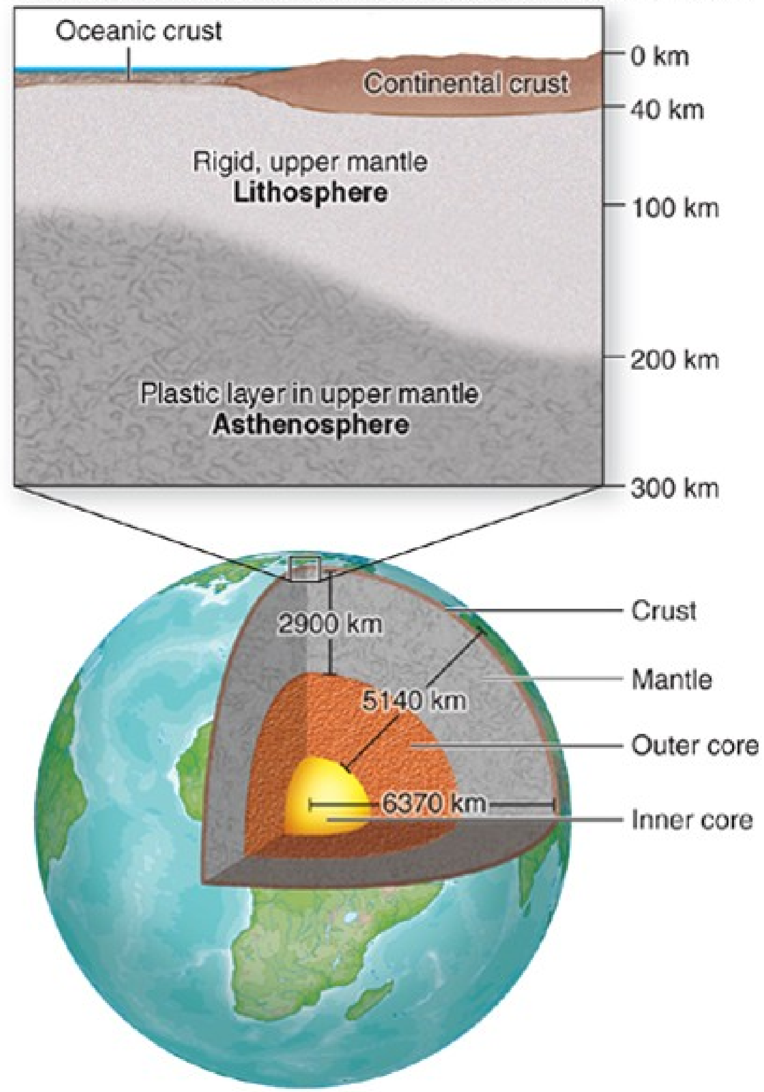
Go to the next section: ***Igneous Rocks***

The Unique Composition of Earth

- Earth's interior can be divided into three major compositional layers
  - Crust – composed of lighter elements (e.g., silicon, oxygen)
  - Mantle – composed of rocks made up of 3 key elements (oxygen, silicon, magnesium)

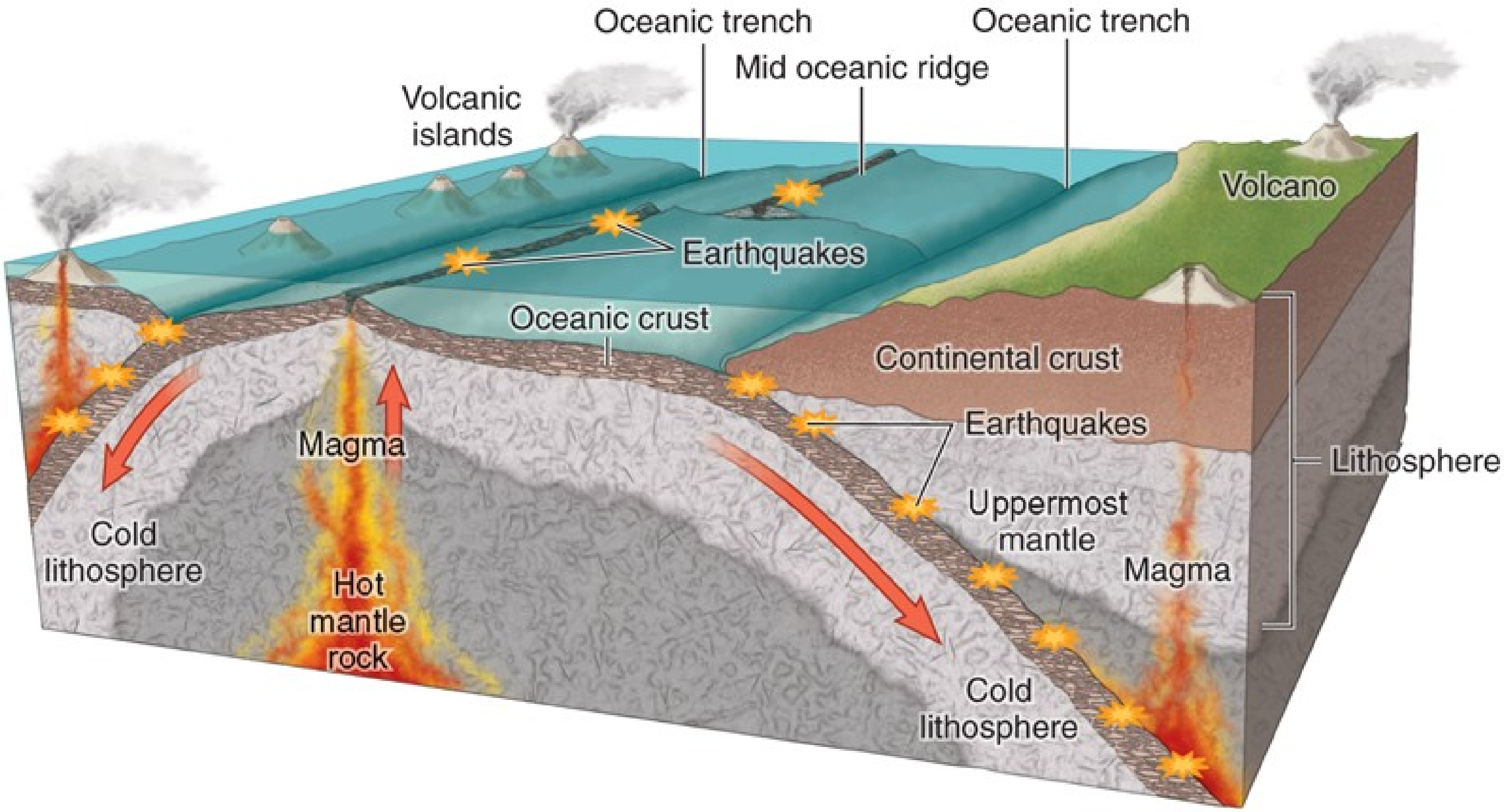
    Lithosphere – rigid outer layer composed of crust and upper mantle

    Asthenosphere – plastic, slowly flowing layer in uppermost part of mantle
  - Core – iron and nickel
    - solid inner core
    - partially melted outer core is source of Earth's magnetic field



The Unique Composition of Earth

- Lithosphere divided into large slabs known as tectonic plates
  - Plates move over Earth's surface to produce earthquakes, volcanoes, mountain belts, and various features on the seafloor

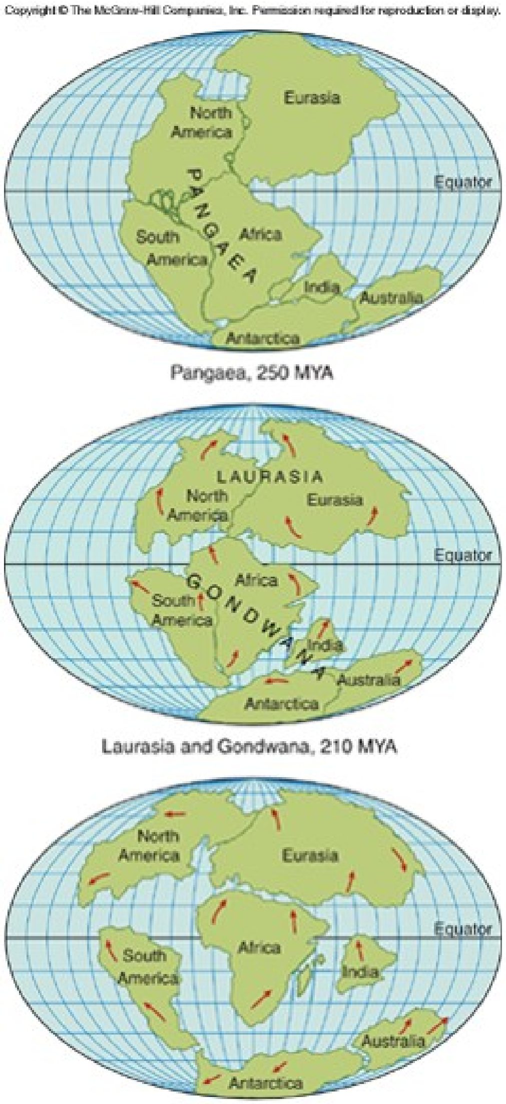


The Unique Composition of Earth

Geothermal gradient

- Earth's temperature increases with depth
  - Average temperature rise is 25°C/kilometer
- Heat generated by the:
  - Formation of the planet – all terrestrial planets cooled following formation
    - Only large planets still retain heat
    - Smaller planet interiors cool faster (Merury, Mars)
  - Radioactive decay of elements / isotopes in Earth's interior maintains liquid outer core

Continental Drift



Pangaea, 250 MYA

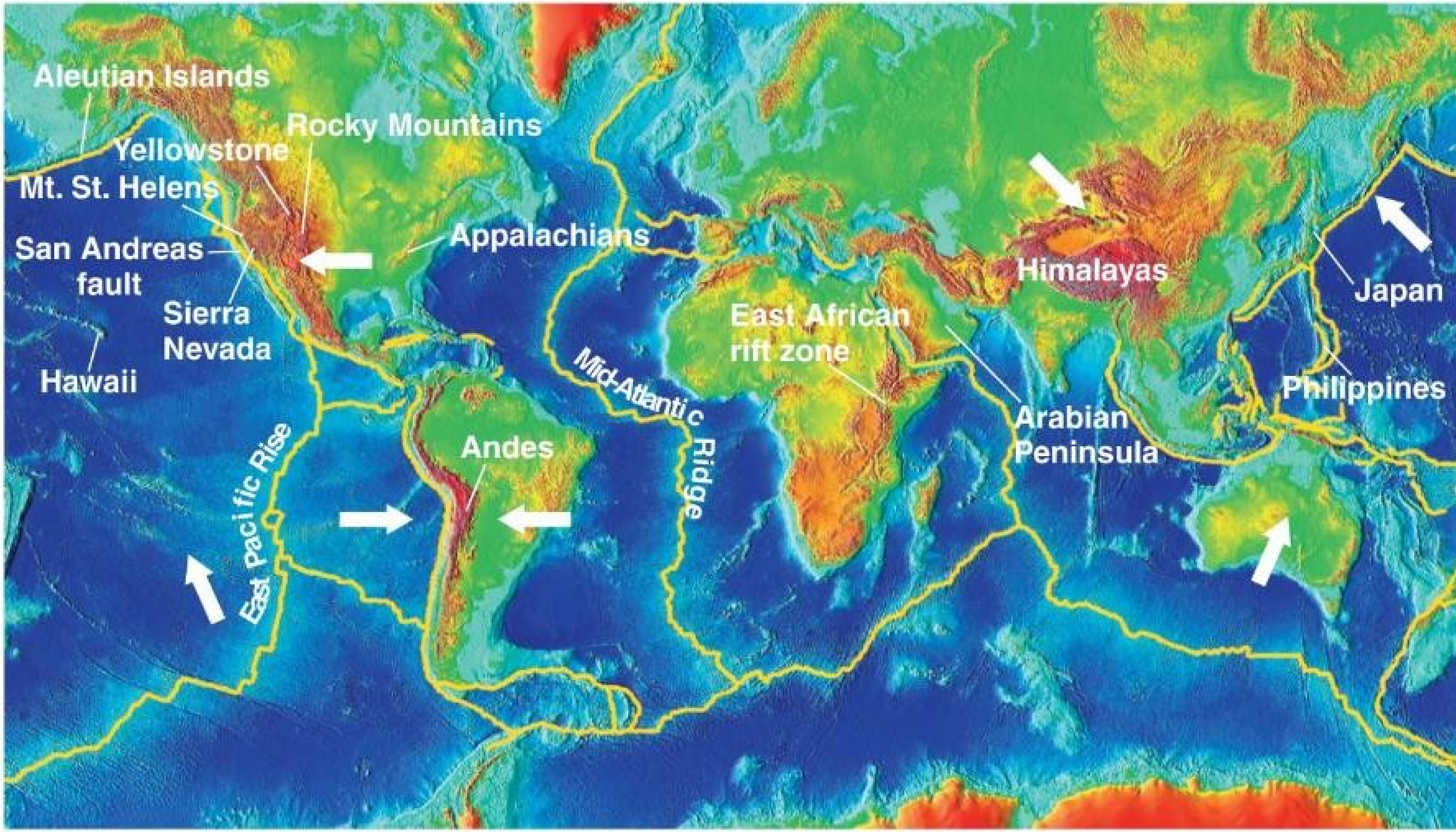
Laurasia and Gondwana, 210 MYA

Most modern continents had formed by 65 MYA

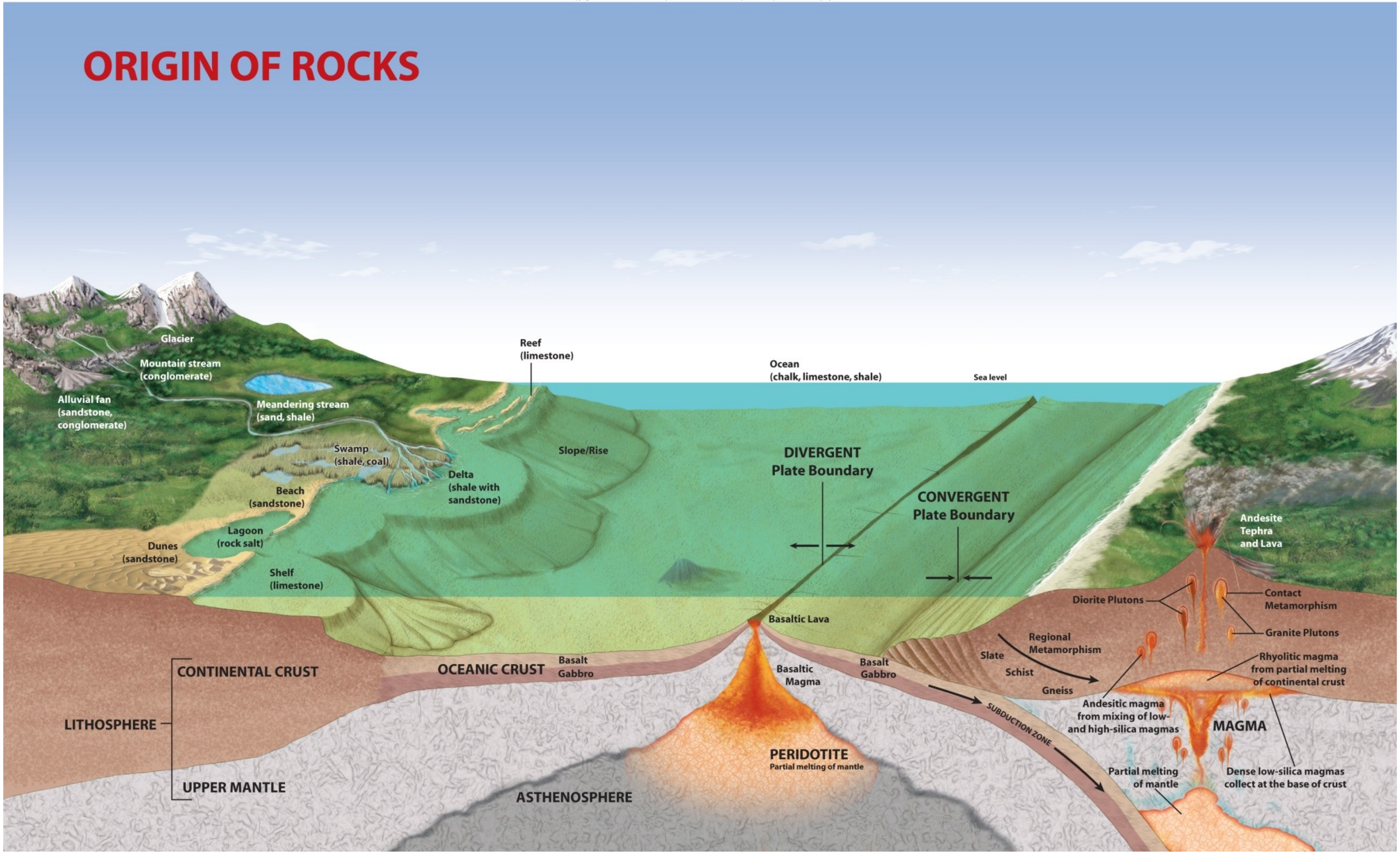
Wegener's Alternative Paradigm:

- **Continental Drift**: continents have occupied different locations on Earth's surface in the geologic past
  - 250 million years ago the continents were all together in a "supercontinent", **Pangaea**
  - Continents "drifted" across surface of Earth to their present locations

Earth's surface -- shaped by plate tectonics



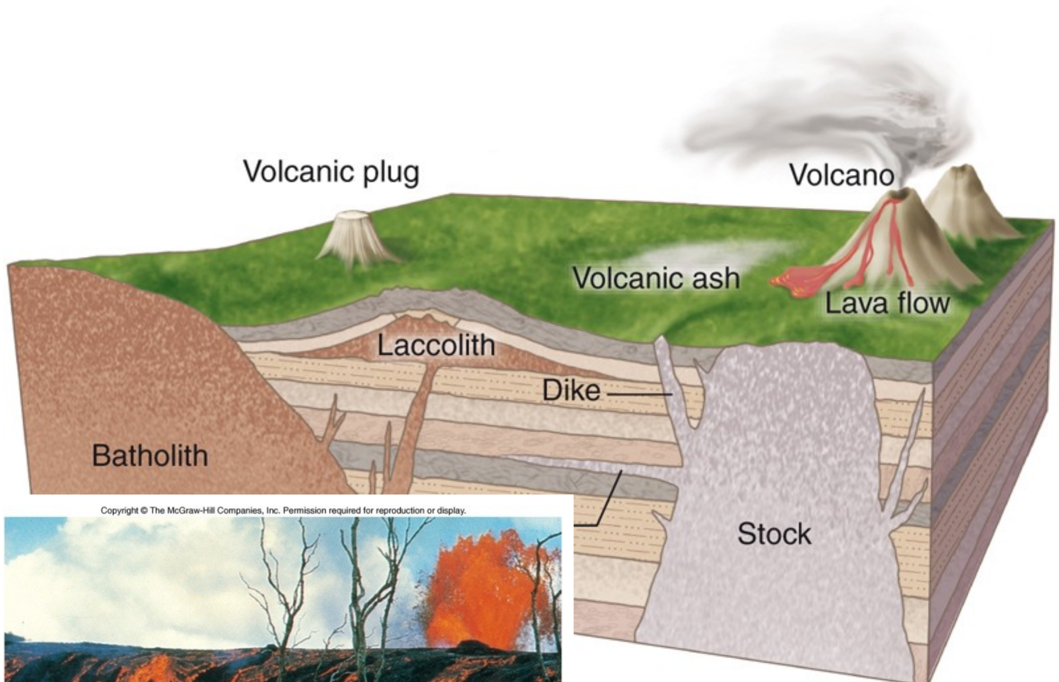
Igneous Rocks



Igneous Rocks

Two types of igneous rocks are classified based on texture and composition

The same magma can form both rock types

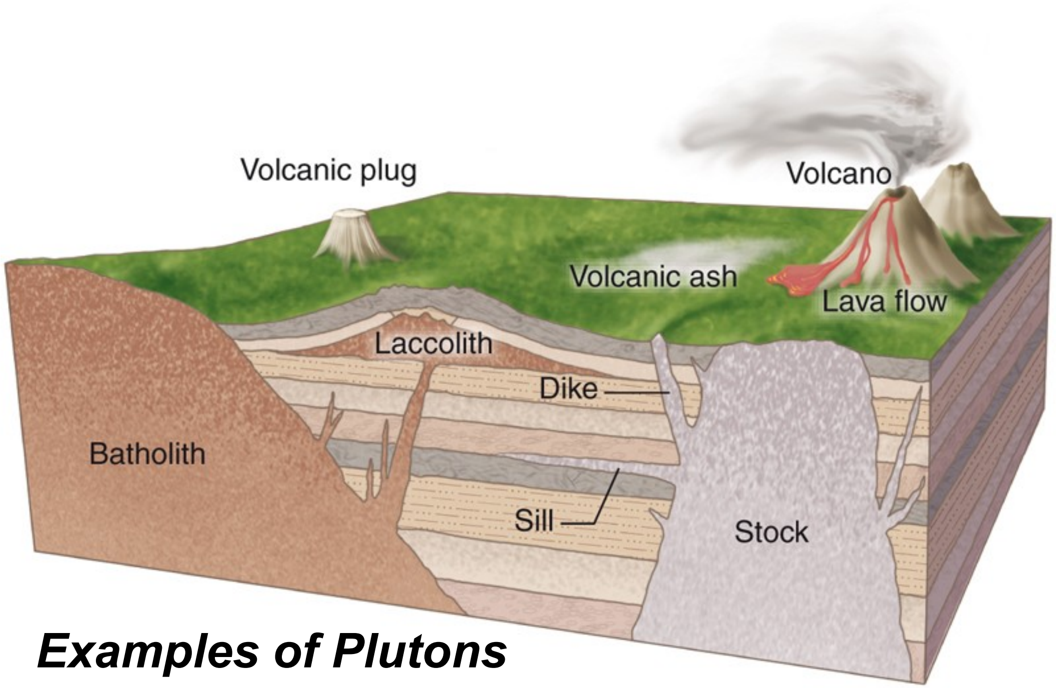


1. **Volcanic rocks** – form when magma rises to Earth's surface
   - Produces volcanoes, lava flows, tephra
   - Molten rock cools rapidly

Igneous Rocks

Two types of igneous rocks are classified based on texture and composition

The same magma can form both rock types



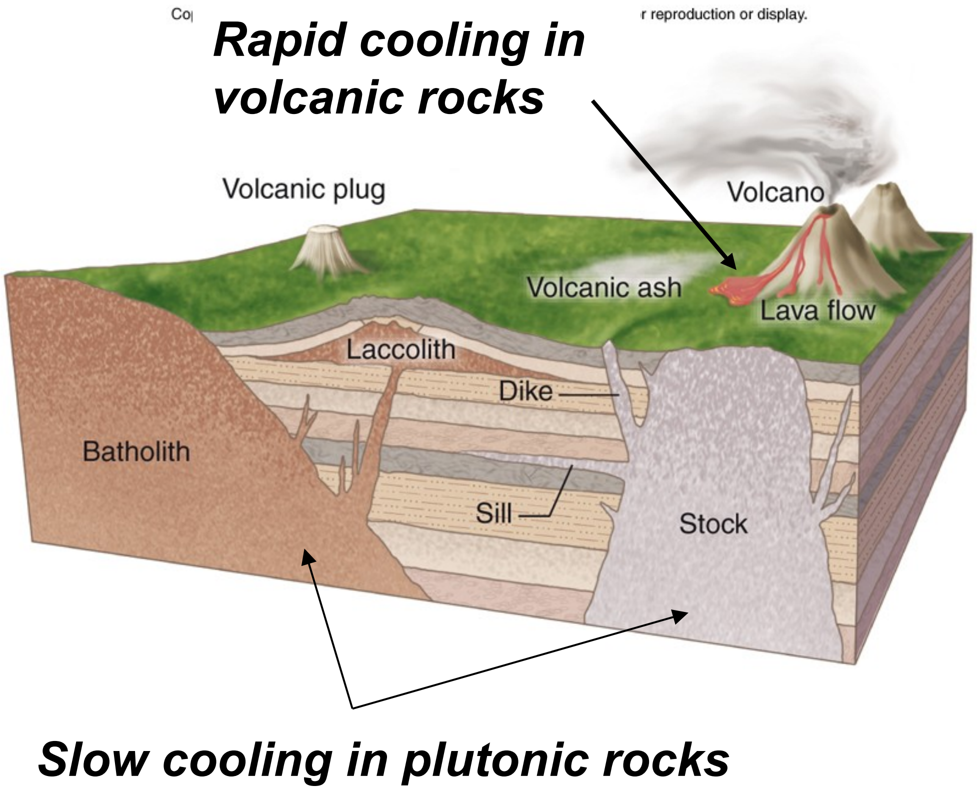
Examples of Plutons

Batholith, stock, sill, dike, laccolith

2. Plutonic rocks – form when magma solidifies below Earth's surface

- Produces **plutons** that remain hidden until exposed by erosion
- Molten rock cools slowly

Igneous Rocks



Texture

- Size of crystals of minerals in igneous rocks depends on rate of cooling of magma
  - Rapid cooling produces small microscopic crystals
  - Slow cooling produces large, visible crystals
- Crystal size interpreted to learn where rocks formed

Igneous Rocks

© C. C. Plummer, Larry Davis

Color

- Color varies with silica content (composition)
  - Silica-rich minerals such as quartz and feldspar are light-colored
  - Silica-poor minerals such as amphibole, biotite mica are dark colored

Igneous Rocks


Granite


Diorite

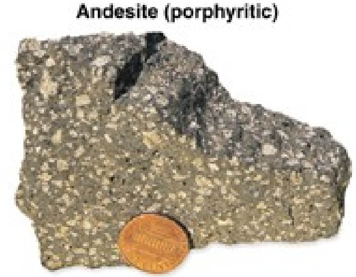

Gabbro

Table 7.4 Silica Content of Igneous Rocks

Silica content	Volcanic rocks	Plutonic rocks	Common minerals
High	Rhyolite	Granite	Quartz, feldspar
Intermediate	Andesite	Diorite	Feldspar, amphibole, pyroxene
Low	Basalt	Gabbro	Pyroxene, feldspar, olivine


Basalt

Rhyolite


Andesite (porphyritic)


Rocks and Minerals Conceptest

Geologists sometimes find a type of igneous rock known as porphyry, which contains both large and small crystals. Which is the best explanation for the formation of this rock?

The rock experienced a two-stage cooling process . .

A. **. . with initial slow cooling at depth followed by rapid cooling at the surface.**

B. . . with initial rapid cooling at depth followed by slow cooling at the surface.

C. . . with initial rapid cooling near the surface followed by slow cooling at depth.

D. . . with initial slow cooling near the surface followed by rapid cooling at depth.

Rocks and Minerals Conceptest

This rock sample corresponds to . . .

A. **A low silica volcanic rock. Basalt – low silica, small grain, rapid cooling at Earth's surface**

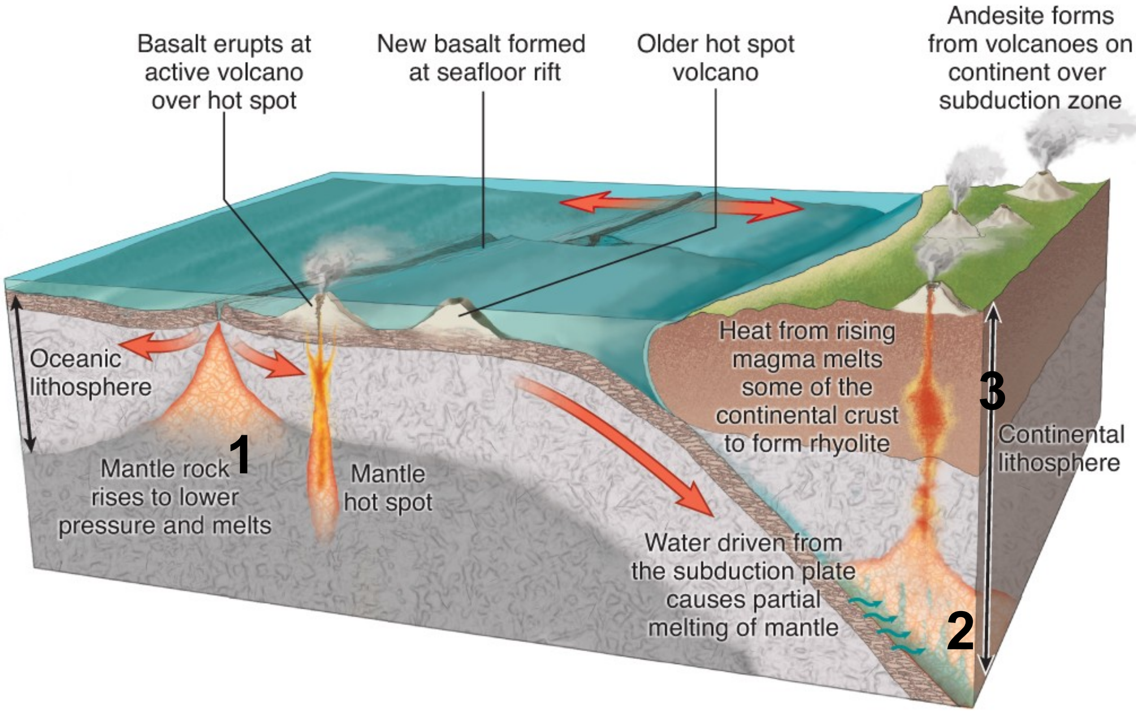
B. A low silica plutonic rock.

C. A high silica plutonic rock.

D. A high silica volcanic rock.

Igneous Rocks

Rock Types and Magma Types



Each magma type may produce volcanic and plutonic rocks

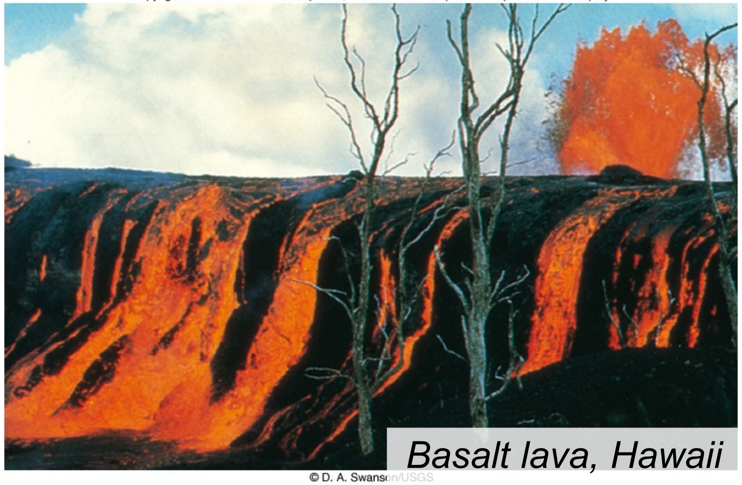
3 Magma Types

- **Basaltic magma** – partial melting parts of asthenosphere
- **Andesitic magma** – partial melting of mantle rocks (with water)
- **Rhyolitic magma** - melting of parts of continental crust

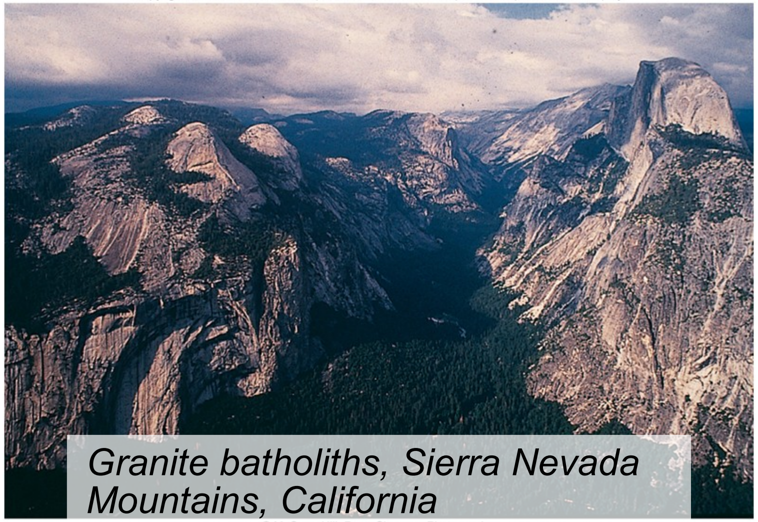
Igneous Rocks

Rock Types and Magma Types

- Less viscous, low silica magma likely to reach surface to form volcanic igneous rocks (e.g., basalt)



Basalt lava, Hawaii

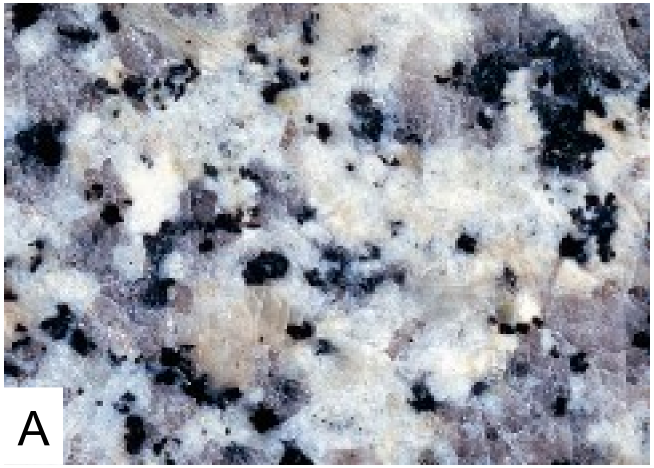


Granite batholiths, Sierra Nevada Mountains, California

- More viscous, high silica magma likely to cool below surface to form plutonic igneous rocks (e.g., granite)

Rocks and Minerals Checkpoint 7.10

granite



A

B

basalt

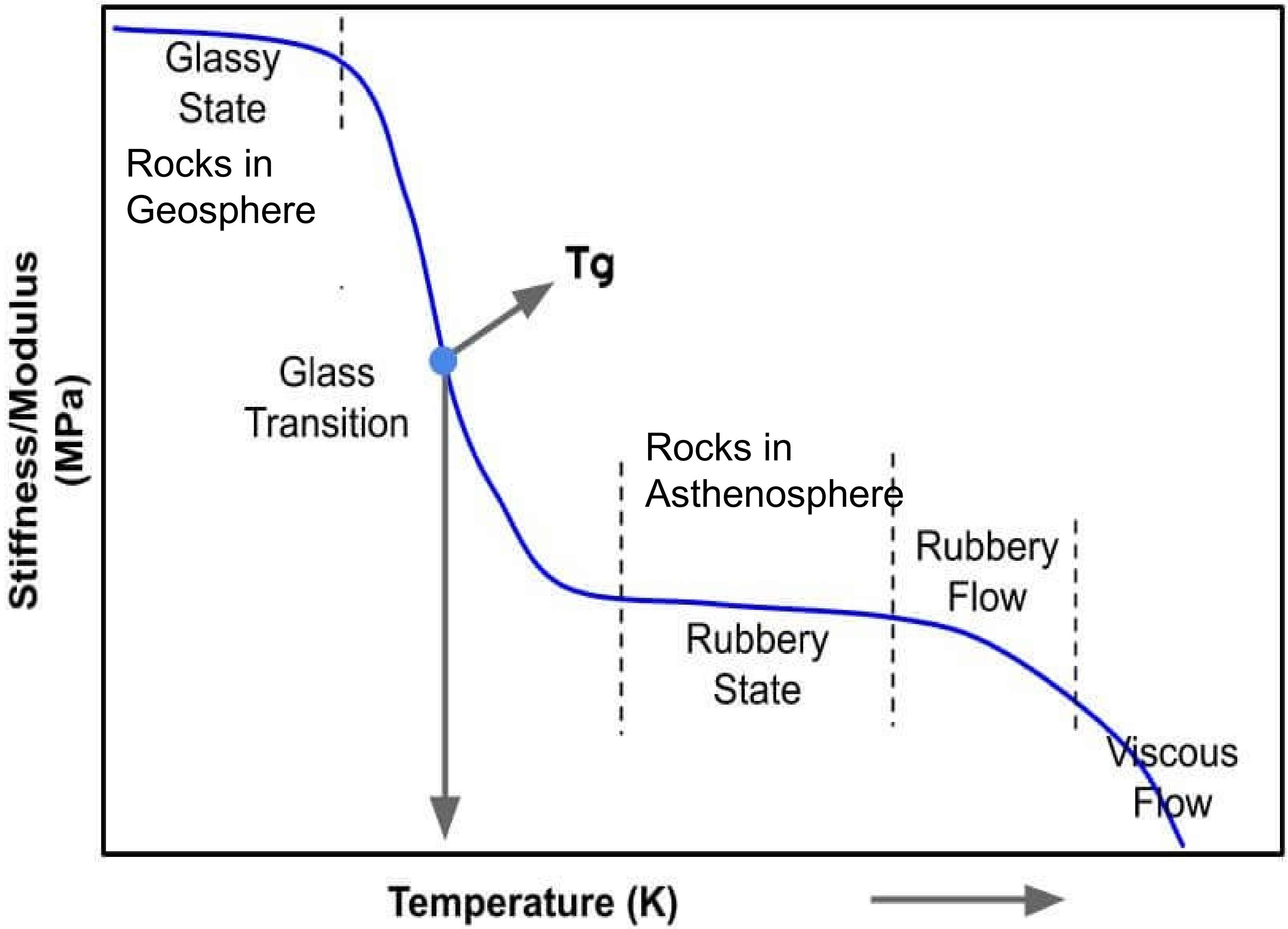
Name these igneous rocks and explain the reasons for your choices.

rhyolite

C

D

diorite


Glassy
State
Rocks in
Geosphere
Tg
Glass
Transition
Rocks in
Asthenosphere
Rubbery
Flow
Rubbery
State
Viscous
Flow
Stiffness/Modulus
(MPa)
Temperature (K)

Elastic Modulus vs. Temperature

Something
like strength

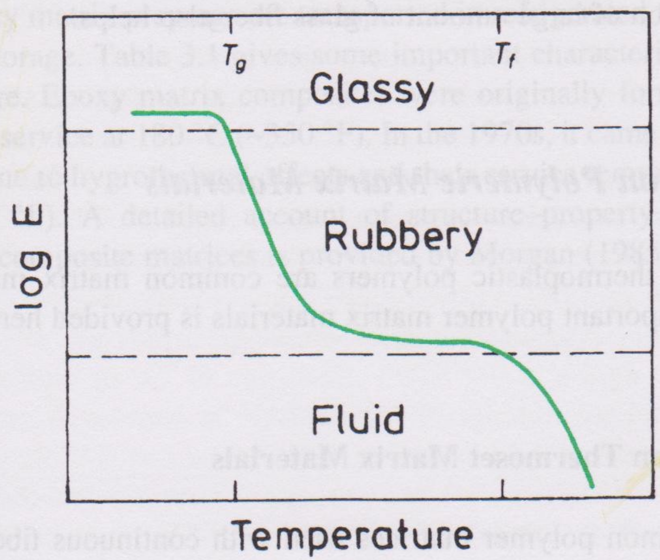
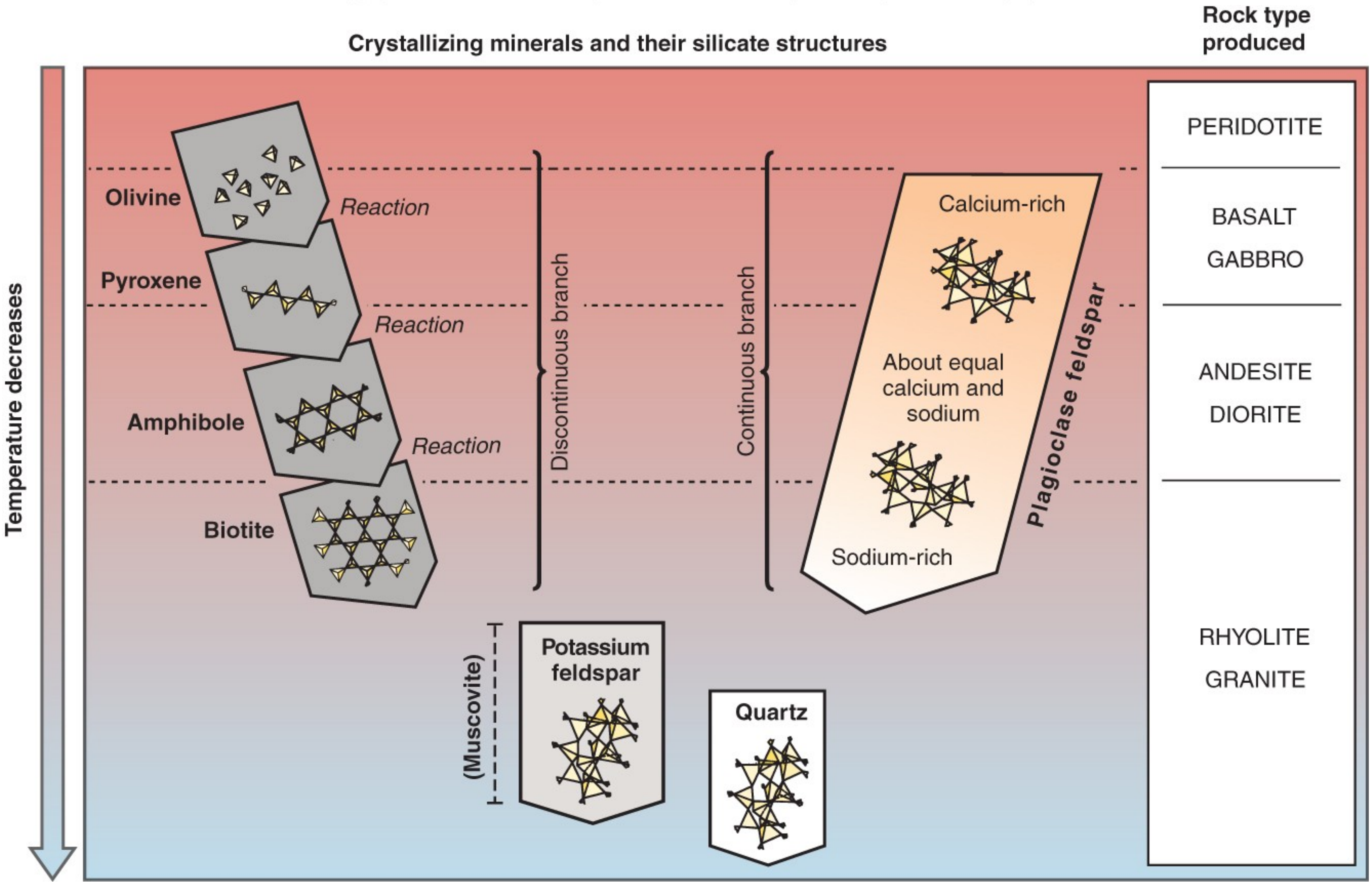


Fig. 3.6 Variation of elastic modulus of an amorphous polymer with temperature (schematic)

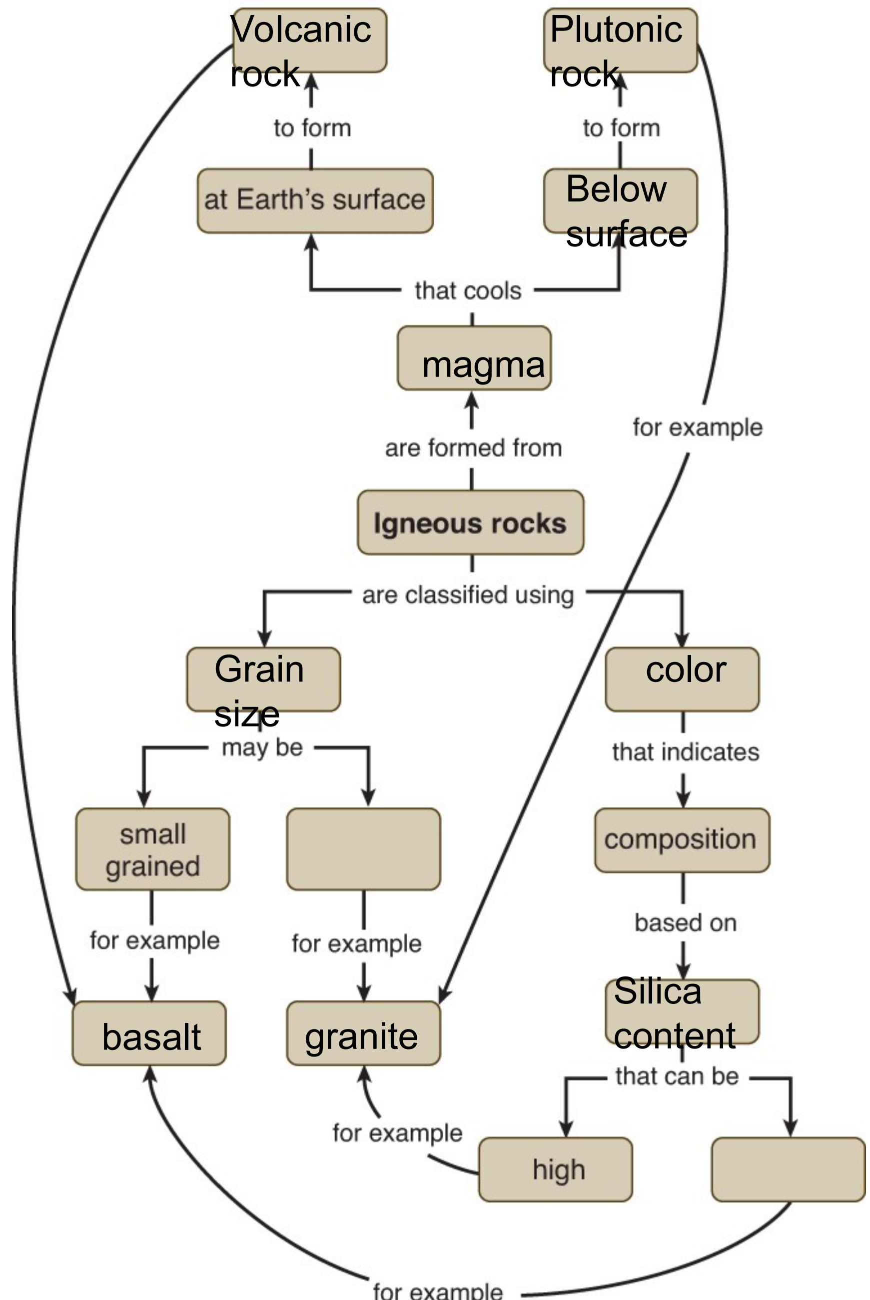
Rocks subduct into asthenosphere where the become rubbery (plastic).
Every mineral becomes rubbery at some temperature.
Temperature of earth increases by ~25oC/km.
So, every mineral becomes rubbery at some depth in the asthenosphere.

Crystallization of silicate minerals from magma.

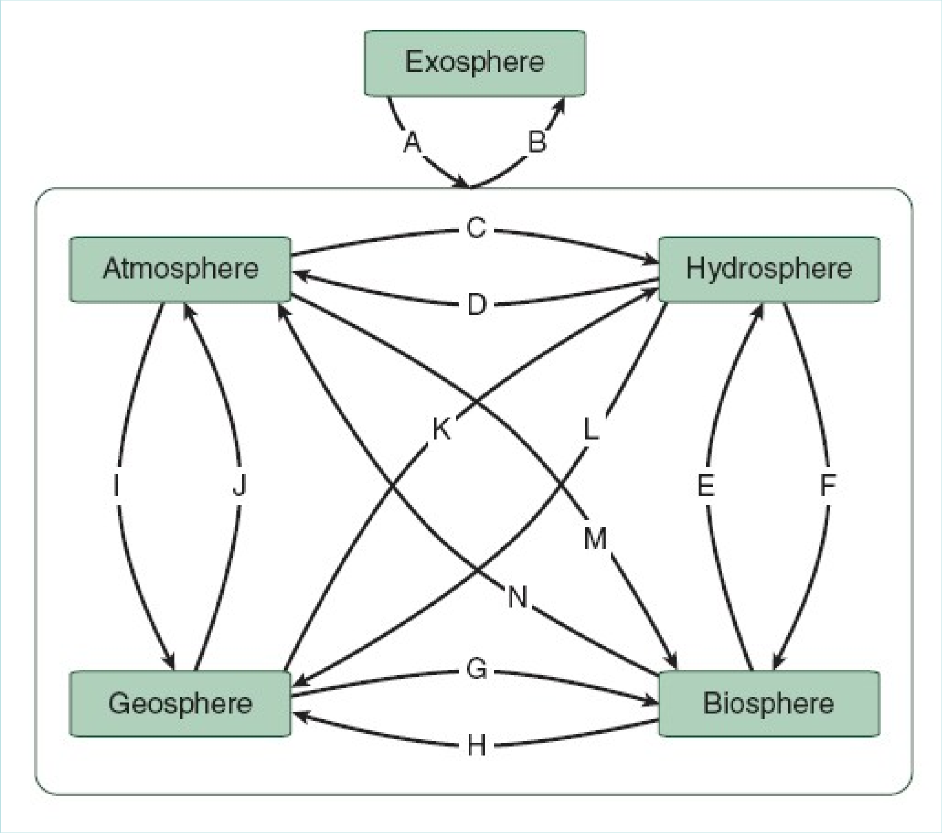


Rocks and Minerals Checkpoint 7.12

Some terms are magma, basalt, plutonic rocks and volcanic rocks



Rocks and Minerals Concept Map



Interactions between the earth system and rocks and minerals.

Some choices (Think of others):

A Solar energy causes evaporation of seawater → chemical sedimentary rocks
C Sahara Dust carried by wind to Atlantic ocean
D Evaporation of sea water → chemical sedimentary rock in Geosphere
F Marine organisms extract calcium carbonate from the ocean
H Formation of biochemical sedimentary rocks, (coal)
I Wind deposits sediment when its velocity decreases
K Weathering dissolves some elements in water
L Formation of chemical sedimentary rock
M Plants that form coal extract carbon in atmosphere
N Burning fossil fuels releases carbon to atmosphere