The Rock Cycle—Extrusive Igneous Rock

BI201 Natural History of Guam

Class Presentation 09

The Rock Cycle

- With few exceptions, rocks are made of minerals
- Some minerals break down chemically to form new minerals when a rock is placed in a new physical environment

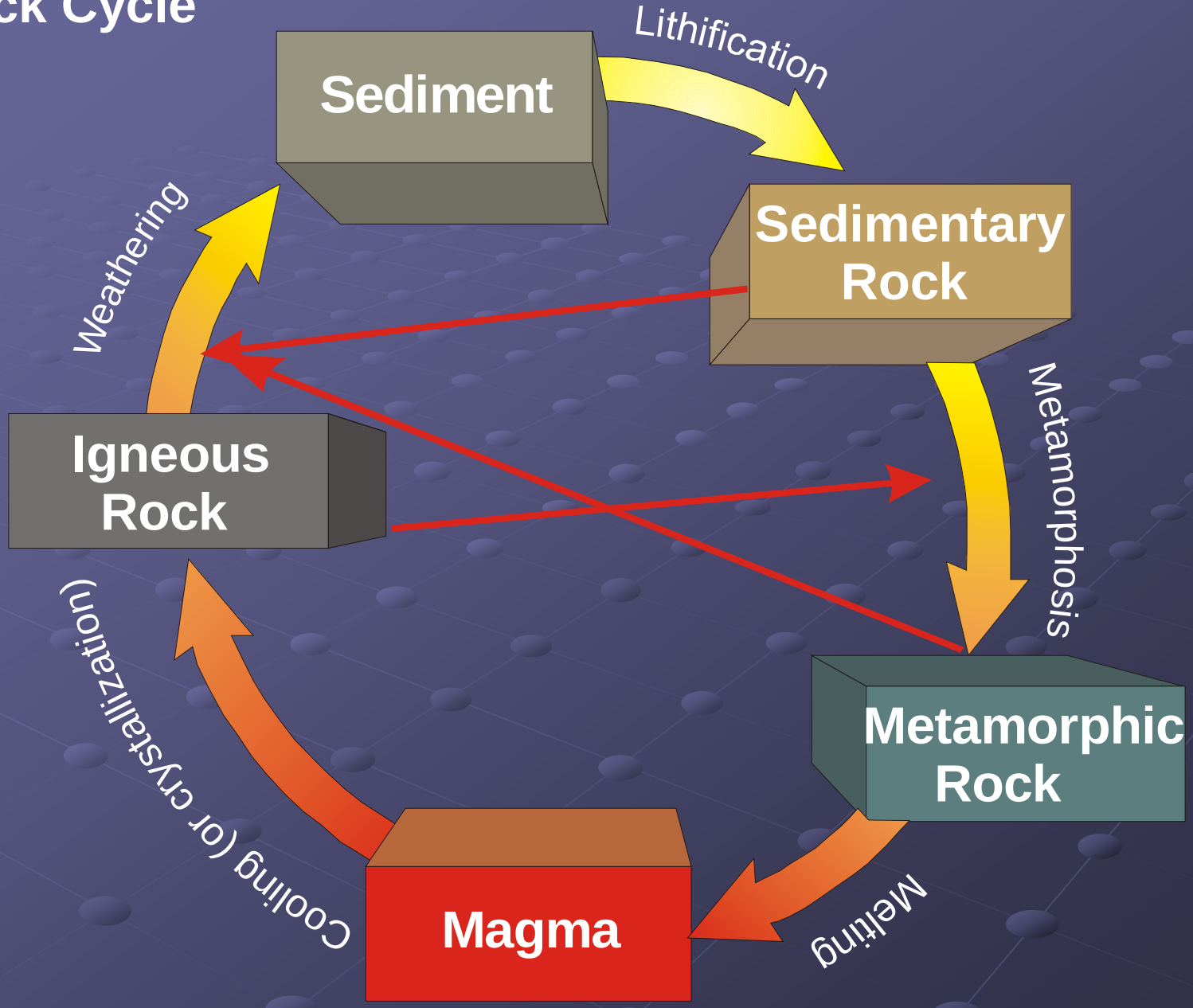
- For example, the **limestone** of coral reefs is the skeletal material of corals and other marine organisms
  - This limestone is chemically known as **calcium carbonate** ($CaCO_3$)
  - Corals produce the limestone in a crystalline form known as **aragonite**
  - However, when the limestone is uplifted tectonically (as in the case of northern Guam) and exposed to air, the calcium carbonate re-crystallizes over geologic time into **calcite**

- Other examples include the feldspars of granitic rock
  - Feldspars form at high temperature deep within Earth's mantle
  - When exposed at the surface of lithosphere, feldspars can be weathered to become clay
- Also, basaltic rock of southern Guam has been weathered to produce lateritic soil, which is characterized by its brick red color

- Such changes indicate that rock of the lithosphere is continually undergoing change from one type of rock to another depending upon conditions of its physical environment

- There are three major types of rock involved in this cycle of change: igneous, sedimentary, and metamorphic rock

The Rock Cycle



Igneous Rock

- Igneous rock is also called primary rock, because it is rock formed from hot, molten magma (>1,000 ˚C) that has cooled and solidified
  - **Magma** is molten, mobile rock within Earth's lithosphere or mantle
  - Once it reaches the surface of the **lithosphere** and enters either the **hydrosphere** or **atmosphere**, magma becomes **lava,** which cools and solidifies to form igneous rock

A wedge taken out of Earth would reveal its four major layers:

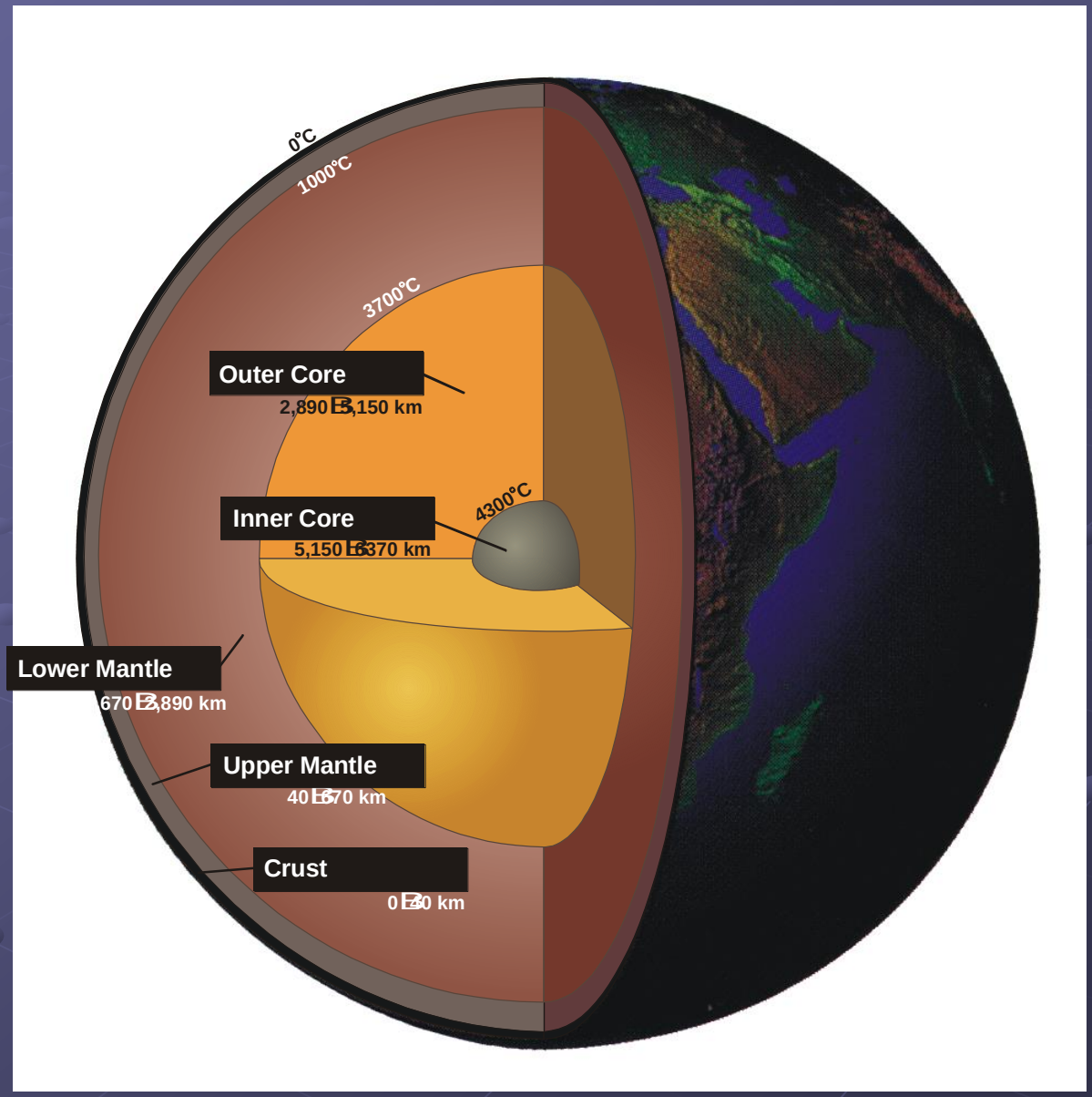
The thin and brittle crust

The plastic (Mg, Fe, Al, Si, O) mantle

The liquid iron-sulfur outer core

And the solid iron inner core.

Depth shown in kilometers and temperature in degrees Celsius.



- Types of igneous rock
  - All igneous rock can be classified as either
    - **Intrusive rock**
      - Intrusive rock is formed from magma that has cooled and solidified within the lithosphere
      - Intrusive rock occurs on Guam, but it is not common on the surface
      - Intrusive rock is also known as *plutonic* rock [after Pluto—Greek god of the underworld]

- **Extrusive rock**
  - Extrusive rock is any rock derived from lava that is poured out or ejected at the Earth's surface, either in the hydrosphere or the atmosphere
  - Extrusive rock makes up most of the igneous rock on surface on Guam
  - Extrusive rock is also known as *volcanic* rock
  - There are two types of extrusive rock
    - Volcanic flow rock
    - Tuffs, or tuffaceous rock

- **volcanic flow rock**
  - Volcanic flow rock is sometimes called *lava flow rock*, or “flows”
  - Volcanic flow rock is formed from the outpouring of lava at the surface
  - It may form sheets in either air or water
  - Under water flows form pillow-form basalt

Pillow-form basalts at Umatac Bay

- There are two types of lava flows
  - **Pahoehoe**
  - **Aa**
    - These terms are taken from the Hawaiian vernacular, which is the only language in the world to distinguish between lava flows having different surface features

- Pahoehoe [from Hawaiian *pähoehoe*, smooth]
  - Pahoehoe is formed at the surface by rapid cooling and solidification from surface downward
  - A thin, congealed skin remains plastic over the red hot fluid interior

- Pahoehoe has a rope-like or billowy texture, and its skin is smooth and continuous, producing an undulating surface
  - The wrinkling of the plastic skin by flow movement may cause the ropy texture

Smooth pahoehoe flow

- A pahoehoe flow may be sturdy enough to permit someone to walk across the moving lava
- The underside and pockets of cooled, solidified pahoehoe may be glassy in appearance
- Lithified pahoehoe is usually kind of **vesicular** [i.e., having bubble-shaped cavities formed by gases trapped in lava at the time that it cools & hardens]

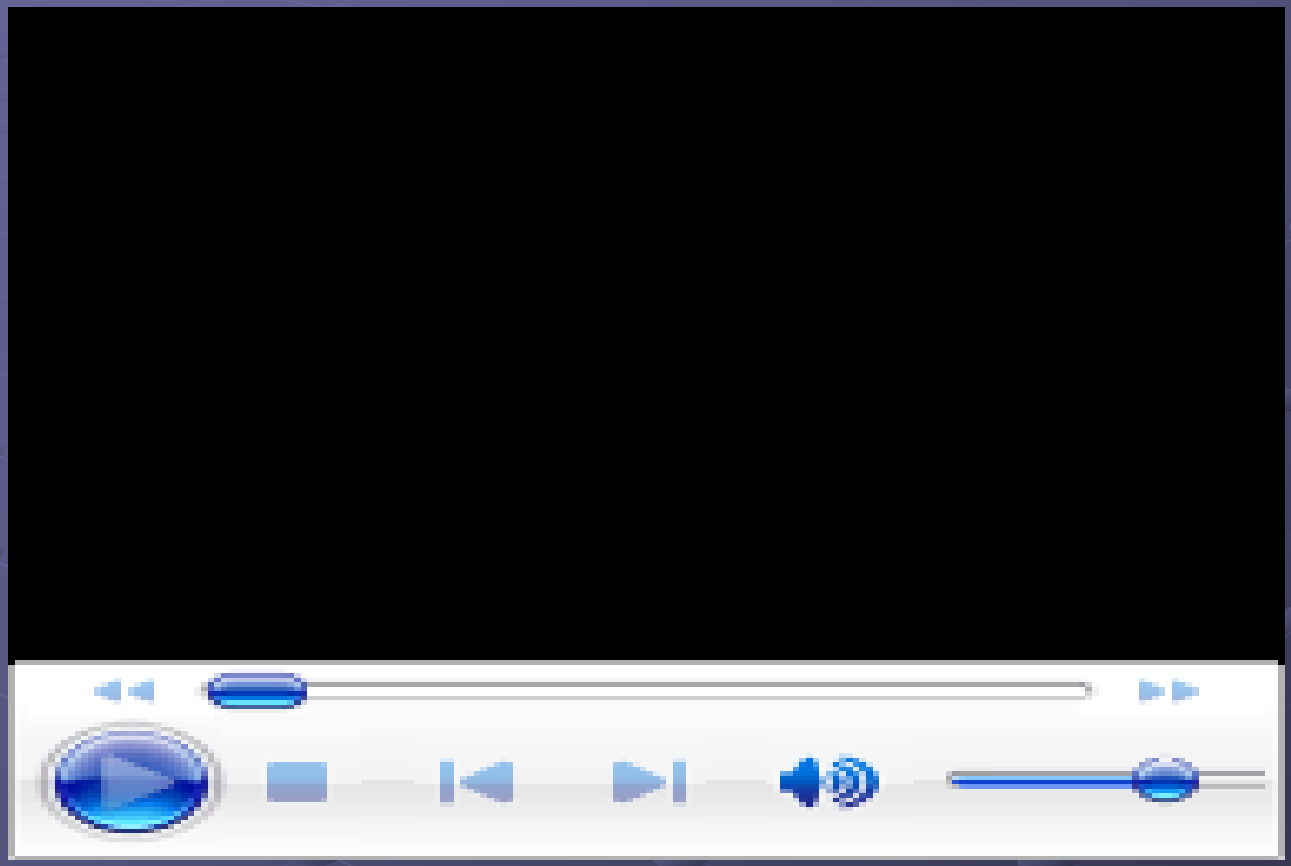
Vesicular basalt

- **Aa** [from Hawaiian *a'a* burning, raging]
  - Aa flows are rivers of lava that congeal on the front and sides to form steep flow-fronts that are overridden by molten lava within the flows
  - Aa heavier than pahoehoe
  - Aa has rough, jagged surface

- Aa consists of large, angular pieces of lava that cooled on the surface of a partially solidified flow
- Streams of aa do not harden on the surface as do pahoehoe flows
- Pahoehoe may change into aa, particularly where the lava plunges over a steep slope & causes differences in the rate of cooling & gas separation
- There is no chemical difference between pahoehoe and aa

Aa flow

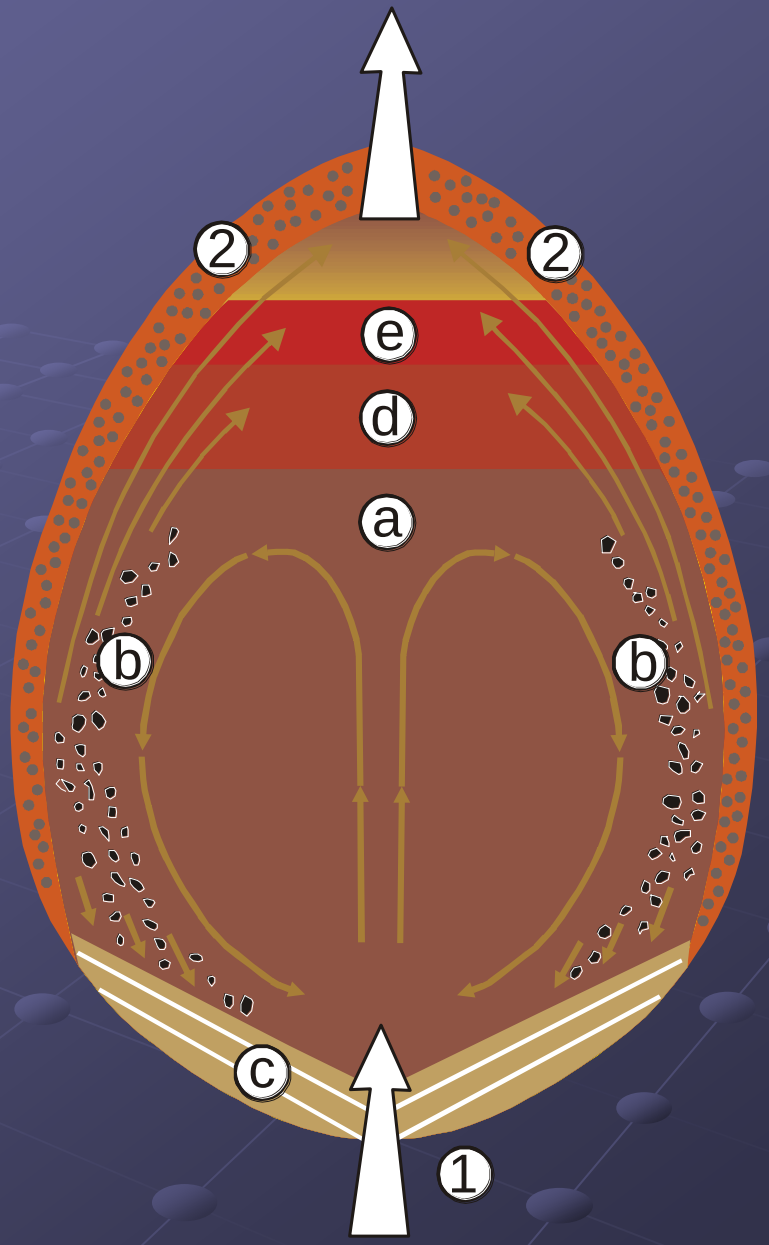
An old aa flow at Sarigan, Mariana Islands



- Identification of flow rock
  - **Basalt**
    - Basalt is a fine-grained, extrusive igneous rock
    - Basalt is defined as a **mafic** rock
      - Mafic rock is silica-poor, ca. 50% by weight, igneous rock with a relatively high content of magnesium, iron, and calcium
      - Most of the silica is bonded to iron and magnesium, forming either ferromagnesian minerals (color: dark green or black, e.g., olivine) or calcium-rich plagioclase feldspar [silica with aluminum and calcium] (color: dark gray)]

- Basalts are generally non-vesicular in rocks of the oceanic region
- On Guam, basalt usually has **phenocrysts**
  - Phenocrysts are large crystals visible to unaided eye
  - What is the origin of phenocrysts?
    - Phenocrysts are formed by crystallization of minerals near the cool walls of the magma chamber

- The magma chamber is initially filled with a parental basaltic liquid, derived from melting of the mantle (1), which crystallizes when it comes into contact with the cooler wall-rocks (2).
- The liquid is convecting in the lower part of the chamber (a); olivine, pyroxene, and plagioclase phenocrysts are precipitated towards the margins (b) and then begin to separate from the residual liquid.
- These minerals are dragged downwards by descending currents and accumulate on the floor (c).
- The residual liquids migrate up to the chamber roof,where they undergo stratification according to their density; the more differentiated liquids are concentrated into the uppermost zones (d-e). [Redrawn from Guille et al., 1996].



- Any rock containing phenocrysts is described as **porphyritic**
- Vesicular basalt usually has no phenocrysts

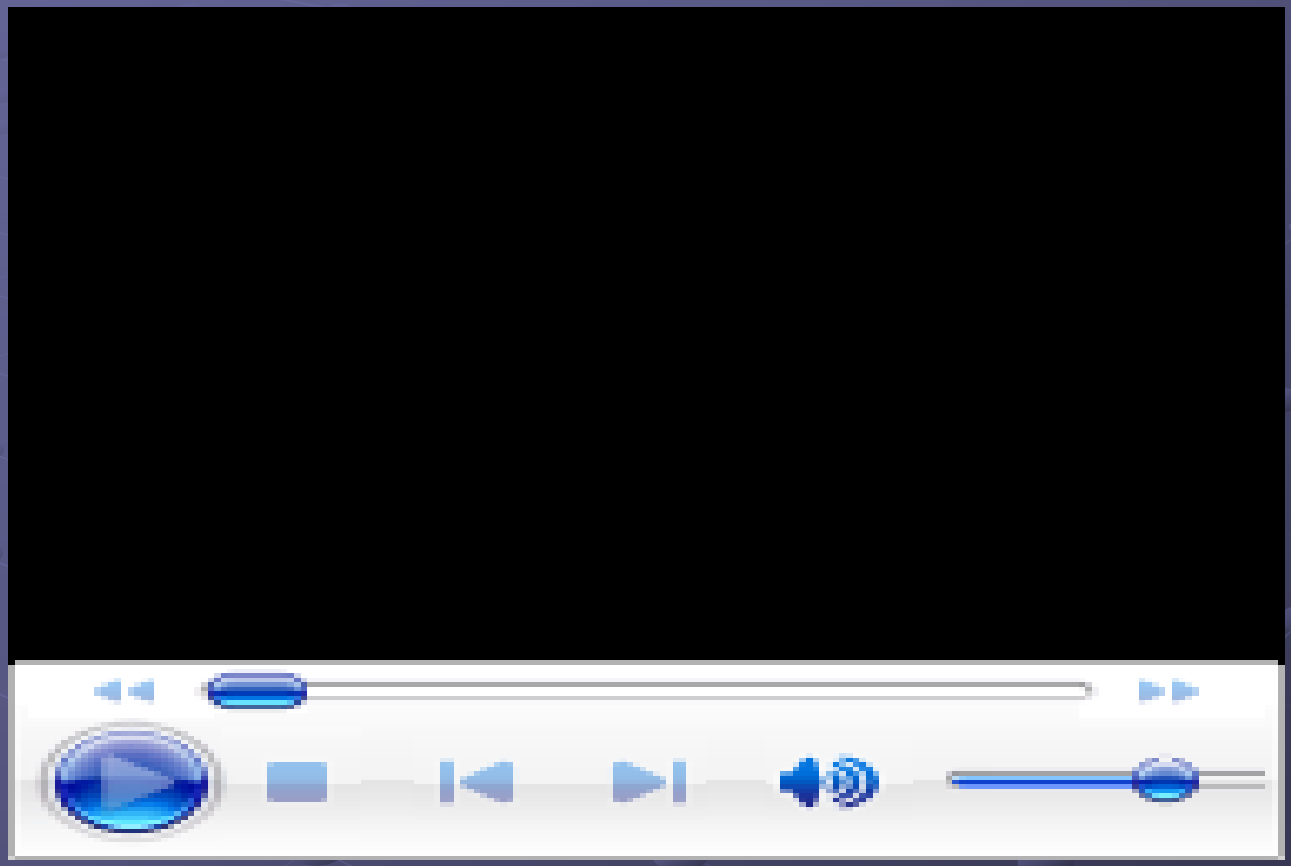
- **Andesite**
  - Andesite, or andesitic basalt, is a fine-grained igneous rock composed of about equal amounts of ferromagnesian minerals and plagioclase feldspar
  - The color of andesite is moderately gray or green
  - In the Mariana Islands, andesite is usually porphyritic, and it may occur in either vesicular or non-vesicular forms

- **Rhyolite**
  - Rhyolites are characterized as **felsic** rock, i.e., silica-rich igneous rock with a relatively high content of potassium and sodium [felsic from felspar and silica making up the rock]
  - Rhyolites are made up mostly of feldspar, but always contains some quartz
  - Rhyolites are usually cream-colored, e.g., **dacite** [= rock making Bird Island in Saipan & also assoc/ w/ 1980 Mt. St. Helens eruptions
  - Rhyolite includes most volcanic glass or **obsidian**
    - Volcanic glass is amorphous [not made up of individual crystals or particles]
    - Volcanic glass is formed by fire fountains

- **Tuffs, or tuffaceous rock**
  - Tuffs are formed by lithification of **tephra**, or **pyroclastic ejecta**
    - “pyro” = fire
    - “clastic” = broken fragment or particle
  - Tuffs are the most common type of extrusive surface rock on Guam
  - Tuffs are formed from lava that has been ejected forcefully into the atmosphere or hydrosphere by volcanic explosions
    - Therefore, tephra forms individual particles

- Tephra particles may be ejected vertically and fall back to Earth as **ash fall deposits** or they may be ejected in **pyroclastic flows**
  - Pyroclastic flows are high-density mixtures of hot (200°C and 700°C), dry rock fragments and hot gases that move away from the vent that erupted them at high speeds.
  - They may result from the explosive eruption of molten or solid rock fragments, or both.
  - They may also result from the nonexplosive eruption of lava when parts of dome or a thick lava flow collapses down a steep slope.

- Most pyroclastic flows consist of two parts: a basal flow of coarse fragments that moves along the ground, and a turbulent cloud of ash that rises above the basal flow.
- Ash may fall from this cloud over a wide area downwind from the pyroclastic flow.
- Pyroclastic flows may move downhill at speeds up to 200 km/hr and come to rest on the lower slopes of the volcano and surrounding terrain



- There are three main types of pyroclastic flows:
  1) glowing ash clouds (or nuée ardente)
  2) ash flows
  3) mudflows

- Tephra is classified by particle size
  - **volcanic dust** <1/16 mm in diameter
  - **volcanic ash** 1/16–2 mm in diam.
  - **volcanic cinders** 2–32 mm in diam.
    - a.k.a. *scoria*
    - usually **vesicular**; e.g., pumice, which has so many vesicles it will float on water
  - **volcanic bombs** >32 mm in diam.
    - vesicular, rounded
  - **volcanic blocks**
    - chunks of parent rock that are blown off either from lithosphere or from previously cooled volcanics during a violent eruption
    - usually solid, angular

- Tephra is usually a mixture of the various particle sizes rather than a uniform layer of material
- When pyroclastic debris lithifies, it forms the rock equivalent of tephra
- Therefore, lithified tephra forms tuffs

- Tuffs are classified by their texture
  - **Tuffaceous mudstone**
    - Texture: particles <1/16 mm in diameter
    - Forms from volcanic dust
  - **Tuffaceous sandstone**
    - Texture: particles 1/16–2 mm in diam.
    - Forms from volcanic ash
  - **Volcanic breccia** [a.k.a. lapilli tuff]
    - Texture: particles 2–32 mm in diam.
    - Formed of larger pieces of debris (cinders, bombs, blocks)
    - Particles are fragmented, angular
    - Generally, indicates close proximity to volcanic vent

Incompletely lithified volcanic breccia at Sarigan, Mariana Islands

Close-up of tephra clasts in volcanic breccia at Sarigan