

Physical Geology Lecture Tutorials

Third Edition

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The Physical Geology Lecture Tutorials (3rd Edition) are available at:

<https://erikharoldson.com/pglt3/>

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Table of Contents

Science:.....	1
Cosmology:.....	7
Big Picture Earth:.....	13
Plate Tectonic Theory History:.....	15
Plate Boundary Types:.....	19
Atoms and Minerals:.....	25
Mineral Categories:.....	31
Mineral Variations:.....	315
Rock Cycle:.....	39
Igneous Rocks:.....	45
Melts:.....	51
Volcanoes:.....	57
Weathering:.....	63
Soils:.....	67
Sediment and Sedimentary Rocks:.....	71
Sedimentary Structures and Interpretations:.....	77
Metamorphism Controlling Factors:.....	83
Metamorphism Types:.....	89
Relative Age Principles:.....	95
Unconformities:.....	103
Numerical Ages:.....	107
Stress and Strain:.....	113
Folds:.....	119
Faults:.....	125
Earthquake Waves:.....	133
Earthquake Hazards:.....	141
Mass Wasting Controls:.....	147
Mass Wasting Prevention:.....	151
Water Cycle:.....	157
Streams:.....	161
Floods:.....	167
Groundwater Storage:.....	173

Groundwater Contamination:.....	179
Groundwater Geology:.....	185
Carbon Cycle:.....	191
Climate Change:.....	197
Energy Resources:.....	201
Mineral Resources:.....	207

First some review of Science:

“Science is a way of thinking much more than it is a body of knowledge”

– Carl Sagan

Falsifiability

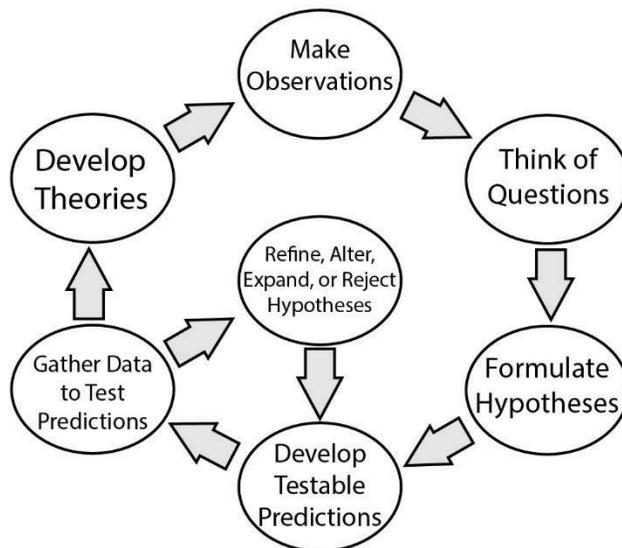
All scientific claims are falsifiable, meaning they could be tested and proven wrong. An explanation that is not testable is considered *pseudoscience*.

Scientific Method

Hypothesis - an educated guess based on limited evidence; a starting point.

Objective Observations – unbiased (as much as possible) direct observations of natural phenomenon either with our natural senses or with instruments.

Theory – an explanation of natural phenomenon that can successfully tested repeatedly.



The scientific method is often presented as a linear arrangement from initial question to developed theory, the above depiction of the scientific method emphasizes the cyclical nature of science (Modified from opengeology.org (CC-BY-NC-SA)).

Now, test your knowledge:

Briefly define the following terms:

hypothesis -

theory -

objective -

subjective -

quantitative -

qualitative -

pseudoscience -

Answer the following:

1. True/False: A claim that has been around for a very long time can be trusted as it has “stood the test of time”.
2. Take a moment to look up any of the terms that you’re unfamiliar with. Which of the following would be considered to be pseudoscience (select all that apply):
 - A. Flat Earth
 - B. Evolution
 - C. Phrenology
 - D. Astrology
 - E. Race Science
 - F. Economics

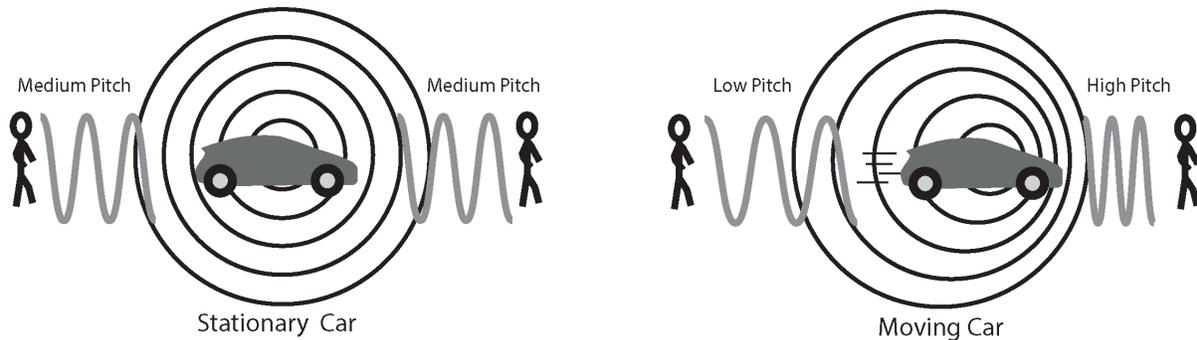
3. In the scientific method, this would be considered an initial proposed explanation for an observed phenomenon:
 - A. Objective Observation
 - B. Subjective Observation
 - C. Hypothesis
 - D. Pseudoscience
 - E. Theory

4. In the scientific method, this would be considered a very well tested explanation for an observed phenomenon:
 - A. Objective Observation
 - B. Subjective Observation
 - C. Hypothesis
 - D. Pseudoscience
 - E. Theory

5. True/False: Once developed, a scientific theory is considered to be 'fact', and therefore no longer in question.

First some review of Cosmology:

Doppler Effect



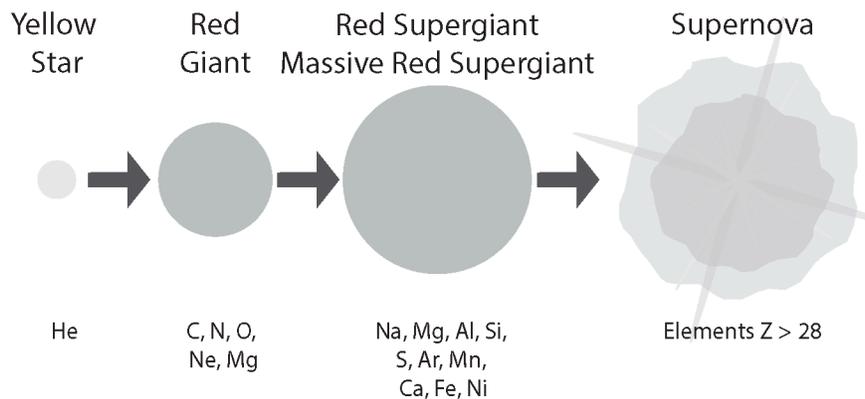
The Doppler Effect is perhaps more easily understood when related to the sound we hear from a passing car blowing its horn. In the same way sound shifts, light emitted from objects moving away or towards the viewer will shift in color. The *red shift* we see in distant stars tells us they are moving away from us.

Big Bang



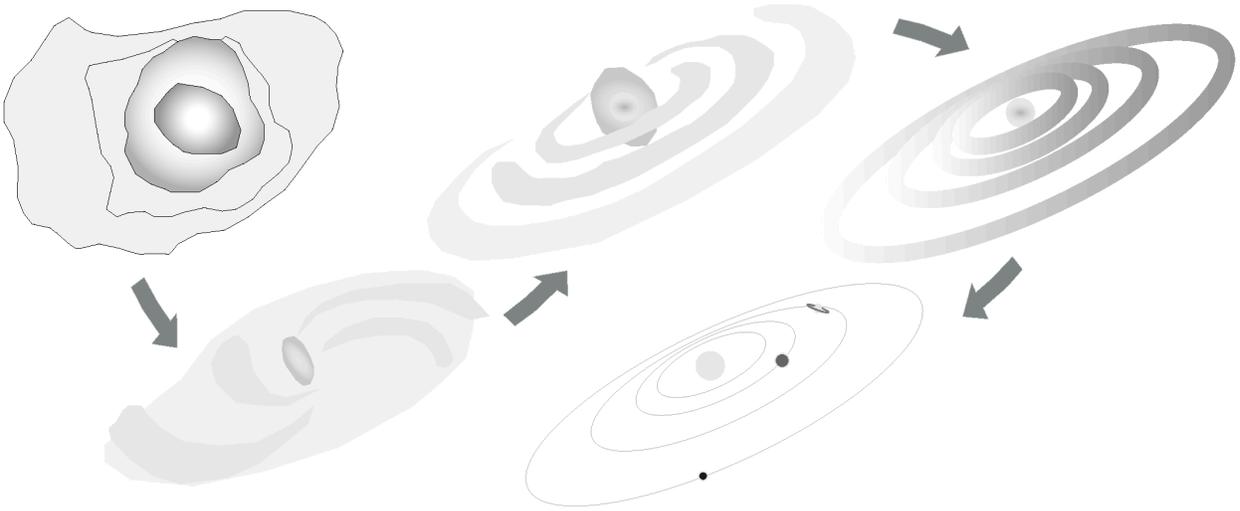
By observing red shift in distant stars, we can tell the universe is expanding. If we rewind the expansion into the past, we know that ~13.8 billion years ago the universe emerged from an infinitely dense and hot core of material in an event known as the *big bang*.

Stellar Evolution



The big bang produced lighter elements such as hydrogen and helium. The remaining elements were all created later, primarily during **fusion** reactions in stars where lighter elements are combined in nuclear reactions to form heavier elements. Heavier elements up to iron are created at different stages of a star's evolution (i.e. stellar evolution). Elements heavier than iron are created during the death of a star in an event known as a **supernova**.

Nebular Hypothesis



~4.6 billion years ago the solar system formed from an interstellar cloud of gas and dust that began to collapse together due to gravity. The cloud flattened and began to rotate. Dust grains clumped together into planetesimals. The planetesimals collected into planets. Temperate zones allowed for condensation of metals and silicates near the center, while light molecules of gas condensed further away. This is why we have rocky planets near the center, and gas giants near the outer portions of the solar system.

Now, test your knowledge:

Briefly define the following terms:

doppler effect –

electromagnetic spectrum –

redshift –

blueshift –

big bang -

fusion –

stellar evolution –

supernova -

nebular hypothesis –

Answer the following:

1. True/ False. The Earth was created in the big bang.
 - A. True
 - B. False
2. True/False. Our sun is a yellow star, it has remained this way since the big bang.
 - A. True
 - B. False
3. True/False. Our sun is a yellow star, it will remain this way for all eternity.
 - A. True
 - B. False

4. We know distant stars are moving away from us due to an observed *redshift*. This redshift is caused by a property known as the _____.
- A. Hubble Effect
 - B. Doppler Effect
 - C. Einstein Effect
 - D. General Relativity Effect
 - E. $E = MC^2$ Effect
5. In the electromagnetic spectrum, blue is a higher frequency (shorter wavelength) than red. Therefore, a shift towards red indicates an object is _____.
- A. moving towards us.
 - B. moving away from us.
 - C. not moving toward or away from us.
6. The element silver has an atomic number (Z) of 47. All atoms of this element were formed in a _____.
- A. red giant star
 - B. the big bang
 - C. yellow star
 - D. supernova
 - E. red supergiant star
7. The idea that the solar system formed from a collapsing cloud of dust and gas that began to rotate as a disc, with a star forming at the center, is known as the _____.
- A. Big Bang
 - B. Nebular Hypothesis
 - C. Supernova
 - D. Doppler Effect
 - E. Black Hole Sun Theory

Now, think deeper:

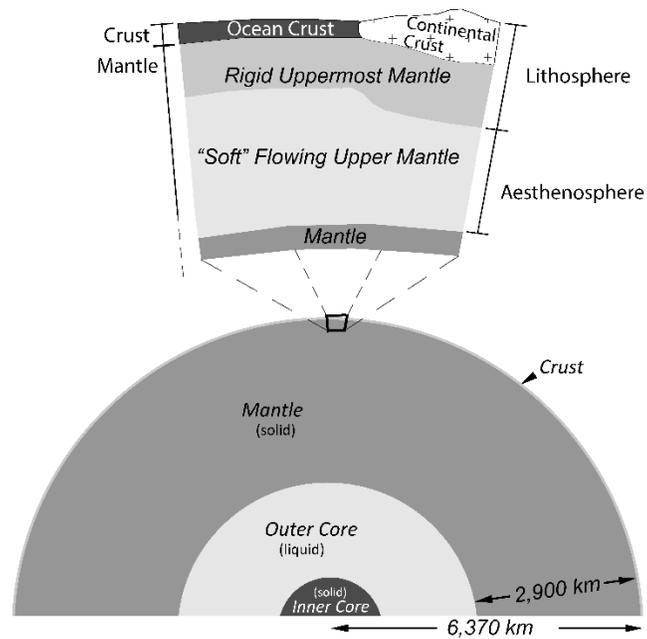
On your own:

8. What does knowing about cosmology have to do with studying the earth?

Working in groups of 2 or 3:

9. Discuss your answers to questions 8. Note any differences in your partner's answers here.

First some review of Big Picture Earth: Layers of the Earth



The Earth is divided into 3 main concentric zones: **Crust**, **Mantle**, and **Core**. These zones are broken up further, based on composition and physical properties (as in above image).

Earth Systems



The Earth can be thought of as a single "system" operating within the solar system. The Earth system can be broken further into sub-systems (as in above image). Although they are unique, a lot of Earth Science is about understanding the interaction between these subsystems or "Earth Systems".

Now, test your knowledge:

Briefly define the following terms:

chemical properties -

physical properties -

system -

isolated system -

closed system -

open system –

atmosphere –

hydrosphere –

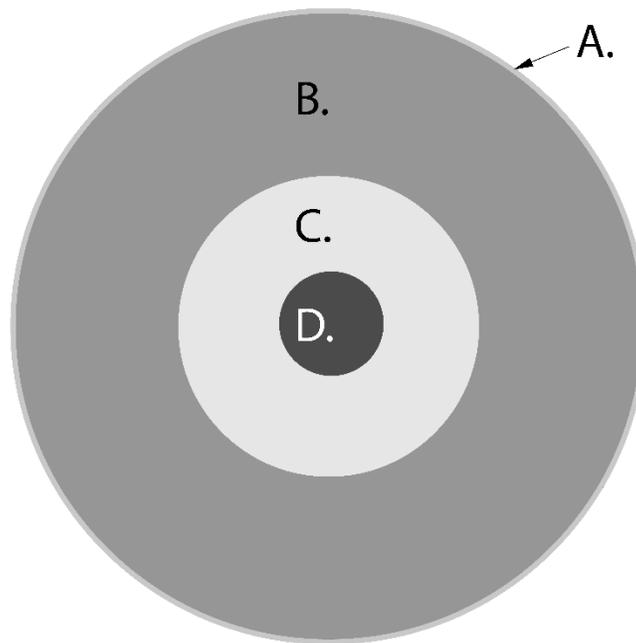
biosphere –

geosphere –

heat engine -

dynamic -

Answer the following:



In the above illustration, the interior of the Earth is broken into the 4 important layers.

14. Match the layers with the correct name below:

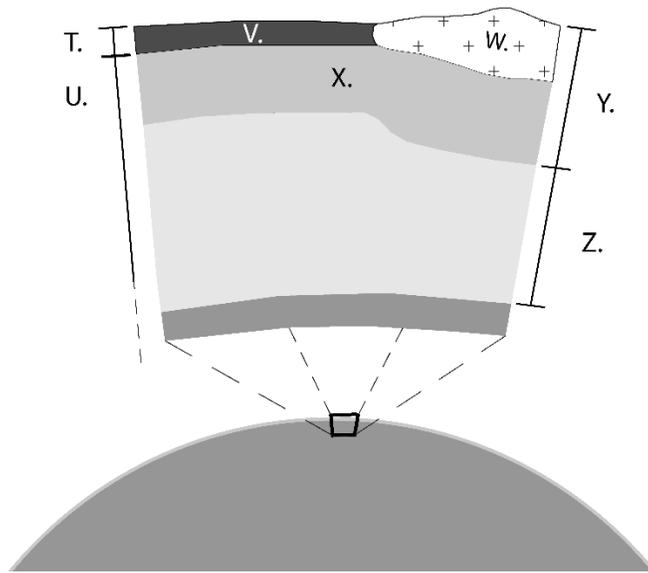
- G. Mantle: _____
- H. Outer Core: _____
- I. Crust: _____
- J. Inner Core: _____

15. Which of the Earth's main layers is molten (liquid)?

- A. Mantle
- B. Outer Core
- C. Crust
- D. Inner Core

16. Which layer is the largest portion of Earth (i.e. largest by volume).

- A. Mantle
- B. Outer Core
- C. Crust
- D. Inner Core



In the above illustration, numerous layers make up the outermost portion of the Earth.

17. This layer is solid rock, but it is hot and soft and it flows, allowing the overlying plates to slide around the surface of the Earth.
 - A. W
 - B. X
 - C. Y
 - D. Z

18. The answer to the previous question (#4) is named the:
 - A. Outer Crust
 - B. Lithosphere
 - C. Asthenosphere
 - D. Uppermost Mantle

19. Which combination of layers makes up the “Lithosphere”?
 - A. Y and Z
 - B. V and W
 - C. V, W and U
 - D. V, W and X

20. A system represents “a set of things working together as parts of a mechanism or an interconnecting network”.
 - A. True
 - B. False

21. Match the following items into the Earth Systems that they are most associated with.
 - A. Metamorphic Rock

Physical Geology Lecture Tutorials
Earth

- B. Snail
 - C. Nitrogen Gas
 - D. River
 - E. Bison
 - F. Glacier
 - G. Inner Core
 - H. CO₂

 - I. Atmosphere 1: _____
 - J. Atmosphere 2: _____
 - K. Geosphere 1: _____
 - L. Geosphere 2: _____
 - M. Hydrosphere 1: _____
 - N. Hydrosphere 2: _____
 - O. Biosphere 1: _____
 - P. Biosphere 2: _____
22. Of the following scenarios, which best describes an interaction of the Hydrosphere and the Atmosphere.
- A. Soil is made from weathered rocks, and contains gas as well as organic material.
 - B. Burning of coal and other fossil fuels releases CO₂.
 - C. A large tsunami is created when an earthquake shifts tectonic plates.
 - D. Evaporation of ocean water creates water vapor.

Now, Think Deeper:

23. How might you explain the existence of the heavy elements like iron (Fe) and nickel (Ni) being concentrated in the center of the planet, while lighter elements like silica (Si) and oxygen (O) being concentrated toward the outer part of the planet? (hint: what fundamental force might have played a role)

24. A balloon filled with helium gas will rise in the atmosphere because it is lighter than the surrounding air (atmosphere is made mostly of nitrogen (N)). If the outer core is molten (liquid) and made of heavy elements (iron, nickel), do we expect that molten material to rise through the mantle (made of magnesium and silica) to the planet surface?

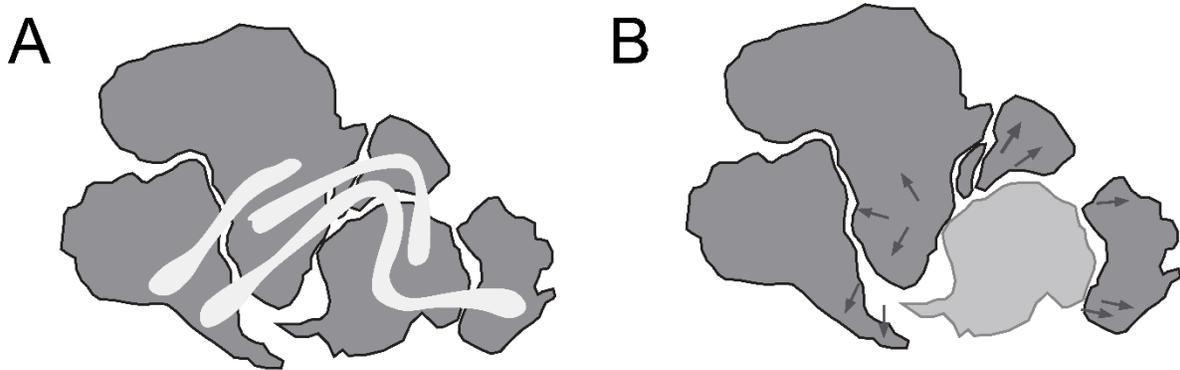
25. Is it likely that humans will ever be able to visit the center of the Earth?

26. Describe 2 unique Earth systems which are unlikely to be connected. What is keeping them apart?

27. Describe 2 unique Earth systems that are very interconnected. What physical process connects them?

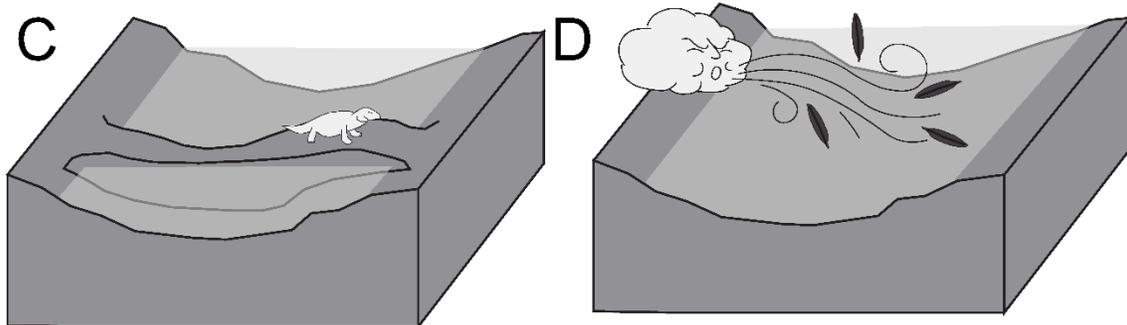
First some review of Plate Tectonic Theory History:

Early Evidence:



- (A) The locations for unique plant and animal fossils are observed on 5 continents, and they line-up well when continents are re-oriented like a jig-saw puzzle.
- (B) Similarly, the location of markings (scratches) on rock surfaces that indicate the presence of ice (and ice flow directions) in the past, align well when re-oriented to form a supercontinent.

Skeptics:



- (A) Skeptics pointed to the potential for land-bridges that may have existed to have allowed animals to get across oceans.
- (B) Skeptics also pointed to the possibility for wind currents to have carried plants (seeds) across great distances.

Now, test your knowledge:

Briefly define the following terms:

land bridge -

polar wander -

continental drift -

pangaea -

curie temperature -

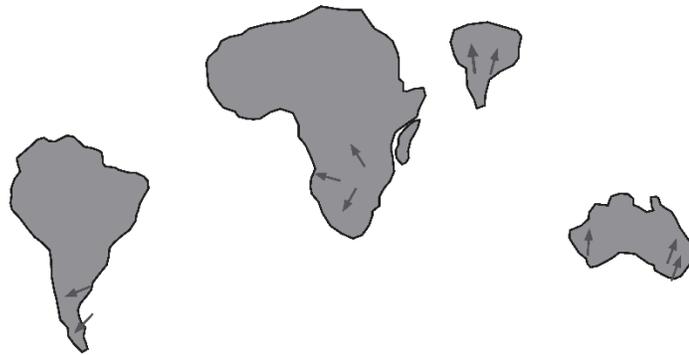
seafloor spreading –

Answer the following:

1. Alfred Wegener was this type of scientist:
 - A. Geologist
 - B. Biologist
 - C. Meteorologist
 - D. Chemist
 - E. Botanist
2. Wegener's idea that the continents move around on the surface of the Earth was known as _____.
 - A. Continental Drift
 - B. Polar Wander
 - C. Pangaea
 - D. Ice Flow Direction
 - E. Sea Floor Spreading
3. What was the name Wegener gave to the supercontinent formed when the continents were re-assembled like a jigsaw puzzle?
 - A. Gondwana
 - B. Pangaea
 - C. Laurasia
 - D. Rodinia
 - E. Arctica

4. Which of the following was not a reason that skeptical scientists argued against Wegener's theory? (you may have to consult your textbook)
 - A. Land-dwelling reptiles moved across oceans on land bridges.
 - B. Plants could have been spread along wind currents.
 - C. The Earth was only hotter in the past, so ice could not have been present during a supercontinent.
 - D. Polar wander could have been due to the poles moving, and not the continents.

5. Many similar plant fossils are spread across the continents of S. America, Africa, India, Australia, and Antarctica. However, no land animals are found outside a single continent.
 - A. True
 - B. False



In the above image, the continents with paleo ice location and flow direction markings have been re-oriented to locations similar to modern.

6. If you could not imagine the plates to have been shifted in the past, and instead assumed they were fixed in place since they were created, which statement best describes your observations of the above image?
 - A. The direction of paleo (ancient) ice flow was from continents into oceans.
 - B. The direction of paleo (ancient) ice flow was from oceans onto continents.
 - C. The direction of paleo (ancient) ice flow was only recorded in continents in the northern hemisphere.
 - D. The direction of paleo (ancient) ice flow was from south to north.

7. One of the most important fossil plants used as evidence for continental drift was glossopteris, why was this?
 - A. This plant had very heavy seeds, which could not have been transported by wind.
 - B. This plant had fossil leaves that were very difficult to identify in the fossil record.
 - C. This plant had only one growth formation.
 - D. This plant is adaptable to a large variety of climate regimes.

Now, think deeper:

On your own:

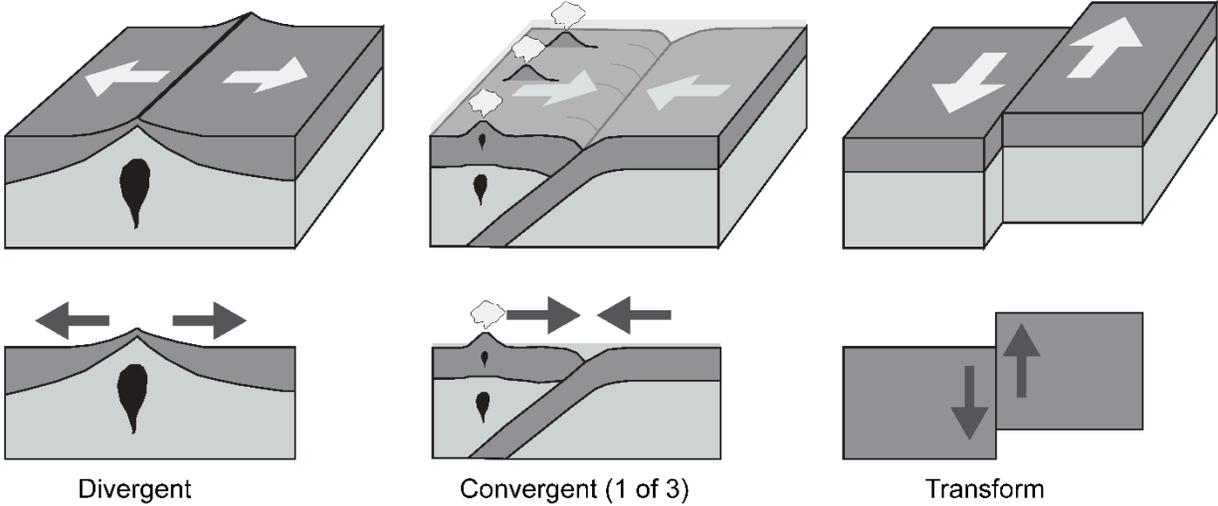
8. List some major scientific breakthroughs that have occurred throughout human civilization.
9. What other factors do you suppose lead to skepticism from the general public and science communities regarding the various breakthroughs you've listed above?

Working in groups of 2 or 3:

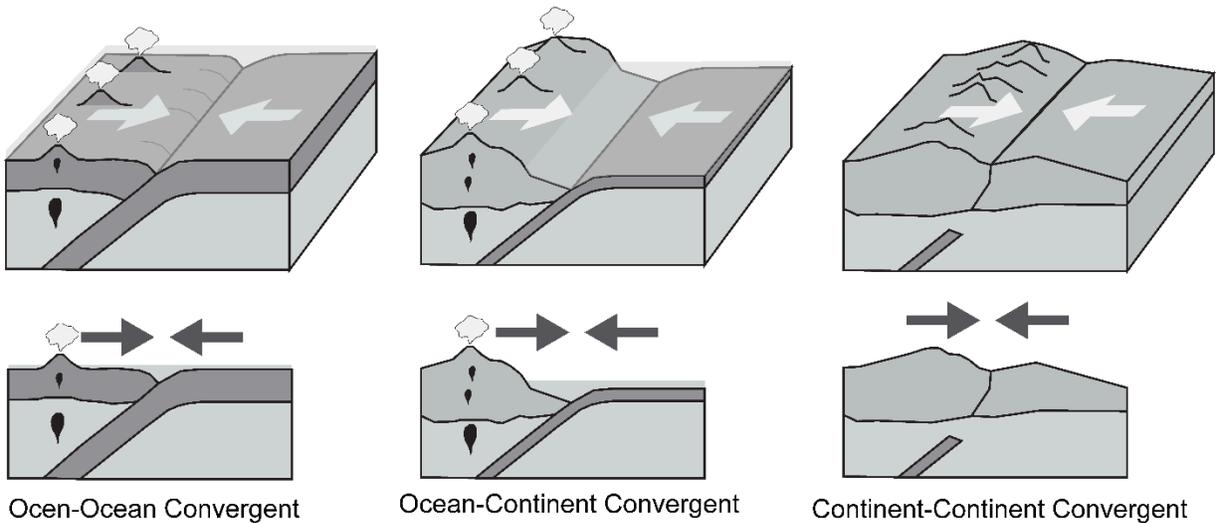
10. What other factors do you suppose lead to skepticism from the public and the science community regarding Alfred Wegener's ideas?
11. List some other geologic phenomenon that you think we now better understand thanks to knowledge of continental drift (plate tectonics)?
12. What about continental drift (plate tectonics) specifically helps us understand your listed geologic phenomenon?

First some review of Plate Boundary Types:

Boundary Types



Further Classification: Convergent Types



Now, test your knowledge:

Briefly define the following terms:

transform boundary -

divergent boundary -

convergent boundary -

mantle plume -

hot spot -

ridge push -

slab pull –

Answer the following:

1. At this type of boundary, two tectonic plates are moving away from each other:
 - A. Ocean-ocean convergent
 - B. Ocean-continent convergent
 - C. Continent-continent convergent
 - D. Divergent
 - E. Transform

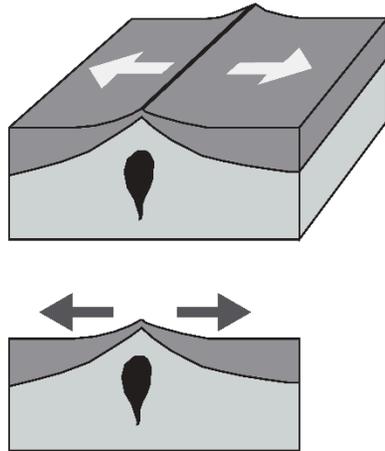
2. At this type of boundary, two tectonic plates are moving horizontally past each other:
 - A. Ocean-ocean convergent
 - B. Ocean-continent convergent
 - C. Continent-continent convergent
 - D. Divergent
 - E. Transform

Physical Geology Lecture Tutorials
Plate Tectonics - Boundary Types

3. At this type of boundary, an oceanic part of a tectonic plate is colliding with a continental portion of a tectonic plate:
 - A. Ocean-ocean convergent
 - B. Ocean-continent convergent
 - C. Continent-continent convergent
 - D. Divergent
 - E. Transform

4. True/False, an oceanic plate is either made of oceanic crust or continental crust, but not a mixture of both.
 - A. True
 - B. False

5. The Himalayan mountains contain the highest elevations on Earth. These high mountains form in what type of plate tectonic boundary?
 - A. Ocean-ocean convergent
 - B. Ocean-continent convergent
 - C. Continent-continent convergent
 - D. Divergent
 - E. Transform



6. In the above image, a spreading center is depicted, and at this location, the following is likely forming:
 - A. A mountain range at the edge of a continent
 - B. A mountain range at the center of a continent
 - C. A mountain range in the ocean
 - D. A subduction zone

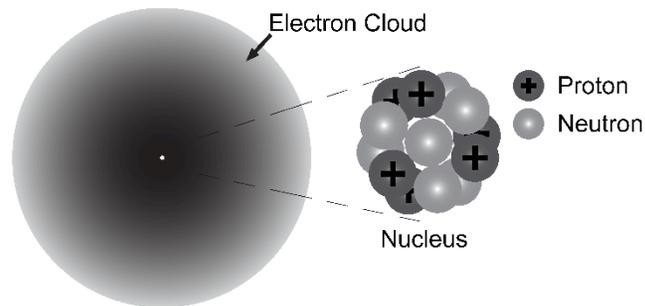
7. Igneous (volcanic) activity is common in which group of plate tectonic settings:
- A. Continent-Continent, Ocean-Continent, Ocean-Ocean
 - B. Ocean-Continent, Ocean-Ocean, Divergent
 - C. Continent-Continent, Ocean-Continent, Transform
 - D. Ocean-Ocean, Divergent, Transform
8. True/False, you are likely to find a volcano forming at a transform plate boundary, as in Los Angeles, California along the San Andreas fault.
- C. True
 - D. False

First some review of Atoms and Minerals:

Mineral Definition

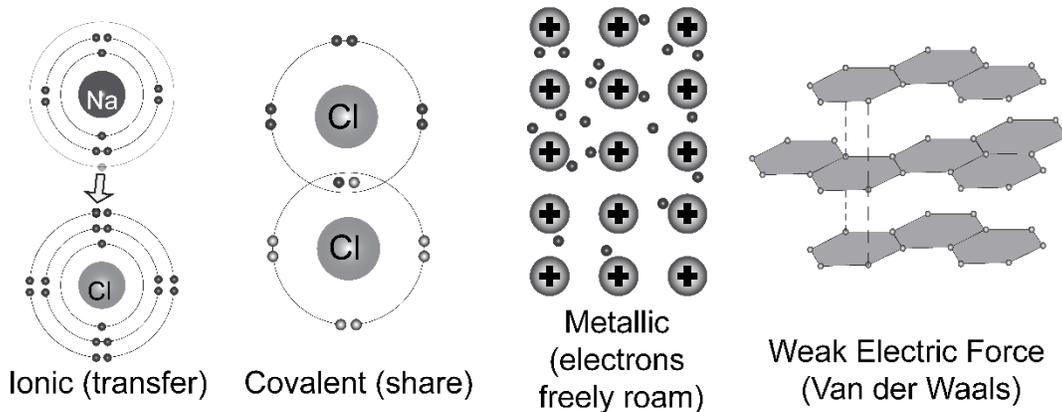
Naturally occurring, inorganic, crystalline solid with set chemical composition.

Atoms



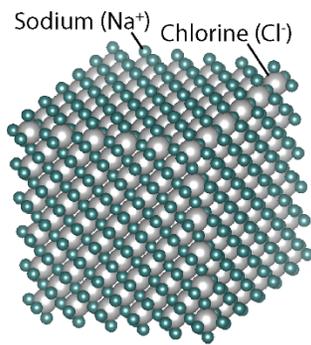
An atom has a nucleus which is made up of protons and neutrons. A cloud of electrons surrounds the nucleus. The number of protons in an atom defines what element it is.

Bonds

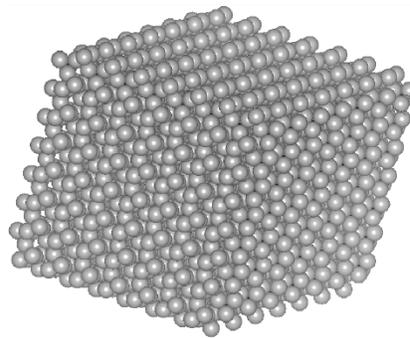


Ionic bonds involve the transfer of an electron from a cation to an anion. Two atoms which share electrons therefore giving each a complete outer shell are said to be covalently bonded. In metallic bonds, the atoms are closely spaced and electrons are allowed to roam about the network of atoms. Some atoms or groups of atoms are held together by weak electrical forces.

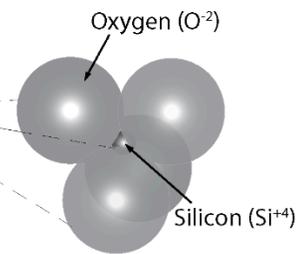
Crystal Structures



Halite



Quartz



Silicon-Oxygen
"Tetrahedron"

In minerals, atoms bond together arranging themselves in packages of cations (positive charged ions) surrounded by anions (negative charged ions). The arrangement of atoms often has a distinctive outer shape that repeats from the atomic level to the macro scale that you might see in macro-scale (a hand sample in the palm of your hand).

Now, test your knowledge:

Briefly define the following terms:

mineral -

rock -

atom -

element -

isotope -

cation –

anion -

ionic bond -

covalent bond –

metallic bond –

Van der Waal's force –

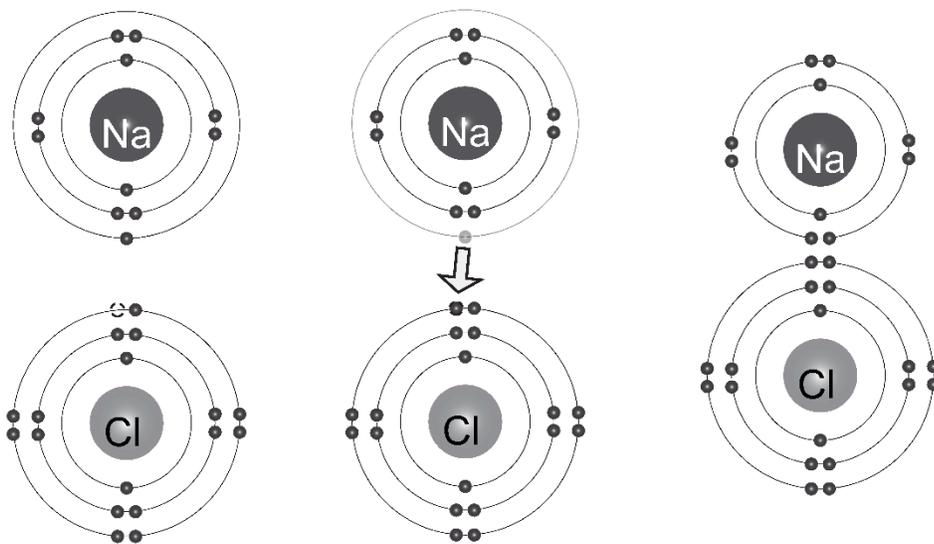
Answer the following:

1. True/False. Ice is a mineral.
 - A. True
 - B. False

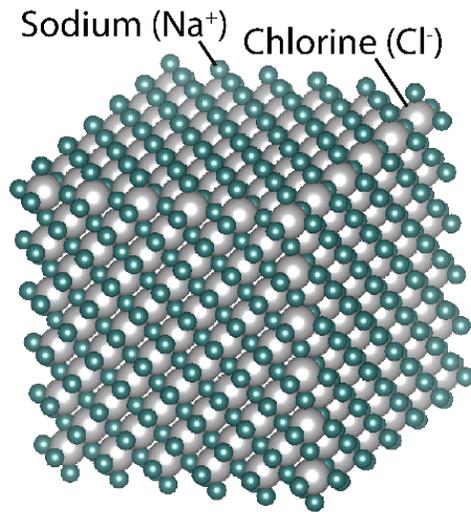
2. An atom is the smallest, electrically neutral assemblage of energy and matter, consisting of:
 - A. Protons, Neutrons, and Electrons.
 - B. Protons, Electrons, and Positrons.
 - C. Neutrons, Ionic Bonds, and Protons.
 - D. Positrons, Neutrinos, and Covalents.

3. An atom is determined to be a particular element, according to the:
 - A. Number of Neutrons in the nucleus.
 - B. Number of Protons in the nucleus.
 - C. Number of Electrons in the nucleus.
 - D. Number of Electrons in the electron cloud.

4. Which of the following describes an isotope of an element?
 - A. An atom of a particular element with more Neutrons than Protons
 - B. An atom of a particular element with more Protons than Neutrons
 - C. An atom of a particular element with more Electrons than Neutrons
 - D. An atom of a particular element with more Electrons than Protons



5. In the above image, the two atoms become bonded by what type of bond?
 - A. Ionic
 - B. Covalent
 - C. Metallic
 - D. Weak Force



Halite

6. In the above diagram, which is the cation?
 - A. Halite
 - B. Sodium
 - C. Chlorine
 - D. Cube

7. In the diagram from the previous question, how many cations surround 1 individual anion?
 - A. 2
 - B. 4
 - C. 6
 - D. 8

8. If I were to grind a large crystal of halite so that it was ground to the size of common table salt, what shape do you think the small crystals would tend to be?
 - A. Traingular prisms
 - B. Hexagonal prisms
 - C. Cubes
 - D. Round Balls

Now, think deeper:

On your own:

9. Ignore for a moment that to be defined a mineral it must form “naturally”. Can you think of places where you live that ‘minerals’ are forming?

10. Have you ever grown rock candy? Describe what you think is happening in a jar in which rock candy is being grown.

Working in groups of 2 or 3 answer the following:

11. Compare your answers to question 9. If you had different ideas, do they represent different types of mineral growth?

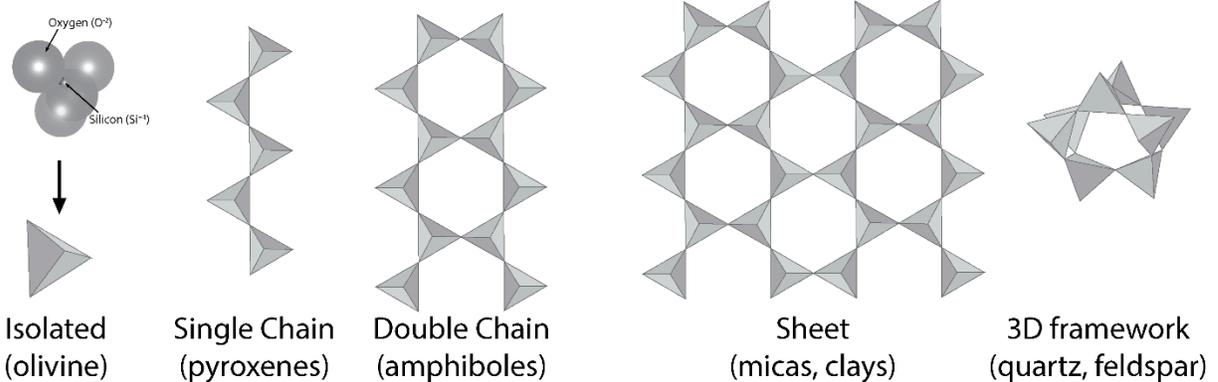
12. Compare your answers to question 10. Note any differences in your explanation from your partner’s here:

First some review of Mineral Categories:

Mineral categories

Minerals are categorized by composition and atomic structure, the most abundant minerals being from the *silicate* category.

Silicates and polymerization



The basic unit of a silicate structure is the silicon-oxygen tetrahedra. This feature may be found as individual isolated features within a structure or linked together (polymerized) in unique repeating patterns.

Non-silicates

Carbonates are the second most abundant group in Earth's crust. They contain CO_3

Common carbonates are: calcite (CaCO_3), aragonite (CaCO_3), and dolomite ($\text{CaMg}(\text{CO}_3)_2$)

Oxides contain O, but not bonded to Si, C, or S

Hematite (Fe_2O_3) and magnetite (Fe_3O_4) are ores of steel (being primarily composed of iron (Fe))

Corundum (Al_2O_3) can be cut into ruby and sapphire gemstones

Halides have cations bonded to halogens (i.e. F, Cl)

Halite (NaCl) is the mineral name for common table salt

Fluorite (CaF_2) is the source for fluoride in toothpaste

Sulfides contain S (but no O)

Sulfides are ores for many metals, like chalcopyrite (CuFeS_2) is an ore of copper (Cu)

Sulfates contain the sulfate ion complex (SO_4)

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is used to make drywall (aka gypsum board)

Phosphates contain the phosphate ion complex (PO_4)

A variety of the mineral apatite is found in teeth and bones, and the phosphorous is used in many things like fertilizers, paints and detergents.

Native elements are composed entirely of one element

Some examples are diamond (C), gold (Au), copper (Cu), and sulfur (S)

Now, test your knowledge:

Briefly define the following terms:

silicate tetrahedron -

polymerization -

Answer the following:

1. The silicate tetrahedra is composed of atoms of _____ and _____.
 - a. carbon; oxygen
 - b. oxygen; carbon
 - c. olivine; amphibole
 - d. silicon; oxygen
 - e. quartz; oxygen
2. In the above question, the correct answer has a ratio of ____ to ____ in a silicate tetrahedral.
 - a. 4:1
 - b. 1:4
 - c. 1:1
 - d. 2:1
 - e. 1:2
3. True/False. In a single chain of silica tetrahedral, all of the apical (top corner) oxygen atoms point in the same direction relative to the chain.
 - a. True
 - b. False
4. True/False. Sheet silicates are essentially the same as “infinite chains”.
 - a. True
 - b. False
5. A mineral that is used to make drywall for construction is:
 - a. quartz
 - b. plaster
 - c. gypsum
 - d. chalcopyrite
 - e. fluorite

Physical Geology Lecture Tutorials
Mineral Categories

6. A mineral that is used to season food is:
 - a. fluorite
 - b. gypsum
 - c. sulfur
 - d. halite
 - e. quartz

7. This group of non-silicate minerals has a PO_4 in their chemical formula:
 - a. potassium
 - b. phosphorous
 - c. phosphates
 - d. oxides

Now, think deeper:

On your own:

8. List five products that you have utilized today (e.g. hair brush, pencil)

9. Which of these products do you think are made from resources that are found as minerals in nature?

Working in groups of 2 or 3 answer the following:

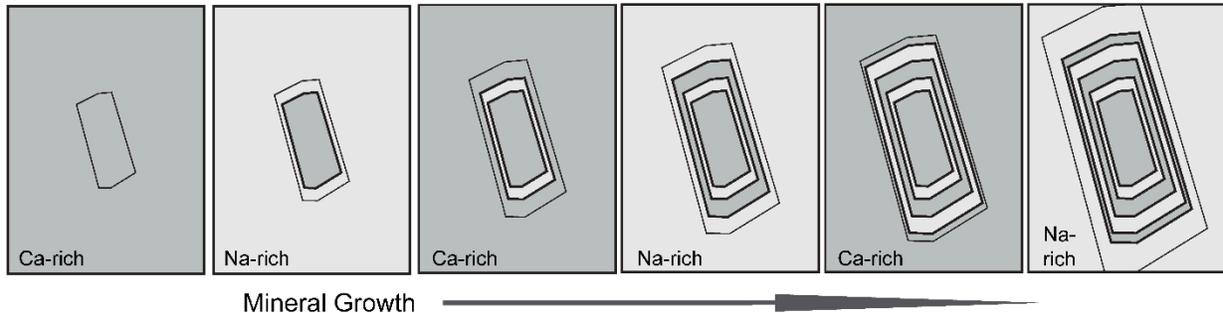
10. Compare your lists. Discuss what other natural resources are commonly utilized in the making of your various items.

First some review of Mineral Variations:

Solid Solution Series

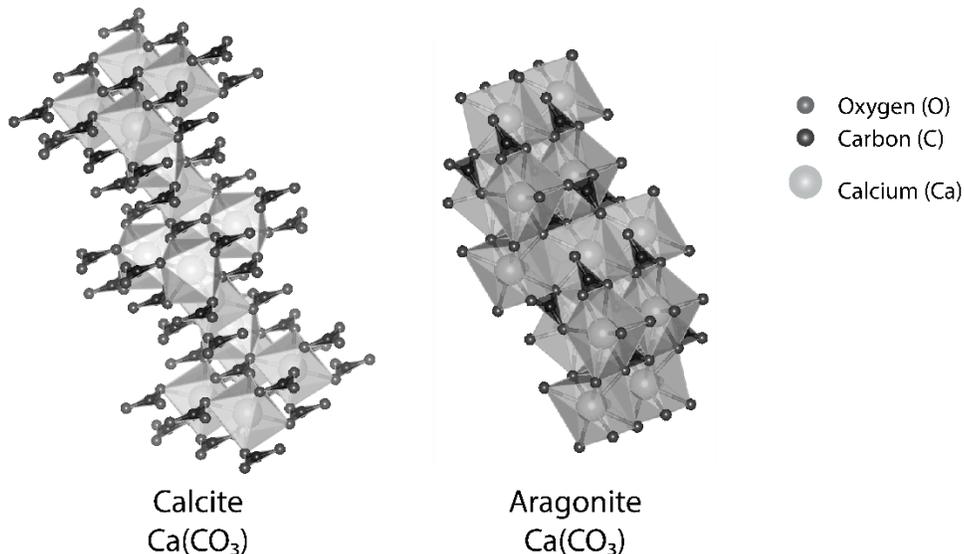
Some minerals allow for substitution of similar ions within their crystal structure. For instance, a solid solution exists between calcium (Ca) rich anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$) and sodium (Na) rich albite ($\text{NaAlSi}_3\text{O}_8$). These are collectively known as the plagioclase solid solution series. Because Ca and Na are similar sized ions, the plagioclase structure can substitute one for the other.

Compositional Zoning



In minerals that have solid solution, an oscillatory (back and forth) zoning pattern may form during crystal growth. In the above example, the initial crystal growth uses up a lot of the surrounding Calcium ions, in turn making the surrounding melt more Na-rich. Consequently, a more Na-rich rim grows on the crystal and the system then oscillates back to Ca-rich, and so on.

Polymorph



Polymorphs are two individual minerals with the same chemical composition, but formed with different crystal structures. In the above models, shapes (polyhedral) are drawn around certain atoms to make the repeated patterns more visible.

Now, test your knowledge:

Briefly define the following terms:

solid solution -

compositional zoning -

polymorph -

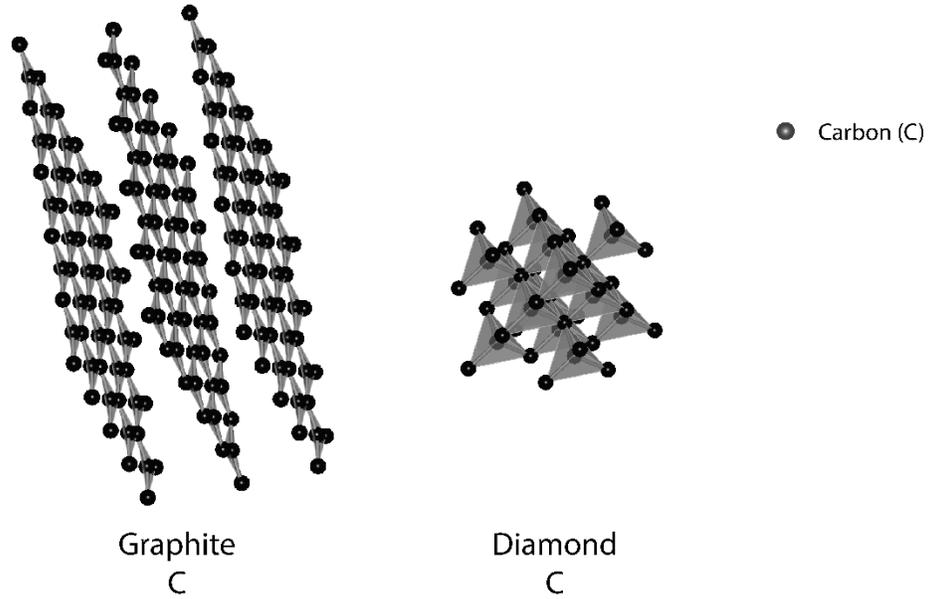
Answer the following:

2. In the mineral olivine, the compositional end-members are:

forsterite (Mg_2SiO_4) and fayalite (Fe_2SiO_4).

These two minerals are an example of _____.

- A. Compositional Twins
 - B. Polymorphs
 - C. Solid Solution Series
 - D. Mica Groups
 - E. Silicate Structures
3. In the olivine example (previous question), what elements are being substituted in the atomic structure?
- A. Si, O
 - B. Fe, O
 - C. Mg, Fe
 - D. Fe, Si
 - E. Mg, Si
2. At higher temperatures, the plagioclase structure is more accommodating of large calcium ions. Therefore, as a magma (liquid rock) cools, which end-member of the plagioclase series do you suppose will crystallize firstly?
- A. Albite (Na-plag)
 - B. Anorthite (Ca-plag)
 - C. Plagioclase
 - D. Forsterite
 - E. Fayalite



4. In the above example, the two minerals graphite and diamond are an example of _____>
- A. Compositional Twins
 - B. Polymorphs
 - C. Solid Solution Series
 - D. Mica Groups
 - E. Silicate Structures
5. Which mineral do you suppose is more stable at higher pressure conditions? (Hint: decide which atomic structure represents the closest packed arrangement of individual atoms.)
- A. Graphite
 - B. Diamond
6. The atomic structure of graphite is made of individual sheets of carbon rings. What type of bond is holding the individual sheets together?
- A. Ionic
 - B. Covalent
 - C. Metallic
 - D. Weak Electric Force

Now, think deeper:

On your own:

7. In chemistry, we're often interested in liquid solutions.
 - a. What do *liquid solutions* and *solid solutions* have in common?

 - b. What makes *liquid solutions* unique from *solid solutions*?

8. Is a mineral with compositional zoning likely to have unique crystal structures amongst the alternating mineral zones? Why or why not?

Working in groups of 2 or 3 answer the following:

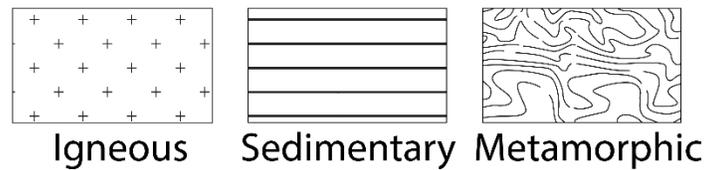
9. Compare your answers to questions 6. Write down interpretations that were unique from your own.

10. Compare your answers to questions 7. Write down interpretations that were unique from your own.

11. Decide as a group; what are the primary physical (environmental) factors that lead to the formation of different polymorphs.

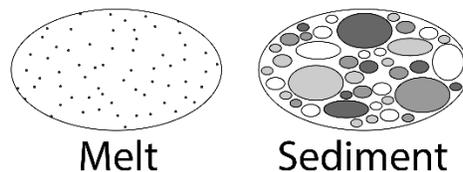
First some review of The Rock Cycle:

Rock Types



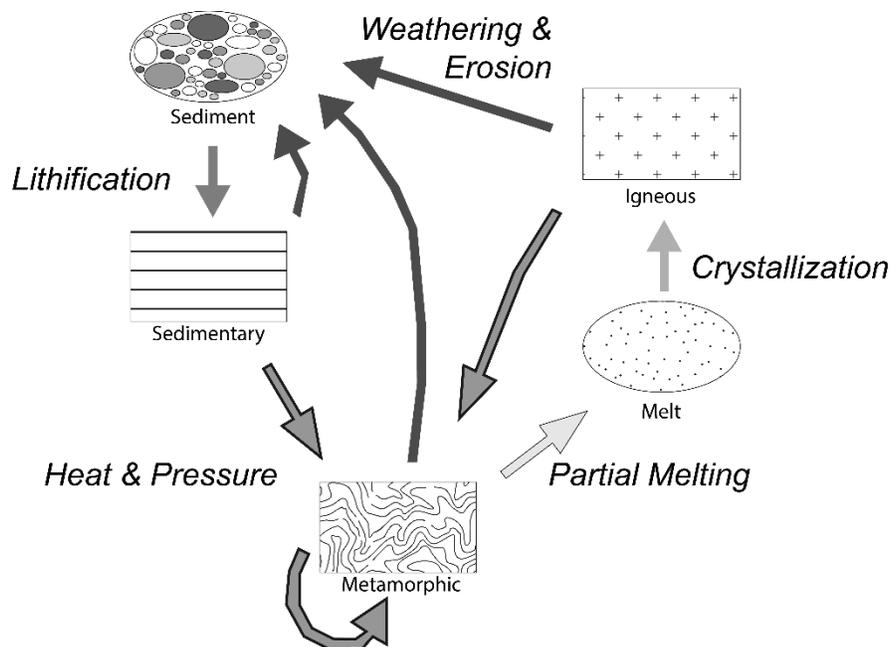
There are three main rock types: **Igneous** – formed from crystallized melt, **Sedimentary** – formed by lithified sediment, and **Metamorphic** – formed as heat and pressure applied to previously formed rock.

Intermediate Stages



Under certain conditions, rock forming material is found to be in an intermediate stage. **Melt** is liquid (molten) rock. **Sediment** refers to loose particles of rock created during weathering and erosion.

The Rock Cycle



Earth materials are constantly being cycled through the reservoirs described above via geologic processes described as: Partial Melting, Crystallization, Weathering & Erosion, Lithification, and Heat & Pressure. Note; the relative height in the diagram is an approximation for height encountered in the crust, but this is only a relative approximation, not a steadfast rule.

Now, test your knowledge:

Briefly define the following terms:

melt -

sediment -

igneous rock -

sedimentary rock -

metamorphic rock -

crystallization-

heat & pressure -

partial melting -

weathering and erosion –

Answer the following:

12. This type of rock forms from molten (liquid) rock (known as “melt”).
- A. Igneous
 - B. Sedimentary
 - C. Metamorphic
 - D. Sediment
 - E. Melt

Physical Geology Lecture Tutorials
Rock Cycle

13. This type of rock forms when pre-existing rock is transformed into new rock under conditions of increased heat and pressure.
- A. Igneous
 - B. Sedimentary
 - C. Metamorphic
 - D. Sediment
 - E. Melt
14. This type of rock forms when loose material becomes buried, and is then subjected to compaction and cementation, lithifying the rock together.
- A. Igneous
 - B. Sedimentary
 - C. Metamorphic
 - D. Sediment
 - E. Melt
15. Weathering & Erosion will break down rocks that are exposed to wind and rain at the surface. Which rock type is susceptible to Weathering & Erosion?
- A. Igneous
 - B. Sedimentary
 - C. Metamorphic
 - D. All of the above
16. If buried, sediment will eventually become lithified through the process(es) of:
- a. Heat & Pressure
 - b. Compaction and Cementation
 - c. Partial Melting
 - d. Crystallization
17. The lower temperature boundary of *metamorphism* (heat and pressure applied to rock and transforming them) is the upper temperature boundary of what geologic process?
- a. Weathering & Erosion
 - b. Lithification
 - c. Crystallization
 - d. Partial Melting
18. The upper temperature boundary of *metamorphism* (heat and pressure applied to rock and transforming them) is the lower temperature boundary of what geologic process?
- a. Weathering & Erosion
 - b. Lithification
 - c. Crystallization
 - d. Partial Melting

19. True/False. When rock melts, it usually does this wholesale, meaning the entire batch of rock becomes molten, including all mineral phases in that rock.
- a. True
 - b. False
20. True/False. It is possible to melt a sedimentary rock without it first becoming a metamorphic rock.
- a. True
 - b. False
21. True/False. It is possible to re-metamorphose a metamorphic rock.
- a. True
 - b. False

Now, think deeper:

On your own:

22. -Make sure you're unable to view any depictions of the rock cycle (put away your notes).
 - Take out a blank piece of paper.
 - Draw a diagram of the rock cycle to the best of your ability.

Working in groups of 2 or 3 answer the following:

23. Do not look at any notes, compare your drawing with 1 or more classmates. Write down the major differences here.

24. Now, compare your rock cycle diagrams with the review section above. Write down the major differences here.

On your own:

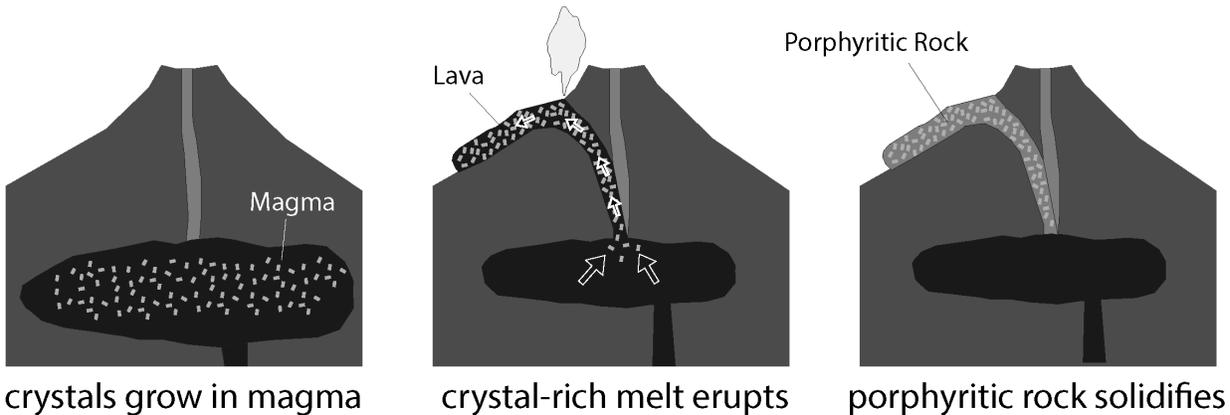
25. -Make sure you're unable to view any depictions of the rock cycle (put away your notes).
 - Take out a blank piece of paper.
 - Draw a diagram of the rock cycle to the best of your ability.

First some review of Igneous Rocks:

Melt

When **melt** (molten rock) is below ground, we refer to it as **magma**. When it is above ground we refer to it as **lava**.

Porphyritic Texture



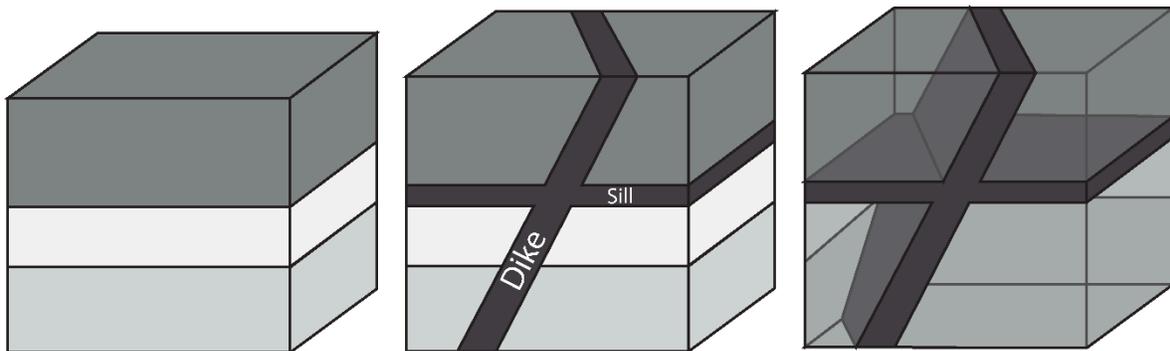
crystals grow in magma

crystal-rich melt erupts

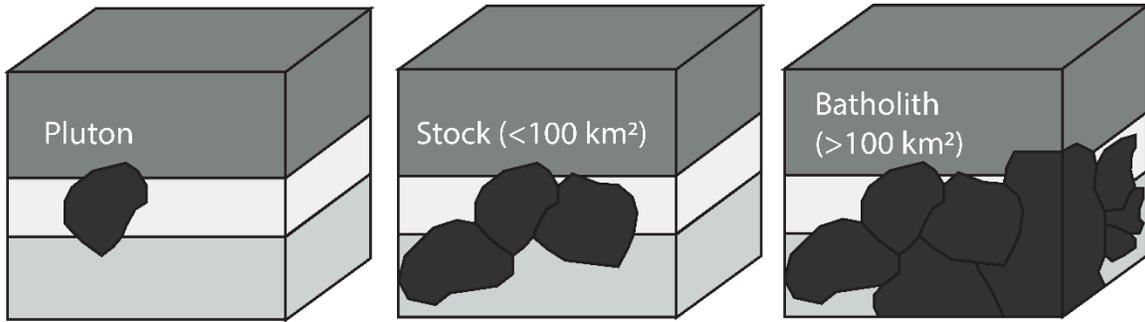
porphyritic rock solidifies

A **porphyritic texture** represents two cooling stages: 1. An earlier underground stage in which large crystals grew slowly, and 2. A final stage in which crystals grew rapidly at or near the surface.

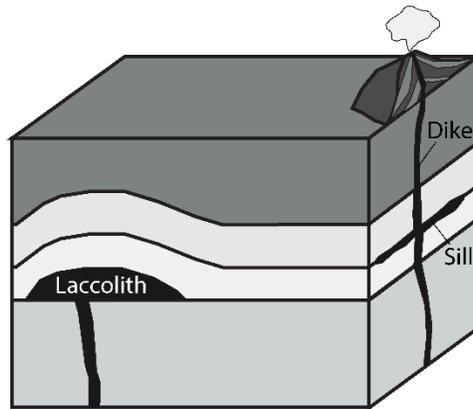
Intrusive Structures



A **dike** is a relatively planar igneous body that cross-cuts the primary fabric of the rock (stratigraphy). A **sill** is a relatively planar igneous body that utilizes pre-existing weaknesses in the rock, such as the contact between two sedimentary units.



A singular non-tabular (non-planar) intrusive body is commonly referred to as a **pluton**. Two or more plutons emplaced in direct contact, but at different times may be termed a **stock**. A very large collection of several plutons is referred to as a **batholith**.



An igneous intrusion which intrudes the crust causing uplift in the shape of a dome is known as a **laccolith**.

Now, test your knowledge:

Briefly define the following terms:

melt –

phaneritic –

aphanitic –

porphyritic –

glass –

vesicular –

xenolith –

dike –

sill –

volcanic neck -

Answer the following:

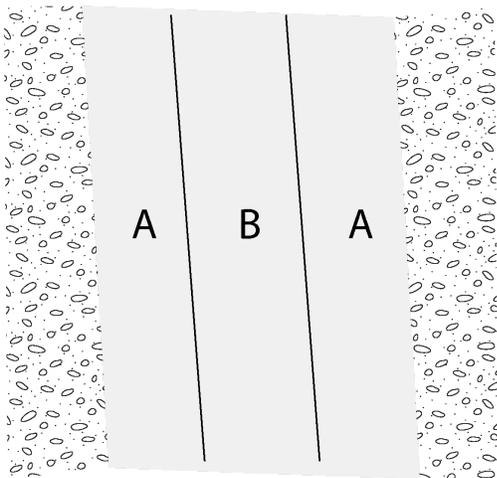
1. A granite and rhyolite are chemically equivalent phaneritic and aphanitic rocks, respectively. Therefore, the rhyolite must have formed:
 - A. Deep underground where crystals had time to cool.
 - B. Above ground where crystals cooled rapidly.

2. By cooling underground, crystals are insulated from surface conditions and cool very slowly. Rocks that form in this way have a _____ texture.
- A. aphanitic
 - B. phaneritic
 - C. glassy
 - D. vesicular
 - E. porphyritic
3. A rock with a texture from question 2 above will display the following:
- A. coarse-grained sized grains in a fine-grained matrix
 - B. fine-grained sized crystals in a coarse-grained matrix
 - C. coarse-grained sized crystals
 - D. fine-grained sized crystals
 - E. no crystals
4. Which of the following is a tabular (planar) igneous body that cross-cuts stratigraphy?
- A. Sill
 - B. Lacolith
 - C. Batholith
 - D. Dike
 - E. Pluton
5. Which of the following is a tabular (planar) igneous body that intrudes along geologic contacts?
- A. Sill
 - B. Lacolith
 - C. Batholith
 - D. Dike
 - E. Pluton
6. Which of the following is a non-tabular igneous body?
- A. Sill
 - B. Lacolith
 - C. Batholith
 - D. Dike
 - E. Pluton
7. Which of the following is a combination of several non-tabular igneous bodies intergrown with each other, > 100 km² in volume?
- A. Sill
 - B. Lacolith
 - C. Batholith
 - D. Dike
 - E. Pluton

Now, think deeper:

On your own:

8. Glass forms when melt comes into contact with water, causing the melt to quench before crystals have time to form. List some tectonic settings where you think it would be most likely to find volcanic glass forming.
9. In the below illustration, a melt (light grey area) has intruded as a dike into an area of country rock (patterned areas). Two zones have been designated in the dike, the *A zone* is in contact with the country rock, the *B zone* is in the center of the dike, isolated from the country rock. Knowing what you know about igneous rock textures and temperature of crystallization, which zone do you suspect will have relatively coarser sized crystals?

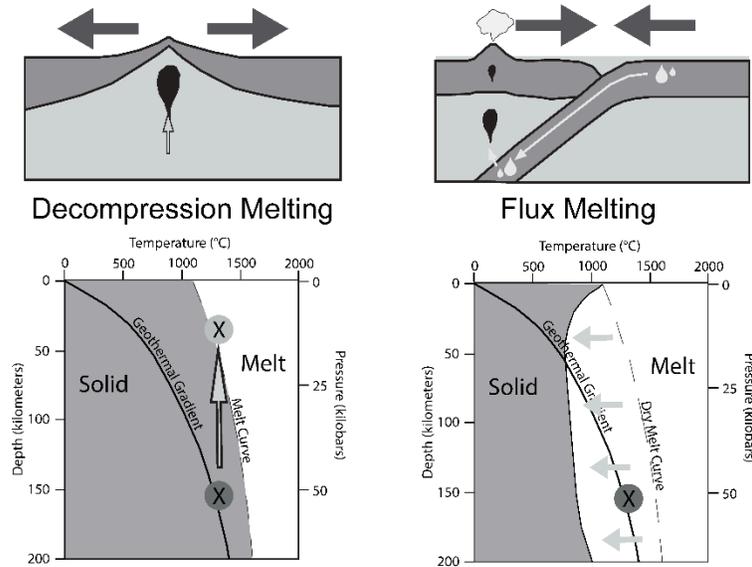


Working in groups of 2 or 3:

10. Discuss your answers to questions 8 and 9.

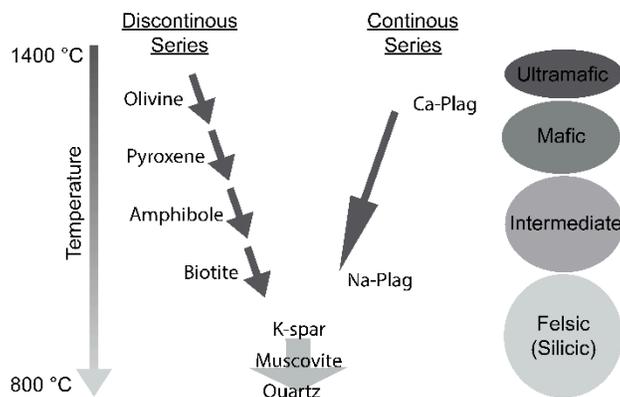
First some review of Melts:

Melting



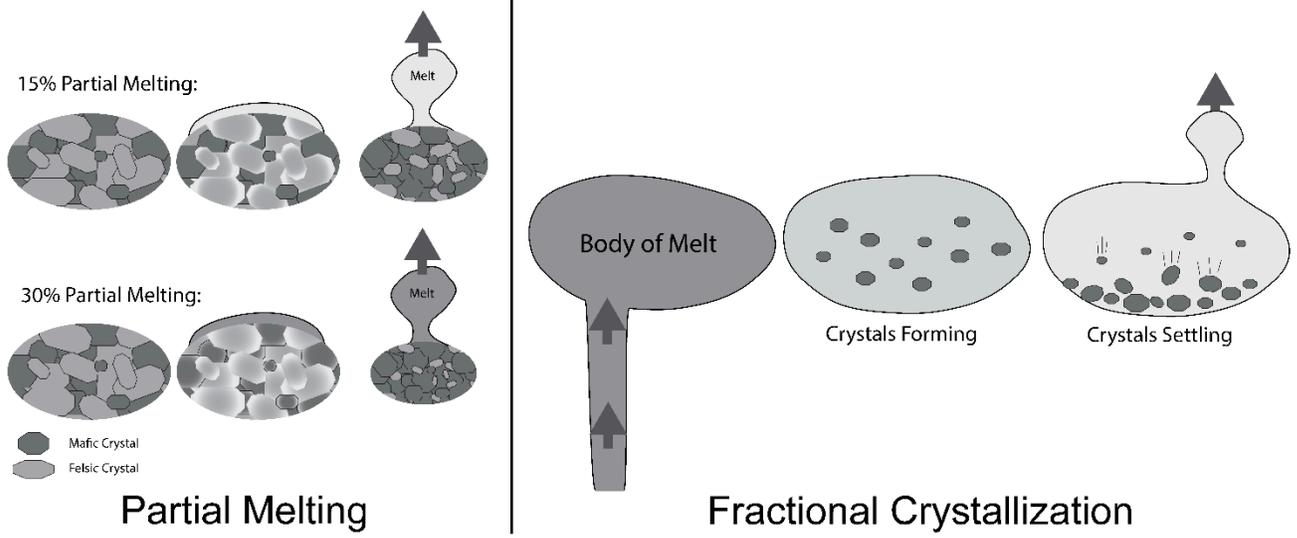
Most melt is generated in the upper mantle, just underneath the crust. The primary way (decompression) is through the upwelling of mantle at spreading centers. By rising quickly, pressure drops substantially before temperature can lower, and the system crosses into the zone of melt. The secondary way (Flux) is the addition of water from a subducting slab to the mantle. Addition of water to the system lowers the melting curve, allowing some melting of the mantle to occur.

Crystallizing (Bowen's reaction series)

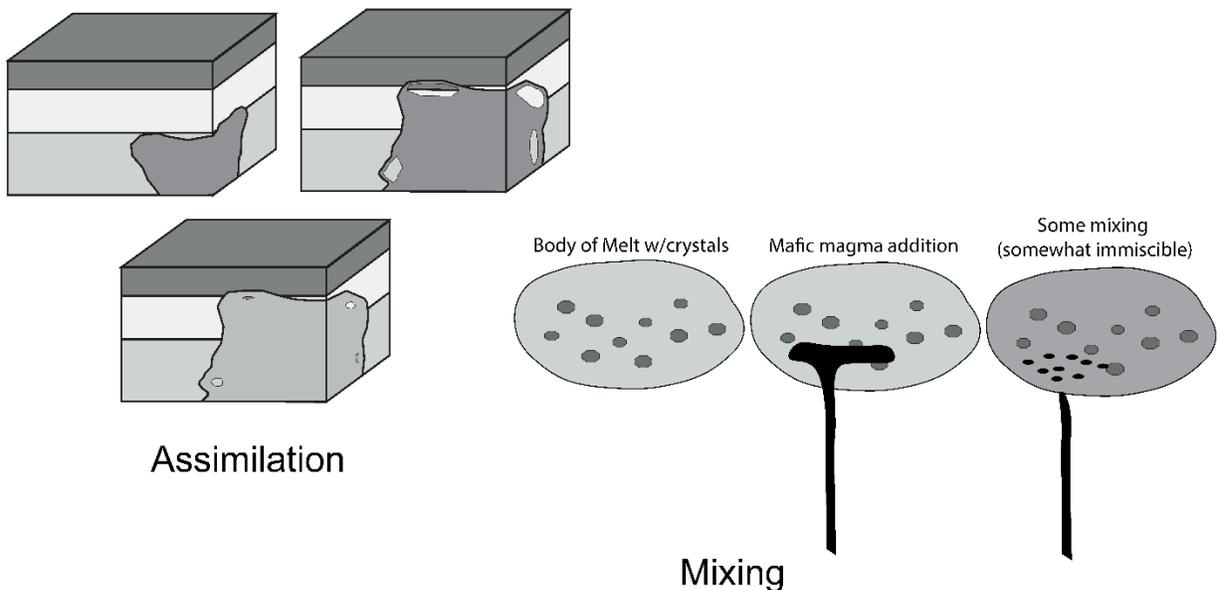


Developed by N.L. Bowen (and colleagues) in the early 1900's. This reaction series represents the results of many melting and crystallization experiments aimed at determining the sequence of minerals that crystallize from a melt. The Bowen's reaction series has exceptions, however it is still accepted as the general model today.

Modifying Melt Compositions



[Partial melting] affects the melt where it is created, depending on how much material is melted, with higher amounts of melting, more mafic minerals will melt and contributed to the melt composition.
 [Fractional crystallization] affects the melt as mafic crystals form first (recall: Bowen's Reaction Series), they effectively remove mafic components from the remaining melt.



[Assimilation] affects the melt when large blocks of country rock are incorporated into the melt, and if some melting of those blocks occurs, their chemistry will be added to the melt.
 [Mixing] affects the melt when two melts of different chemistry come into contact.

Now, test your knowledge:

Briefly define the following terms:

geothermal gradient –

decompression melting –

flux melting –

felsic –

mafic -

partial melting –

fractional crystallization –

assimilation –

mixing –

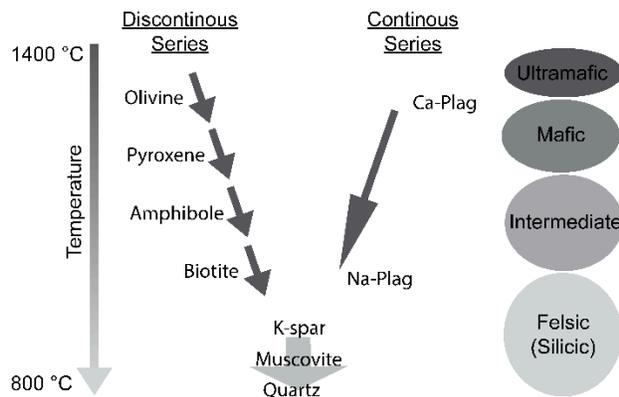
Answer the following:

1. There are many places on Earth's surface where we can observe active volcanoes. There is also a large amount of rocks on or near the surface which formed from intrusive (plutonic) or extrusive (volcanic) igneous processes. Where does all the melt fueling volcanoes and forming igneous/volcanic rocks come from?
 - A. The outer core is molten (liquid), much of this material finds its way to the surface.
 - B. The crust is melted by the Earth's interior heat.
 - C. Select areas of mantle rock will melt in certain special conditions.
 - D. Mantle plumes are the source of melt on the surface.

2. During decompression melting, a portion of the mantle will experience significant:
 - A. Increased Temperature
 - B. Increased Pressure
 - C. Decreased Temperature
 - D. Decreased Pressure

3. The answer to question #2 is best explained to occur during decompression melting because:
 - A. The mantle rises quickly, not allowing enough time for the rock to cool through conduction.
 - B. Water is added to the mantle, lowering the melting temperature of the rock.
 - C. Part of the mantle is uncovered in an area between two spreading tectonic plates.
 - D. New material from the liquid outer core arrives, heating the surrounding rock.

4. What causes flux melting?
 - A. The mantle rises quickly, not allowing enough time for the rock to cool through conduction.
 - B. Water is added to the mantle, lowering the melting temperature of the rock.
 - C. Part of the mantle is uncovered in an area between two spreading tectonic plates.
 - D. New material from the liquid outer core arrives, heating the surrounding rock.

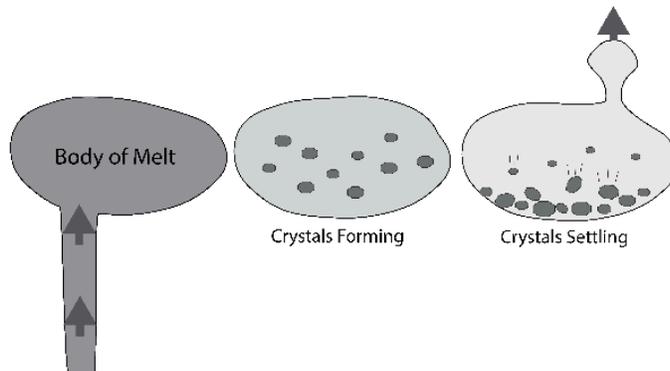


5. According to Bowen's reaction series, the first types of rocks (collection of crystals) to form from a melt would be:
 - A. Ultramafic (ultra-low silica)
 - B. Mafic (low silica)
 - C. Intermediate (intermediate silica)
 - D. Felsic (silicic)

6. In the Bowen's reaction series diagram, "Ca-Plag" stands for:
 - A. Calcedonic Plagioclase
 - B. Calcium Plagioclase
 - C. Calcitrant Plagioclase
 - D. Calvin Plagioclase

7. According to Bowen's reaction series, what mineral pair is unlikely to be found together in nature?
 - A. Olivine and Ca-Plag
 - B. Ca-Plag and Quartz
 - C. Olivine and Quartz
 - D. Biotite and K-spar

8. When heating a hypothetical rock made of Muscovite, Na-Plag, Biotite, and Amphibole; you would anticipate which phase to begin melting firstly?
 - A. Muscovite
 - B. Na-Plag
 - C. Biotite
 - D. Amphibole



9. Use Bowen's reaction series to determine which type of minerals (i.e. mafic or felsic) will crystallize from a melt firstly. Based on your answer, what affect does 'removing' these crystals from the melt (by virtue of them sinking to the bottom of the magma chamber) have on the residual (remaining) melt?
 - A. Makes the melt more mafic.
 - B. Makes the melt more felsic.
 - C. Makes the melt more capable of accepting more melt from below.
 - D. Forces the crystals to settle to the bottom of the melt.

10. Melt will ascend (rise) in the crust until it stalls, meaning it reaches equal buoyancy with the surrounding country rock. This means that the melt has a similar mafic/felsic character as the surrounding rock. What do you think changing the melt through fractional crystallization will allow to happen?
 - A. The residual melt will become more felsic, and will again ascend in the crust.
 - B. The residual melt will become more mafic, and will again ascend in the crust.
 - C. The residual melt will become more felsic, and will begin to descend in the crust.
 - D. The residual melt will become more mafic, and will begin to descend in the crust.

Now, think deeper:

On your own:

11. Where do you suppose is the closest place to you where you could go to physically see molten rock?

12. What tectonic setting do you suppose creates the most melt on Earth (by volume)? Why?

13. Why do we characterize melts and igneous rocks according to their silica content?

Working in groups of 2 or 3 answer the following:

14. Discuss your answers to question 12. If you had different answers, discuss reasons why, write them here. If you had the same answer, can you rank different melt producing tectonic settings in order of volume of melt produced?

15. Discuss your answers to question 13. Did your partner have a different answer than you? Write it down here.

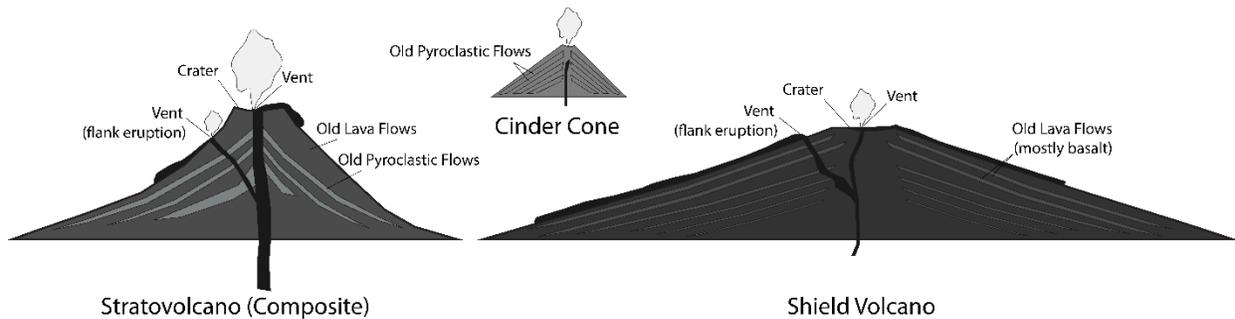
First some review of Volcanoes:

Explosiveness

Controlled by:

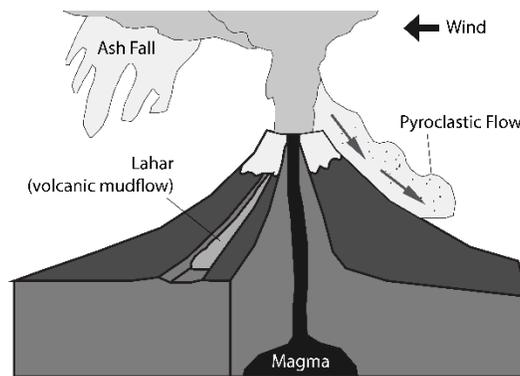
- 1) Amount of gas in melt
- 2) If gas in melt is allowed to escape easily (**viscosity** = resistance to flow (ie melts with low viscosity allow gas to escape more easily))

Types



Shield volcanoes form long gentle slopes from low viscosity (basalt) lava flows. Stratovolcanoes form steep slopes from a mixture of high viscosity explosive pyroclastic eruptions and (intermediate to felsic) lava flows. Cinder cones form steep slopes, almost entirely of consisting of pyroclastic eruptions. Other volcanic features include: Lava domes that form from viscous lava, often within the crater of composite volcanoes, and calderas that form from enormous eruptions in which the underlying magma chamber empties and the local crust collapses into the chamber.

Hazards



Some important volcanic hazards include pyroclastic flows, and lahars (mudflows). A less visible hazard is the presence of volcanic gases such as CO_2 , which can be lethal in high enough concentrations.

Now, test your knowledge:

Briefly define the following terms:

shield volcano –

a'a –

pahoehoe –

composite volcano –

ash -

lapilli –

blocks and bombs –

flood basalts –

columnar jointing -

caldera –

lahar –

pyroclastic flow -

Answer the following:

11. Which term do we use to refer to melt on the Earth's surface?
 - A. Magma
 - B. Rhyolite
 - C. Tuff
 - D. Tephra
 - E. Lava

12. Which term do we use to refer to melt below the Earth's surface?
 - A. Magma
 - B. Rhyolite
 - C. Tuff
 - D. Tephra
 - E. Lava

13. A melt's viscosity is dependent on these factors:
 - A. Pressure, Temperature, height over subduction zone
 - B. Temperature, Amount of silica, dissolved gases
 - C. Amount of gas, ability for gas to escape
 - D. Water pressure, dissolved gases, Temperature

14. The explosiveness of a volcanic eruption is dependent on these factors:
 - A. Pressure, Temperature, height over subduction zone
 - B. Temperature, Amount of silica, dissolved gases
 - C. Amount of gas, ability for gas to escape
 - D. Water pressure, dissolved gases, Temperature



15. The above image shows the size of each of the three main volcano types relative to each other. Match the image to the name below.
 - A. Stratovolcano = ____
 - B. Cinder Cone = ____
 - C. Shield Volcano = ____

16. True/False. A volcano will always erupt from its main vent.
 - A. True
 - B. False

17. During an explosive eruption, a flow of hot gas and pyroclastic material will hug the ground and flow at great speed down the volcano. This flow is known as a _____.
- A. Pahoehoe flow
 - B. Ahah flow
 - C. Pyroclastic flow
 - D. Lava flow
 - E. Lahar flow
18. During an explosive eruption, melted snowpack near the volcano peak will mix with pyroclastic material and ash forming a mud flow. This flow is known as a _____.
- A. Pahoehoe flow
 - B. Ahah flow
 - C. Pyroclastic flow
 - D. Lava flow
 - E. Lahar flow
19. The Hawaiian islands are examples of shield volcanoes, dominantly formed from this type of lava.
- A. Rhyolite
 - B. Diorite
 - C. Obsidian
 - D. Basalt
 - E. Andesite

Now, think deeper:

On your own:

20. In the table below, list the differences between the character and potential hazards associated with Kilauea volcano in Hawaii and Mt. Rainier in Washington.

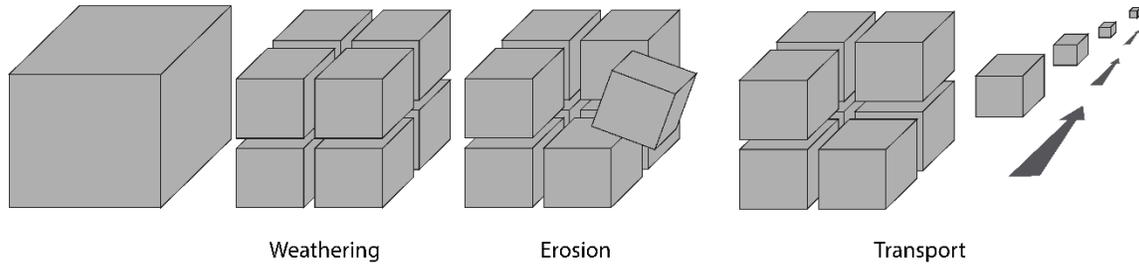
Kilauea (Shield Volcano)	Mt. Rainier (Composite Volcano)
Characteristics:	Characteristics:
Hazards:	Hazards:

Working in groups of 2 or 3 answer the following:

21. Compare your responses to question 11. Write what your partner had differently from you in the space below.

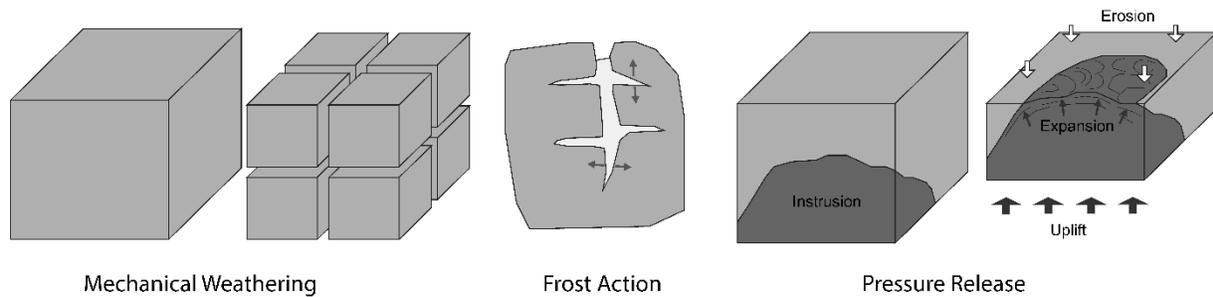
First some review of Weathering:

Weathering, Erosion, and Transport



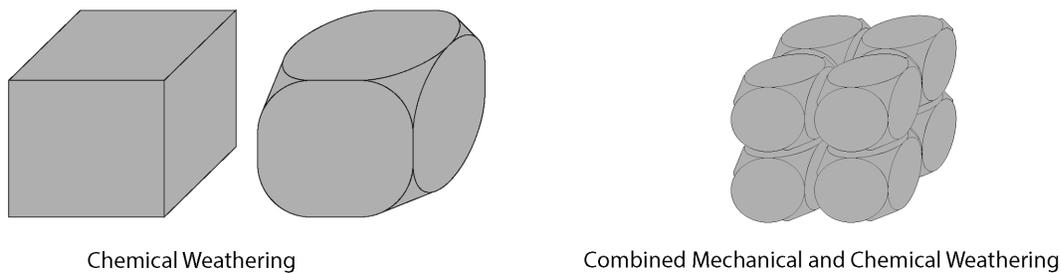
Weathering is the breakdown of material, erosion is the removal of that material from its place, and transport is the movement of that material. Weathering continues to the material during transport.

Mechanical Weathering



Mechanical weathering is the breakdown of material into smaller pieces. The most effective processes are frost action and pressure release. Other mechanical weathering might include the action of plants and animals, thermal variations, and mineral (salt) wedging.

Chemical Weathering



Oxidation – (Rusting) Minerals formed at depth in the crust are unstable in an oxygen rich environment at the surface, many of which will react readily with oxygen to form new minerals.

Acid – (Acid Rain) Acids present in the environment will dissociate in water producing excess H^+ ions that in turn react with minerals, causing those minerals to change into new minerals.

Dissolution – (Cave formation) Some minerals are completely soluble in water when the right chemistry is present.

Now, test your knowledge:

Briefly define the following terms:

weathering –

erosion –

mechanical weathering –

chemical weathering –

frost action -

pressure release –

oxidation –

dissolution –

Answer the following:

1. The physical removal of material from its place is the process of:
 - A. Weathering
 - B. Erosion
 - C. Transport
 - D. Exfoliation
 - E. Hydrolysis
2. True/False. During transport a material will continue to be weathered.
 - A. True
 - B. False

Physical Geology Lecture Tutorials
Weathering

3. In high latitudes (near the poles), this type of weathering is the most common, as water is more often frozen.
 - A. Pressure Release
 - B. Hydrolysis
 - C. Erosion
 - D. Oxidation
 - E. Frost Action

4. Sheetting is a form of this type of mechanical weathering, which occurs when granitic intrusions are uplifted and exposed through erosion, unloading pressure.
 - A. Pressure Release
 - B. Hydrolysis
 - C. Erosion
 - D. Oxidation
 - E. Frost Action

5. The reaction of an iron bearing mineral to become an oxide, such as hematite or limonite is this type of chemical weathering.
 - A. Oxidation
 - B. Acid attack
 - C. Dissolution
 - D. Hydrolysis
 - E. Erosion

6. The development of caves in carbonate (limestone) rock is attributed to this type of chemical weathering.
 - A. Oxidation
 - B. Acid attack
 - C. Dissolution
 - D. Hydrolysis
 - E. Erosion

7. The breakdown of minerals into clay minerals by the abundance of H^+ ions is credited to this type of chemical weathering.
 - A. Oxidation
 - B. Acid attack
 - C. Dissolution
 - D. Hydrolysis
 - E. Erosion

Now, think deeper:

On your own:

8. Describe a place (anywhere in the world) where you have seen weathering (either mechanical or chemical) of a human-made object. (where would you go right now to showcase this phenomena to your family/friends?)

9. Describe a place (anywhere in the world) where you have seen weathering (either mechanical or chemical) of natural earth materials. (where would you go right now to showcase this phenomena to your family/friends?)

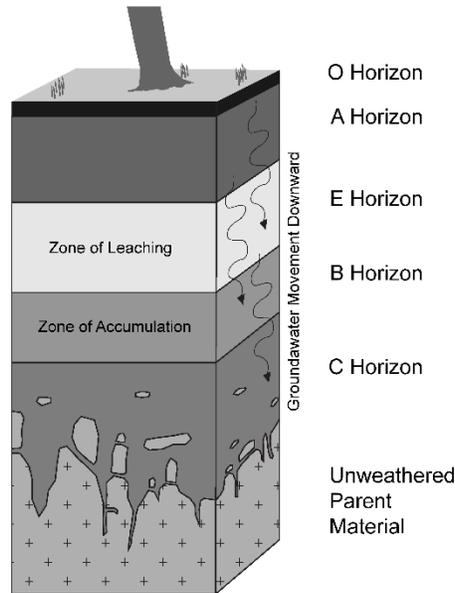
10. What is a more prominent type of weathering in the area where you live? Can you list 5 local environmental factors that contribute to either type of weathering?

Working in groups of 2 or 3:

11. Take turns describing your answers to questions 8 and 9 above.

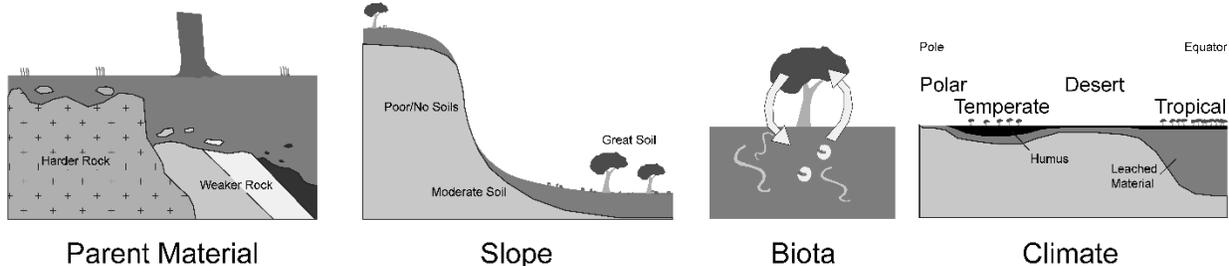
12. Compare your answers to question 10 and decide on the 5 most prominent local environmental factors.

First some review of Weathering and Soils: Soil Horizons



Soils form distinctive layers as they mature. Dependent on the local environment, a soil may or may not develop any of the particular layers illustrated above.

Soil Development



Soil developments depends on several factors illustrated above.

The **parent material** plays a role in providing certain minerals, and amount of material through time.

The **slope** of a particular area can be more or less conducive to soil development.

The **plants and animals** that live in the soil play a role in circulating the material.

The **local climate**, exemplified by latitude above, plays a role in controlling the abundance of rain, temperature, etc.

The other factor not illustrated but also important is that it takes significant **time** for soils to develop.

Also, a soil will change its character through time.

Now, test your knowledge:

Briefly define the following terms:

horizon -

parent material -

Answer the following:

1. The development of caves in carbonate (limestone) rock is attributed to this type of chemical weathering.
 - A. Oxidation
 - B. Acid attack
 - C. Dissolution
 - D. Hydrolysis
 - E. Erosion
2. The breakdown of minerals into clay minerals by the abundance of H^+ ions is credited to this type of chemical weathering.
 - A. Oxidation
 - B. Acid attack
 - C. Dissolution
 - D. Hydrolysis
 - E. Erosion
3. This soil horizon represents incompletely weathered parent material, and is a transition zone between the soil and the bedrock.
 - A. O horizon
 - B. A horizon
 - C. E horizon
 - D. B horizon
 - E. C horizon
4. This soil horizon is formed in soils that are heavily leached by down moving groundwater. The organic acids and CO_2 formed in overlying horizons work to leach material from this horizon.
 - A. O horizon
 - B. A horizon
 - C. E horizon
 - D. B horizon
 - E. C horizon

5. The abundance of organic material (recently fallen leaves, etc.) and highly decomposed plant material (i.e. humus) are unique to this layer.
 - A. O horizon
 - B. A horizon
 - C. E horizon
 - D. B horizon
 - E. C horizon

6. This horizon forms the bulk of the “subsoil”, an area of accumulation of materials leached from above.
 - A. O horizon
 - B. A horizon
 - C. E horizon
 - D. B horizon
 - E. C horizon

7. The best environment for soil (humus) development would be the following
 - A. Weaker parent material, steep slopes, dry climate, and abundant biota.
 - B. Weaker parent material, flat laying topography, temperate climate, and abundant biota.
 - C. Strong parent material, moderate slopes, temperate climate, low biodiversity
 - D. Strong parent material, flat laying topography, desert climate, and abundant biota.
 - E. Weaker parent material, moderate slopes, tropical climate, abundant biota.

Now, think deeper:

On your own:

8. Describe what you know about the soils in your area according to the different soil development factors.

9. Describe what you don't know about the soils in your area according to the different soil development factors.

Working in groups of 2 or 3

10. Compare your answers to questions 8 and 9 above. Write anything that you learned from your group partners here.

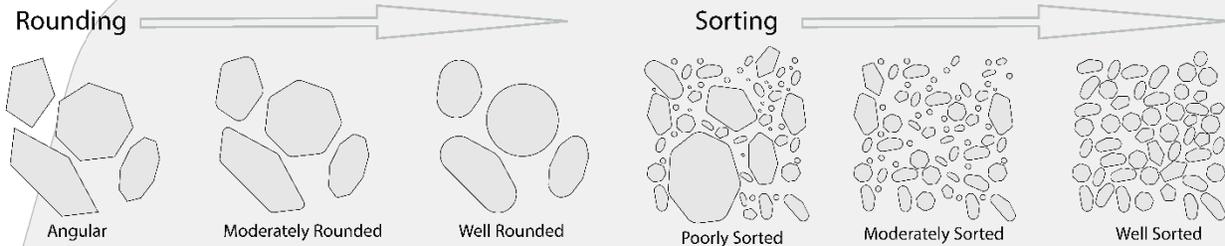
First some review of Sediment and Sedimentary Rocks:

Sediment



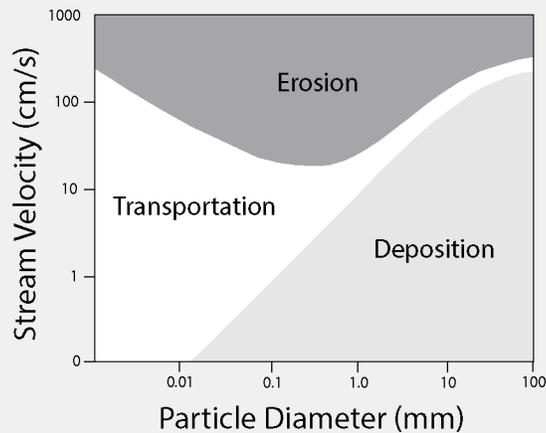
Sediment consists of loose grains either: 1) weathered and eroded from rocks or 2) precipitated from solution or secreted by organisms. Detrital particles are classified according to size (as above).

Transportation



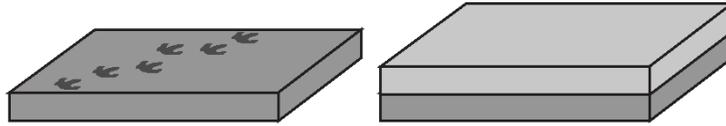
During transport by wind, water or ice (all three being driven by gravity), particles become rounded and sorted.

Deposition



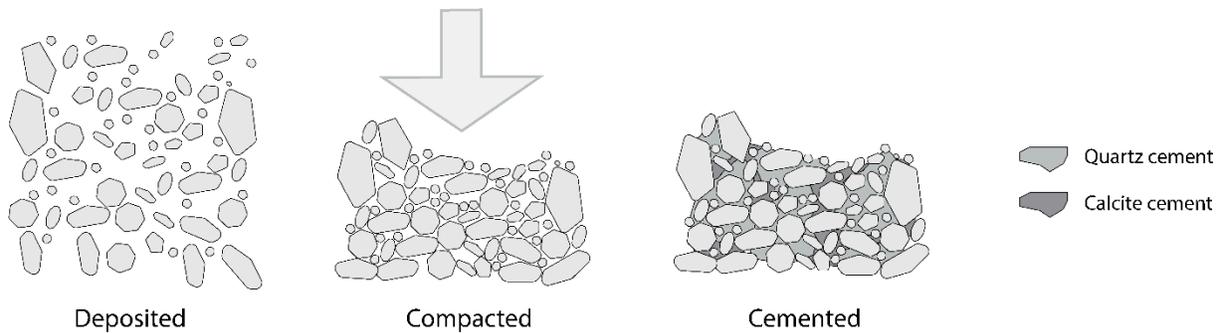
Stream velocity is equivalent to energy. It takes a large amount of energy to erode (break loose) a large particle, and similarly for very small particles as well. Once eroded and in suspension (transport), a lowering of stream velocity (energy) will cause large particles to deposit (stop moving), whereas a small particle will carry on in transport almost indefinitely.

Burial (Preservation)



Once sediment is deposited somewhere, it needs to be buried in order to be preserved. If not, the material would eventually become re-mobilized when conditions change.

Lithification



Lithification is the process in which loose sediment is compacted under pressure and growth of mineral cement locks the grains together as rock. This process occurs as sediment becomes buried deep below younger sediment deposited above.

Evaporite Deposits



When large salty lakes and seas evaporate, they leave behind extensive deposits of halite and gypsum, which may become buried and preserved, similar to detrital sediments described above.

Now, test your knowledge:

Briefly define the following terms:

sediment -

transportation -

rounding -

sorting -

deposition -

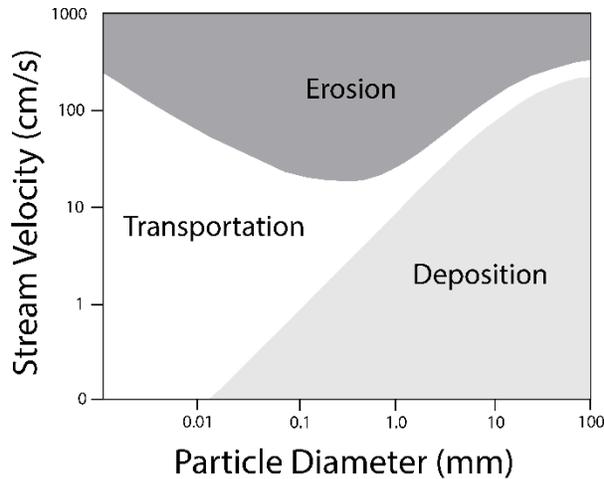
burial -

lithification -

Answer the following:

26. True/False. Sand is a size classification, not a composition.
F. True
G. False
13. True/False. Clay can be used to refer to a mineral type, as well as a particle size.
A. True
B. False
14. In the following environment, sediment can become rounded.
A. In a glacier
B. In a river
C. On a beach
D. In a wind-blown desert
E. All of the above

15. During transport in a river, energy is highest near the headwaters, and consequently sediment particle size becomes _____ downstream.
- Larger
 - More elongate
 - Shorter
 - Smaller
 - Taller



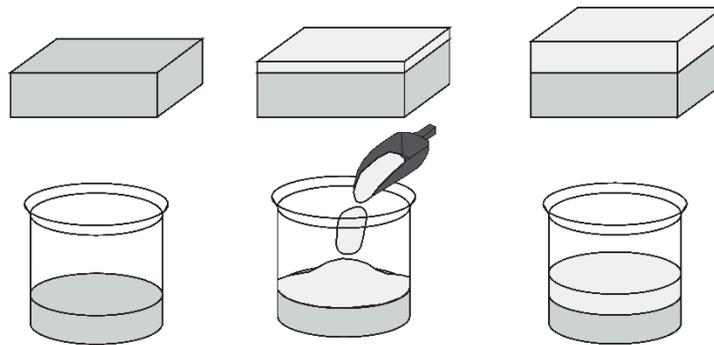
16. During flood stage, when stream velocity is at 100 cm/s, which size particles will become eroded from the river bottom? (Be careful, perhaps use a pencil and straight edge)
- 0.01 mm only
 - 0.01, and 0.1 mm
 - 0.01, 0.1, and 1.0 mm
 - 0.01, 0.1, 1.0, and 10 mm
17. When the river slows again to 10 cm/s, which size particles will become deposited. (Again, be careful. You may want to check your answer by using a straight edge on the plot).
- 10, 1, 0.1, and 0.01 mm
 - 10, 1, and 0.1 mm
 - 10, and 1 mm
 - 10 mm only



18. In the above scenario, dinosaur footprint *trace fossils* (more on trace fossils in another unit) are preserved in the dark grey sediment. What is the primary process responsible for making sure these trace fossils are not destroyed?
- A. Transport
 - B. Sorting
 - C. Deposition
 - D. Burial
 - E. Lithification
19. Pore space is the space between sediment grains in deposited material. This space will often be filled with water. Which stage do you think has the highest amount of pore space, therefore the most water in a given volume of sediment?
- A. Freshly deposited sediment
 - B. Compacted sediment
 - C. Cemented sediment
20. Evaporites are deposits of minerals crystallized out of water as the water was evaporated away. Much of the material that forms these deposits did not start in the now evaporated seawater, but instead was transported to the seaway as _____.
- A. Detrital sediment grains
 - B. Dissolved ions
 - C. Halite
 - D. Gypsum
 - E. Calcite cement

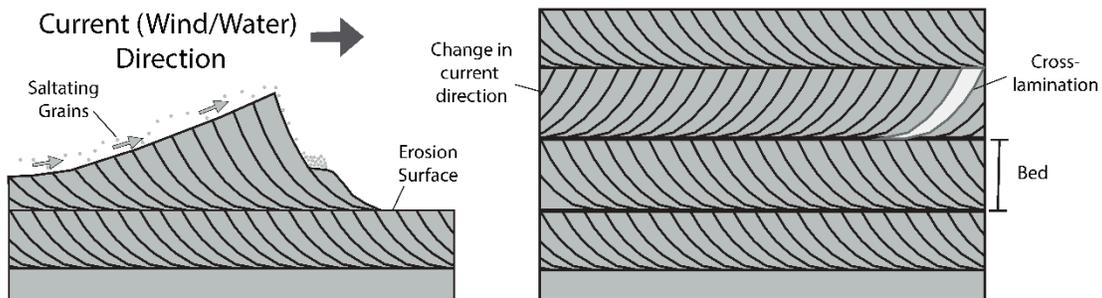
First some review of Sedimentary Structures and Interpretations:

Bedding



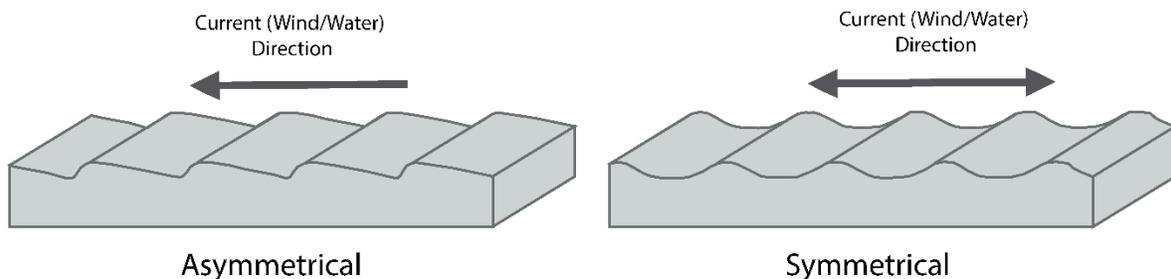
Bedding is a common sedimentary structure. Sediment is deposited in large basins, and as conditions change, the changing sediment character is visible in variable beds.

Cross-Bedding



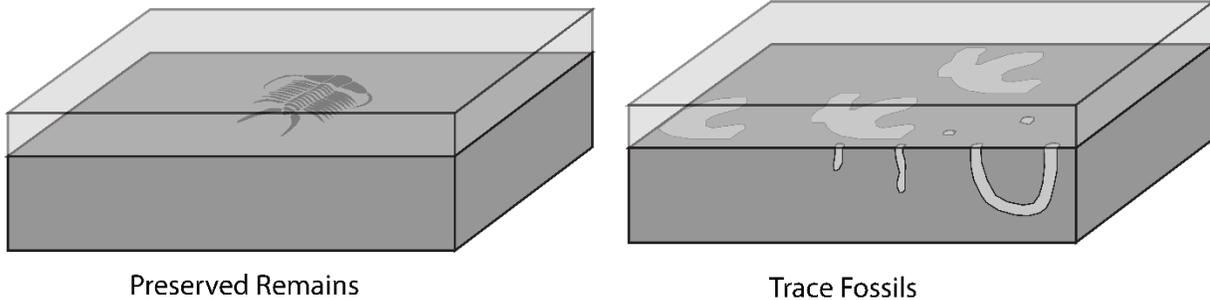
Saltating grains travel up the shallow slope side of a migrating dune. The grains pile up on the current protected steep side of the dune forming individual cross-laminations. Subsequent migrations will pile on top of each other forming a package of cross-bedded sedimentary beds.

Ripple Marks



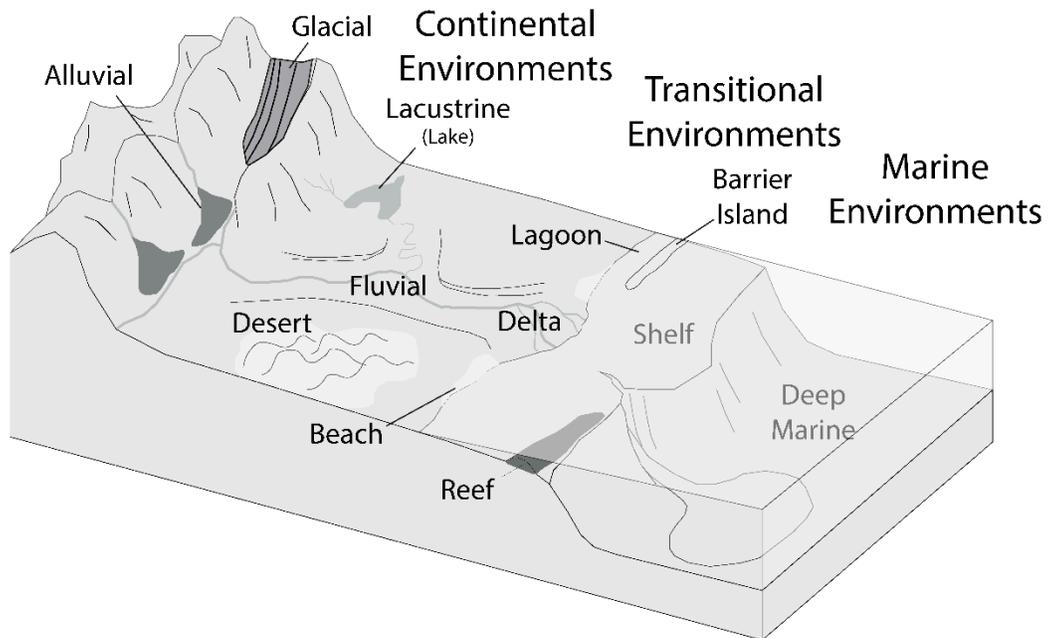
A current can create *ripple marks* on the surface of a bed. Asymmetrical ripples migrate and will form cross laminations as described above.

Fossils



Fossils are a sedimentary structure indicating the presence of organisms during or after deposition of sediment. The hard parts of an organism can be preserved by being replaced by minerals, such as petrified wood. An indication of activity (e.g. footprints, worm burrows, etc.) by an organism is known as a *trace fossil*.

Depositional Environments



“The present is the key to the past”. By understanding process in modern environments, geologists are able to interpret the features of sedimentary rocks (i.e. composition, rounding, and sorting of grains, along with sedimentary structures, and fossils) and determine their depositional environment.

Now, test your knowledge:

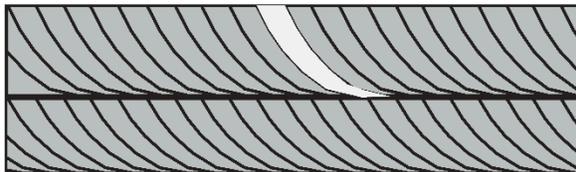


A



B

1. In the above image depicting a cross-section of sedimentary rocks, what are the individually colored horizontal layers known as?
 - A. Beds
 - B. Cross-beds
 - C. Ripple marks
 - D. Graded beds
 - E. Mud cracks
2. In the above image, which package of layers is more likely the product of repeated variation, such as the sediment deposited in a lake during winter and summer seasons?
 - A. A
 - B. B



A



B

3. In the above image depicting a cross-section of sedimentary rocks, what do we call the highlighted (lightened) units?
 - A. Beds
 - B. Cross-beds
 - C. Ripple marks
 - D. Graded beds
 - E. Mud cracks
4. In the previous image, what do we refer to the package of sedimentary rock identified as "YZ"?
 - A. Beds
 - B. Cross-beds
 - C. Ripple marks
 - D. Graded beds
 - E. Mud cracks

5. In the previous image, which package of layers is likely the product of oscillating (repeated back and forth) flow, like water on a beach?
 - A. A
 - B. B

6. In the previous image, what type of ripple marks would you expect to have formed on the surface of package A?
 - A. Graded
 - B. Cross
 - C. Symmetrical
 - D. Asymmetrical
 - E. Fluvial-Deltaic

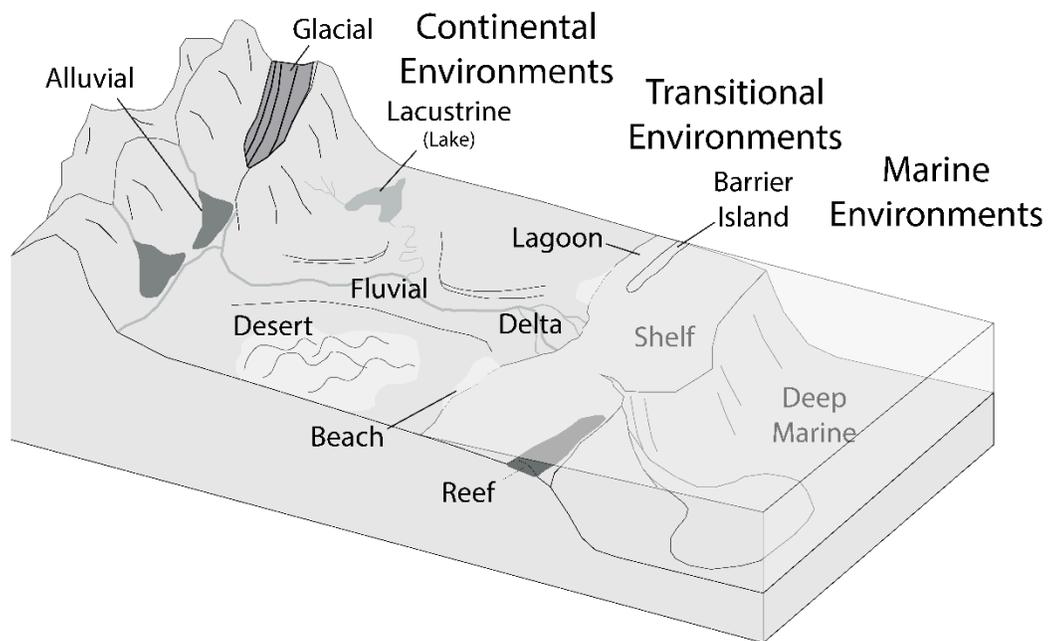
7. In a sedimentary sequence, a geologist notes the presence of microfossils known as planktonic foraminifera. These tiny plankton were once alive floating in the ocean. What depositional environment do you suppose these rocks formed in?
 - A. Glacial
 - B. Deep Marine
 - C. Delta
 - D. Desert
 - E. Lagoon

8. In a sedimentary sequence, a geologist notes very large-scale beds (2-5 meters high) of cross-stratified sandstone likely formed by the migration of very large sand dunes. What depositional environment do you suppose these rocks formed in?
 - A. Glacial
 - B. Deep Marine
 - C. Delta
 - D. Desert
 - E. Lagoon

9. In a sedimentary sequence, a geologist notes extremely poorly sorted sediment, with clast sizes ranging from finest clay all the way up to the size of small cars. The geologist gives this unit a name of "till", it likely was deposited in what environment?
 - A. Glacial
 - B. Deep Marine
 - C. Delta
 - D. Desert
 - E. Lagoon

Now, think deeper:

On your own:



10. Which of the depositional environments pictured above do you suspect may be now or in the past would have been present on other planets? Describe your reasoning.

Working in groups of 2 or 3

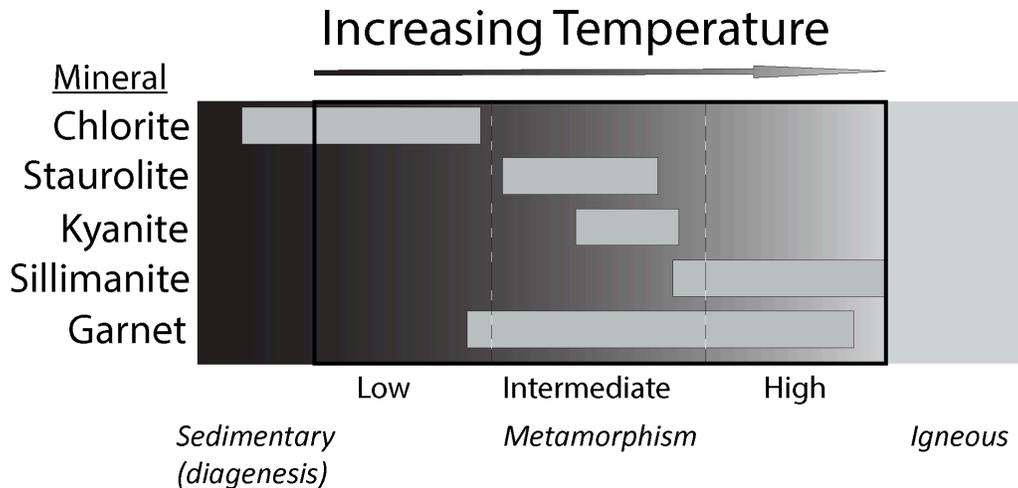
11. Compare your answers to question 13.

First some review of Metamorphism Controlling Factors:

Metamorphism

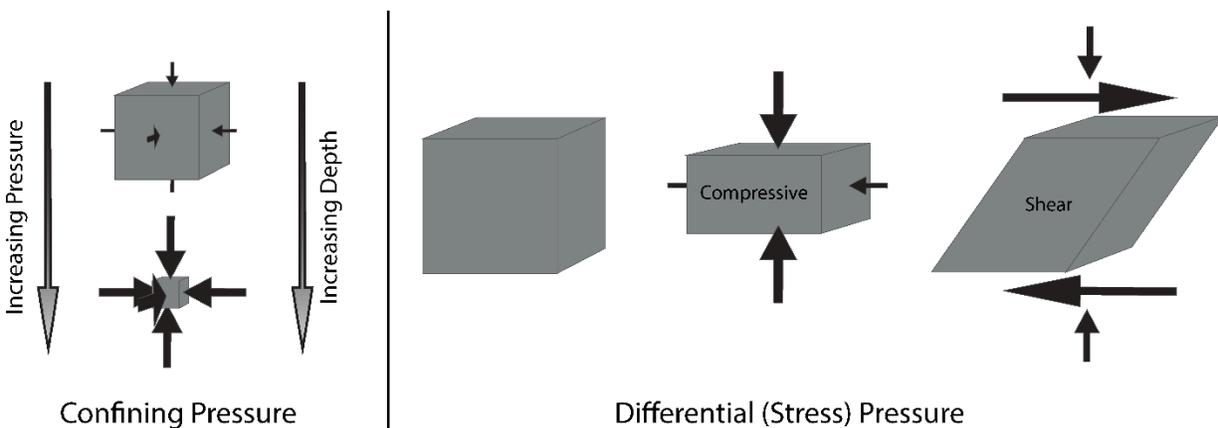
Metamorphism is the solid-state change of rocks. Rocks will generally experience the conditions along the geothermal gradient (discussed during igneous), increasing in temperature and pressure. In some places temperature may increase faster, like near magmatic intrusions. Still, in other places the pressure might increase faster, like in subduction zones.

Temperature



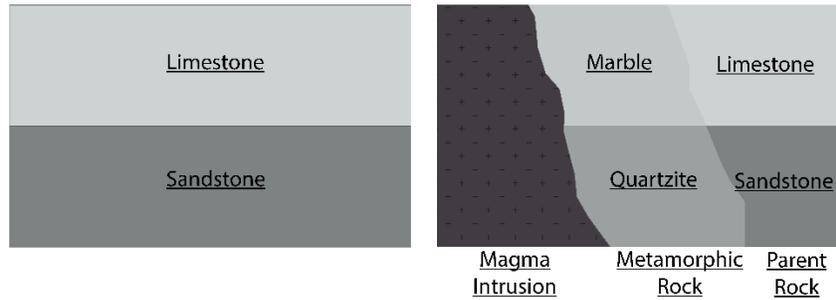
Metamorphism takes place in the temperature between the upper limits of the sedimentary rock lithification process (aka “diagenesis”) all the way up to partial melting of the rock, which then becomes an igneous process. As a rock is heated, new minerals will become stable. At even higher temperatures, some will remain stable while others will return to instability.

Pressure



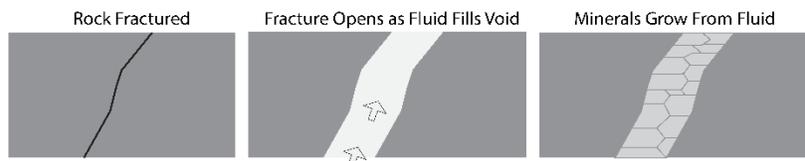
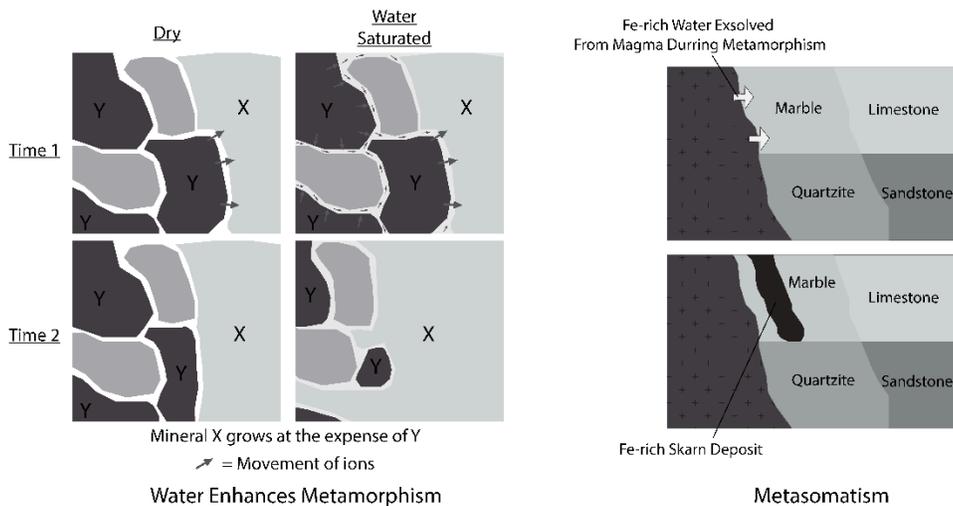
Pressure increases with depth in the Earth, and the pressure at any depth is equivalent to the weight of the material directly above. New minerals formed at depth tend to be denser because of the increased confining pressure.

Parent Composition



Indeed, the most important controlling factor, new minerals can only form in metamorphic rock if the elements needed to form those minerals are present in the parent rock. “You get out what you put in”.

Fluids



The primary fluid present during metamorphism is water. Water can play three important roles: 1. Mediate the movement of ions between grains in a rock, 2. Transport in new ions or remove ions away from a metamorphic environment (metasomatism), 3. Create new rock in void spaces (geodes, veins, etc.).

Now, test your knowledge:

Briefly define the following terms:

confining pressure -

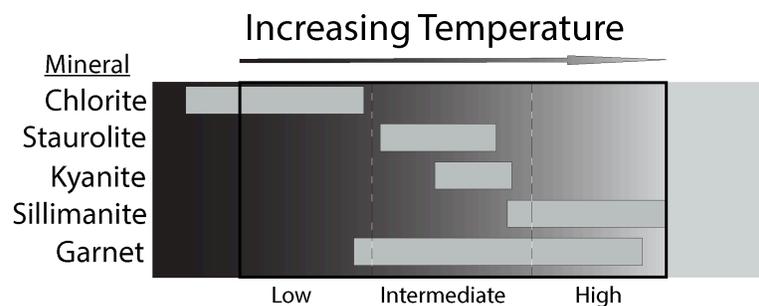
differential stress -

metasomatism -

protolith -

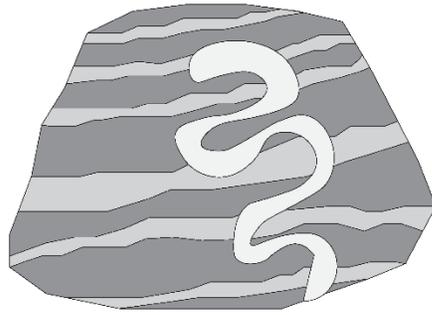
Answer the following:

1. True or False. As temperature increases, new more stable minerals will form in a rock, while remaining solid.
 - A. True
 - B. False

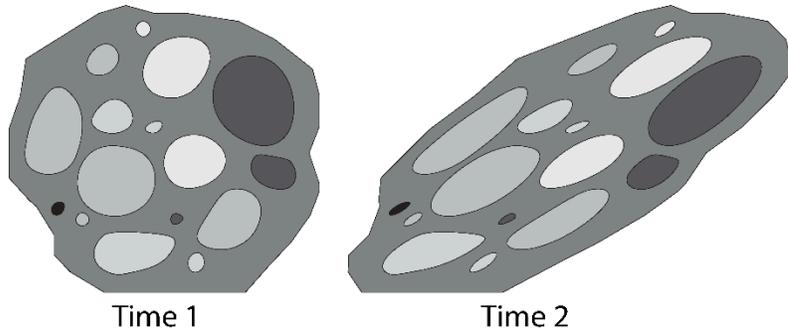


2. According to the mineral stability chart above, if a rock contains kyanite, it likely was metamorphosed to what conditions?
 - A. Sediment diagenesis
 - B. Low grade
 - C. Intermediate grade
 - D. High grade
3. According to the mineral stability chart above, a rock may contain garnet, signifying it to likely be a metamorphic rock having experienced at least intermediate grade metamorphism. However, the presence of what mineral is required to signify that the rock in fact experienced high grade metamorphism?
 - A. Chlorite
 - B. Staurolite
 - C. Kyanite

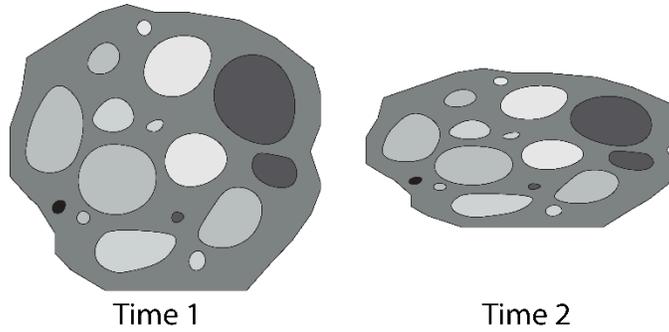
D. Sillimanite



4. The above illustration represents a high grade metamorphosed *migmatite*. The word means mixed rock because it contains both metamorphic and igneous components. The folded light colored vein likely formed from a melt. What conditions do you suppose this rock formed in?
- A. Sediment diagenesis
 - B. Low grade
 - C. Intermediate grade
 - D. High grade
5. True or False. Pressure and Temperature act independently on rocks in the crust.
- A. True
 - B. False
6. True or False. Pressure in the crust is always felt equal from all directions.
- A. True
 - B. False



7. In the above image, the starting conglomerate has experienced a unique pressure experience in the crust. What type of pressure (stress) was emplaced on this rock?
- A. Confining Pressure
 - B. Compressive Differential Pressure
 - C. Shear Differential Pressure
 - D. Hydrostatic Pressure



8. In the above image, the starting conglomerate has experienced a unique pressure experience in the crust. What type of pressure (stress) was placed on this rock?
- Confining Pressure
 - Compressive Differential Pressure
 - Shear Differential Pressure
 - Hydrostatic Pressure

<u>Rock</u>	<u>Mineral 1</u>	<u>Mineral 2</u>	<u>Mineral 3</u>
Carbonate (Limestone)	Calcite (CaCO_3)	n/a	n/a
Peridotite (Mantle Rock)	Olivine ($\text{Fe,Mg}_2\text{SiO}_4$)	Pyroxene ($\text{Fe,Mg}_2\text{Si}_2\text{O}_6$)	Plagioclase ($\text{CaAl}_2\text{Si}_2\text{O}_8$)

In the above table, two rock types are listed (limestone and mantle rock) along with their mineralogy.

9. Which of the above rock types would you expect to form garnet ($\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$) if metamorphosed to intermediate grade metamorphism?
- Carbonate
 - Peridotite
10. What type of fluid interaction would allow for garnet to form in a carbonate?
- Intragrain ion movement
 - Metasomatism
 - Hydrothermal rock (veins)

Now, think deeper:

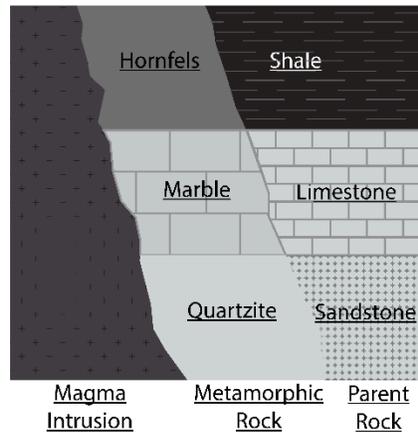
On your own:

11. In what ways does our understanding of rock metamorphism contribute to society?

Working in groups of 2 or 3

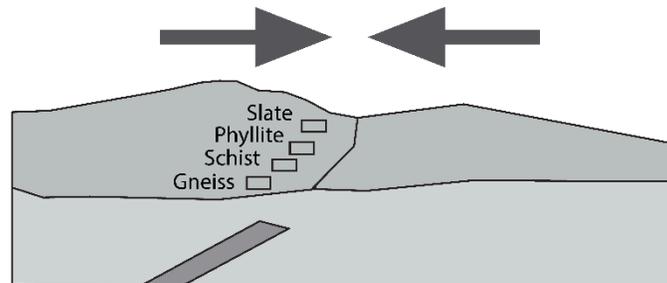
12. Compare your answers to question 11.

First some review of Metamorphism Types and P-T paths: Contact Metamorphism



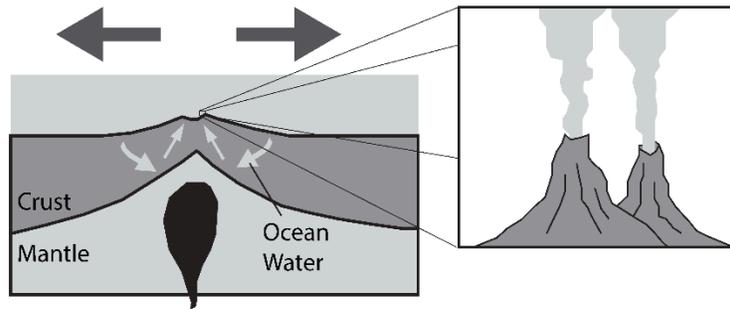
Contact metamorphism is associated with high temperatures around magmatic intrusions. Rocks in the metamorphic aureole (immediate surroundings) typically have grains welded together, and will also see an increase in grain size.

Regional Metamorphism



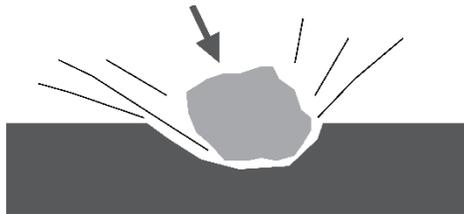
Rocks metamorphosed in mountain building environments (orogens) will have an increasing metamorphic grade according to depth of metamorphism. Slate rocks have foliation. Phyllites show a characteristic sheen from microscopic mica minerals. A schist is identified by having visible (to unaided eye) mica grains. Gneiss has characteristic banding of mafic mineral- and felsic mineral-rich layers.

Hydrothermal Metamorphism



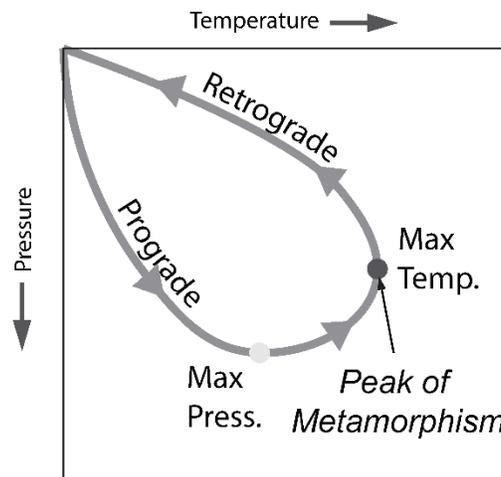
Ocean water circulated into the crust at mid-ocean ridge spreading centers will hydrate some minerals. Evidence for circulation of water is observed where the water vents back into the ocean.

Shock Metamorphism



Although relatively uncommon, meteor impacts do occur on Earth. The intense pressure forms unique minerals, and alters the crystal structure of others. Some local melting occurs, and that material may be ejected from the impact site.

P-T time paths



Rocks undergoing metamorphism will follow some sort of Pressure-Temperature (PT) time (or P-T-t) path. Increasing temperature during prograde causes changes in the rock. We often see the *peak of*

metamorphism (maximum temperature) recorded in the mineral assemblage of rocks. Most water has been driven off, and system is losing energy (heat loss), so not many reactions occur during retrograde.

Now, test your knowledge:

Briefly define the following terms:

metamorphic grade –

prograde -

retrograde -

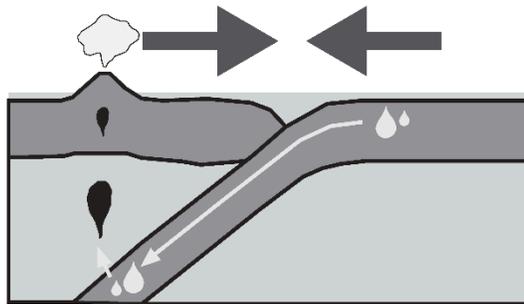
foliated -

non-foliated -

Answer the following:

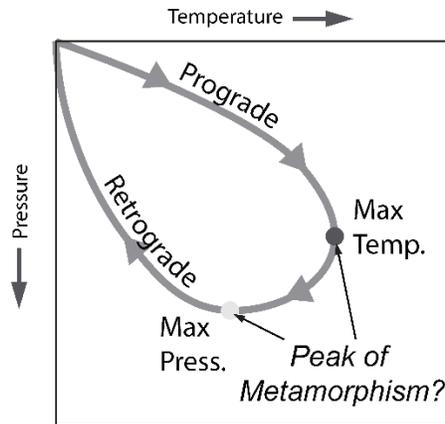
1. Match the parent rock type with the equivalent contact metamorphosed rock:
 - A. Limestone
 - B. Sandstone
 - C. Shale
 - D. Granite
 - E. Basalt
 - i. Marble: _____
 - ii. Hornfels: _____
 - iii. Quartzite: _____
2. In question 1, “Marble” is the:
 - A. Parent Rock
 - B. Metamorphosed Rock
3. True/False. During metamorphism, grain size tends to increase in rocks.
 - A. True
 - B. False
4. Which of the following tectonic settings would you expect regional metamorphism?
 - A. Mid-ocean ridge spreading center
 - B. Transform fault

- C. Rift basin
 - D. Continent-Continent convergent zone
5. True/False. The rocks formed in regional metamorphism are foliated.
- A. True
 - B. False
6. Which of the following gives the correct order of increasing metamorphic grade?
- A. Schist, Phyllite, Gneiss, Schist
 - B. Slate, Phyllite, Gneiss, Schist
 - C. Slate, Phyllite, Schist, Gneiss
 - D. Phyllite, Schist, Gneiss, Slate
 - E. Gneiss, Schist, Slate, Phyllite
7. Which of the following minerals likely formed in a hydrothermal metamorphic setting at a mid-ocean ridge? (hint: circulating ocean water (H₂O) was involved)
- A. Chlorite (Mg₅Al)(AlSi₃)O₁₀(OH)₈
 - B. Quartz SiO₂
 - C. Pyroxene MgSiO₃
 - D. Olivine (Mg,Fe)₂SiO₄



During hydrothermal metamorphism at mid-ocean ridges, the newly created ocean crust becomes hydrated, as new minerals form that contain water in their crystal structure. When ocean crust is subducted, those minerals become unstable at depth. They give off their water and become new phases.

8. Which of the following minerals likely formed in a subducting ocean crust slab, when pressures forced water out of the rocks?
- A. Pyroxene MgSiO₃
 - B. Chlorite (Mg₅Al)(AlSi₃)O₁₀(OH)₈
 - C. Serpentine (Mg, Fe)₃Si₂O₅(OH)₄



9. In the above P-T time path figure, the prograde and retrograde paths travel in a clockwise direction (note pressure increases downward in the diagram). Which condition is considered to be the *peak of metamorphism*?
- A. Maximum Temperature
 - B. Maximum Pressure
 - C. Prograde
 - D. Retrograde

Now, think deeper:

On your own:

10. List some specific places on Earth today where metamorphism is occurring.

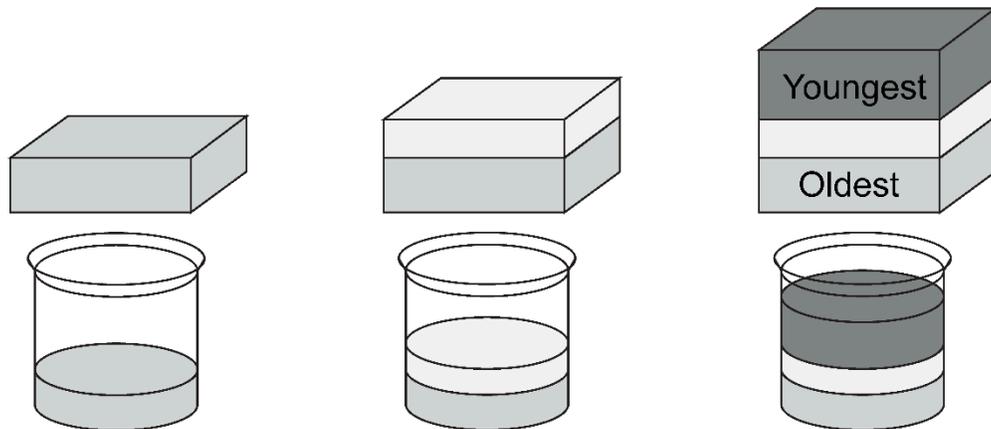
11. What type of metamorphism is occurring at each one of the locations you listed above?

Working in groups of 2 or 3

12. Take turns sharing your answers to questions 10 and 11. Discuss any different interpretations you might have with your partner's locations. Also, write down any changes your partner would make to your interpretations.

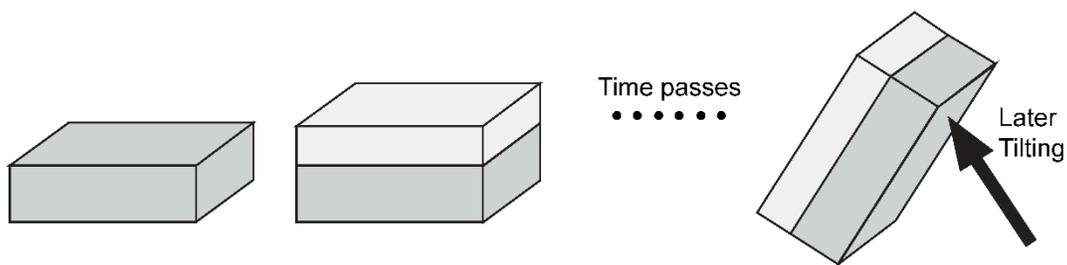
First some review of relative age principles:

Superposition



The principle of superposition states that within a sequence of undisturbed sedimentary or volcanic rocks, the oldest layer is at the bottom and layers are progressively younger upward in the stack.

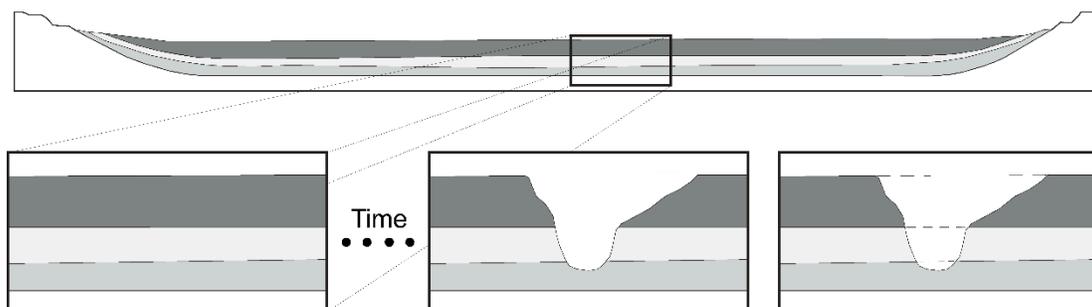
Original Horizontality



The principle of original horizontality states that beds of sediment in water and some volcanic rocks are deposited as horizontal or nearly horizontal layers. A separate, later, geologic event (e.g. orogenesis or mountain building) must have acted on any layers observed to be non-horizontal.

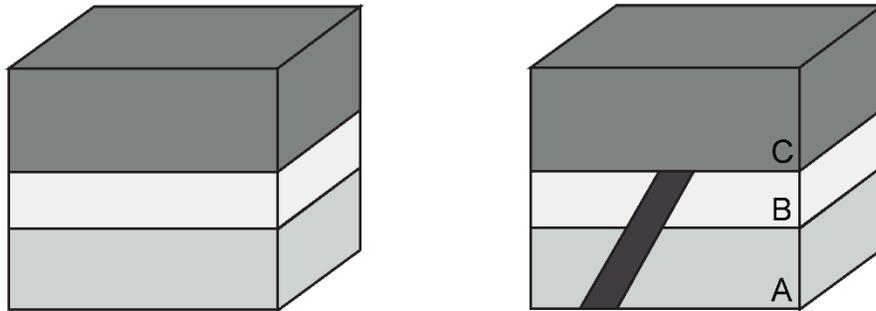
Lateral Continuity

The principle of lateral continuity states that an original sedimentary layer and some volcanic rocks extend laterally until they taper at their edges.



Geologists might use this principle to determine similar rock formations on either side of an eroded canyon were originally the same formation.

Cross-Cutting Relationships

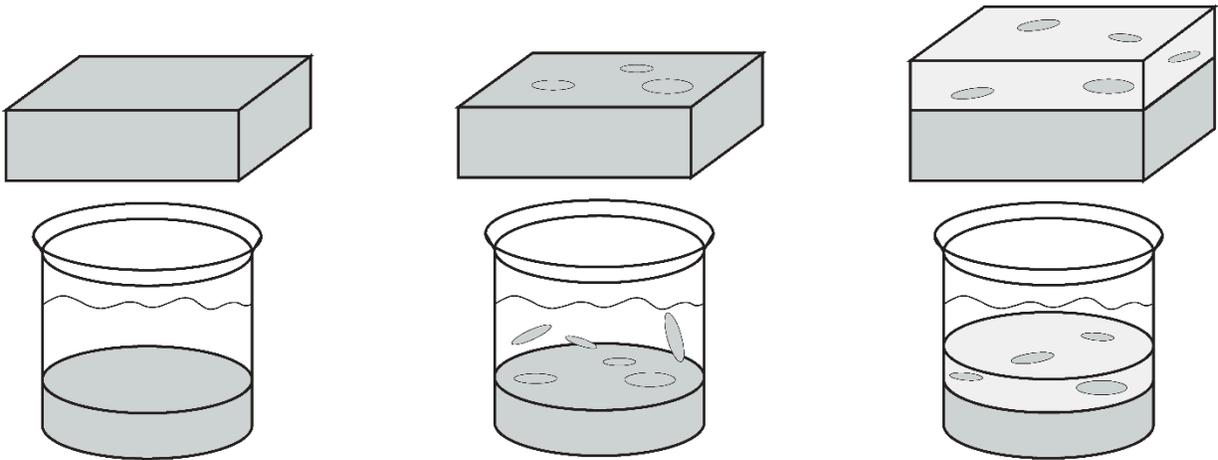


The principle of cross-cutting relationships states that a disrupted pattern is older than the cause of the disruption. In the above example, the mafic dike cross-cuts the contact between formations A and B.

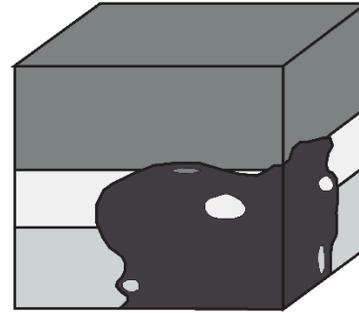
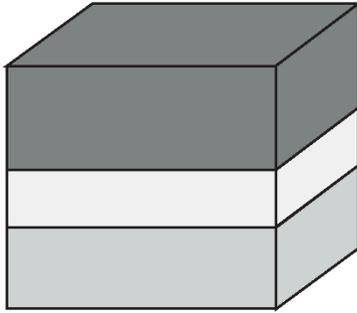
Therefore, the dike is younger than that relationship, and consequently, younger than units A and B.

Notice also, the dike does not cross-cut unit C. Therefore, the dike is older than unit C.

Inclusions



The principle of inclusions states that if inclusions (clasts) are found in a rock formation, then the inclusions must be older than the formation that contains them. In the above example, during an intermediate stage, small clasts of the underlying formation were ripped up due to some sort of current and later these clasts were included in the sedimentary layer that was deposited afterwards. In the below example, inclusions of the country rock are contained (included) within an igneous intrusion.



Now, test your knowledge:

Briefly define the following terms:

uniformitarianism -

relative age -

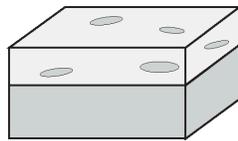
numerical age -

contact -

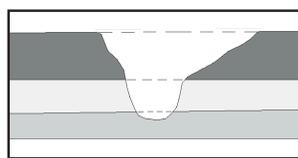
formation -

Answer the following:

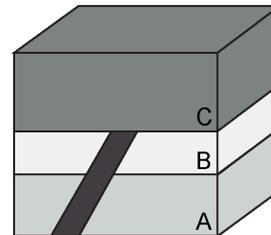
1.



2.



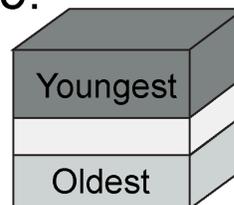
3.



4.

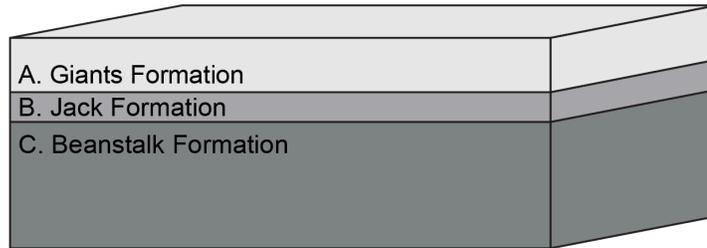


5.



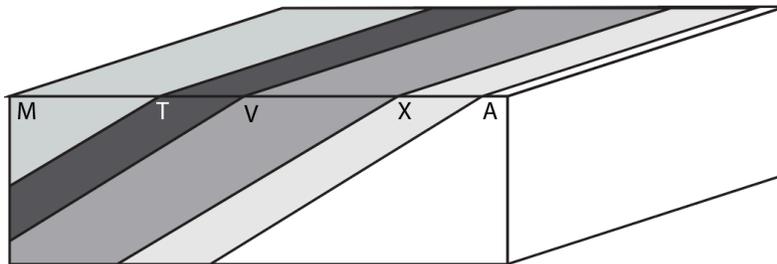
1. Match the following principles with the illustration that best exemplifies that principle.

- A. Cross-Cutting Relationship _____
- B. Superposition _____
- C. Inclusions _____
- D. Lateral Continuity _____
- E. Original Horizontality _____



1. Using the above diagram; list the sedimentary units in order from youngest to oldest:
 - A. $A > B > C$
 - B. $C > B > A$
 - C. $B > C > A$

2. What principle best helped you determine the relative ages in the units from the diagram above?
 - A. Cross-Cutting Relationships
 - B. Original Horizontality
 - C. Lateral Continuity
 - D. Inclusions
 - E. Superposition



In the above diagram, the sedimentary units are tilted, dipping towards the left side of the block. It is alright if you are unable to visualize this now, it comes with practice. Regardless, using this description, you should be able to determine the following:

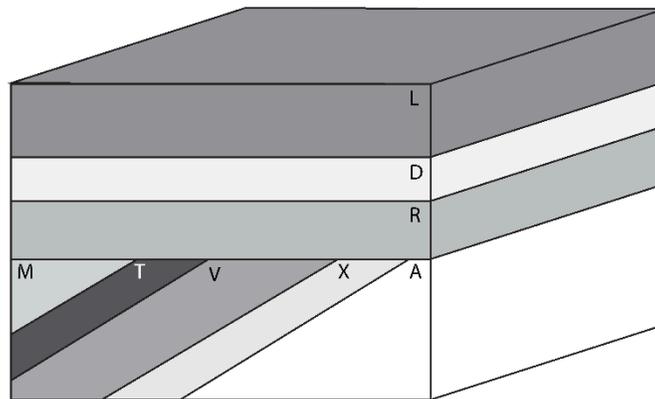
3. These sedimentary units formed in this (tilted) orientation.
 - A. True
 - B. False

4. Assuming the units were not tilted to such an extreme that they were overturned, which unit is the oldest?

Physical Geology Lecture Tutorials
Relative Age Principles

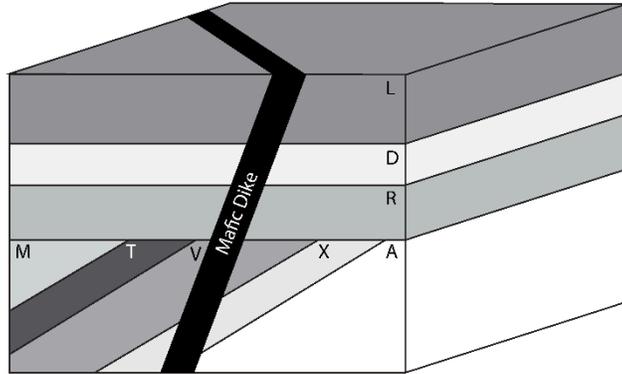
- A. M
- B. X
- C. A

5. (Continuing with diagram from the previous page) What principle best helped you determine the relative ages in the units (be careful)?
- A. Cross-Cutting Relationships
 - B. Original Horizontality
 - C. Lateral Continuity
 - D. Inclusions
 - E. Superposition

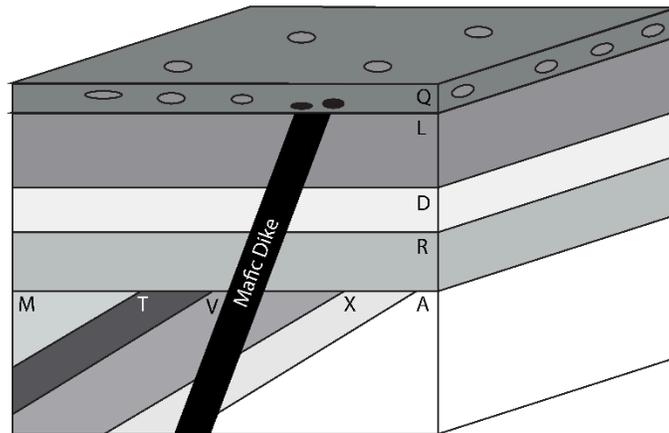


In the above diagram, three new sedimentary units (L, D, and R) have been deposited on top of the units from the previous diagram (M, T, V, X, and A). The boundary between these two packages (the base of unit R) is known as an *angular unconformity*. We will discuss *angular unconformities* more in the future, but for now, determine the following from the above diagram:

6. Which is older in the diagram:
- A. The lower package of units (M, T, V, X, and A)
 - B. The upper package of units (L, D, and R)
7. Which is the youngest unit in the diagram?
- A. A
 - B. V
 - C. M
 - D. R
 - E. L

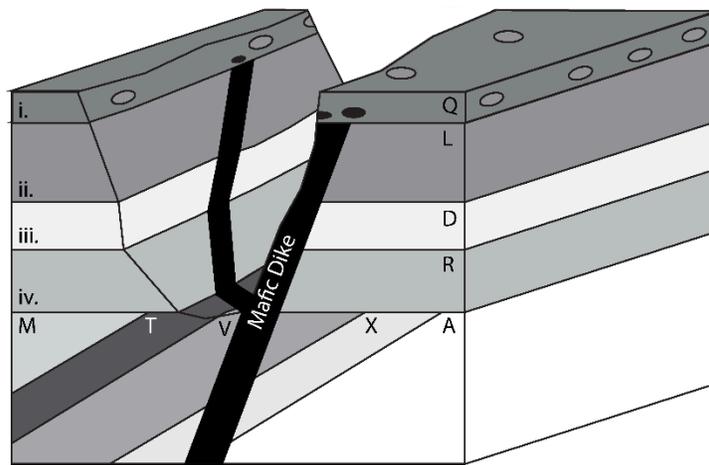


8. In the above diagram; which is the youngest unit?
- A. A
 - B. M
 - C. Mafic Dike
 - D. R
 - E. L
9. What principle best helped you determine the relative ages for the answer to the previous question (question 9)?
- A. Cross-Cutting Relationships
 - B. Original Horizontality
 - C. Lateral Continuity
 - D. Inclusions
 - E. Superposition



10. In the above diagram; What principle best helped you determine the relative age between unit Q and unit R?
- A. Cross-Cutting Relationships
 - B. Original Horizontality
 - C. Lateral Continuity
 - D. Inclusions
 - E. Superposition

11. In the diagram from the previous question; unit Q contains fragments (clasts) of the underlying unit L and of the mafic dike, what relative age principle helps you determine the age of the fragments?
- A. Cross-Cutting Relationships
 - B. Original Horizontality
 - C. Lateral Continuity
 - D. Inclusions
 - E. Superposition
12. Are the fragments in unit Q, older or younger than unit Q?
- A. Older
 - B. Younger



In the above diagram, a canyon has now formed, further exposing several sedimentary units, as well as the mafic dike.

13. Four units are identified as i., ii., iii., and iv., on the left side of the diagram. To which units do they correspond from the right side of the canyon?
- i. _____
 - ii. _____
 - iii. _____
 - iv. _____
14. What principle best helped you assign units to match those on opposite sides of the canyon?
- A. Cross-Cutting Relationships
 - B. Original Horizontality
 - C. Lateral Continuity
 - D. Inclusions
 - E. Superposition

Now, think deeper:

On your own:

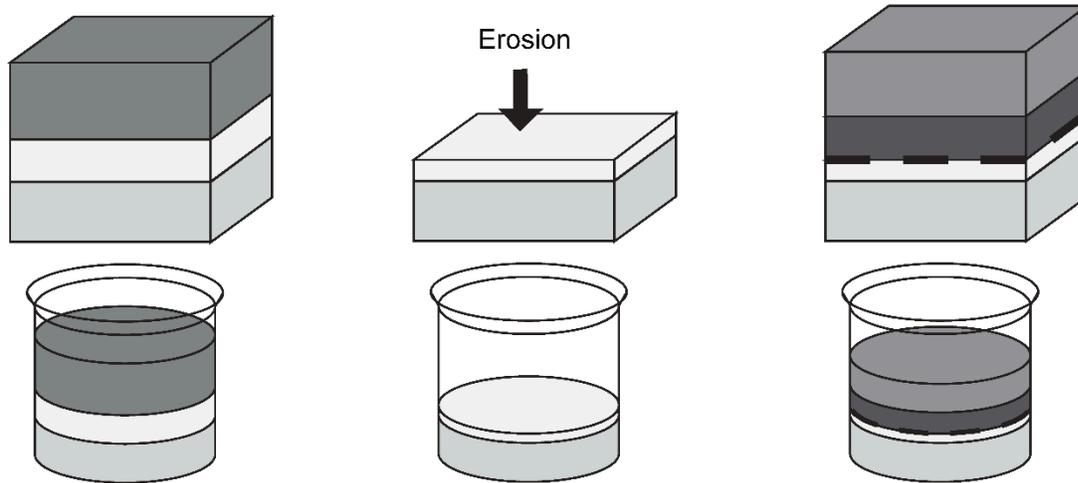
15. Describe some objects in your daily life that follow relative age principles, or that you can use relative age principles to determine something about them relative to each other.

Working in groups of 2 or 3 (if possible):

16. Compare with your partner your answers to question 15. Did you use the same principle? Can you work together to come up with at least one more instance of where you can use a different relative age principle?

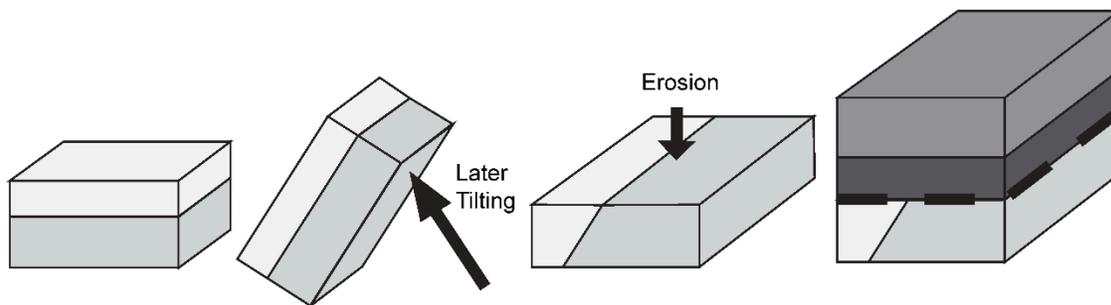
First some review of Unconformities:

Disconformity



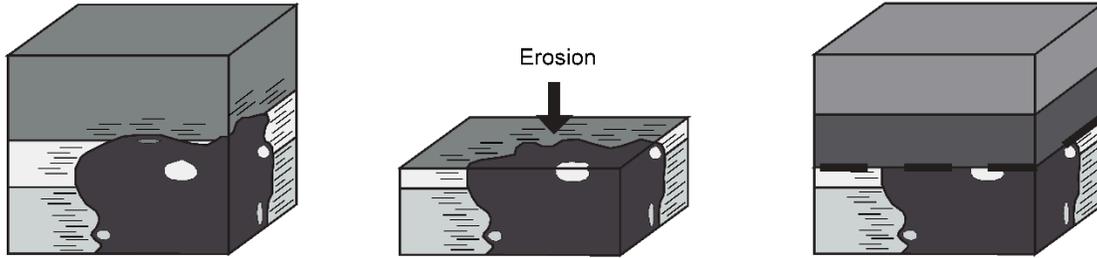
A disconformity is a geologic contact in which significant missing rock layers (strata) represents a large gap in the geologic record (a gap in time). In the above example, previously deposited rocks were eroded flat prior to deposition of later units. A disconformity could also arise from simply having a period of non-deposition (erosion not required).

Angular Unconformity



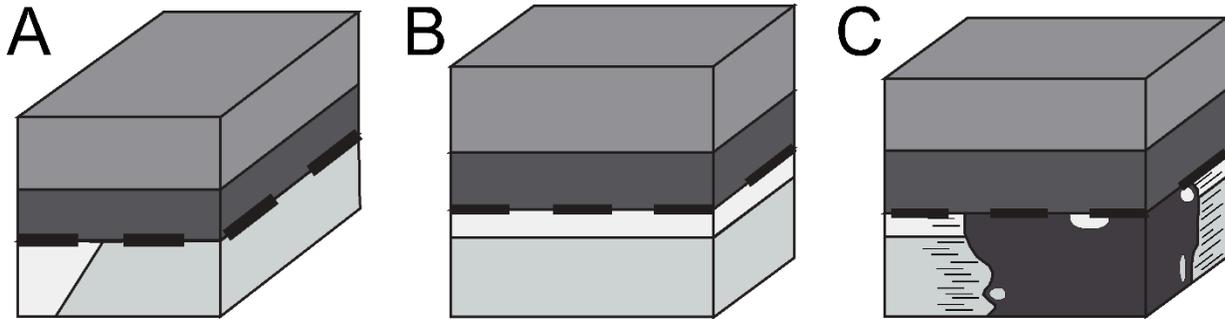
An angular unconformity is a contact in which younger sedimentary rocks (strata) overlie an erosion surface, and the underlying sedimentary rocks (strata) have been folded or tilted.

Nonconformity



A nonconformity is a contact in which younger sedimentary rocks overlie an erosion surface, and the underlying rock is plutonic (igneous) or metamorphic.

Now, test your knowledge:



17. Match the following unconformities with the above illustration that best exemplifies that unconformity.

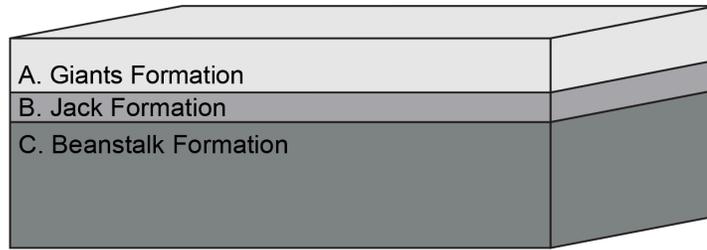
- i. Disconformity: _____
- ii. Angular Unconformity: _____
- iii. Nonconformity: _____

18. Which of the unconformities is arguably the most difficult to identify in the field?

- A. Disconformity
- B. Angular Unconformity
- C. Nonconformity

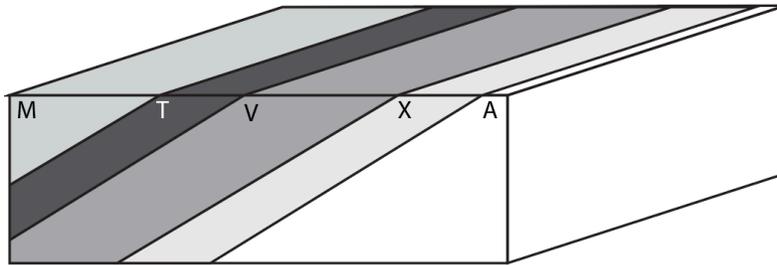
19. Which of the following observations would best help in identifying the “difficult to identify” unconformity in the previous question?

- A. Structural measurements of tilted strata
- B. Fossil records of individual units
- C. Geologic map showing extent of metamorphic aureole in underlying basement rocks.



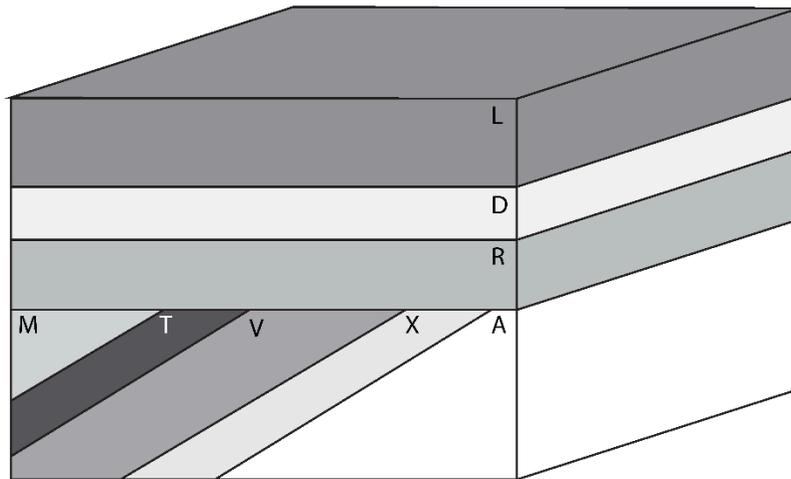
20. With the information in the above diagram, what type of unconformity can you eliminate as possible in this area of the crust?

- A. Disconformity
- B. Angular Unconformity
- C. Nonconformity



21. If further deposition were to occur on top of the above block, what relative age principle tells us the orientation of the new units?

- A. Cross-Cutting Relationships
- B. Original Horizontality
- C. Lateral Continuity
- D. Inclusions
- E. Superposition



22. Indeed, new units have been deposited. What type of unconformity is present at the base of unit R?

- A. Disconformity
- B. Angular Unconformity
- C. Nonconformity

23. Match the following brief definitions to their corresponding unconformities

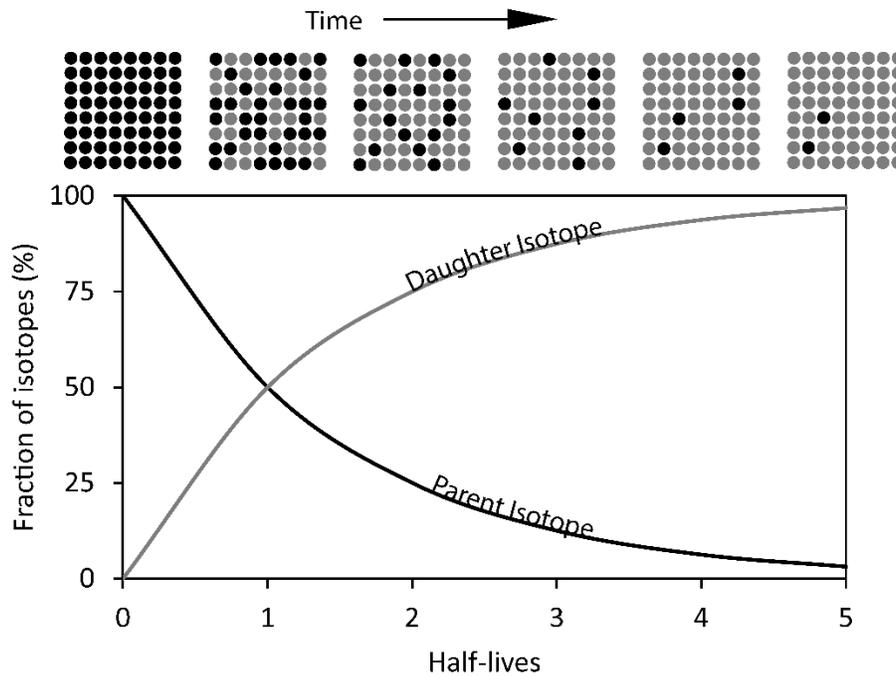
- A. Horizontal strata deposited onto region of exposed metamorphic rocks.
- B. Horizontal strata deposited onto a region of exposed tilted strata.
- C. Horizontal strata deposited onto a region of exposed horizontal strata.

- i. Disconformity: _____
- ii. Angular Unconformity: _____
- iii. Nonconformity: _____

First some review of numerical ages:

Half-life and the age equation

Recall that an isotope is an atom of an element with a varying amount of neutrons. Atoms with too many, or too few neutrons are unstable. Radioactive decay is the spontaneous nuclear change (decay) of isotopes with unstable nuclei to a more stable state. The rate of proportional decay is expressed as half-life.



Every isotope system (e.g. U-Pb, K-Ar, etc.) has a unique half-life (rate) that we use to calculate an age.

To calculate the age, we use the age equation: $N = N_0 e^{-\lambda t}$

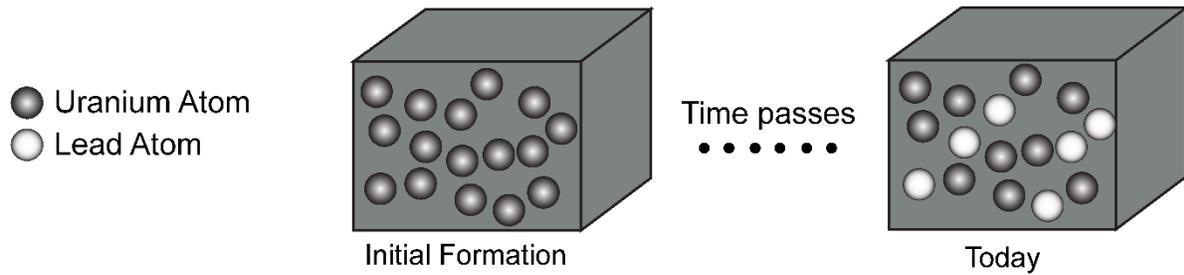
Converting this equation into something more useful involves first recognizing that $\lambda = \ln 2 / t_{hl}$

$\ln 2 = 0.693$

t_{hl} = the isotope system half-life

Then, converting the equation to natural log form we get: $t = - \frac{t_{hl}}{0.693} \ln \ln \frac{N}{N_0}$

Now, test your knowledge:



In the above illustration, a mineral has formed at some time in the past. During formation, the mineral incorporated uranium atoms into its crystal structure, while lead atoms were excluded. Through time (between formation and today) some of those uranium atoms spontaneously decayed to atoms of lead, with a half-life of 703 million years (703,000,000 years).

28. How many uranium atoms were contained in the mineral when first formed? $N_0 =$ _____
29. How many uranium atoms remain in the mineral today? $N =$ _____
30. How many lead atoms were present in the initial formation of the mineral? _____
31. How many lead atoms are present in the mineral today? _____

Recall the natural log form age equation from the intro: $t = -(t_{hl}/0.693) * \ln (N/N_0)$

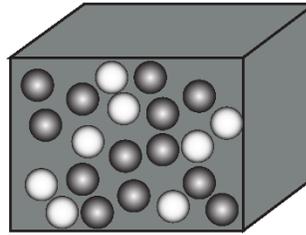
32. Now, using the information you obtained above, plug values into the equation below to obtain the age of the rock (t). Report your answer using scientific notation with 2 decimals.

$$t = - \frac{t_{hl}}{0.693} \ln \ln \frac{N}{N_0}$$

t =

(did you get 4.77×10^8 ?)

● Uranium Atom
 ○ Lead Atom



Today

In this next illustration (above), a mineral has been sampled from a rock completely different from the first example.

33. How many uranium atoms are in the mineral today? $N =$ _____

34. How many lead atoms are present in the mineral today? _____

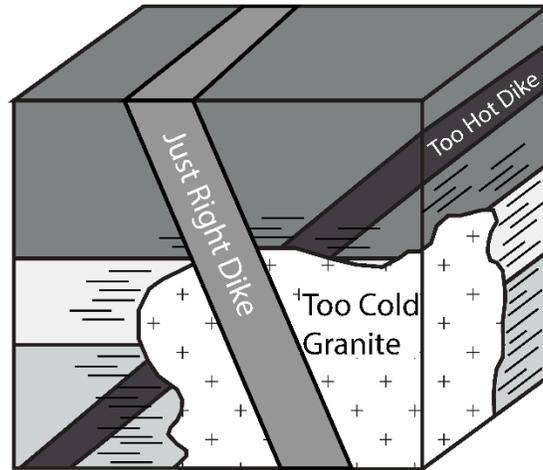
35. Assuming no lead atoms were present in the initial formation of this mineral. How many uranium atoms were contained in the mineral when it first formed? $N_0 =$ _____

The previous question demonstrates an important aspect of numerical age dating. We are unable to directly measure a mineral when it first formed. We have to make some assumptions about how much of an atom is incorporated when the mineral first formed. Some minerals are much more useful for numerical dating, such as zircon, which takes uranium, but excludes lead from its crystal structure.

36. Now, recalling that the U-Pb system half-life is 703 million years, Use the information you obtained from this new rock to obtain the age of the rock (t). Report your answer using scientific notation with 2 decimals.

$$t = - \frac{t_{hi}}{0.693} \ln \ln \frac{N}{N_0}$$

$t =$



In the above illustration, three igneous intrusions have intruded the region at various times.

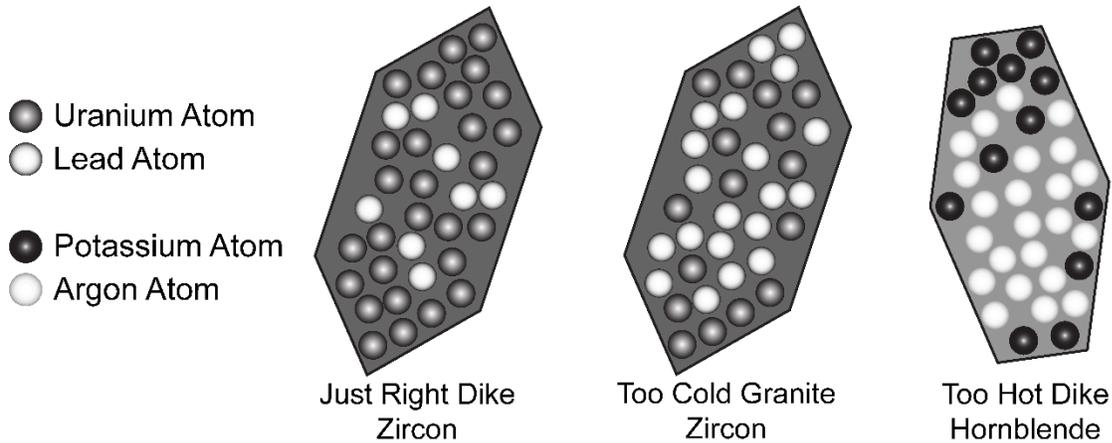
37. Using the above diagram; list the igneous units in order of youngest to oldest:

Youngest: _____

Oldest: _____

38. What relative age principle best helped you determine the relative ages of the igneous units in the above diagram?

- A. Cross-Cutting Relationships
- B. Original Horizontality
- C. Lateral Continuity
- D. Inclusions
- E. Superposition



Zircon crystals were obtained from the Too Cold Granite and the Just Right Dike. No zircon crystals were recovered from the Too Hot Dike, and instead the mineral Hornblende was recovered. In order to obtain an age from the hornblende, the Potassium (K) to Argon (Ar) decay system was used (the K/Ar system has a half-life = 1.3 billion years (1,300,000,000 years)).

Determine an age for each of the crystals:

39. How many U atoms when Too Cold Granite Zircon first formed? $N_0 =$ _____

40. How many U atoms in the Too Cold Granite Zircon today? $N =$ _____

41. Too Cold Granite Zircon $t =$ _____ years (answer using scientific notation rounding to 2 decimals)

42. Just Right Dike Zircon: $t =$ _____ years (answer using scientific notation rounding to 2 decimals)

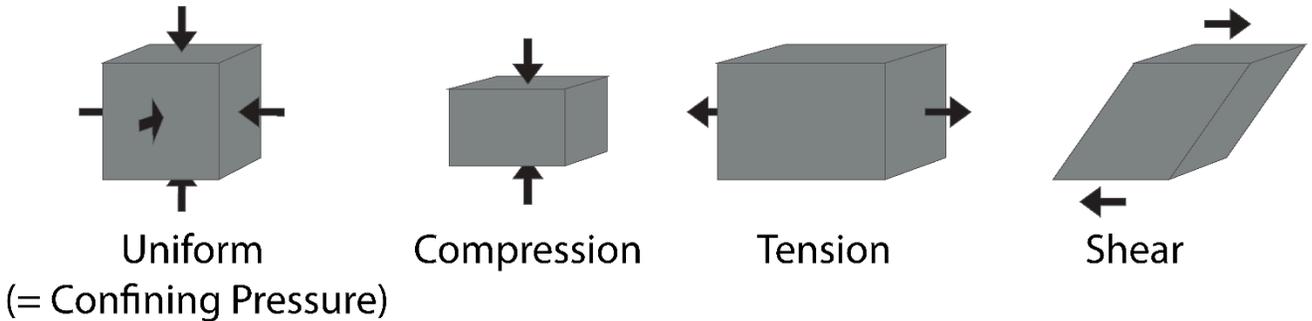
43. Too Hot Dike Hornblende: $t =$ _____ years (answer using scientific notation rounding to 2 decimals)

44. Do the numerical ages obtained from the three igneous units match the relative ages obtained using relative age principles in question 10?

- A. True
- B. False

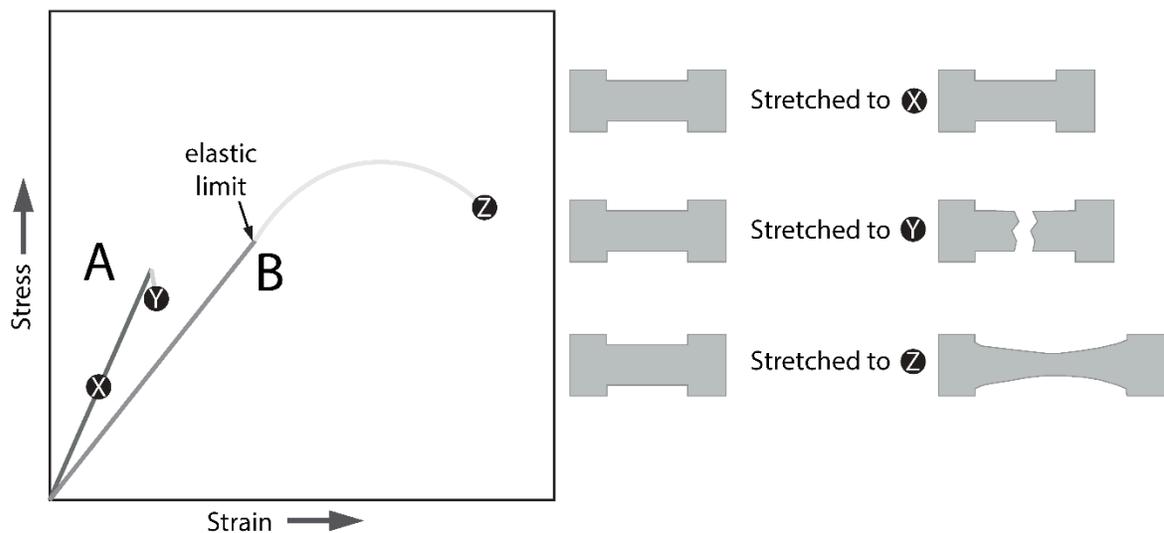
First some review of Stress and Strain:

Stress



Stress is force per unit area applied to rocks.

Strain



Strain is the modification of rock caused by stress. An important control on observed stress is the *rate* which stress is applied. In scenario A, increase in stress is applied quickly, the material breaks in a **brittle** way when stretched to point Y. If only stretched to point X, **elastic** behavior will cause the material to return (bounce back) to original shape. If instead stress is increased slowly, a material will deform in a **ductile** way, as in scenario B. If a material deforms in a brittle or ductile way is also dependent on the type of rock and the temperature and pressure conditions.

Now, test your knowledge:

Briefly define the following terms:

stress -

strain -

uniform -

compression -

tension -

shear -

brittle -

elastic -

ductile -

Answer the following:

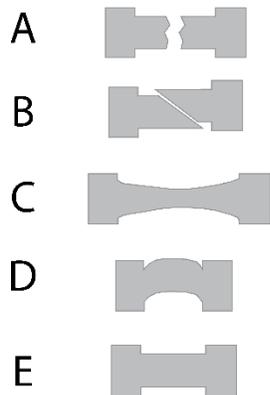
1. Which form of stress will cause a rock to become flattened or shortened?
 - A. Uniform
 - B. Compressive
 - C. Tensional
 - D. Shear
2. Which form of stress will cause a rock to become stretched or extended?
 - A. Uniform
 - B. Compressive
 - C. Tensional
 - D. Shear

3. Which form of stress will cause a rock to show shear strain?
- A. Uniform
 - B. Compressive
 - C. Tensional
 - D. Shear

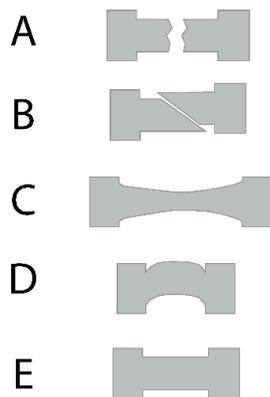


4. Which form of stress is indicated in the above image?
- A. Uniform
 - B. Compressive
 - C. Tensional
 - D. Shear

5. In the above image, which result would occur if the material deformed in a **brittle** way during the stress indicated?



6. In the above image, which result would occur if the material deformed in a **ductile** way during the stress indicated?

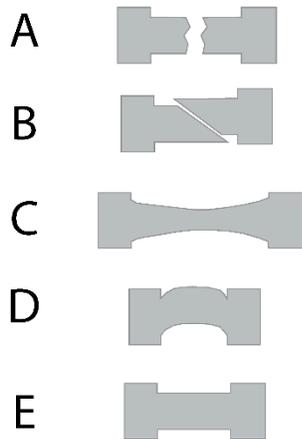




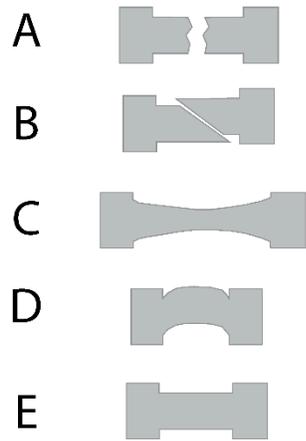
7. Which form of stress is indicated in the above image?

- A. Uniform
- B. Compressive
- C. Tensional
- D. Shear

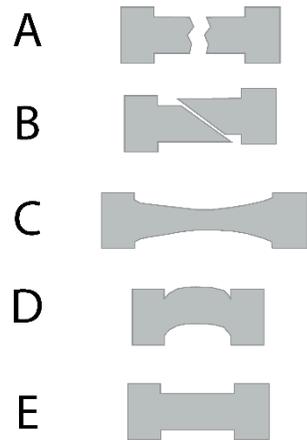
8. In the above image, which result would occur if the material deformed in a **brittle** way during the stress indicated?



9. In the above image, which result would occur if the material deformed in a **ductile** way during the stress indicated?

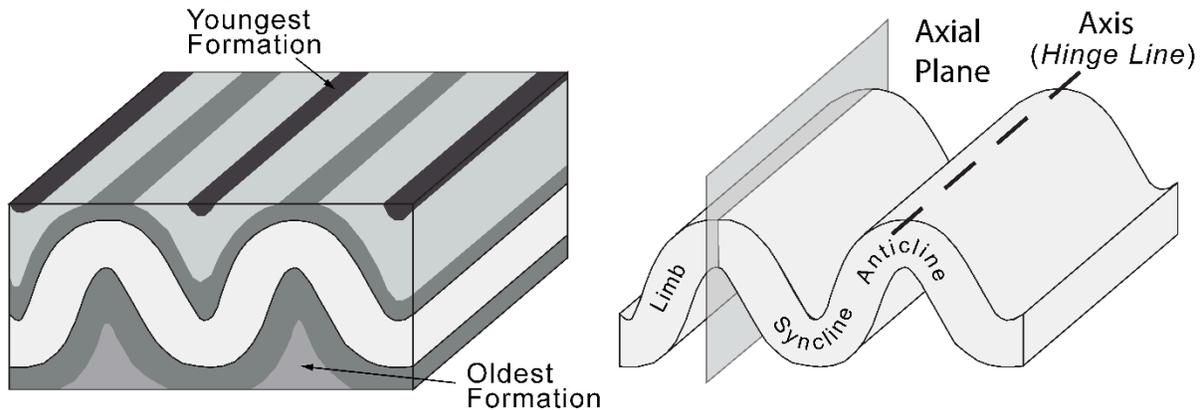


10. In the above image, which result would occur if the material deformed in an **elastic** way after the stress indicated?



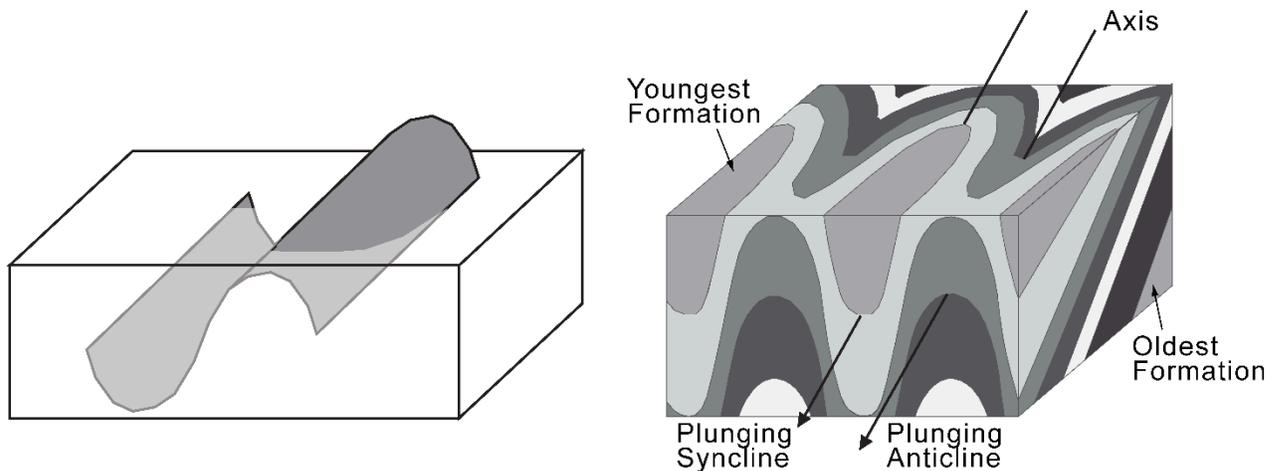
First some review of Folds:

Fold Geometry



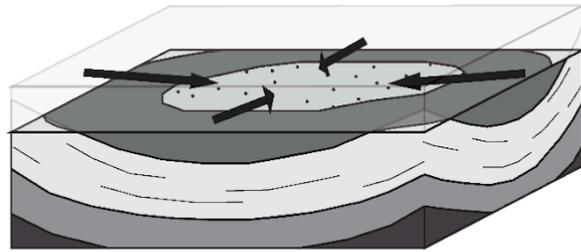
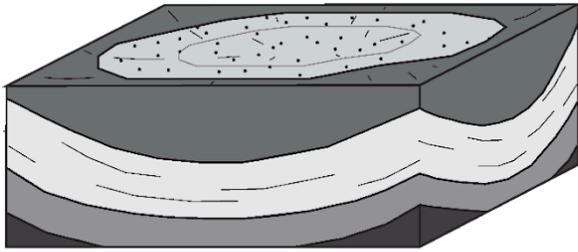
A fold geometry is described to understand how the rocks were deformed. The terminology used aids in consistent discussion in the scientific community.

Plunging Folds

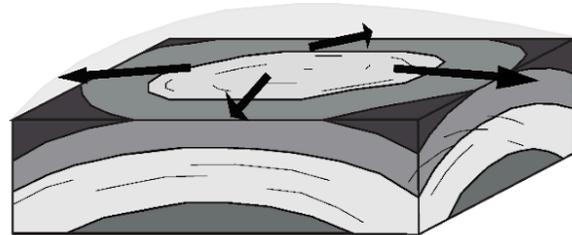
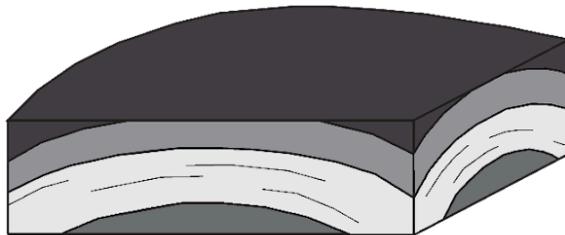


A fold geometry can be distinguished by a dipping (non-horizontal) hinge line. Plunging folds are distinguished by the relationship of old and young formations. On surface a plunging syncline opens in the plunge direction, while a plunging anticline closes in the plunge direction.

Basins and Domes



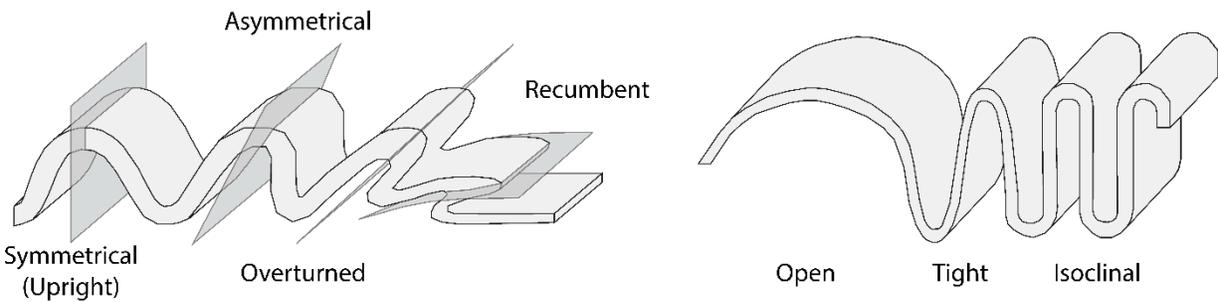
Basin



Dome

In a structural basin, all of the beds dip towards a central point, and the youngest bed is found in the center of the basin. In a structural dome, all of the beds dip away from a central point, and the oldest (exposed) bed is found in the center.

Types of Folds



A variety of fold types exist in nature, displayed above in two spectrums of fold symmetry and tightness respectively. In many cases the boundary between fold types is not clear, or the boundary is not sharp. In other cases a definition is more finite, such as: *overturned*, where the beds of one of the limbs is literally 'overturned'; *recumbent*, where the limbs of a fold are roughly horizontal; *isoclinal*, where the limbs are parallel. Also, it is possible to have combinations of the above, such as a *recumbent isoclinal* fold.

Now, test your knowledge:

Briefly define the following terms:

anticline -

syncline -

basin -

dome -

symmetrical -

asymmetrical -

overturned -

recumbent -

open -

tight -

isoclinal -

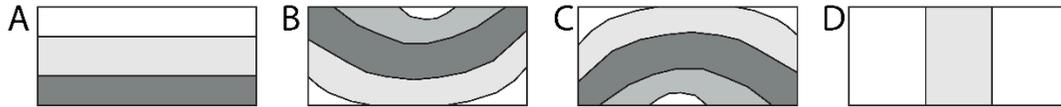
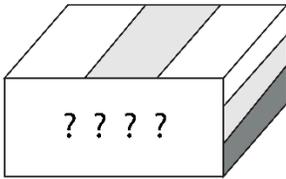
Answer the following:

1. The down and under (U-shaped) part of a fold is referred to as a(n) _____.
 - A. Syncline
 - B. Anticline
 - C. Axis
 - D. Axial Plane

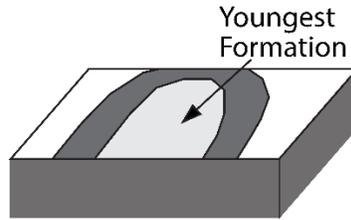
2. The up and over (A-shaped) part of a fold is referred to as a(n) _____.
- A. Syncline
 - B. Anticline
 - C. Axis
 - D. Axial Plane

3. The hinge line of a fold is also known as the _____.
- A. Syncline
 - B. Anticline
 - C. Axis
 - D. Axial Plane

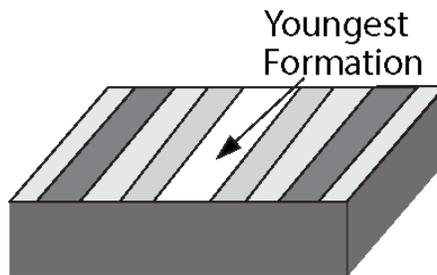
4. Which of the faces is the correct one for the one missing from the block model?



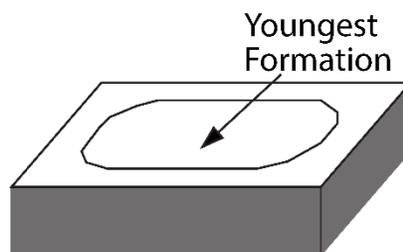
5. In the above image, what type of fold is displayed?
- A. Upright
 - B. Asymmetrical
 - C. Overturned
 - D. Recumbent
 - E. Isoclinal



6. In the above illustration, the sides of the block model have been greyed out so you can't see what is happening in the subsurface. What type of fold is this?
- A. Basin
 - B. Anticline
 - C. Plunging Anticline
 - D. Plunging Syncline
 - E. Syncline



7. In the above illustration, the sides of the block model have been greyed out so you can't see what is happening in the subsurface. What type of fold is this?
- A. Basin
 - B. Anticline
 - C. Plunging Anticline
 - D. Plunging Syncline
 - E. Syncline

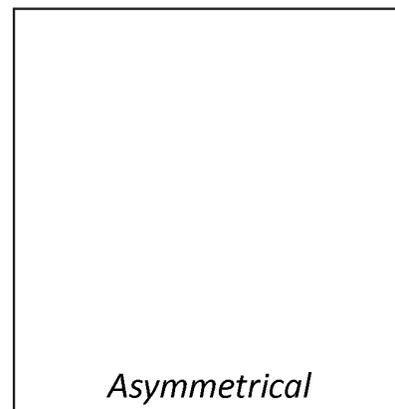
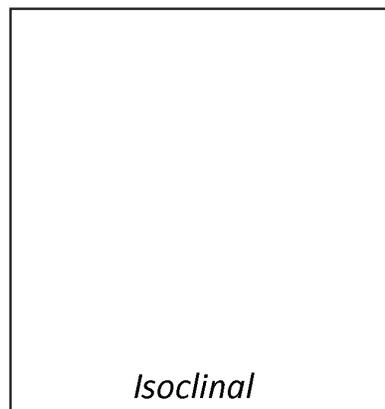
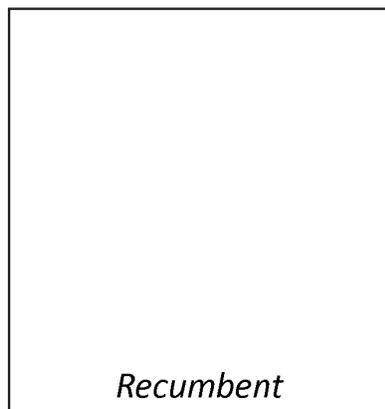
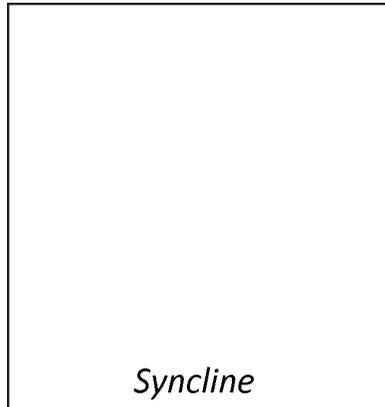
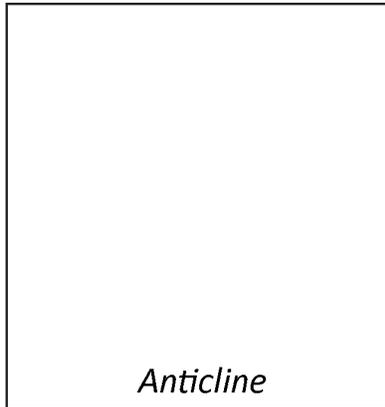


8. In the above illustration, the sides of the block model have been greyed out so you can't see what is happening in the subsurface. What type of fold is this?
- A. Basin
 - B. Anticline
 - C. Plunging Anticline
 - D. Plunging Syncline
 - E. Syncline

Now, think deeper:

On your own:

- Put away all of your notes. Draw the following types of folds to the best of your ability. They do not need to be 3D blocks, they can be 2D sections.



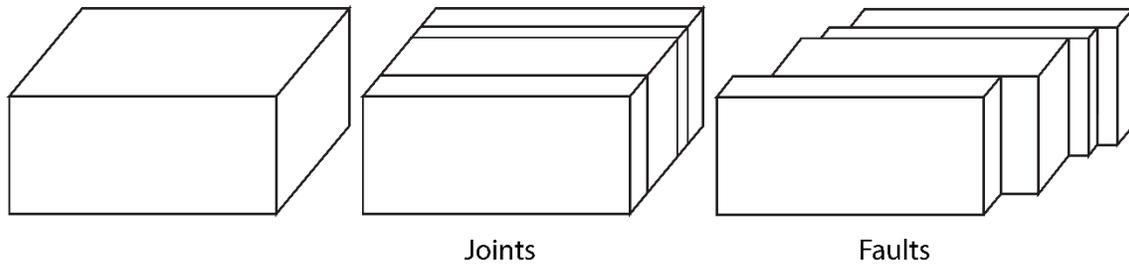
- With your notes still out of sight, describe as many differences you can between a *structural basin* and a *structural dome*.

Working in groups of 2 or 3

- Compare your answers to questions 9 and 10. Write (draw) any differences between your answers and your partner's.

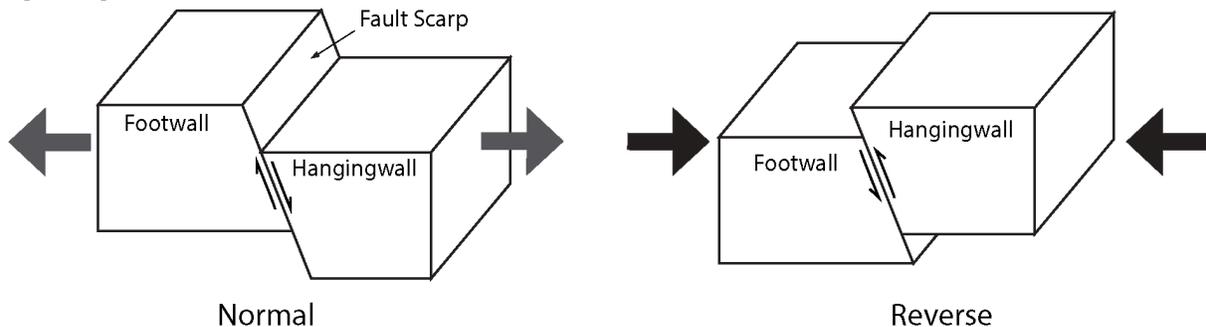
First some review of Faults:

Joint vs. Fault



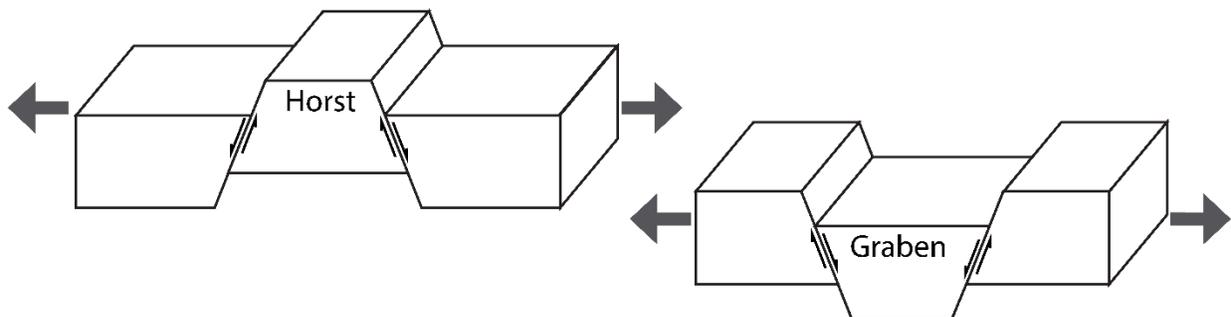
A *joint* is a brittle fracture of rock along which essentially no movement has occurred. A fracture along which significant movement has occurred is referred to as a *fault*.

Dip-slip faults



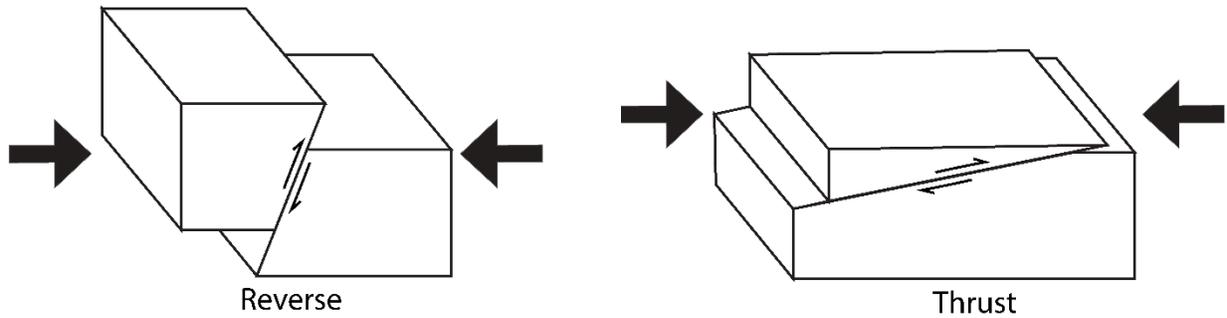
Movement along the fault plane that is vertical is known as a dip-slip fault. Along any non-vertical fault plane, the overhanging block, regardless of sense of movement, is known as the hangingwall block, while the underlying block is known as the footwall block.

Horst and Graben



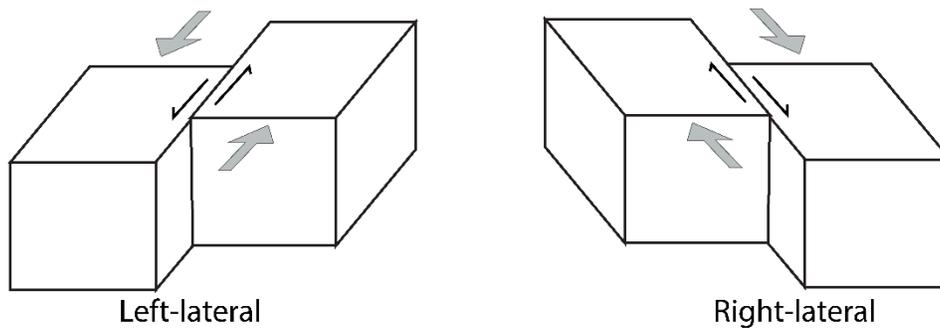
A block bounded by normal faults that has been uplifted relative to the surrounding blocks is known as a *horst block*. A *graben* is a block bounded by normal faults that has been dropped downward relative to the surrounding blocks.

Thrust faults



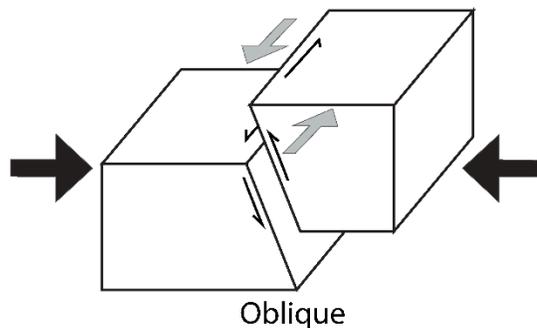
A low angle (less than 30°) reverse fault is referred to as a *thrust fault*.

Strike-slip



A *strike-slip* fault has dominantly horizontal movement. If you stand on one block, looking across the fault at the other block, and you see the other block has moved to your left, this is referred to as a *left-lateral fault*. The opposite is true for a *right-lateral fault*.

Oblique faults



A fault that displays a combination of dip-slip and strike-slip fault movements is referred to as an *oblique* fault.

Now, test your knowledge:

Briefly define the following terms:

joint -

fault -

hangingwall -

footwall -

dip-slip -

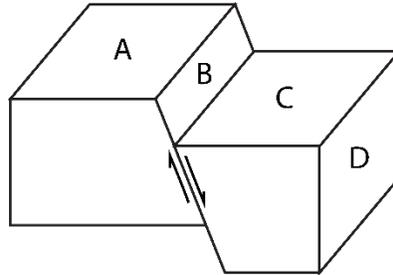
strike-slip -

oblique -

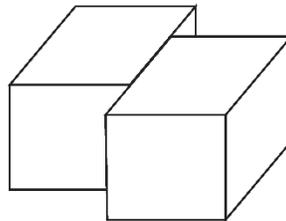
Answer the following:

1. True/False. A joint that has movement along the fracture surface is known as a fault.
 - A. True
 - B. False
2. The block that rests **above** the fault plane of a non-vertical fault is known as the _____ block.
 - A. Normal
 - B. Reverse
 - C. Hanging-wall
 - D. Footwall
 - E. Scarp
3. The block that rests **below** the fault plane of a non-vertical fault is known as the _____ block.
 - A. Normal
 - B. Reverse
 - C. Hanging-wall
 - D. Footwall
 - E. Scarp

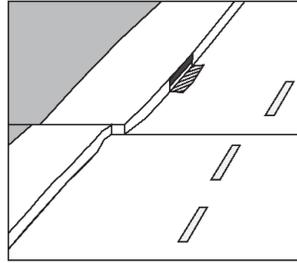
4. The fault type most associated with extensive tectonic forces is known as a _____ fault.
- A. Reverse
 - B. Thrust
 - C. Oblique
 - D. Normal



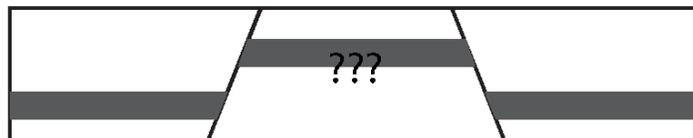
5. In the above image, which letter is located on the *fault plane*?
- A. A
 - B. B
 - C. C
 - D. D



6. In the above image, what type of fault is displayed?
- A. Normal fault
 - B. Right-lateral fault
 - C. Reverse fault
 - D. Thrust fault
 - E. Left-lateral fault



7. In the above image, what type of fault is displayed?
- Normal fault
 - Right-lateral fault
 - Reverse fault
 - Thrust fault
 - Left-lateral fault
8. When a block is bounded by normal faults, if it has moved **downward** relative to the bounding blocks it is referred to as a _____ block.
- Normal
 - Reverse
 - Horst
 - Graben
 - Thrust
9. When a block is bounded by normal faults, if it has moved **upward** relative to the bounding blocks it is referred to as a _____ block.
- Normal
 - Reverse
 - Horst
 - Graben
 - Thrust



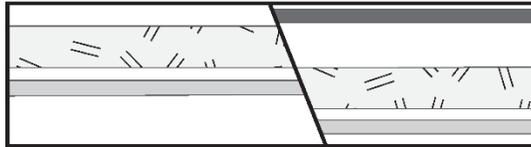
10. In the above image, you are given a cross-sectional view of the crust (the surface having been eroded flat). Decide what name you would give to the center block. (Hint: Use the grey marker beds, that have been offset, as a guide to recognize the sense of movement along the two high angle faults.)
- Normal
 - Reverse
 - Horst
 - Graben

E. Thrust



11. In the above cross section image, what type of fault is displayed?

- A. Normal
- B. Reverse
- C. Horst
- D. Graben
- E. Thrust



12. In the above cross-section image, what type of fault is displayed?

- A. Normal
- B. Reverse
- C. Horst
- D. Graben
- E. Thrust

Now, think deeper:

On your own:

13. Put away all of your notes. Draw the following types of faults to the best of your ability. They do not need to be 3D blocks, they can be 2D sections.

<p><i>Normal</i></p>	<p><i>Reverse</i></p>	<p><i>Thrust</i></p>	
<p><i>Horst</i></p>		<p><i>Graben</i></p>	

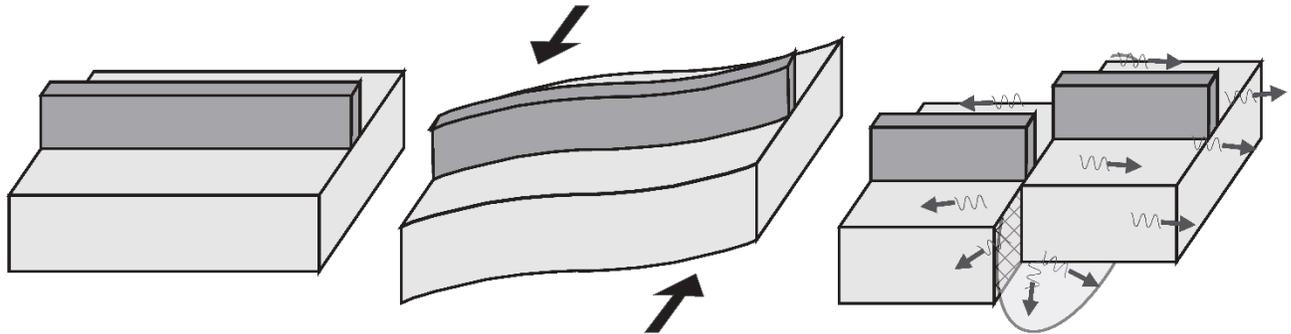
14. With your notes still out of sight, describe how you determine if a *strike-slip fault* is *right-lateral* or *left-lateral*.

Working in groups of 2 or 3

15. Compare your answers to questions 13 and 14. Write (draw) any differences between your answers and your partner's.

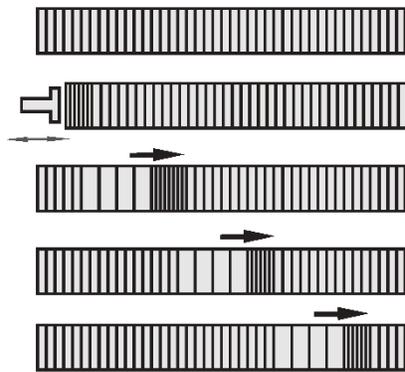
First some review of Earthquake Waves:

Elastic Rebound

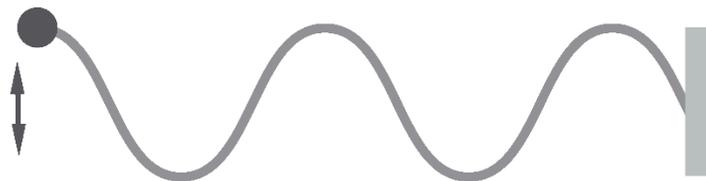


The classic explanation for the source of earthquakes. A section of the crust under some stress will build up strain. A fault rupturing will allow the crust to rebound (elastically), albeit some offset remains. As the crust rebounds, the strain that was built up in the rock is released in the form of wave energy.

Body Waves



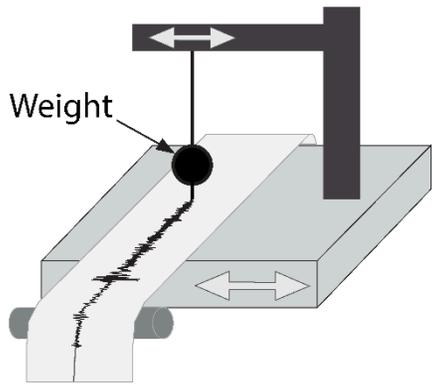
Primary Waves



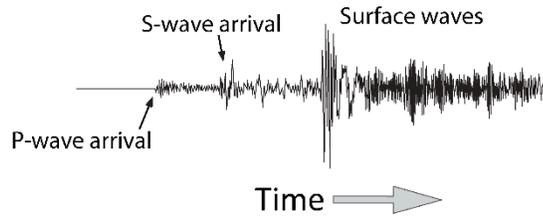
Secondary Waves

The two types of body waves, are named as such because they travel through the body of the Earth. Primary waves are compressional in nature, also referred to as P waves. Secondary waves travel by a shearing motion, not unlike a rope that is tied to a wall and shaken vertically, also referred to as S waves.

Seismogram



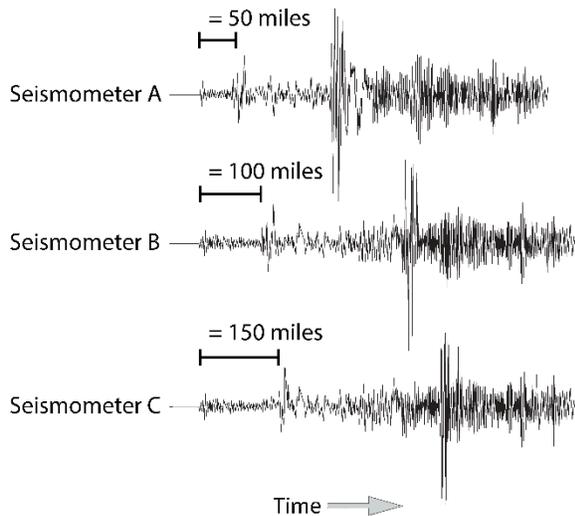
Seismometer/Seismograph



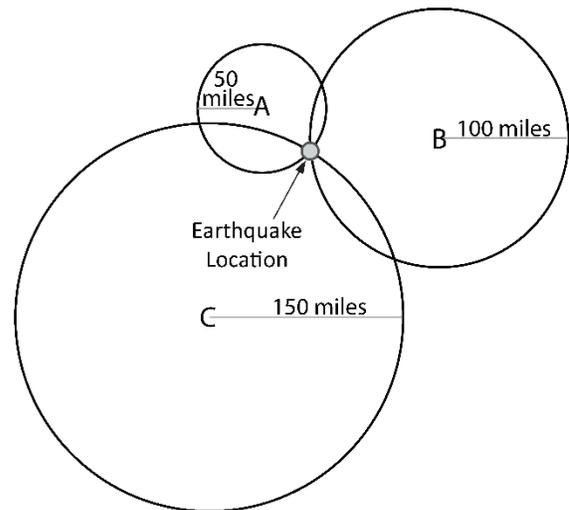
Seismogram

Seismometers are positioned across the Earth's surface. Attached to the Earth, they record the local movement felt by earthquake waves. The seismogram is the record of earthquake waves having influenced the seismometer. The arrival of different wave types can be identified in the record.

Triangulating Earthquake Location



Difference between P- and S-wave arrival



Triangulation on a map

Because the speed of P- and S-waves is known, the difference in their arrival indicates the distance the seismometer is located from the earthquake location. In practice; 100's to 1,000's of seismographs can be used to find a very precise location.

Now, test your knowledge:

Briefly define the following terms:

elastic rebound -

body wave -

p-wave -

s-wave -

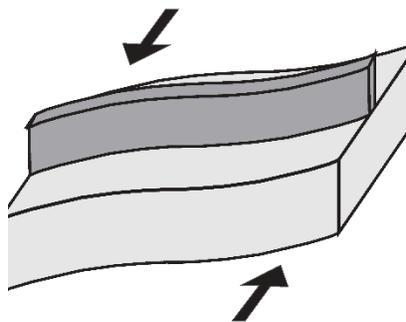
surface wave -

seismometer -

seismograph -

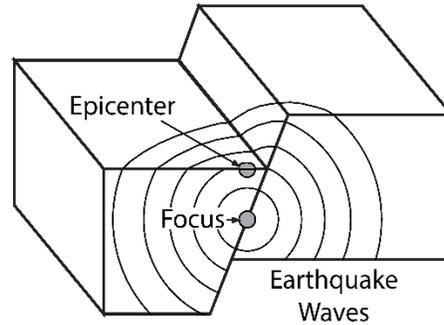
seismogram -

Answer the following:



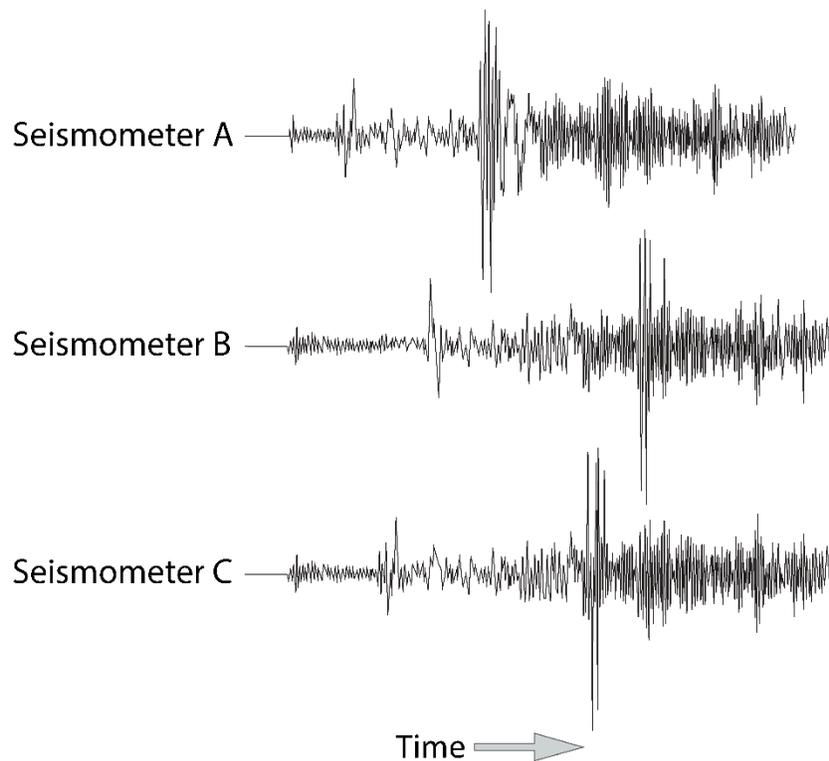
1. True/False. The above image shows a block of crust that is experiencing an earthquake.
 - A. True
 - B. False

2. When the friction on a fault is overcome, the adjacent blocks will rebound to their original shape, albeit offset in locations along the fault. This is due to a release of _____ built up in the blocks.
- Stress
 - Strain
 - Brittle Friction
 - Elastic



3. Earthquake waves travel outward from the fault "focus", the precise point on the fault surface where the earthquake propagates from. These waves will _____.
- Travel outward along the fault only, as far as the fault stretches.
 - Travel outward in all directions along the surface of the Earth.
 - Travel outward in all directions, along the fault, along the surface of the Earth and throughout the body of the Earth.
 - Travel only through the body of the Earth.
4. True/False. The Epicenter is the location on the surface, directly above the focus of an Earthquake.
- True
 - False
5. True/False. Body waves are named because they travel through the body of the earth
- True
 - False
6. Which waves are the first to arrive at a particular location away from the earthquake focus?
- All Body waves
 - P-waves
 - S-waves
 - Surface waves
7. Which waves are the second to arrive at a particular location?
- All Body waves
 - P-waves
 - S-waves
 - Surface waves

8. Which waves travel the fastest?
- A. All Body waves
 - B. P-waves
 - C. S-waves
 - D. Surface waves
9. What is the minimum number of seismometer records (seismograms) you need to find the location of an earthquake?
- A. 1
 - B. 2
 - C. 3
 - D. 4
 - E. 5



10. In the above image, which of the seismometers is the closest to the earthquake location?
- A. Seismometer A
 - B. Seismometer B
 - C. Seismometer C
11. In the above image, which of the seismometers is the furthest away from the earthquake location?
- A. Seismometer A
 - B. Seismometer B

C. Seismometer C

12. You know the answer to question #11 because _____.

- A. The correct answer has the largest difference between arrivals of P-waves and surface waves.
- B. The correct answer has the largest difference between arrivals of P- and S-waves.
- C. The correct answer has the shortest difference between arrivals of P-waves and surface waves.
- D. The correct answer has the shortest difference between arrivals of P- and S-waves.

Now, think deeper:

On your own:

13. Describe what you understood an earthquake to be prior to today (or prior to taking this course).

14. In what ways has your knowledge of earthquakes changed? What information is new?

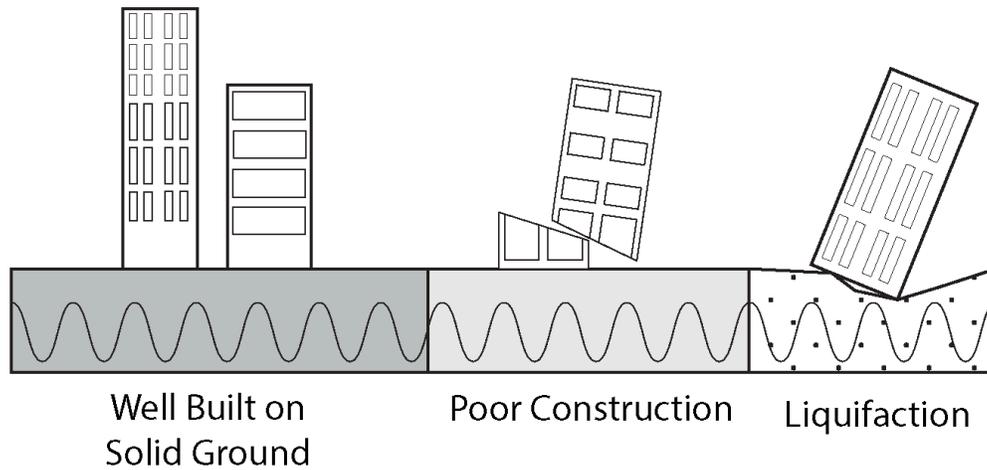
15. What questions do you still have about earthquakes?

Working in groups of 2 or 3:

16. Discuss your answers to questions 13-15. Write down similarities and differences amongst your group partners for each of the questions.

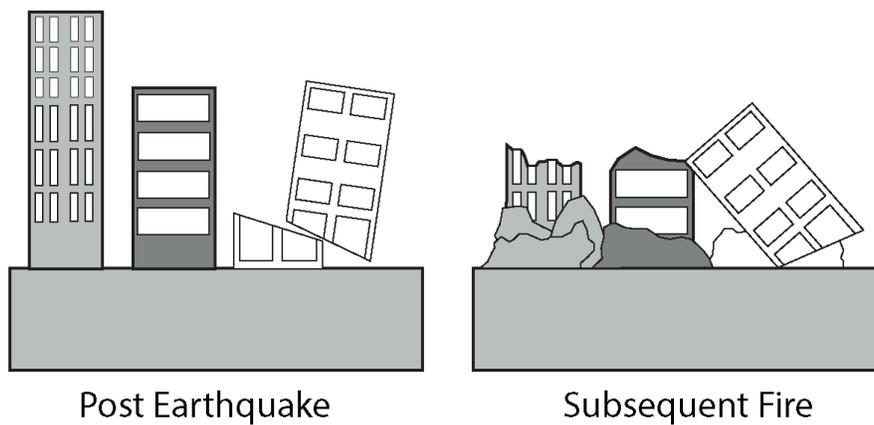
First some review of Earthquake Hazards:

Ground Motion



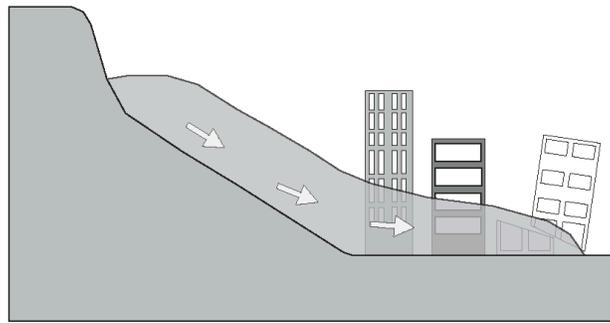
A major hazard associated with earthquakes is the effects that ground motion has on infrastructure. The saying goes: “earthquakes don’t kill people, buildings do”. The above is very schematic, but it brings attention to major considerations, such as if buildings are built on solid ground not susceptible to liquefaction, as well as if they are built to withstand earthquakes through reinforcement, flexible foundations and dampening measures where appropriate.

Fire



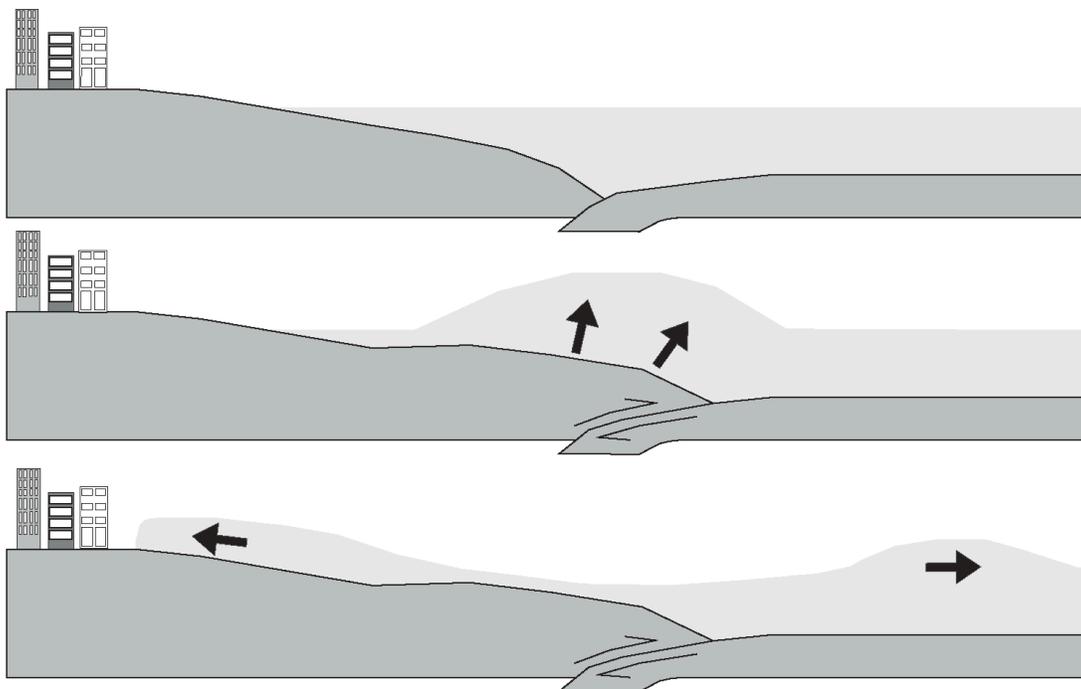
In the aftermath of a major earthquake, the disruption to utilities such as water for putting out fires can lead to major destruction with few ways to battle the flames.

Mass Wasting



In places an earthquake can trigger a mass wasting event, such as the landslide imaged here.

Tsunami



When released during an earthquake on the ocean floor, the energy may generate very large waves out at sea. Upon arriving near shore, the wave can be elevated significantly higher by the underlying topography.

Now, test your knowledge:

Briefly define the following terms:

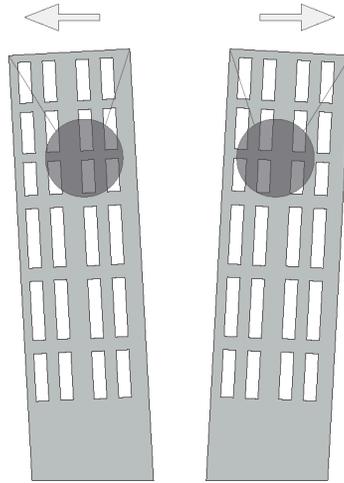
liquefaction -

mass wasting -

tsunami -

Answer the following:

1. What is the primary reason fire can be so destructive in an earthquake?
 - A. Building materials become particularly dry during an earthquake.
 - B. Water utility lines are severed during an earthquake, making fire-fighting efforts all but hopeless.
 - C. Friction between grains in underlying soil will create enough heat to start buildings on fire.
 - D. Lava is allowed to reach the surface along ruptured faults, igniting many buildings on fire.
2. When loose soil becomes inundated with water and can no longer support buildings, this is known as _____.
 - A. a Tsunami
 - B. a Secondary Wave
 - C. Liquefaction
 - D. a Fault
 - E. Hydraulic Fracturing
3. Something to consider in determining the destructive effects of an earthquake would be _____.
 - A. Building materials
 - B. Building construction
 - C. Duration of earthquake waves being felt
 - D. The intensity of the earthquake shaking
 - E. The subsurface that a building is built upon
 - F. All of the above



4. True/False. A well-designed skyscraper might use a large counterbalance (weight) suspended near the top of the building to *dampen* or dissipate the energy as it sways like a pendulum.
 - A. True
 - B. False

5. Which substrate is generally the best for buildings to be built upon in earthquake prone areas.
 - A. Loose soil
 - B. Compacted soil
 - C. Bedrock

6. True/False. We are able to predict earthquakes in a relatively short time frame. News stations in California have seismologists that discuss the earthquake forecast, and they usually come on right after the meteorologist discusses the weather forecast.
 - A. True
 - B. False

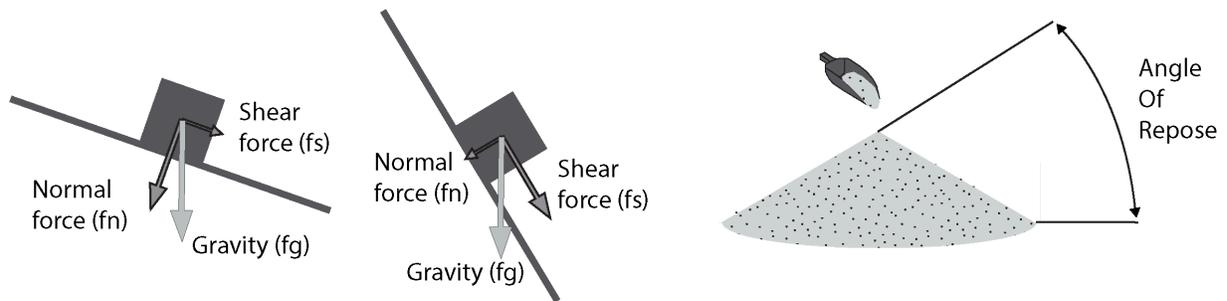
7. True/False. A Tsunami approaches land and breaks in a large curl.
 - A. True
 - B. False

First some review of Mass Wasting Controls:

Mass Wasting

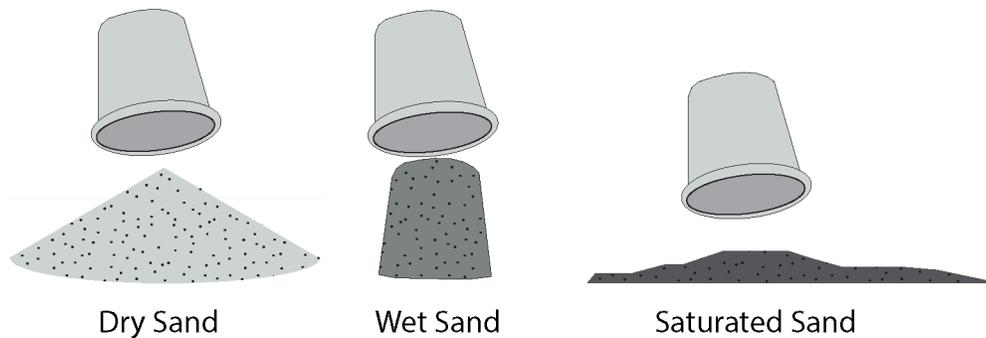
Material moving downslope due to gravity.

Gravity



The gravity force acting upon material on a slope can be broken into two individual components. The normal force is perpendicular (normal) to the slope and works to keep the material in place by friction. The shear force is parallel to the slope and works to move the material downslope. When the slope is increased, eventually the shear force becomes larger than the normal force, and the material moves downslope. The angle of repose is the equilibrium (balance) point for a given material, meaning the angle where the normal force and shear force are the same.

Water



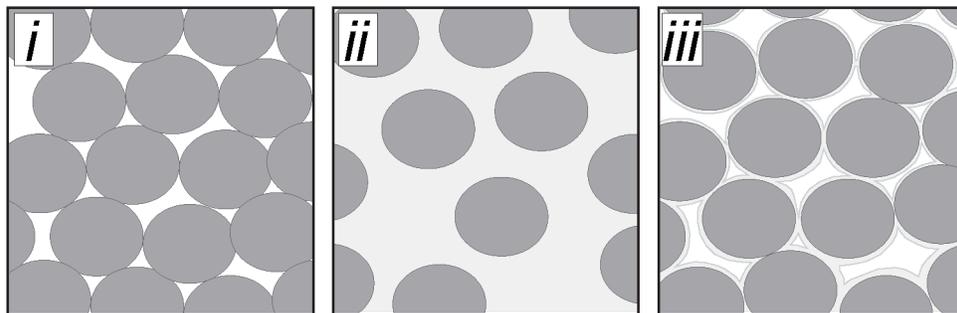
When making sand castles, dry material will form with an angle of repose, supported only by the individual grains. Water can act to hold materials together through surface tension, by creating a thin film on the material grains, locking them together. However, too much water and the material is now supported by that water, not the individual grains, which has the effect of making a material very runny and no longer able to support very much weight.

Triggers

Slopes may become unstable slowly over time. There may also be a more sudden trigger. Two common sudden triggers are earthquakes that may mobilize material physically, or heavy rainfall events that suddenly saturate the slope material.

Now, test your knowledge:

- True/False. Gravity acting on a block of material is always the same, regardless of the angle of the slope.
 - True
 - False
- The gravity force acting on a block of material can be broken into two different components, the _____ and the _____.
 - Downward force, Upward force
 - Shear force, Shear stress
 - Normal force, Shear force
 - Normal strength, Shear strength
- True/False. When $f_s \gg f_n$, material will move downslope.
 - True
 - False
- A pile of loose material will form a natural slope, known as the _____.
 - Angle of incidence
 - Shear stress
 - Shear strength
 - Shear force
 - Angle of repose



- Match the following water concentrations with the above images.
 - Particle supported (Dry): _____
 - Surface tension supported (Wet): _____
 - Water supported (Saturated): _____
- What affect do you suppose the removal of vegetation will have on the stability of material on a slope?
 - Roots act to disrupt the H_2O surface tension holding sand grains together and so removal will stabilize the slope.
 - Roots act to bind soil together, and so removal will destabilize the slope.

Physical Geology Lecture Tutorials
Mass Wasting Controls

7. What do wildfires contribute to the destabilization of slopes?
 - A. Removal of vegetation (by burning).
 - B. Drying out the upper soil (removing water).
 - C. Baked soil becomes impenetrable to rainwater.
 - D. All of the above.

8. True/False. Landslides require an obvious trigger event, such as an earthquake or a large rainfall event.
 - A. True
 - B. False

Now, think deeper:

On your own:

9. Describe what you understood about *mass wasting* prior to today (or prior to taking this course).

10. In what ways has your knowledge of *mass wasting* changed? What information is new?

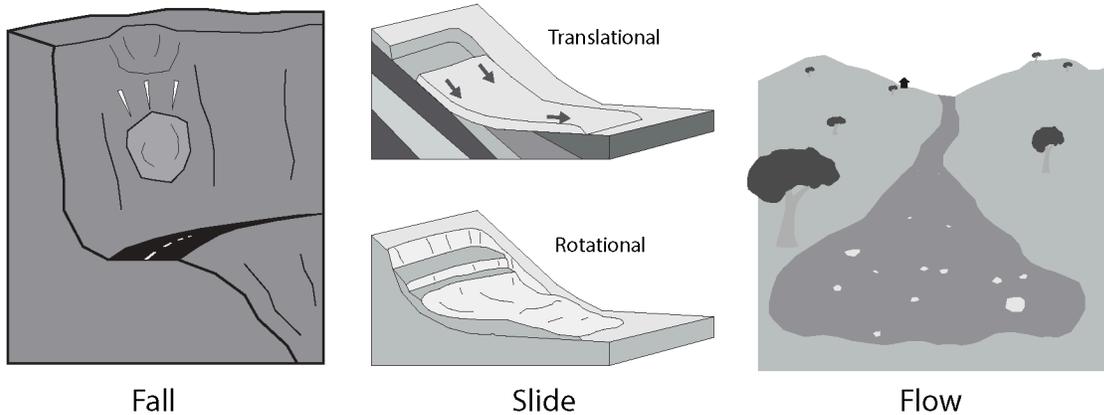
11. What questions do you still have about *mass wasting*?

Working in groups of 2 or 3:

12. Discuss your answers to questions 9-11. Write down similarities and differences amongst your group partners for each of the questions.

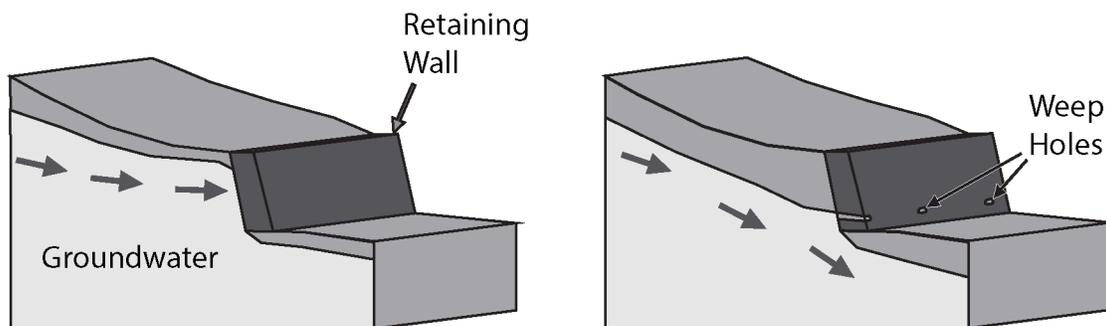
First some review of Mass Wasting Prevention:

Classification



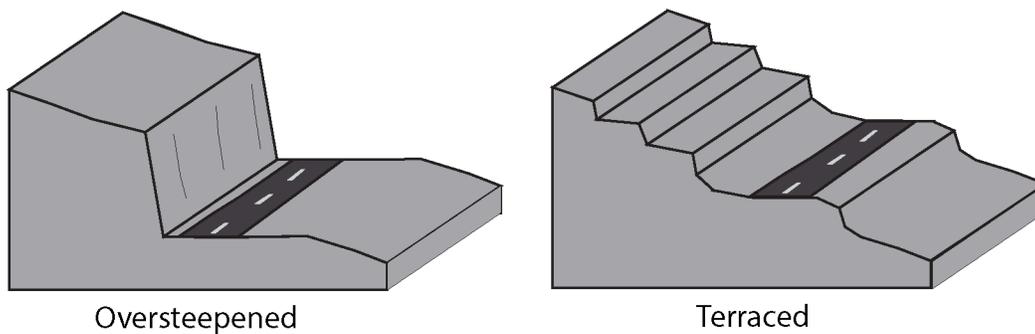
Classification schemes vary, but they are commonly based on: 1. Rate of Movement, 2. Material that is moving (Rock, or Unconsolidated Material), and 3. Type of Movement (as above).

Water Drainage



A retaining wall built with weep holes will mitigate the groundwater behind the wall putting significant hydraulic pressure onto the wall.

Minimize Over Steepening



For solid rock and unconsolidated material conditions, the over steepening (naturally or through engineering) can cause mass wasting. Construction of terraces may help to mitigate this hazard.

Now, test your knowledge:

Briefly define the following terms:

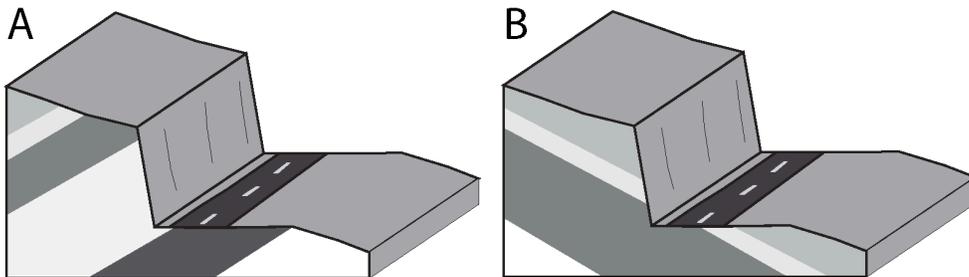
fall -

slide -

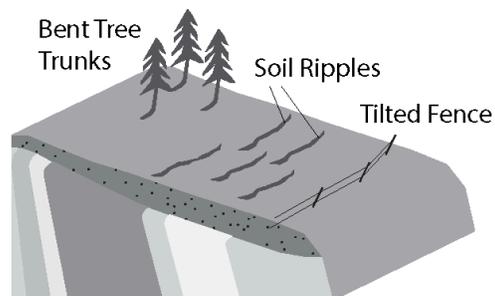
flow -

Answer the following:

1. This type of mass wasting involves large boulders breaking free from a cliff and falling freely.
 - A. Mudflow
 - B. Translational slide
 - C. Rock fall
 - D. Talus pile
 - E. Earthflow



2. In the above image, a section of roadway has been cut into the hillside. Which scenario is more likely to have a catastrophic slope failure, due to the underlying geology?
 - A. A
 - B. B



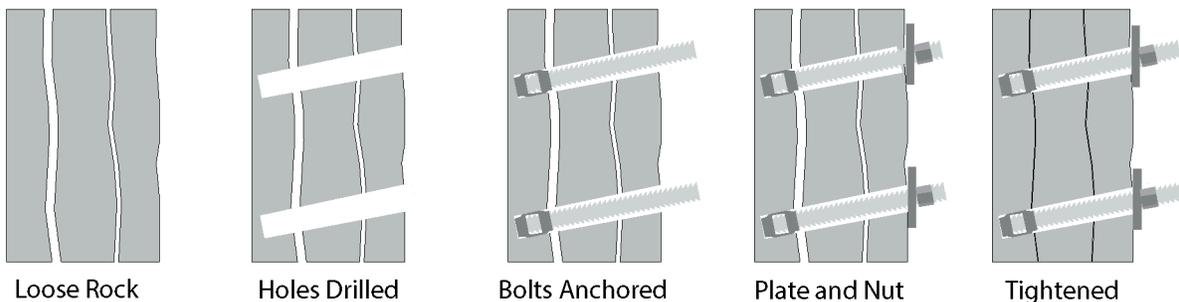
3. The features in the previous image are indicative of what common type of mass wasting?
 - A. Earthflow
 - B. Mudflow
 - C. Rock fall
 - D. Soil creep
 - E. Tilted slide

4. In the above image, one prominent indicator depicted has not been annotated (highlighted), can you determine which it is?
 - A. Bent retaining wall
 - B. Bedrock bent downslope
 - C. Tilted gravestones
 - D. Freeze-thaw
 - E. Wetting and drying

5. True/False. Mountainous areas with steep cliffs are an important area to consider soil creep.
 - A. True
 - B. False

6. The difference between a mudflow and a debris flow is that _____.
 - A. A mudflow commonly has coarse sized sediment entrained in the flow.
 - B. A mudflow will start in an area that has thick vegetative cover.
 - C. A mudflow is made up of primarily fine sized sediment.

7. Over steepening of slopes is not always a human induced situation. What natural ways might a slope become over steepened?
 - A. Wave erosion undercuts a coastal cliff.
 - B. River meander undercuts boundaries of a flood plain.
 - C. Dynamite blasting is done to deepen an open pit mine.
 - D. Daily shifts in the moon's gravitational pull.
 - E. All of the above.
 - F. Both A and C.
 - G. Both A and B.



8. Besides on a road cut, where might you also see the use of rock bolts to stabilize recently excavated bedrock?
 - A. Subway tunnel
 - B. Underground mine
 - C. Roadway tunnel
 - D. All of the above

9. What might be an important consideration for installing rock bolts?
 - A. The distance between the loose slope area and the roadway.
 - B. Where to cut the roadway.
 - C. Bolt spacing required to be certain slope is strengthened beyond failure.

First some review of The Water Cycle:

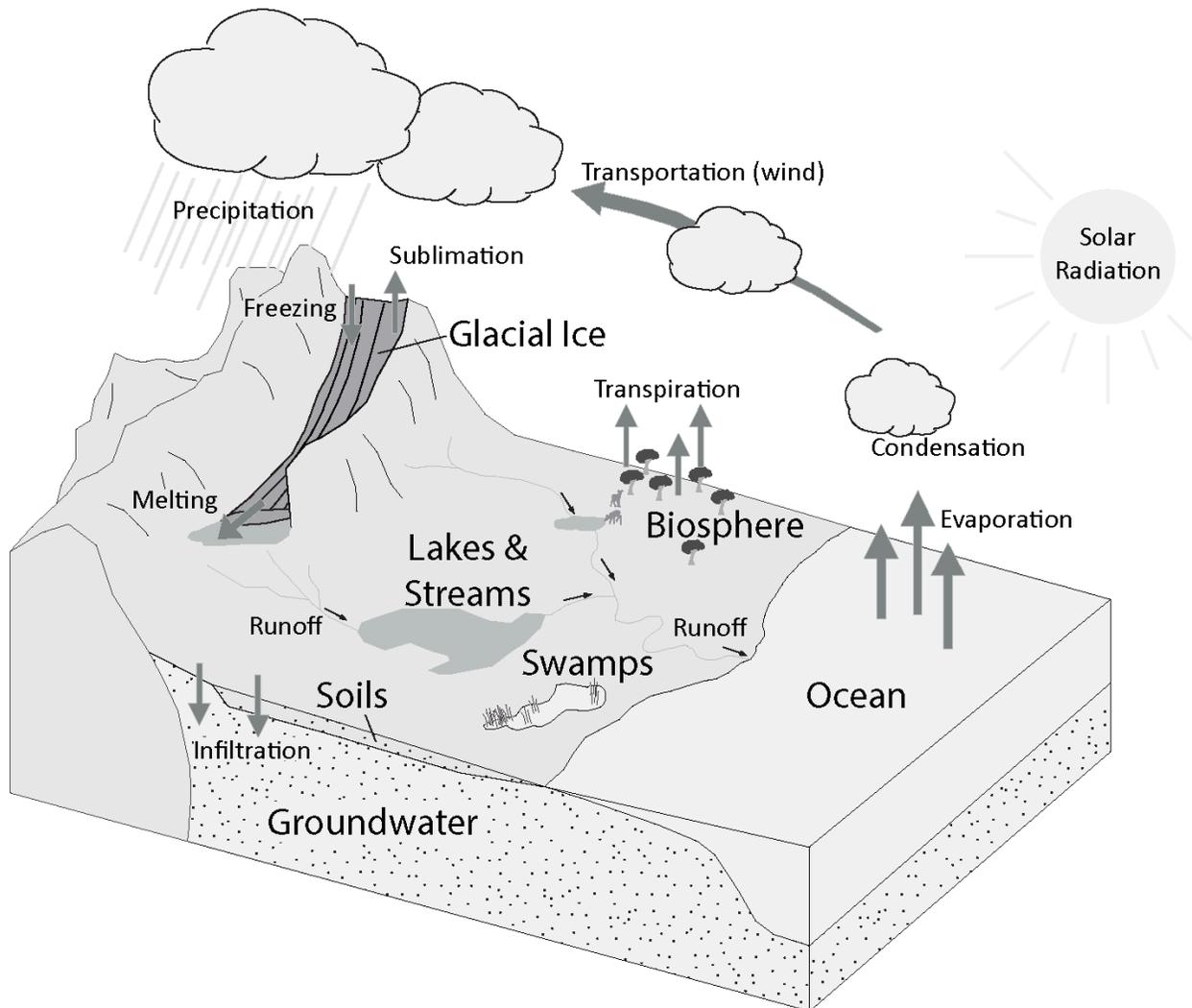
Water Reservoirs

The overwhelming majority of water on Earth is contained in the **oceans**.

Only a tiny fraction of water on Earth is **freshwater**, which is mostly made up of **glacial ice**, and **groundwater**.

The remaining freshwater is found in (in order of decreasing abundance): **permafrost, lakes, soils, the atmosphere, swamps, rivers, and living things**.

The Water Cycle



Water is constantly being cycled through the reservoirs via the primary processes of: **evaporation, condensation, precipitation, and run-off**. Although relatively less abundant, still notably important fluxes between reservoirs also includes: **freezing, thawing, sublimation, transpiration, and infiltration**.

The primary drivers of the hydrologic cycle are incoming **solar radiation** and **gravity**.

Now, test your knowledge:

Briefly define the following terms:

run-off -

sublimation -

infiltration -

(evapo)transpiration -

permafrost -

Answer the following:

27. An important driver (energy source) of the water cycle is _____.

- A. Melting
- B. The Sun
- C. The Outer Core
- D. Gravity
- E. Both B and D

28. Perhaps the sun's most important role is in driving this process:

- F. Freezing
- G. Melting
- H. Evaporation
- I. Precipitation
- J. Run-off

29. True/False. Surface water in oceans, lakes, streams, and swamps does not need to reach a boiling temperature (100 C) in order to evaporate. Instead, the temperature required need only allow the liquid water to overcome the ambient vapor pressure in the surrounding atmosphere.

- a. True
- b. False

30. True/False. Condensation into clouds requires dust particles in the air for water droplets to condense onto.

- a. True
- b. False

Physical Geology Lecture Tutorials
Water Cycle

31. Frozen ice (glaciers) is the most abundant reservoir of fresh water on the planet. What is the second most abundant reservoir?
- Rivers
 - Living Things
 - Soils
 - Groundwater
 - Permafrost
32. When plants release water into the atmosphere, this is known as _____.
- Melting
 - Evaporation
 - Sublimation
 - Transpiration
 - Infiltration
33. If extremely dry conditions allow water to move directly from a solid (ice) to a gas (water vapor), this is known as _____.
- Melting
 - Evaporation
 - Sublimation
 - Transpiration
 - Infiltration
34. Groundwater is a very important freshwater resource. Water is added to groundwater via _____.
- Melting
 - Evaporation
 - Sublimation
 - Transpiration
 - Infiltration

Now, think deeper:

On your own:

35. -Make sure you're unable to view any depictions of the water cycle (put away your notes).
-Write down a list of the major water reservoirs (places where water is found) and what state (i.e. solid, liquid, gas) the water is in in each.

-Write down a list of the major processes that move water, along with any respective phase changes (e.g. melting) that occur during that process.

-Take out a blank piece of paper and draw a diagram of the water cycle to the best of your ability. You can draw depictions of actual landforms, or a simple diagram with boxes and connecting lines.

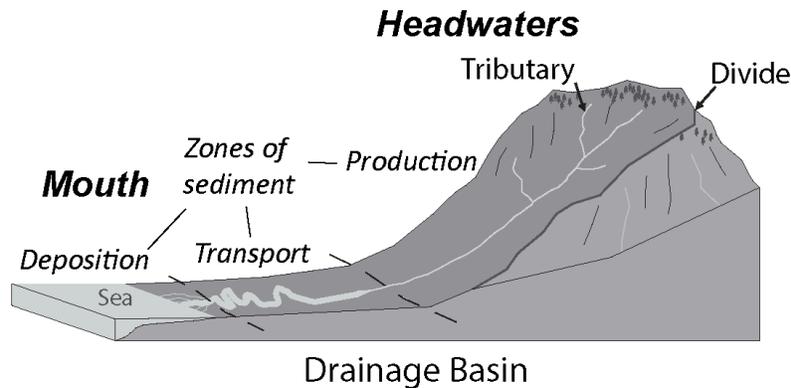
Working in groups of 2 or 3:

36. Do not look at any notes yet, compare your drawing with 1 or more classmates. Write down the major differences here.

37. Now, compare your water cycle diagrams with the review section above. Write down the major differences here.

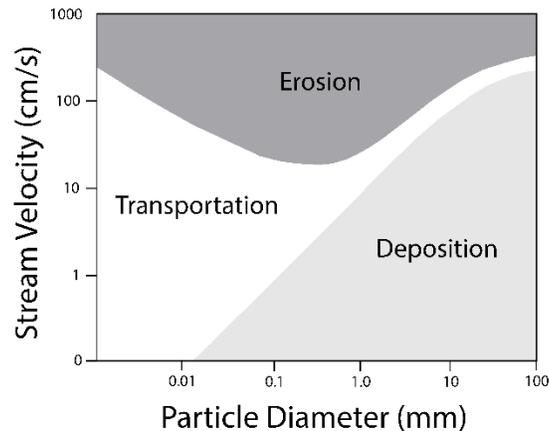
First some review of Streams:

Drainage Basin Stream Profile



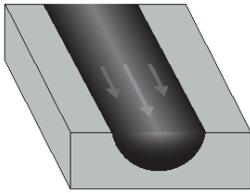
A **drainage basin** is an area that any drop of water falling in it, that water will eventually flow downhill and drain out of that area. Basins are divided by an imaginary line known as a **divide**. Notice the overall profile of the stream, starting very steeply in the Headwaters region, and flattening out in the lower half, with an overall concave pattern.

Erosion, Transport, Deposition

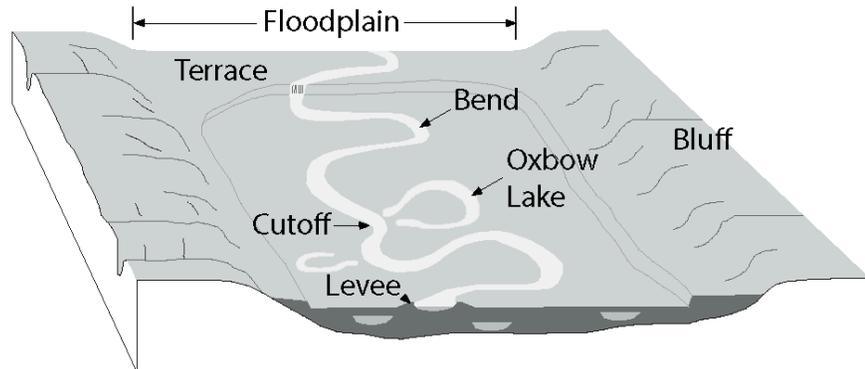


Stream velocity is equivalent to energy. It takes a large amount of energy to erode (break loose) a large particle, and similarly for very small particles as well. Once eroded and in suspension (transport), a lowering of stream velocity (energy) will cause large particles to deposit (stop moving), whereas a small particle will carry on in transport almost indefinitely.

Stream valleys



Velocity Gradients



Within a stream channel, the water in contact with the sides and bottom is slowed due to friction. When flowing around a corner, higher velocity water on the outside will erode the outer bank or **cut bank**, whereas material is deposited in the inner bank or **point bar**. In time, a stream will meander back and forth within the floodplain, expanding the floodplain at times by eroding outward, and leaving behind oxbow lakes when shortcutting itself (cutoff). Major down-cutting events may form a stream terrace.

During a flood, there is a large velocity gradient between water flowing within the channel and the floodplain. This causes sediment to deposit immediately adjacent to the channel, forming a natural levee.

Now, test your knowledge:

Briefly define the following terms:

drainage basin -

divide -

drainage pattern -

erosion -

transportation -

deposition -

braided stream -

meandering stream -

ox-bow lake -

floodplain -

natural levee -

stream terrace -

incised meander -

delta -

Answer the following:

1. True/False. Within a given drainage base, the steepest gradients (slopes) are commonly found near the mouth of the stream.
 - a. True
 - b. False

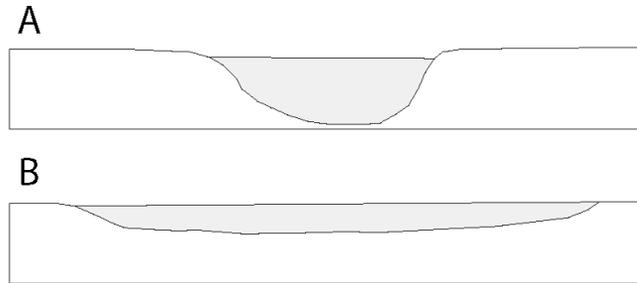
2. True/False. In general, sediment is produced in the upward, steeper portions of a stream profile, it is transported along the middle portions and deposited near the seaway or washed out to sea.
 - a. True
 - b. False

3. True/False. A drainage basin is separated from an adjacent drainage basin by a line called a _____.
 - a. divide
 - b. break
 - c. tributary
 - d. bluff
 - e. terrace

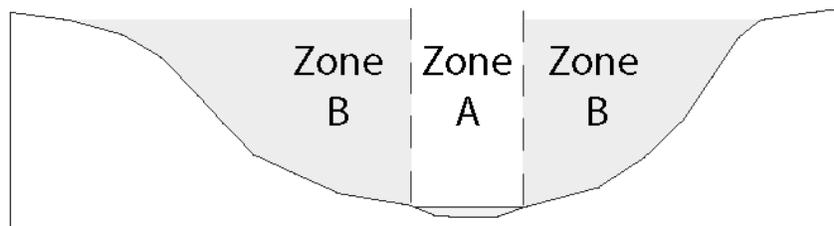
4. Increasing the overall profile length of a given stream can be done by *headward erosion*, or _____.
 - a. building the delta further out to sea.
 - b. uphill growth.
 - c. capturing another already established stream channel.
 - d. lateral erosion.

5. Widening the floodplain of a given stream is known as _____.
 - a. building the delta further out to sea.
 - b. uphill growth.
 - c. capturing another already established stream channel.
 - d. lateral erosion.

6. Within a river channel section profile, the greatest velocity water is _____.
 - a. at the bottom of the channel.
 - b. on the sides of the channel
 - c. at the top of the channel.
 - d. the water furthest from the sides and the bottom.



7. Recall that a major factor in a stream's velocity is the friction with the bed (bottom) and banks (sides). Knowing this, which of the above stream profiles do you think contains the greatest stream velocity.
- A
 - B
8. The amount and type (size) of sediment carried by a stream is dominantly controlled by _____.
a. the stream sediment source.
b. stream velocity.
c. stream profile height.
d. stream erosivity.
9. True/False. A *natural levee* is created to keep flood water from overflowing the river banks and causing damage to homes built within a floodplain.
a. True
b. False



10. In the above image, a stream profile indicates two primary zones where material has been removed by erosion. Zone A would have been removed by _____.
a. wind erosion
b. mass wasting.
c. downcutting
d. meandering stream cut bank erosion.
11. Again, referring to the previous image, zone B would have been removed by _____.
a. wind erosion
b. mass wasting.
c. downcutting
d. meandering stream cut bank erosion.

Now, think deeper:

On your own:

12. Using what you've learned. Describe the characteristics of the streams in the area where you live.

13. Question 2 suggested sediment from streams is eventually washed out into the greater waterbody where the stream ends. Where do you think this sediment is eventually deposited?

Working in groups of 2 or 3:

14. Discuss your answers to question 12 and 13. Write down answers that were unique to your own.

First some review of Floods:

Types of floods

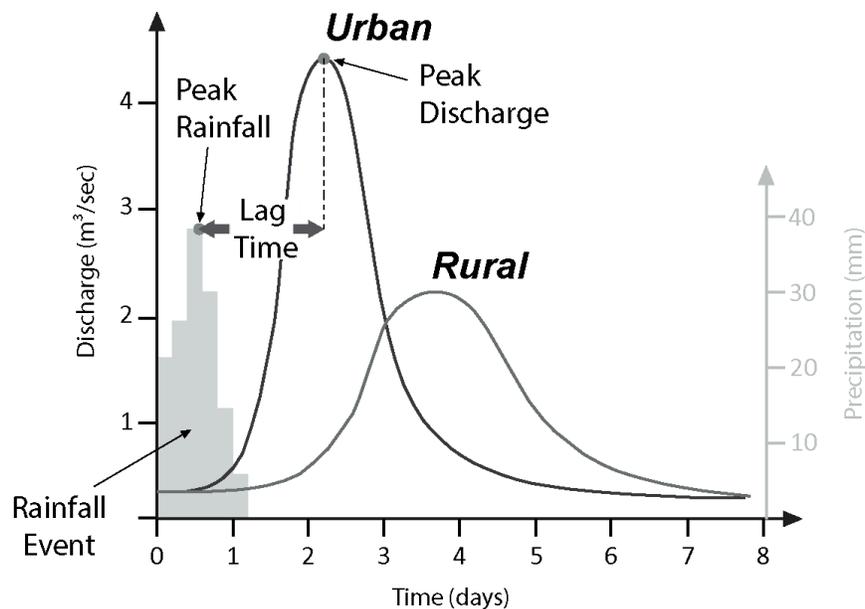
Regional Floods – seasonal flooding from extensive snow melt, or possibly from series of intense rain events.

Flash Floods – intense rain events in areas where runoff is concentrated quickly, such as a mountain canyon or an urban setting.

Debris-jam – natural dams may form from accumulated debris, such as ice or tree debris, causing water to quickly build behind the dam.

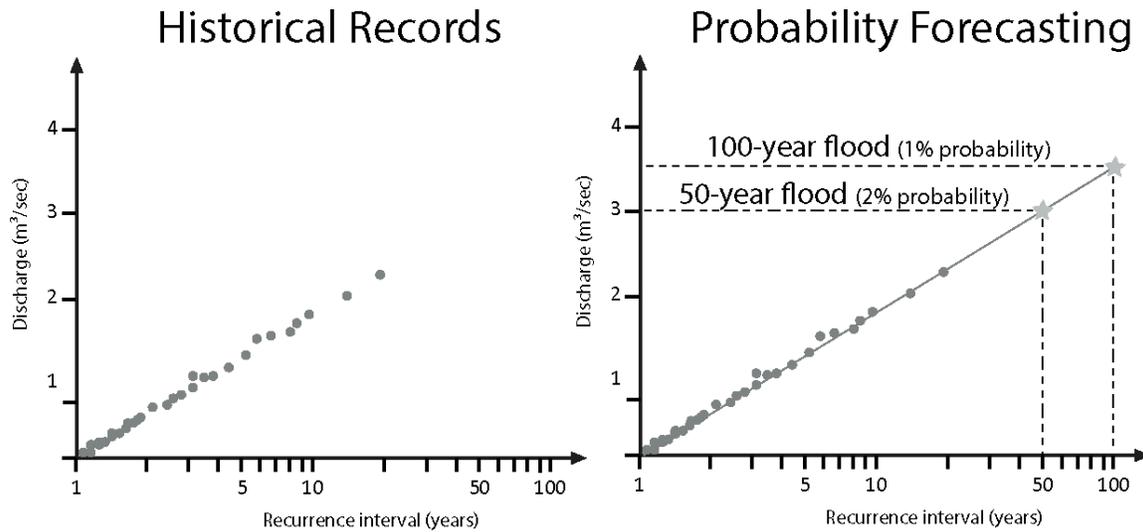
Dam-failure – the failure of natural or built water containments (dams and levees) can lead to flash flood events.

Hydrograph



A hydrograph is used to plot the flow of a river (discharge) at a specific location in a river through time. In the hydrograph we can see that after a significant rainfall event, it takes some time for water throughout a drainage basin to flow into the river and increase discharge. The delay in time it takes to reach maximum (peak) discharge is known as lag time. Notice, the lag time is significantly shorter in urban environments where concrete infrastructure has limited infiltration into groundwater and increased runoff directly into the river.

Recurrence Interval



The occurrence of floods of a given magnitude is random. However, we can use the frequency of floods (of varying magnitudes) in the past to predict their probability of happening in the future by using their *recurrence interval*. For a given river, the recurrence interval is derived mathematically:

$$T = (n+1)/m$$

where T is *recurrence interval*, n is the *number of years on record*, and m is the *magnitude ranking* of a given flood event.

By extrapolating the historical records, we can predict the size of potential larger floods that may not be in the historical record. Discharge m^3/sec

Prevention

Flood control structures (levees and dams) may work to contain minor flood events, but can be overcome in large magnitude floods. Also, historically dams were built with the goal of controlling large flood events. More recently it has become evident that the environmental damage caused by dams may outweigh the benefits. Many argue that more sound land management within a floodplain is required.

Now, test your knowledge:

Briefly define the following terms:

discharge -

hydrograph -

flooding -

flood stage -

100-year flood -

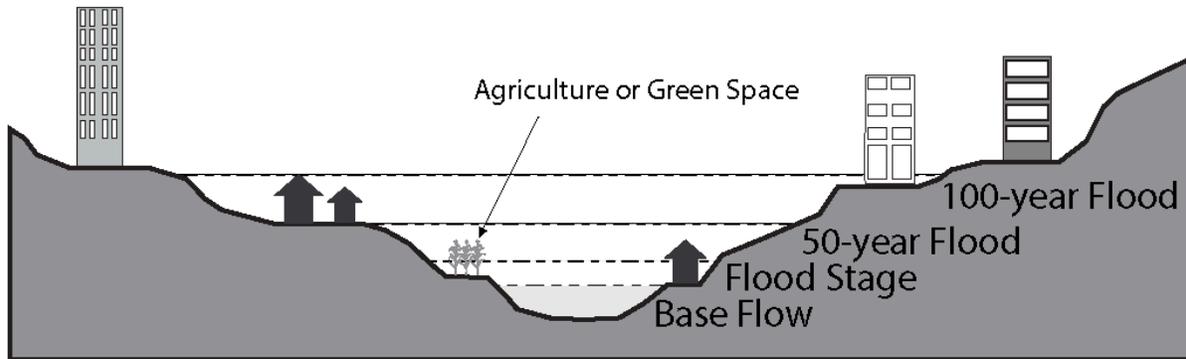
flash flood -

regional flood -

Answer the following:

1. A single large rainstorm event is more likely to cause which of the following flood types?
 - a. Regional Flood
 - b. Flash Flood
 - c. Debris-jam Flood
 - d. Dam Failure Flood

2. In the spring, when the snow melts and many of the regional rivers are at or near *flood stage*, it is known as a _____.
 - a. Regional Flood
 - b. Flash Flood
 - c. Debris-jam Flood
 - d. Dam Failure Flood



3. In the above image, the river level known as *flood stage*, is designated as such because _____.
 - a. Any level above base flow is considered to be flood stage.
 - b. At that level, personal property is potentially at risk.
 - c. Technically any water in a river is considered to be a flooding of that river.
 - d. It is above base flow but below the 50-year flood.

4. In the above image, what might be a good project to develop in the area highlighted as "Agriculture or Green Space"?
 - a. Housing development
 - b. Golf Course
 - c. Apartment Complex
 - d. Retirement Community

5. True/False. Preparing for a 100-year flood is as simple as looking up your local rivers most recent 100-year flood and counting ahead the remaining years.
 - a. True
 - b. False

6. A 100-year flood has the following probability of happening in a given year.
 - a. 100%
 - b. 50%
 - c. 10%
 - d. 1%

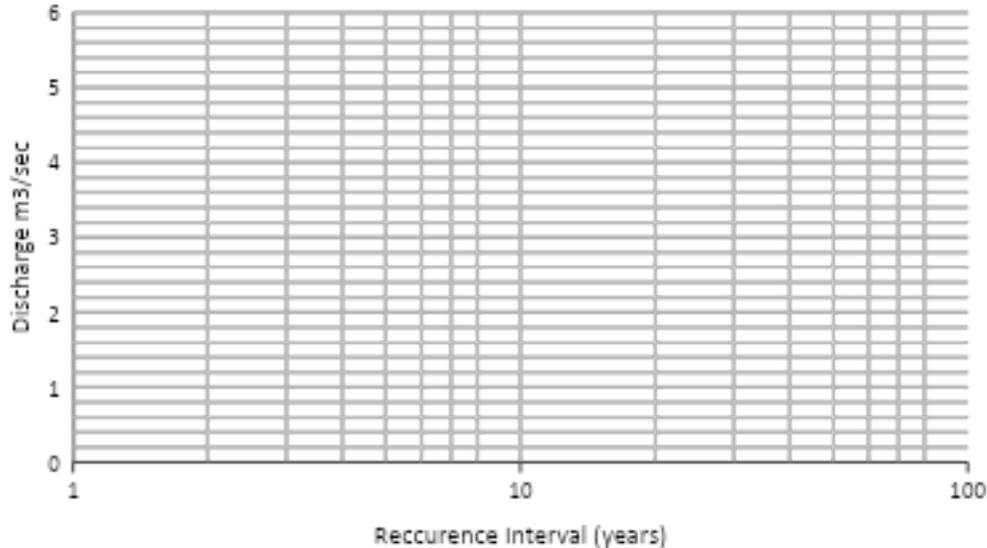
7. True/False. Only rivers that are un-dammed are subject to flooding events.
 - a. True
 - b. False

Now, think deeper:

On your own:

8. Determine the forecasted 50 and 100 year flood discharge levels for a hypothetical stream. Flood discharge records have been kept intermittently for this stream for 10 years.
 - a. Fill in the remaining cells in the table. You will need to use the equation from the review section to calculate T. ($T = (n+1)/m$)
 - b. Plot the data on the graph.
 - c. Using a straight edge, draw a best fit line through the data, extending all the way to the end of the graph.
 - d. Read the approximate discharge levels for the 50 and 100 year flood and report them below the plot.

record #	Discharge (m ³ /sec)	m	n	T
1	1	5.5	10	
3	2.3	1.83	10	
4	0.3	10	10	
6	1.9	2.75	10	
7	2.1	2.2	10	
10	1.5	3.66	10	

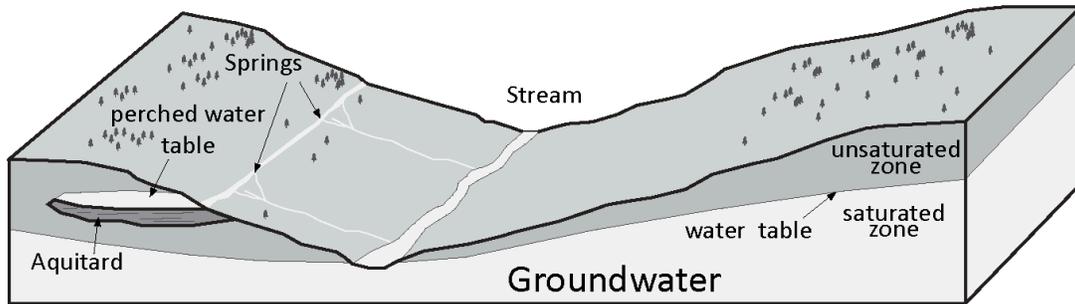


50 year flood discharge: _____ 100 year flood discharge: _____

Working in groups of 2 or 3:

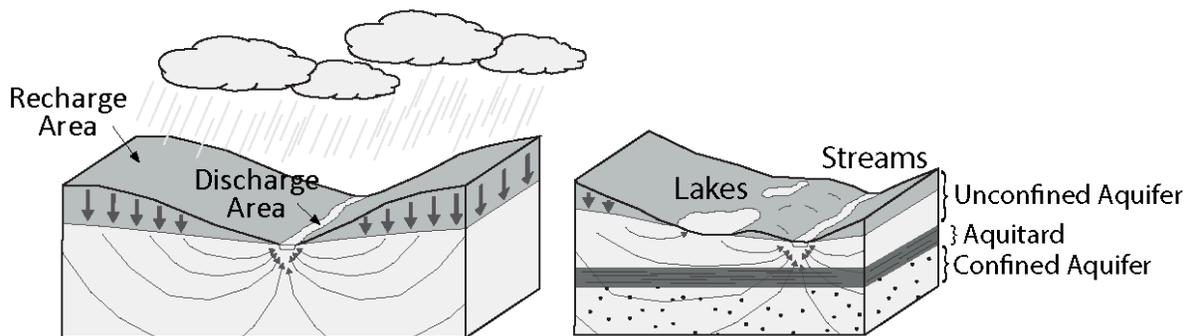
9. Compare your results to question 8.

First some review of Groundwater Storage and Movement: Water Table



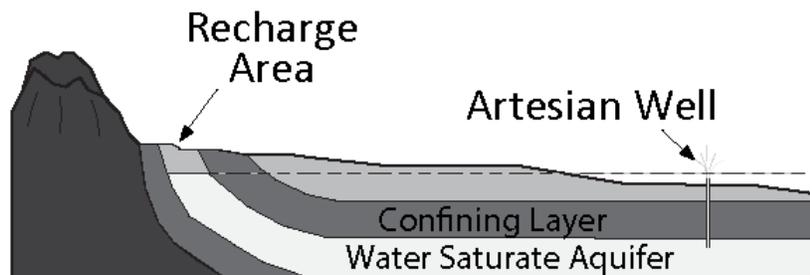
Water in the ground exists in the pore spaces of sediment and rock. In the saturated zone, all pore space is filled with water. This area is separated from the unsaturated zone by a boundary known as the water table.

Groundwater Movement



The water table fluctuates up and down during times of increased recharge relative to discharge to local lakes and streams, and vice versa. Relatively permeable rock capped by relatively impermeable layer (aquitard) is known as a confined aquifer. An aquifer that is in direct communication with the water table is known as an unconfined aquifer. The groundwater can take 100's to 1,000's of years to circulate into and out of a confined aquifer.

Artesian Wells



Water in a confined aquifer is under pressure, and will rise to seek it's own level. The artesian well will flow unless capped.

Now, test your knowledge:

Briefly define the following terms:

water table -

porosity -

permeability -

aquifer -

aquitard -

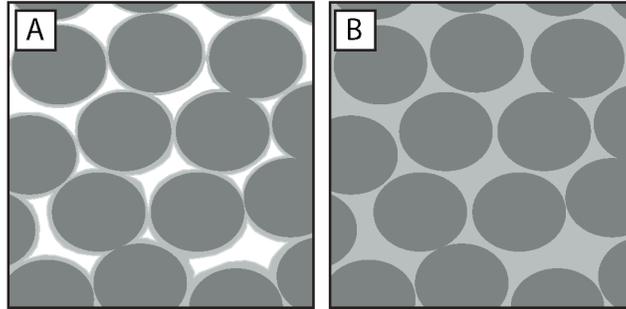
artesian well -

gaining stream -

losing stream -

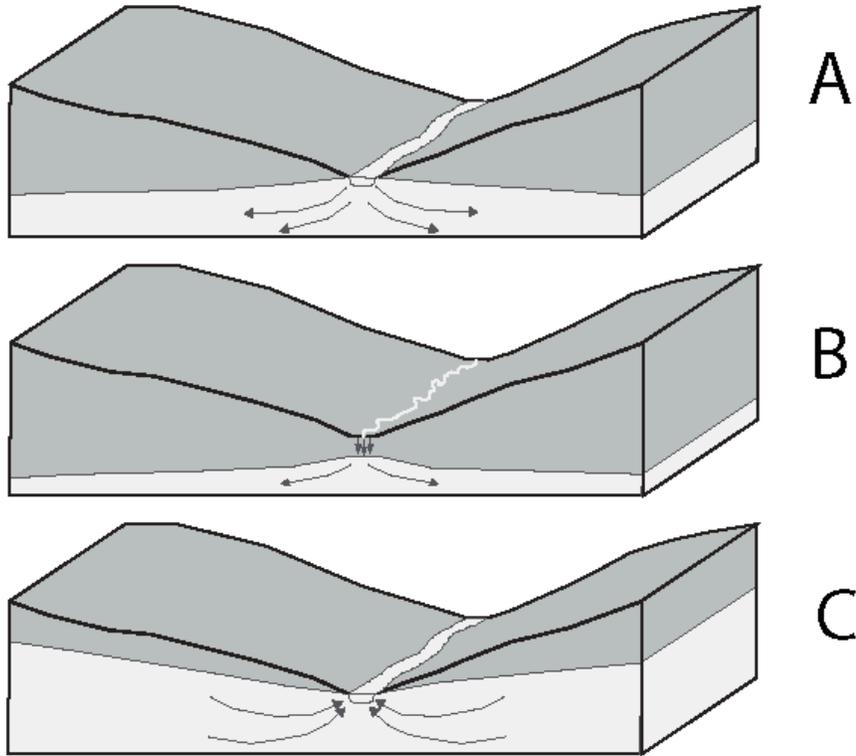
Answer the following:

1. Water beneath the ground surface, that fills the pore spaces between sediment and bedrock grains, is known as _____.
 - a. Surface Water
 - b. Soil Water
 - c. Groundwater
 - d. Geowater



2. In the above image, which scenario represents the water and sediment relationship in an *unsaturated zone*.
 - a. A
 - b. B
3. In the above image, which scenario represents the water and sediment relationship in a *saturated zone*.
 - a. A
 - b. B
4. The boundary between the unsaturated zone and the saturated zone is known as the _____.
 - a. groundwater level
 - b. saturated zone cap
 - c. capillary fringe
 - d. water Table
5. A relatively permeable rock unit that acts as storage for groundwater is known as a(n) _____.
 - a. aquifer
 - b. aquitard
 - c. aguiclude
 - d. aquiesce
6. A body of groundwater that is separated and above the main groundwater by a unique confining layer is known as a _____.
 - a. Elevated Water Zone
 - b. Elevated Water Table
 - c. Perched Water Table
7. True or False. Water can spend 1,000's of years confined within an aquifer.
 - a. True
 - b. False
8. The primary driving force of groundwater movement is _____.
 - a. rain pressure.
 - b. pressure caused by elevation change related to the slope of the water table.
 - c. capillary action on the aquifer rock mineral grains.

- d. confinement of the aquifer.
9. Groundwater flows from an area of recharge towards _____.
- the deepest part of the aquifer.
 - the deepest part of the ground that is permeable.
 - an area of discharge.
 - the unsaturated zone.

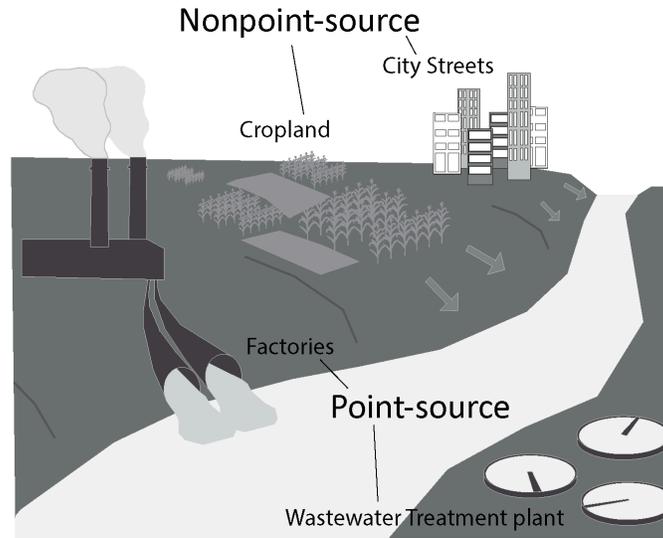


10. In the above image, three relationships between a stream and the groundwater are depicted. Which relationship represents a *gaining stream*.
- A
 - B
 - C

First some review of Groundwater Contamination:

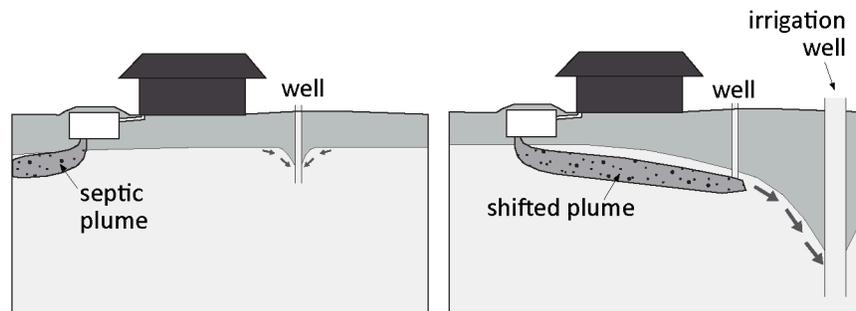
Contaminates

Groundwater is typically relatively pure, and as it is an important drinking water resource, it is important to maintain that purity. However, contaminants may infiltrate the groundwater and this can be extremely costly or next to impossible to clean up in certain situations. A number of substances can infiltrate groundwater locally, including: pesticides and herbicides, sulfuric acid (acid mine drainage), heavy metals, radioactive waste, landfill pollutants, bacteria and viruses, gasoline.



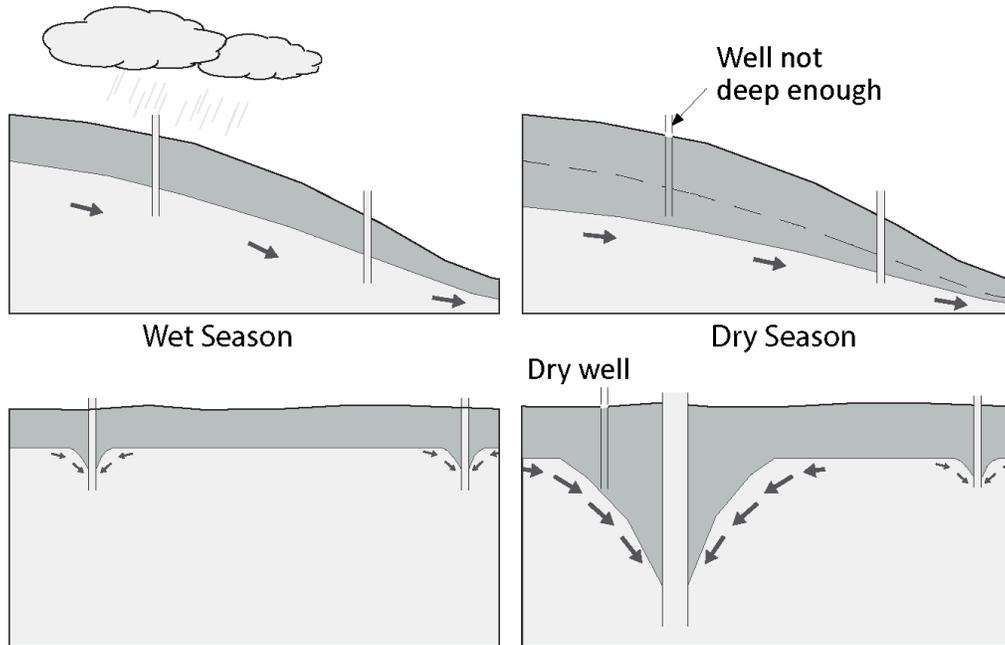
Contamination occurs as point-source or nonpoint-source pollution. Examples of surface contamination are above. Groundwater contaminate point sources include landfills, leaking gasoline and septic tanks, and accidental spills. Groundwater contaminate nonpoint sources are similar to surface water including city street runoff that infiltrates into groundwater.

Contaminate Plume



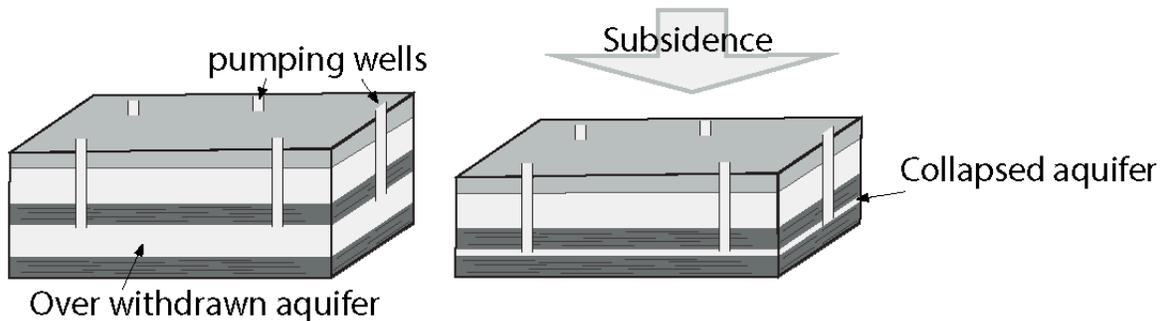
A plume of contamination will travel in the direction of groundwater flow. If the slope of the water table is altered, it can shift the direction of groundwater flow with disastrous consequences.

Wells



We access groundwater through wells. Wells need to be installed carefully to avoid becoming dry during drought periods, and also to avoid overwhelming an aquifer locally, with a drawdown (cone of depression) that overcomes nearby wells.

Withdrawal and Recharge



If water is pulled from an aquifer at a rate greater than its ability to recharge naturally, then it will eventually become depleted. When an aquifer is depleted it may collapse without the water support, and the overlying ground surface will subside.

Now, test your knowledge:

Briefly define the following terms:

contaminate -

plume -

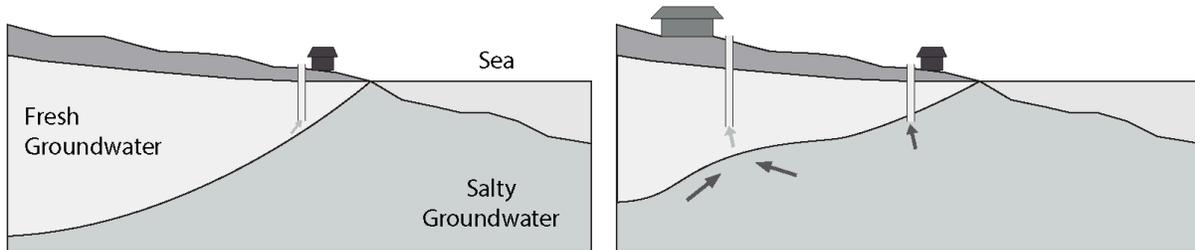
withdrawal -

recharge -

Answer the following:

1. True/False. Water can be 'purified' of contaminants by travelling through an aquifer made of sand or permeable sandstone.
 - a. True
 - b. False
2. Contaminants are termed *hazardous* if they are:
 - a. Flammable
 - b. Corrosive
 - c. Explosive
 - d. Toxic
 - e. All of the above
3. True/False. Often, a volume of contaminated groundwater would be so expensive to clean, that it is simply abandoned as a water source for many years to allow it to clean naturally.
 - a. True
 - b. False
4. True/False. A contaminate plume will travel throughout an aquifer, mixing with groundwater in all directions from the source.
 - a. True
 - b. False
5. True/False. Luckily, subsidence caused by over-pumping of water from an aquifer is easily reversed by hydraulic fracturing the aquifer back into its original shape.
 - a. True
 - b. False

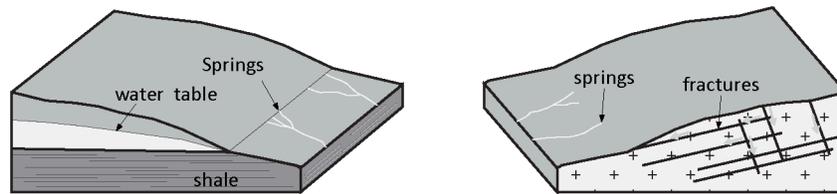
6. Currently, radioactive waste is being stored _____.
- In a permanent national facility called Yucca Mountain in Nevada, selected because the site does not contact the local groundwater, and there is very little rain.
 - In oil barrels marked with radioactive waste symbols, dumped at the bottom of lakes located in proximity to nuclear power plants.
 - Above ground, at individual nuclear power facilities, avoiding contact with the groundwater.



7. In the above image, the boundary between salty groundwater and fresh groundwater is curved, with salty groundwater underneath the fresh water. This is because _____.
- Salty Groundwater is older, emplaced first, and according to the principle of superposition, the older units are on the bottom.
 - This is not a realistic scenario.
 - Salty groundwater is denser relative to fresh groundwater, therefore it rests on the bottom.

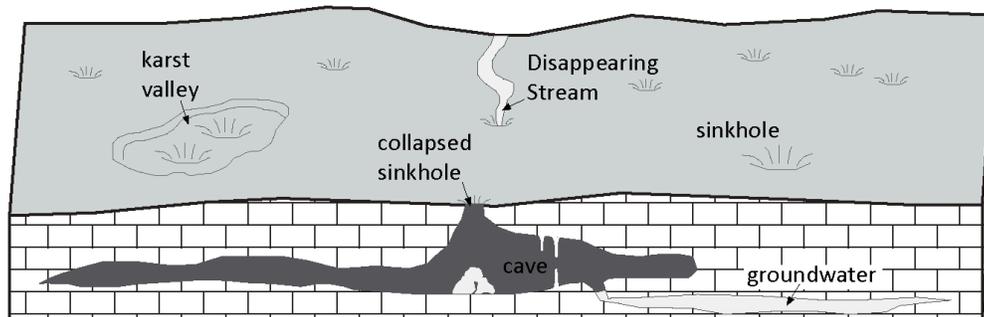
First some review of Groundwater Geology:

Springs



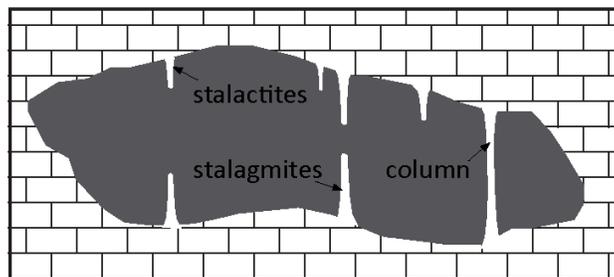
A perched water table, or other saturated permeable zone, that intersects the surface will naturally outflow, producing a spring.

Karst



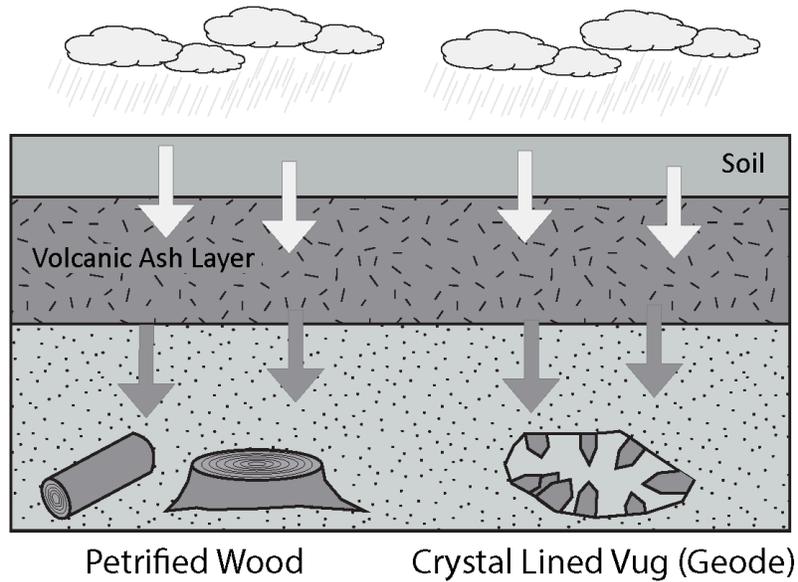
In an area with subsurface geology dominated by carbonate bedrock (limestone), erosion of that bedrock by dissolution will form karst topography.

Caves



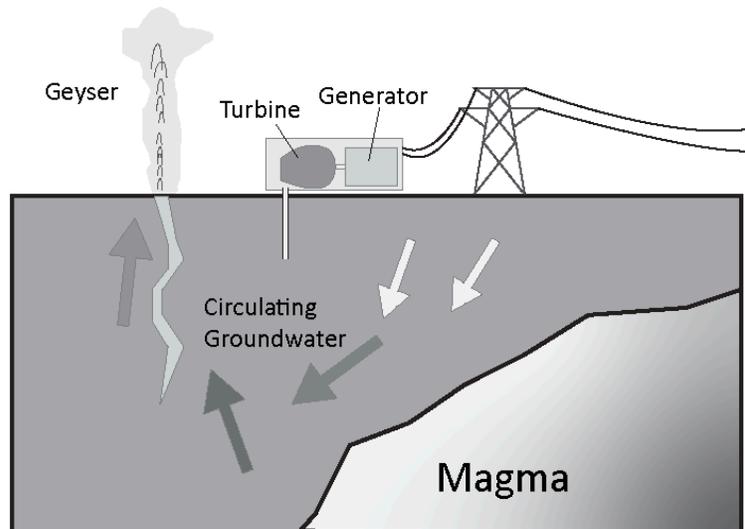
Caverns form by dissolution of limestone. Later, small amounts of groundwater will precipitate (mineralize) calcite forming various deposits of tufa (travertine).

Mineralization



Groundwater can transport ions like silica. For instance, the water may become saturated with silica when it passes through a silica rich volcanic rock, then later it might replace the wood fibers in buried trees, creating petrified wood. Or in another example, the silica may form quartz crystals in a small void, creating a geode.

Geothermal



Magma near the surface will heat the groundwater. In certain situations pressure can build underground and occasional erupt at the surface as a geyser. The heated groundwater can be exploited to generate electricity by circulating steam through a turbine.

Now, test your knowledge:

Briefly define the following terms:

spring -

karst -

sinkhole -

cover collapse -

cave -

geyser -

Answer the following:

1. Groundwater that outflows at the surface due to gravity is known as a _____.
 - a. geyser
 - b. karst
 - c. sinkhole
 - d. spring
2. True/False. Low porosity rock, such as a granite, may not be a good reservoir for groundwater, however a network of fractures (joints) may allow enough permeability to transport large amounts of groundwater quickly.
 - a. True
 - b. False
3. True/False. Karst topography forms in terrains in which the underlying geology is made up of granite.
 - a. True
 - b. False

4. A disappearing stream occurs in places where _____.
 - a. the local limestone dries out the air, causing streams to evaporate faster than the water is replenished.
 - b. to exploit the limestone bedrock, local farmers will dig large caverns to store supplies, and accidentally create places where streams disappear.
 - c. ideal conditions for fish in limestone bedrock causes overpopulation, and fish drink all of the water.
 - d. dissolution creates a conduit into underwater caverns in which a stream will flow, effectively disappearing from the surface.

5. True/False. Karst topography forms where the underlying bedrock (limestone) is dissolved away relatively rapidly. Karst not only forms in areas of limestone bedrock, but also regions underlain by gypsum or rock salt.
 - a. True
 - b. False

6. A collapse (cover collapse) sinkhole will form when _____.
 - a. underlying bedrock will slowly dissolve away, allowing the surface to subside.
 - b. a cave roof, or overlying soil horizon will be eroded from underneath, and eventually the roof or horizon collapses dramatically.
 - c. over-pumping of an oil well occurs.
 - d. a disappearing stream dries up, leaving behind a large cavern.

7. True/False. Stalagmites *might* reach the ceiling someday.
 - a. True
 - b. False

8. True/False. Water forming hot springs at the surface can also be heated in places where the water has the ability to circulate especially deep along deep structures where the ground is hotter because of the geothermal gradient.
 - a. True
 - b. False

Now, think deeper:

On your own:

9. If rainwater is capable of dissolving limestone rock, why do you think that same water would later precipitate (mineralize) that material elsewhere?

10. Acidic rain contains carbonic acid, formed by the following reaction: $\text{H}_2\text{O} + \text{CO}_2 = \text{H}_2\text{CO}_3$. What effect do you think an increase in atmospheric CO_2 has on the production of carbonic acid?

Working in groups of 2 or 3:

11. Discuss your answers to questions 9 and 10.

First some review of The Carbon Cycle:

Atmospheric Flux

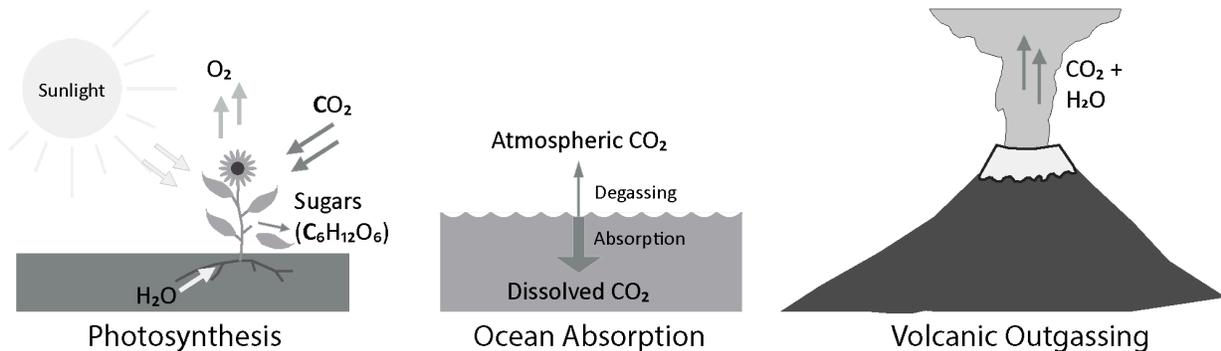


Carbon is found in all of the major Earth Systems: Atmosphere, Biosphere, Hydrosphere, and Geosphere (lithosphere). Carbon is pulled from the atmosphere by plants via photosynthesis, and from the oceans by marine organisms in the creation of shells. When those organisms die, their remains can eventually become sedimentary rock. Throughout Earth's history, a general net flux from atmosphere to geosphere has occurred, giving us a modern atmosphere rich in molecular oxygen (O_2) and a very minor level of carbon (CO_2 , and CH_4). Some natural and anthropogenic processes (such as burning fossil fuels) returns geosphere carbon to the atmosphere. We therefore tend to think of the carbon cycle as processes that either cause carbon to increase or decrease (flux) in the atmosphere.

Carbon Reservoirs

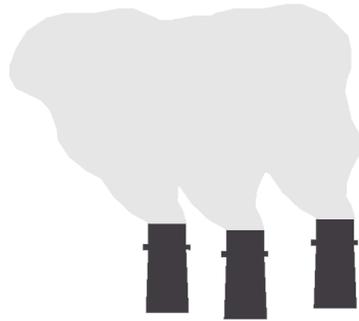
Carbon is found in several reservoirs: 1. The **atmosphere**, 2. living and dead **organisms** (plants, animals), 3. **organic matter in soils**, 4. unburned **fossil fuels**, 5. the **oceans**, 6. marine **sediments** and **sedimentary rocks** in the crust, and 7. the **mantle**.

Natural Processes

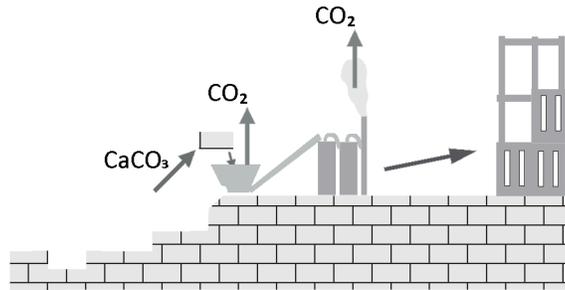


Carbon is moved through the reservoirs by various natural processes such as: **photosynthesis**, plant and soil **respiration**, **absorption** in the oceans, **degassing** from oceans, **volcanic eruptions**, and continental **weathering**.

Anthropogenic Processes



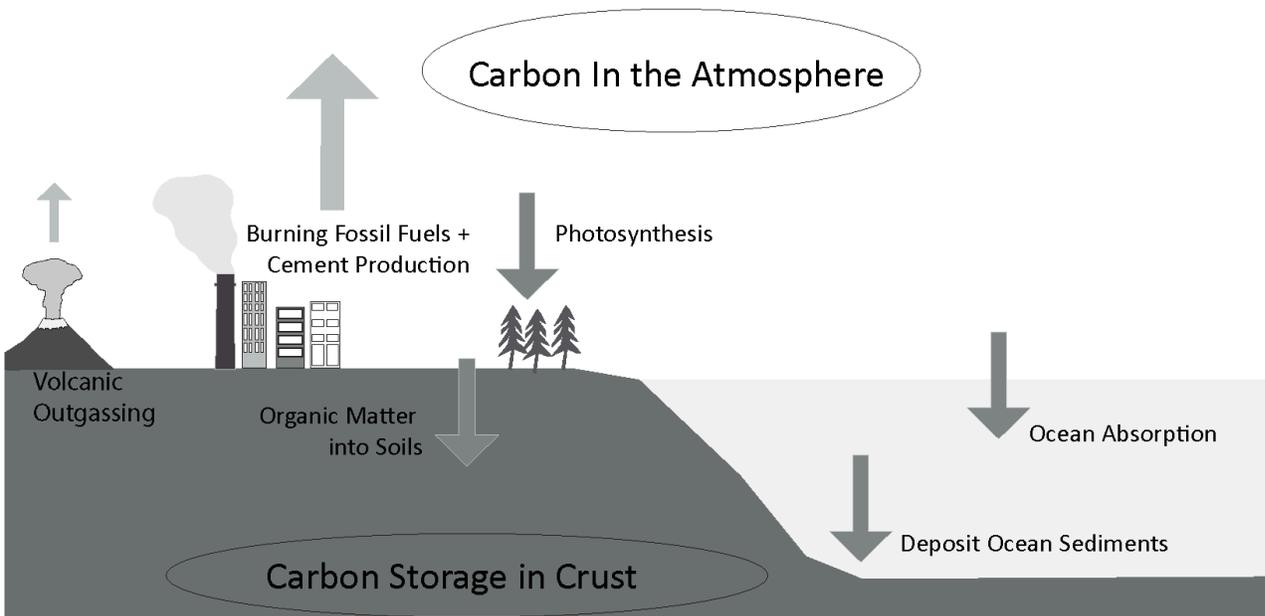
Fossil Fuel Burning



Cement Production

Carbon is also moved through the reservoirs by anthropogenic (human caused) processes, most importantly the burning of fossil fuels and manufacturing of cement. This has and continues to alter the balance established through millions of years of sequestering carbon into the geosphere. Some of the overall flux to the atmosphere is offset by increased absorption by the oceans, but not enough to avoid greatly altering our atmosphere, leading to anthropogenic global climate change.

Carbon Cycle



As described earlier, the carbon cycle moves carbon through various reservoirs of the atmosphere, biosphere, hydrosphere, and geosphere. These movements have been in flux throughout Earth's history, most recently being greatly altered by the increase of human activity.

Now, test your knowledge:

Briefly define the following terms:

greenhouse effect -

photosynthesis -

reservoir -

flux -

Answer the following:

1. Carbon is a component in _____.
 - A. Carbonate rocks (limestone).
 - B. Plants
 - C. Animals
 - D. Volcanic Gas
 - E. All of the Above
2. True/False. The sequestering of carbon into the geosphere is an ongoing process that happens naturally.
 - A. True
 - B. False
3. True/False. The rate at which humans are pumping carbon into the atmosphere by burning of fossil fuels and cement production is much faster than the rate of natural sequestering of carbon by deposition, burial, and lithification of carbon rich sediments.
 - A. True
 - B. False
4. Photosynthesis operates by pulling CO₂ from the atmosphere in the production of _____.
 - A. Water
 - B. CO₂
 - C. Oxygen and Sugars
 - D. Sunlight
 - E. Oxygen and Water

5. Phytoplankton (tiny plants that float in the ocean) grow through photosynthesis, just like plants on land. When phytoplankton die, their remains (or at least derivatives of their remains) settle to the ocean bottom. This has the net effect of _____.
- A. Increasing carbon in the atmosphere
 - B. Decreasing carbon in the atmosphere
 - C. Increasing carbon in the oceans
6. The greenhouse effect is caused by a(n) _____ in CO₂ in the atmosphere, which in turn _____.
- A. Decrease; traps solar radiation from escaping back into space, warming the planet.
 - B. Decrease; allows greater release of solar radiation back into space, cooling the planet.
 - C. Increase; allows greater release of solar radiation back into space, cooling the planet.
 - D. Increase; has no effect on the climate of the planet.
 - E. Increase; traps solar radiation from escaping back into space, warming the planet.

Now, think deeper:

On your own:

7. Make a list of resources that you own (or rent) that contribute in some way to the flux of carbon from the geosphere to the atmosphere.

8. Decide on the top 3 items from your list that contribute the most to flux of carbon from the geosphere to the atmosphere and briefly describe how the items do that.

Working in groups of 2 or 3:

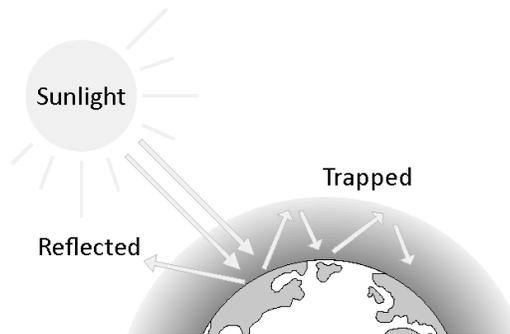
9. Compare your lists from question 8. Do you have similar items? Did you rank similar items differently as far as their overall contribution?

First some review of Climate Change: Climate change

Weather: short-term (days, weeks, months) temperature and precipitation patterns.

Climate: long-term (30 year +) temperature and precipitation patterns.

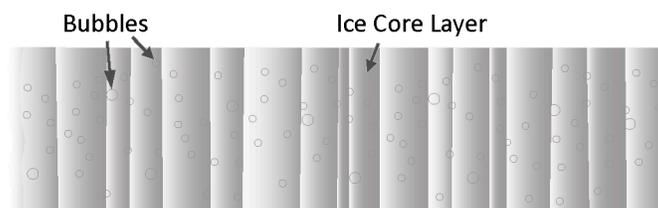
Greenhouse effect



Some sunlight is reflected back out to space. Greenhouse gases (e.g. carbon dioxide (CO_2), methane (CH_4)) in the atmosphere work to trap incoming solar radiation in the atmosphere. In this way, the level of carbon in the atmosphere plays a significant role in the overall global climate.

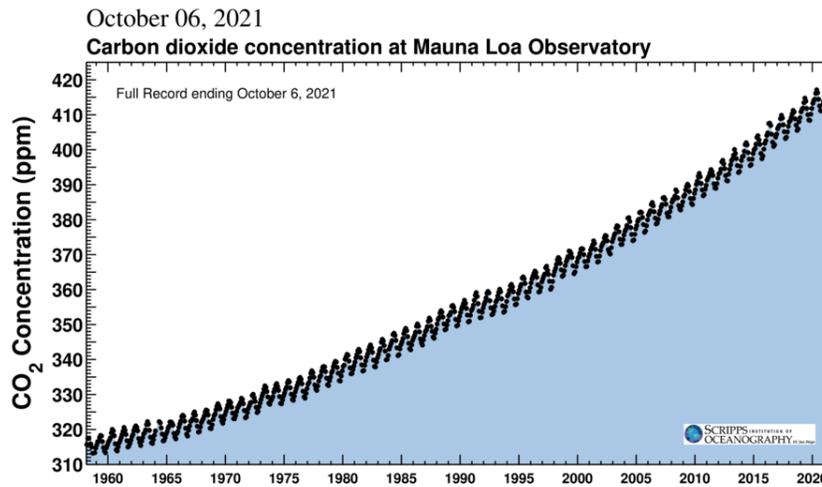
Evidence of change

Ice Cores



As ice accumulates in glaciers it will also trap bubbles of air. These bubbles can be analyzed to determine the concentration of greenhouse gases in the planet's atmosphere in the past. In some places of the Antarctic glaciers, these ice atmosphere records extend 100's of thousands of years into the past.

Atmospheric CO₂ Measurements



Known as the “Keeling Curve”, the concentration of CO₂ in the atmosphere has been measured at the Mauna Loa Observatory (Hawaii) since 1958. The general increase through time is striking, while the zig-zag pattern represents seasonal increase and decrease of biomass (plants) in the northern hemisphere. (CO₂ Keeling curve figure courtesy of UC-San Diego Scripps Institution of Oceanography)

Melting Glaciers

The Greenland and Antarctic ice sheets are shrinking. Most alpine glaciers are also shrinking.

Rising Sea-Level

When glaciers on land melt, that water is added to the oceans. Another cause of sea-level rise is due to the thermal expansion of seawater.

Ocean Acidification

Some of the CO₂ that is released into the atmosphere is absorbed by the oceans. This in turn increases the acidity of the ocean through the creation of carbonic acid.

Extreme Weather Events

Extreme weather systems such as hurricanes are driven by warm surface water. With increasing ocean surface temperatures, this leads to increased frequency, intensity, and duration of storms.

Now, test your knowledge:

Briefly define the following terms:

climate -

ocean acidification -

proxies -

flux -

Answer the following:

38. True/False. The Earth's climate has changed in the past, therefore the current change is natural.
39. True/False. The science regarding human caused climate change is not settled, and there is a general lack in consensus amongst the science community.
40. True/False. An out of the ordinary significant snowfall event late into the spring would bring climate change science into question.
41. True/False. The greenhouse effect is bad and should be eliminated completely.
42. Gases that are trapped in ice bubbles include:
 - a. CO₂ (carbon dioxide)
 - b. O₂ (molecular oxygen)
 - c. CH₄ (methane)
 - d. All of the above
43. The keeling curve increases exponentially, indicating _____.
 - a. the rate of CO₂ increase is steady.
 - b. changes in CO₂ levels can be observed between winter and summer.
 - c. the rate of CO₂ increase is accelerating.
 - d. the rate of CO₂ increase is slowing.
44. True/False. Melting of sea-ice (ice floating in the ocean) will cause sea levels to rise.

Now, think deeper:

On your own:

1. Read the following questions. Decide which you have a good answer for, or have some understanding already, and which you do not.
 - A. In most areas of the planet glaciers are retreating (getting smaller), but in some areas they are in fact growing. How is this possible?

 - B. The Earth's climate has changed in the past, so what's different about the change we see today? Why the concern?

 - C. Are scientists manipulating the data in order to show a warming trend?

 - D. CO₂ is only 0.04% of the atmosphere, how can that possibly have a large heating affect?

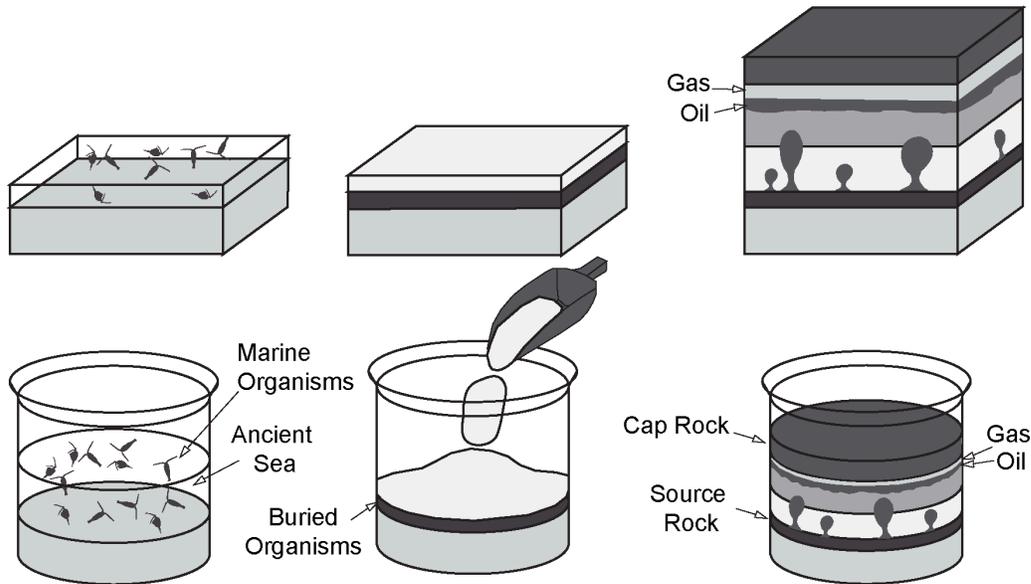
 - E. Is the sun increasing its energy output and therefore causing the climate on Earth to change?

Working in groups of 2 or 3:

2. Discuss at least 2 of the above questions. Do you have similar answers? Write down areas where you disagree.

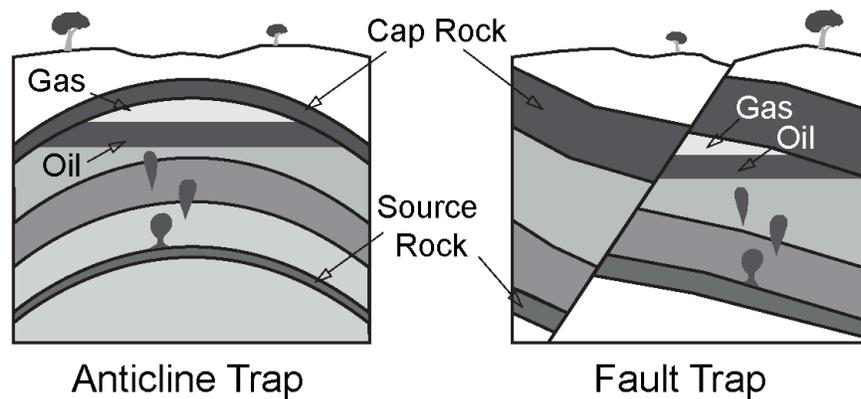
3. Decide as a group what is your most pressing remaining question regarding the above.

First some review of Energy Resources: Oil and Gas



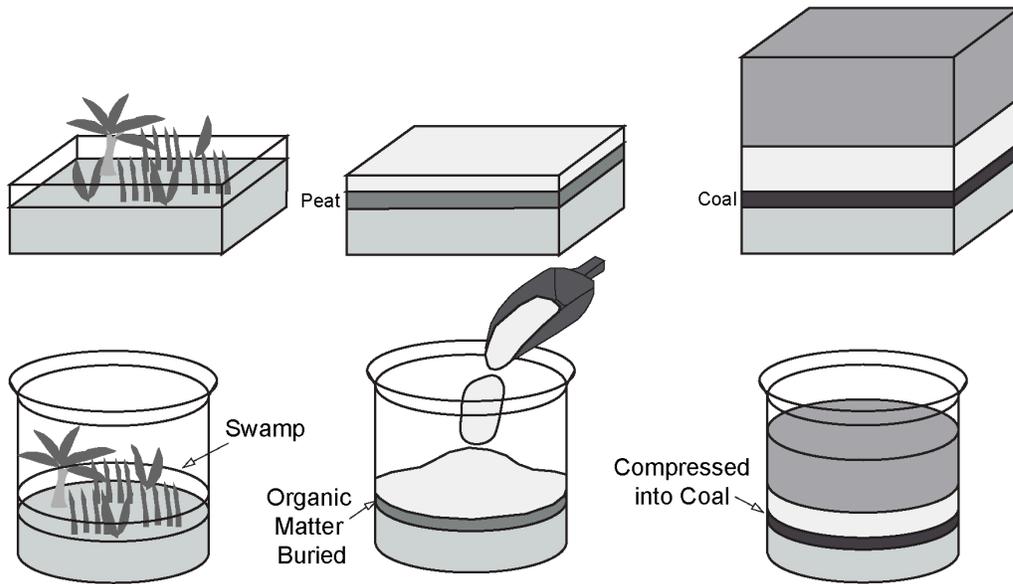
Under deep burial, kerogen in organic rich source rock will convert to oil and gas. The buoyant petroleum will migrate upwards from the source rock (shales) until it encounters an impermeable layer, often referred to as a 'cap rock'.

Oil Traps



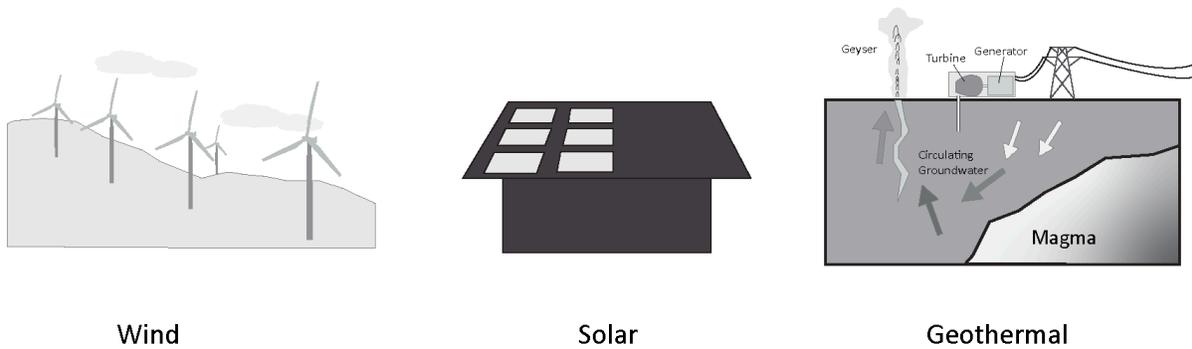
As lightweight (buoyant) oil and gas migrates upward from a **source rock** and through permeable rock it may become trapped within a permeable **reservoir rock** under an impermeable **cap rock**. Structural traps like the ones imaged above are often the target for oil and gas exploration to find these resources. Other similar types of traps may be created around salt domes, or in certain stratigraphic situations.

Coal



Coal is essentially concentrated carbon that forms from organic matter rich layers in sedimentary rocks. With further burial, peat forms lignite forms bituminous coal forms anthracite coal. Each level represents a greater concentration of carbon, eventually metamorphism would turn the anthracite into graphite.

Green Energies



The primary reason for wanting “green” energy, is to produce energy from a renewable resource that does not contribute to global climate change like burning fossil fuels.

The United State Department of Energy also lists water, bioenergy, hydrogen & fuel cells, and nuclear as clean sources of energy.

Amongst wind, solar, water and other renewable energy resources, not one of them can single handedly replace fossil fuels. Instead utilizing a blend of these sources will be required.

Now, test your knowledge:

Briefly define the following terms:

fracking -

directional drilling -

renewable resources -

Answer the following:

45. True/False. Fossil fuels are “non-renewable” because it takes millions of years to make more.
46. The typical fossil fuels include:
 - a. Oil (petroleum)
 - b. Coal
 - c. Natural Gas (methane)
 - d. All of the above
47. True/False. Preservation of organic material in the geosphere requires slow burial by sediments to allow time for decomposition by oxygen.
48. True/False. Once buried, organic material will continue to transform into higher quality materials through heat and pressure.
49. List the following stages of coal in order of increasing grade of metamorphism:
 - a. Sub-bituminous
 - b. Graphite
 - c. Lignite
 - d. Peat
 - e. Anthracite
 - f. Bituminous

- i. _____ < Lowest grade
- ii. _____
- iii. _____
- iv. _____
- v. _____
- vi. _____ < Highest grade

50. What is the most commonly used energy resource today?
- Wind
 - Geothermal
 - Fossil Fuels
 - Solar
51. What are “renewable” energy resources?
- Resources that only take 100 years to make more of.
 - Resources that are not limited in supply.
 - Resources that do not impact the environment.
 - Resources that have only recently been utilized in society.
52. Unconventional oil and gas plays like tar sands and oil shales are unique because _____.
- they are found off-shore.
 - they require mining or fracking to extract.
 - they are lower purity forms of oil and gas.
 - they cause global warming at an increased rate than traditional oil and gas.
53. True/False. The technique known as “fracking” has been around for some time. It is only the recent invention of directional (horizontal) drilling that has made fracking a useful way to extract more natural gas from oil bearing shale rock.

Now, think deeper:

On your own:

4. What role has the scientific discipline of geology played in the usage of fossil fuels?
5. What role does geology play in our understanding of climate change?
6. What role does geology play in our understanding and usage of renewable energy resources?

Working in groups of 2 or 3:

7. Discuss at least 2 of the above questions. Do you have similar answers? Write down areas where you disagree.

