Absolute Dating Techniques:

Radioactive dating

The main technique used to determine the absolute age of features makes use of radioactive elements.

Most atoms are stable.

However, a few are not stable but decay in time into different atoms by emitting various particles.

These atoms are said to be *radioactive*.

The initial atom is known as the *parent* isotope while the decay product is known as the *daughter* isotope.

How can we use radioactive elements to date objects?

Radioactive elements decay spontaneously.

However, when a number of atoms are examined a statistical rate of decay can be determined.

The time it takes for half of the atoms to decay is known as the isotopes *half-life*.

Occurring in the nucleus, the half-life is essentially independent of the environment.

Because of this radioactivity from radioactive elements can be used to date objects.

To see how let us consider an example...

Example: Potassium – Argon Dating

One radioactive isotope often used in dating rocks is Potassium 40.

Potassium 40 decays into Argon 40 via electron capture:

$$K^{40} + e^{-} \longrightarrow Ar^{40}$$

The half-life for this decay is 1.3 billion years.

How might we use this decay to measure the age of a rock?

Difficulties with radiometric dating:

1. Age of rock is much different than 1/2 life.

Suppose a rock is much younger than the 1/2 life of a radioactive element.

How many daughter nuclei will there be?

e.g., suppose the 1/2 life is a billion years but a rock is only 100,000 years old (1/10,000 of a 1/2 life). Then we would have 1 daughter isotope for every 14,427 parent isotopes.

What if the age is much older than a 1/2-life?

This typically occurs at about 12 1/2-lives or so.

Thus, a radioactive isotope is most useful for determining ages near its 1/2 life.

2. When does the radiometric "clock" start?

Radioactive dating techniques are most useful with igneous rocks.

Their formation resets the radiometric "clock."

Clock may not be reset by formation of sedimentary or metamorphic rocks.

3. Atoms may move into or out of rocks.

For example, if an isotope decays into a gaseous element it may escape from the rock.

e.g.: it can be a problem with K->Ar dating

How would the age determination be affected if Argon had excaped from a rock?

4. Contamination to begin with, what if a rock began with some daughter isotopes?

An example where this might occur is the Rubidium–Strontium decay system.

What would happen to the age determination if some daughter isotopes were present and this was not accounted for?

How can one tell what the initial concentration was?

Geologic Time

The Earth is very old.

Current estimates place its age at 4.6 billion years.

Difficult to fathom.

All of human history (~5000 years) is but 0.0001% of this age.

Condense all of Earth history into one year and human history would occupy the last 30 seconds.

While difficult, it is important to try and keep geologic time in perspective.

In the following chapters (and some we have seen) we will see what geologic forces can do over such immense periods of time.

Why do we think the Earth is 4.6 billion years old?

How do we measure such large periods of time?

How can we tell the ages of various landforms?

This is what we will discuss the next couple of days.

Two types of dating are used:

Relative dating—here we try to determine which of two objects is younger, which older.

However, we do not attempt to determine the actual ages.

Absolute dating—here we try to determine the actual age of a feature.

Relative Dating

We can attempt to determine the relative ages of features by making use of some common sense assumptions and principles.

1. Principle of Uniformitarianism

“The present is the key to the past”

We assume that processes which occur today also occured in the past.

Physical laws of the Universe do not change in time.

2. Principle of Original Horizontality

When we see sedimentary layers being layed down today they are always at or nearly horizontal.

Thus if a layer is tilted what must have happened and when?

3. Principle of Superposition

In general, new sedimentary layers are deposited on top of preexisting layers.

Where would the youngest layers be seen? Older?

But what if a layer has been deformed or overturned?

4. Principle of Cross-Cutting Relationships

Sometimes igneous rocks intrude into country rock or a fault cuts through various rock layers.

Which is older, the igneous rock (or fault) or the country rock?

5. Principle of Inclusions

Sometimes rocks contain inclusions within themselves.

Which is older, the inclusion or rock layer?

6. Principle of Faunal Succession

Sometimes rocks contain fossils.

Typically, organisms only appear within a certain time frame on Earth.

The presence of a fossil constrains the age of the rock to the period when the organism existed.

Organisms which make only a brief appearance are particularly useful—if present they can tie the age down well (index fossils).

Thus, the types of fossils seen can be used to gauge the age of a rock.

(And vice-versa, using our previous rules, paleontologists use rocks containing fossils to determine the relative ages of fossils.)

With all these tools we can use to date features it should be easy, right?

Alas, mother nature throws a few curves our way.

Not all (or most) sedimentary rock layers present a nice clean history.

Consider the following sequence of events:

Material is initially deposited in a region.

As material is deposited the layers are built up nicely, young on top, older underneath.

Now suppose the environment changes to one favoring erosion over deposition—

Erosion removes some of the upper (younger) layers.

Then the environment changes again to one favoring more deposition.

What would we see in this case?

When this occurs we have an *unconformity*.

Unfortunately, this sequence of events is more the rule than the exception.

Several types of unconformities exist.

Nonconformity

When sedimentary layers are observed overlying an unlayered body of plutonic igneous rock or metamorphic rock.

Intrusive igneous rock and metamorphic rocks do *not* get produced on the Earth's surface.

==> Must have been some erosion exposing the rock before the new deposition took place.

Angular unconformity

Sometimes sedimentary layers are layed on top of tilted or deformed sedimentary layers.

What must the sequence of events have been in this case?

Disconformity

In a disconformity, the layers are still horizontal but a definite gap exists in the record.

Perhaps the fossils contained in adjacent layers suggest quite different ages.

Sometimes evidence of erosion and weathering can be seen in the underlying layer.

Unfortunately, virtually all outcrops contain unconformities.

Most contain information on only a small fraction the Earth's history.

Correlation

If most of the information is missing in a given outcrop, how do we try to get a coherent history of a region?

How do we relate one region to another?

i.e how can we tell which layers were formed at the same time?

Major Isotope Systems Used in Dating:

1. Rubidium-Strontium (Rb^{87} -> Sr^{87})

1/2-life: 47 billion years—useful for dating old rocks (10 million – 4.6 billion years)

Strontium is a solid, thus not likely to escape.

Occurs in potassium rich rocks—useful check on potassium ages.

2. Uranium, thorium to lead

Long 1/2-lives (713 million to 14 billion years)—date old rocks (10 million years to 4.6 billion years).

3. Potassium-Argon (K^{40} -> Ar^{40})

1/2 life of 1.3 billion years—useful for dating rocks of 100,000 years to 4.6 billion years.

Potassium is abundant making this system quite useful.

Argon is a noble gas which does not normally bond with other atoms—rarely seen in a rock except as a decay product.

However, this is also a bane—gas can easily escape from a rock.

One must be careful especially with old, severely weathered, or metamorphic rocks.

Carbon-14 Dating (C^{14} -> N^{14}):

1/2 life of 5730 years—can be used to date young objects (100 to 70,000 years old).

Often used to date artifacts.

If carbon-14 has a such a short 1/2-life, why is it still around?

Carbon-14 is continuously created by cosmic rays impacting atoms in the atmosphere.

As long as an organism lives it continually recycles its carbon.

When it dies it no longer does and the Carbon-14 clock starts to tick.

Note that carbon-14 dating assumes that the rate of production of carbon-14 by cosmic rays has been constant.

This may not be the case!

Certainly isn't today—atomic bomb tests have substantially increased the amount of carbon-14 seen currently.

Other Absolute Dating Techniques

While radiometric dating is the most widely used technique for absolute dating, other techniques are available.

Fission-track dating—the decay of isotopes create high energy particles

==> upon leaving a rock tend to leave a path of destruction behind.

The more fission tracks seen, the older the rock.

Dendrochronology—due to the variations between winter and summer, trees create alternating dark and light rings, one set per year.

These can be used to date trees and events during a tree's lifetime.

Varve chronology—inflow into lakes may also follow a seasonal cycle leading to sets of sediments layed down each year.

By counting the varves we can determine the timing of various events (e.g. the formation of the lake, times of drought...)

Ice core samples

Similar to varves, glacial ice shows a seasonal cycle.

Can be used to date climate variations on Earth.

Lichenometry—lichen tends to grow on rocks at a relatively constant rate. (Though it depends on the rock and climate).

Can be used to date relatively young rocks (~9000years).

The larger the lichen colony the older the rock.

Surface Exposure Dating

Sometimes we are not only interested in the age of a rock but how long it has been in its current environment.

For example: How long has a rock been on the surface of the planet?

A technique known as surface exposure dating can be used to determine this:

Cosmis radiation is constantly bombarding the surface of the planet.

This radiation can create new isotopes not normally seen on Earth (cosmogenic isotopes).

It can also leave tracks of destruction (much like fission tracks).

Such particles can only penetrate the near surface (upper meter or two or so).

Thus the abundance of these cosmogenic elements and/or tracks is an indication of how long the rock has been within a meter or so of the surface.

Geologic Time Scale

Geologic history is organized into different blocks of time.

The blocks of time are divided on the basis of major events which have occured in the past.

The major divisions are split on the basis of biological events (e.g. the appearance of multicelled organisms).

However nonbiologic events do divide some of the finer time periods.

The largest blocks of time are the *eons*.

The earliest eon is the hadean which extends from the planets formation to ~3.8 billion years ago.

Period before origin of life—very few rocks are seen at the surface from this age.

The *archean* marks the first appearance of life and extends to about 2.5 billion years ago.

The *proterozoic* marked the beginning of multicelled organisms and runs to ~545million years ago.

Together, the hadean, archean, and proterozoic are sometimes referred to as the *precambrian*.

The *phanerozoic* (visible life) eon marks a great diversification in life and runs to the present.

The eons are further subdivided into *eras*.

The phanerozoic is split into 3 eras:

The *paleozoic* (ancient life) 245 – 545 million years ago.

The *mesozoic* (middle life) 65 – 245 million years ago.

The *cenozoic* (recent life) 65 million years ago to the present.

Eras are then further subdivided into *periods*.

Periods are divided into *epochs*.

The age of the Earth

I’ve said the age of the Earth is 4.6 billion years.

How do we determine this age?

Oldest rocks on Earth are dated at 3.96 billion years by radiometric dating techniques.

But the Earth exhibits active geology—thus we believe the oldest rocks have been destroyed.

Lunar rocks have been dated at ~4.55 billion years

Meteorites give a similar age.

Astronomy suggests the sun is about this age.

Structures on Earth:

Stressing and Straining Rocks:

Oftentimes rocks are subject to substantial tectonic forces and pressures.

The force applied to a rock per unit area (pressure) is defined as the *stress* on the rock.

How might we stress rocks?

Strain

When a rock is placed under stress, it will deform.

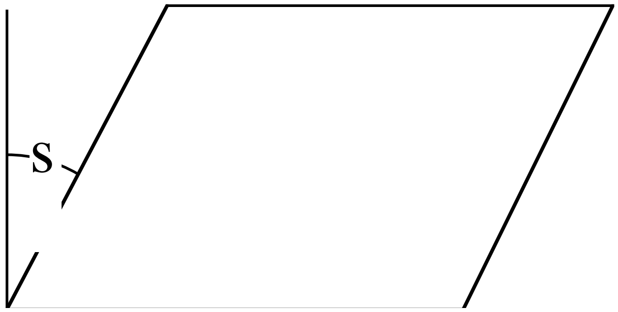
Strain is a measure of how rocks deform under stress.

The strain caused by a compression (or tensional) stress may be defined as the change in length divided by the initial length:

$$\text{strain} = (L_f - L_i) / L_i$$

The shear strain caused by a shear stress may be defined in terms of the angle of deformation:

$$e = \tan(s)$$



In some sense, stress is what we do to a rock.

Strain is a measure of how a rock reacts to the stress.

How do rocks react to stress?

If the stress is not too large, they react *elastically*.

The strain produced in the rock is directly proportional to the applied stress:

Stress = E × Strain

where E is a constant.

If the stress is released the rock rebounds back to its original shape.

==> Can fully recover if stress removed.

If the stress is too large, however, the rock may be permanently deformed.

Increase the stress still further and the rock may fracture (brittle behavior).

Even if the stress is not so large as to fracture the rock, if it is applied over a long period of time it may cause the rock to flow.

Rock deforms plastically.

If the stress is then removed, the rock will *not* return to its original form.

If stresses are applied for long periods of times, rocks can be substantially deformed creating many interesting features.

Faults

At low pressures rocks are brittle and thus often deform by fracture.

Fractures are seen in rocks at a variety of scales.

Fractures in rocks along which little to no movement is seen are called *joints*.

Fractures along which substantial motion is seen are called *faults*.

Several types of faults are seen depending on the motion seen along the fault.

How might rocks move with respect to each other?

Transform or Strike-Slip Faults

Transform or stike-slip faults occur where fault blocks slide by each other.

Strike-slip because slip is along the fault’s strike.

This type of faulting occurs where rocks are placed under shear stress.

Usually occur at transform plate boundaries where plates are sliding by each other but can occur in other environments as well.

Example?

How do we determine the sense of motion along a strike-slip fault?

Compass direction? (e.g. block slips to the north)?

However, people on both sides of the fault will agree that the other is slipping either right or left.

Thus strike-slip faults are classified as either *right lateral* or *left lateral* strike-slip faults.

For example, the San Andreas is a right lateral strike-slip fault.

Dip-Slip Faults

More common than strike-slip faults are faults where the blocks are either pushing into each other or pulling apart.

Sometimes referred to together as *dip-slip* faults.

The fault blocks in dip-slip faults are given names from mining:

The block above the fault is the *hanging wall.*

The block below the fault is known as the *footwall.*

The direction in which the hanging wall and footwall move distinguishes the type of fault.

Normal Faults

In this type of fault the hanging wall slips *downward* with respect to the footwall.

Normal faults occur where the rocks at the fault boundary are under tensional stress.

Thus, often seen at divergent plate boundaries.

Horsts and Grabens

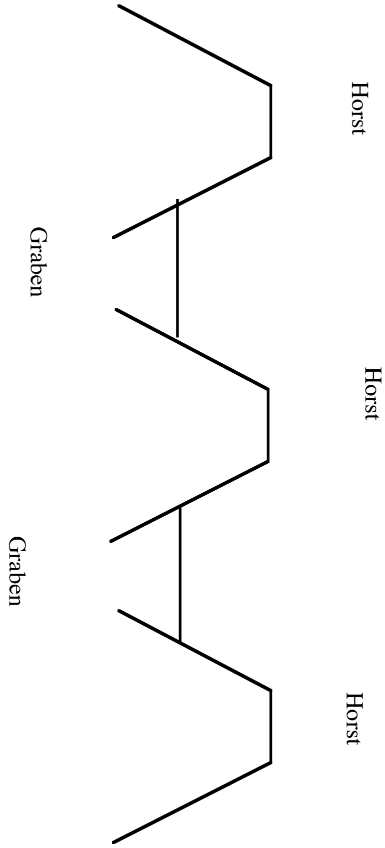
Normal faulting sometimes leads to features known as horsts and grabens.

A fault block may be dropped down between two normal faults.

Such a feature is called a *graben*.

Lake Tahoe is an example.

Block between two grabens is known as a *horst*.



Reverse Fault

In a reverse fault the hanging wall moves *upward* with respect to the footwall.

Occur where rocks are under compressive stresses.

Often occur at convergent plate boundaries.

Often seen in regions of complex geology including both folding and faulting.

Regions of current mountain building.

Thrust Faults

Most normal faults have relatively large dip (~60°).

Most reverse faults have shallower dip angles.

Reverse faults with particularly low dip angles are called *thrust faults*.

Some have quite low angles of dip (10–15°).

Can lead to large sections of rock over thrust over younger rock layers underneath.