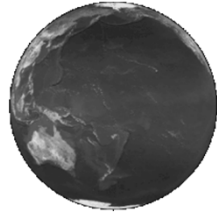


Lecture 6:
The Geological Revolution:
Deep Time and the Age of the Earth



Astronomy 141 – Winter 2012

This lecture explores the geological revolution that revealed the antiquity of the Earth.

Understanding the age of the Earth requires having a conception of a beginning for the Earth.

Historical and Physical age estimates give different answers.

Geological discoveries uncovered the deep history of the Earth, and developed techniques for reading that history.

The Earth is 4.54 ± 0.05 Billion Years old, measured by radiometric age dating of meteorites, the oldest Earth rocks, and Moon rocks.

In order for “what is the age of the Earth?” to make sense, you must conceive of a beginning.

Two ways people have conceived of time:

Cyclical Time:

Earth has no beginning or end, only repeated cycles of birth, death, and rebirth/renewal.

Linear Time:

Earth has a past beginning & will have a future end.

On human scales, time appears to be cyclical

Natural cycles around us:

- Cycle of day & night
- Monthly cycle of moon phases
- Yearly cycle of the seasons
- Generational cycle of birth, life, and death...

Examples:

- Hinduism & Buddhism posit cyclical time
- Plato's 72,000 year cycle:
 - 36,000 Golden Age followed by a
 - 36,000 age of disorder & chaos.

Linear Time posits a definite beginning in the past, and an eventual ending in the future.

Judaism provides an example of linear time:

- Past divine creation of the Earth (Genesis)
- Promised end of times.

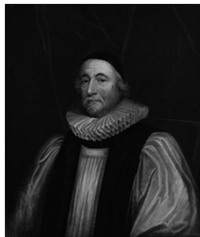
Christianity & Islam adopted this idea:

- See history as fulfillment, not growth.
- No change in the world, except decay from past perfection ("fall from grace").

James Ussher (1581-1656) made one of the most enduring historical age estimates of the Earth.

Protestant Archbishop of Armagh
Classical & biblical scholar

- Produced a critical chronology of human history, including the date of the Creation of the world.



Annals of the World (1658):

- Sunday, October 23, 4004 BC
- First Sunday after the Autumnal Equinox in 4004 BC (Julian Calendar).

All historical ages are based on the assumption that human history and physical history are the same.

This assumption is natural in the context of prevailing cultural and religious thinking of the time.

But why do all estimates get ~6000 years?

Writing emerged in the Near East during the 4th millennium BC.

Human history is traced through its written records, augmented by oral history (legends and traditions) by another millennium.

Is this central assumption correct?

Do you get the same answer if you only consider physical evidence?



Edmund Halley (1656-1742) made one of the earliest physical estimates of the Earth's age.

Estimated the time required for an initially fresh-water ocean to achieve its current salinity:

If only a few 1000 yrs old, the oceans would still be fresh water

If infinitely old, the oceans would be saturated with salts like the Dead Sea.



John Joly (1890s) revised this estimate to 80 – 100 Myr

George-Louis Leclerc (1707-1788) made physical estimates based on cooling times for a hot Earth.

Estimated the time needed for an initially molten Earth to cool down.

Experimented with hot iron spheres and scaled up to an Earth-sized mass.

Got an age of ~75,000 years



Lord Kelvin revised this to between 20 and 400Myr in 1897.

James Hutton (1726-1797) described repeated cycles of uplift and erosion in geologic history.

Theory of the Earth (1795)

Introduced the concept of "repair" into geological history.

Previous idea was decay from an initial creation

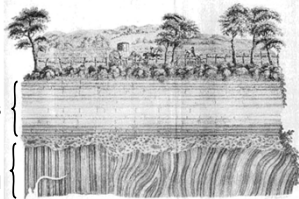


Concluded that the Earth was millions of years old

But, he also asserted that the cycle of decay & repair erased much of this history.

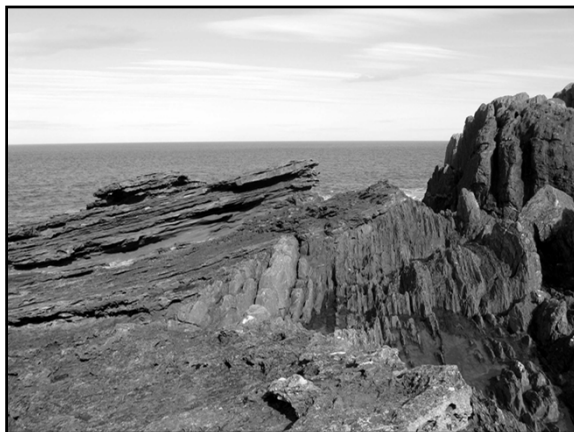
Recent sediments

Older sediments
uplifted and tilted



The Hutton Unconformity
Jedburgh, Scotland





Charles Lyell (1797-1875) introduced methods of stratigraphy for measuring Earth's history.

Used strata of different rocks to separate the ages of previous geological history.

Used changes in fossils in strata as ways to fix their relative ages.

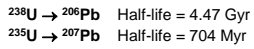


Old rocks are like young rocks, but life shows great variation with time.

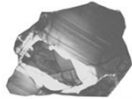
Wrote the *Principles of Geology*, which greatly influenced generations of scientists, including young Charles Darwin.

Radiometric dating measures the ages of rocks by comparing isotopes of radioactive elements.

Zircon crystals can form with inclusions of Uranium isotopes ^{238}U and ^{235}U :



Both lead (Pb) isotopes are *stable*.



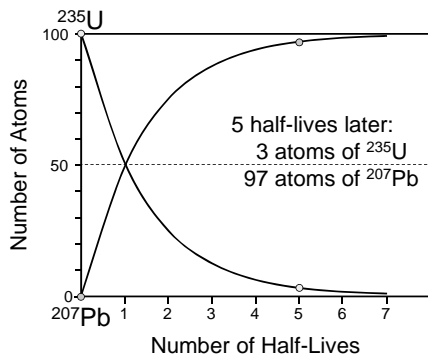
Zircon strongly rejects lead at formation, and so starts out with *zero* lead content.

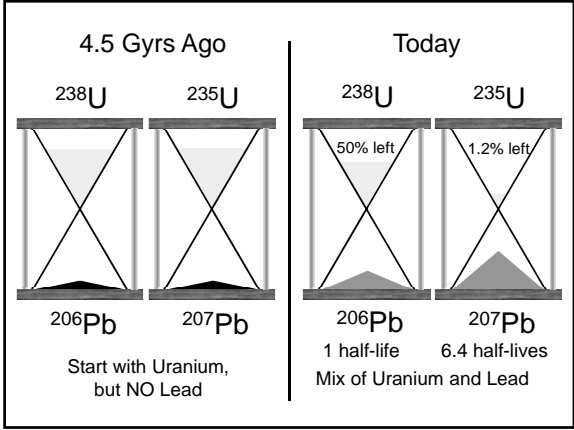


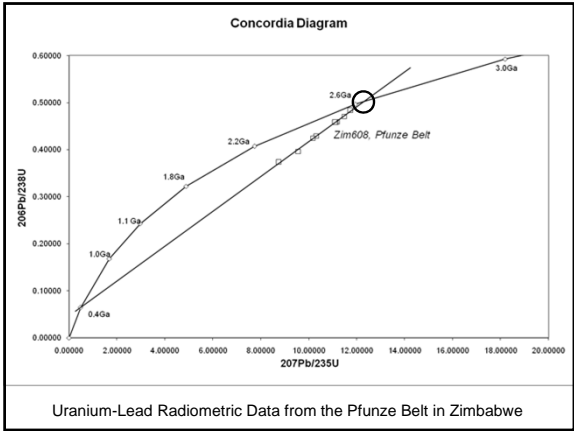
Over time...

There is less ^{238}U and even less ^{235}U as it decays
Accumulate increasing amounts of ^{206}Pb and ^{207}Pb
Also get steady changes in the Pb isotope ratio

Start with: 100 atoms of ^{235}U
0 atoms of ^{207}Pb







The radiometric dating has been greatly refined and now gives highly precise and accurate results

Uranium-Lead method now gives ages with as low as a 2 Myr of error margin in 2.5 Gyr ages.

Other radiometric methods

$^{147}\text{Sm} \rightarrow ^{143}\text{Nd}$ Half-life = 106 Gyr

$^{87}\text{Rb} \rightarrow ^{87}\text{Sr}$ Half-life = 50 Gyr

$^{40}\text{K} \rightarrow ^{40}\text{Ar}$ Half-life = 1.30 Gyr

Combine different measurements to confirm the age of a particular rock sample

Radiometric data measures the time since the rock has solidified.

When a mineral solidifies...

Chemically-allowed elements are locked in.

Chemically rejected elements are locked out.

The daughter products of locked-in radioactive parent isotopes stay locked into the mineral.

Re-melting a mineral releases daughter isotopes, "resetting" the radiometric clock.



Because Earth is geologically active, you need to find the oldest Earth rocks to get Earth's age.

Most of the Earth's crust is less than 100Myr old

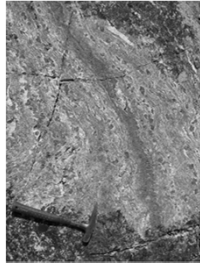
Most surface rocks have been melted & solidified many times.

The World's Oldest Rocks:

Jack Hills of Australia (4.4 Gyr Zircons)

Acasta Gniess in Canada (4.03 Gyr)

Isua Greenstone Belt in Greenland (3.8Gyr)



4.28 Gyr rock in Canada

The Earth is 4.54 ± 0.05 Billion Years old.

Measured by radiometric age dating of meteorites

Consistent with the oldest Earth zircons and Moon rocks returned by NASA and the USSR.

Precision is about 1%

Firmly establishes the great antiquity of the Earth.