Nature of Geology

“Scientific Method”

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- Ask question
- Pose hypothesis (possible answer)
- Test hypothesis
  - Experimentation (identifying and controlling variables)
- Analyze data
- Confirm or reject hypothesis (NOT prove or disprove)
- Theory - hypothesis repeatedly supported by evidence

Is this how we do Earth Science?

- Can’t run experiments or control variables
- Missing data

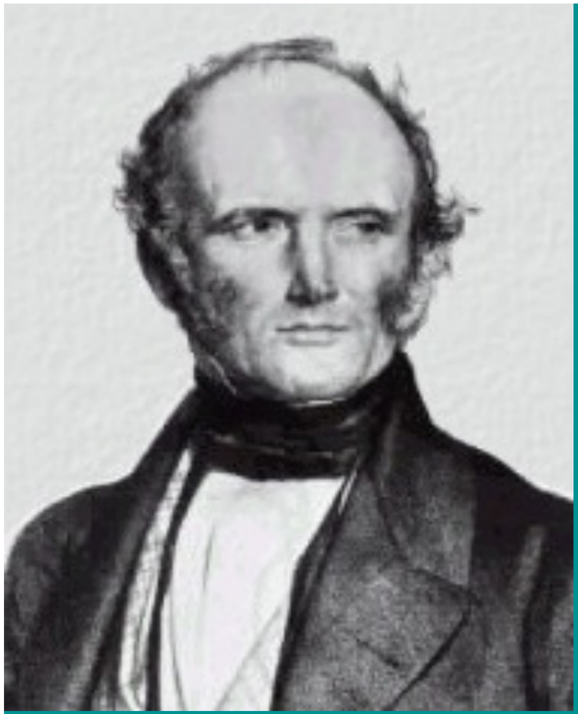
Scientific Models

- Notice an interesting phenomena
- Ask a question about the phenomena
- Gather data
- Look for patterns
- Construct explanations ("multiple working hypotheses") and identify assumptions
- Gather data that tests explanations
- Revise model as necessary

Underlying Paradigm of Earth Science

Uniformitarianism

"Present is the key to the past"



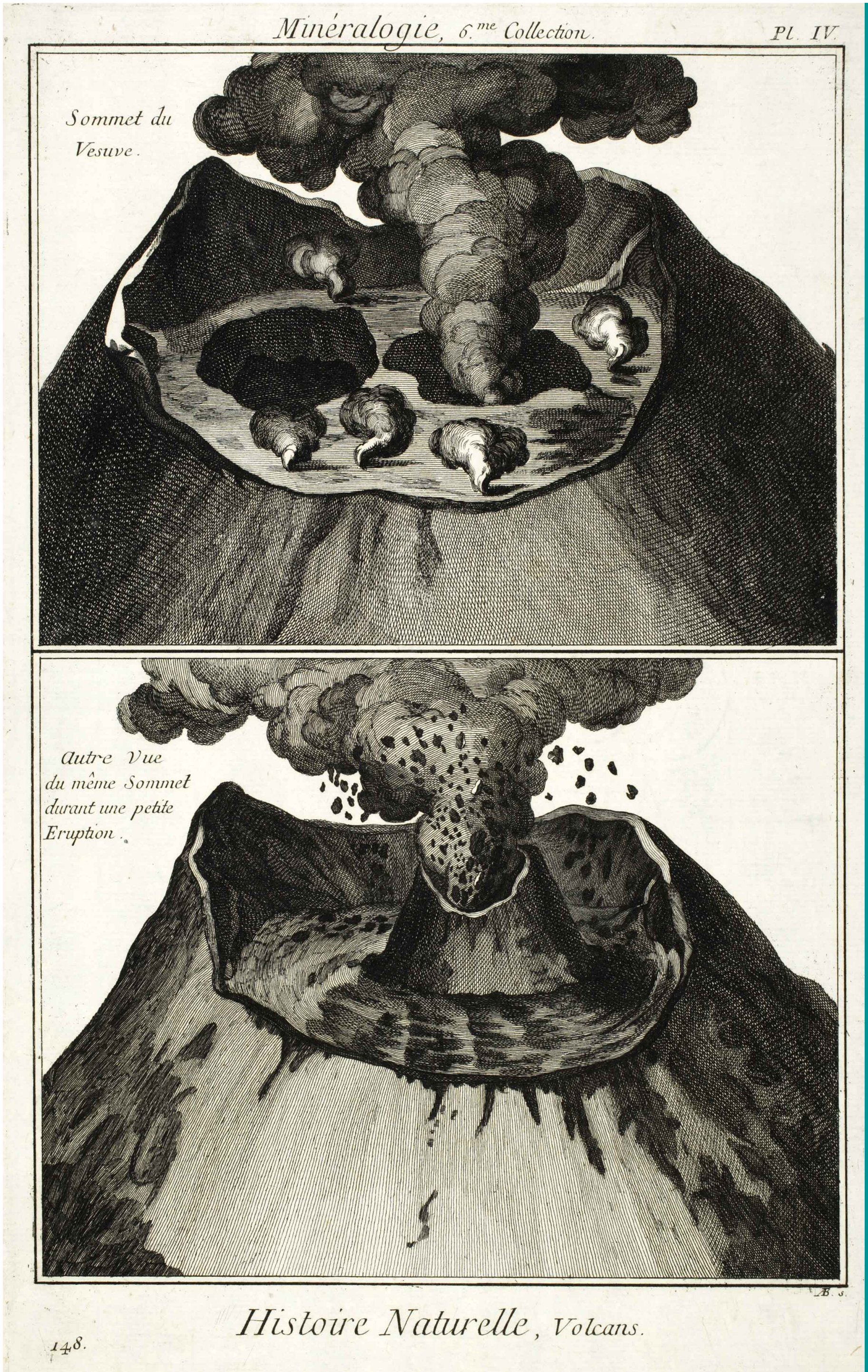
Charles Lyell

19th century lawyer and geologist

Earth processes are uniform: same processes at same rate over time

Earth is in equilibrium - any change is countered by an opposite change

Nile Delta: gradual accumulation of sediment



Catastrophism

Earth has been shaped through sudden, violent catastrophes

- Biblical catastrophism: Flood geology
- Secular catastrophism: earthquakes, volcanoes, etc.

Evidence for uniformitarianism

- We haven't encountered any circumstances yet in which physical laws do not operate.
- We can witness geologic processes and then look at the evidence they leave behind
- We can witness modern catastrophes and see the evidence they leave behind
- Abundant evidence of an ancient Earth allows for plenty of time for gradual processes (and catastrophes) to occur

Modern Uniformitarianism: Actualism

- Physical laws have been constant over Earth's history
- Many processes that happened in the past are similar or identical to processes that happen today, but not necessarily at the same rate
- Catastrophes shape the Earth over time, in the past as they do today
- It's all a matter of scale

What are the differences between catastrophism, uniformitarianism and actualism?

- How does the Earth change?
- Constancy of the Earth
- Rates of change

	Catastrophism	Uniformitarianism	Actualism
How does the Earth change?	Big episodic events	Continuous uniform events	A range of events
Constancy of Earth	Starts out one way (violent), now a different way	Same events over time at same rate: Earth is as it has been	Physical laws are constant, but Earth may be different depending on how conditions change
Rates	Fast things long ago	Constant	Rates can vary, but laws don't

- Original Horizontality: sedimentary rocks and lava flows are originally formed in horizontal layers because of gravity.

http://www.atpm.com/11.08/from-atpm-readers/arizona-grand-canyon-vista.shtml

- Original Horizontality
- Superposition: in an undisturbed sequence of sedimentary or volcanic rock, the oldest is on the bottom

http://www.atpm.com/11.08/from-atpm-readers/arizona-grand-canyon-vista.shtml

- Original Horizontality
- Superposition
- Lateral Continuity: Sedimentary (and many volcanic) rocks are originally deposited in continuous layers that taper out at the edges.

http://www.atpm.com/11.08/from-atpm-readers/arizona-grand-canyon-vista.shtml

- Original Horizontality
- Superposition
- Lateral Continuity
- Cross-cutting Relationships: Anything that disturbs a pattern is younger than the pattern. Features (igneous rock, faults, unconformities) that cut other rock are younger than the rock they cut

http://hays.outcrop.org/images/rocks/igneous/press4e/figure-05-09-3.jpg


http://www.geology.wisc.edu/courses/g112/rock_deformation.html

http://geotripper.blogspot.com/2011/02/death-valley-days-fourth-day-long-road.html

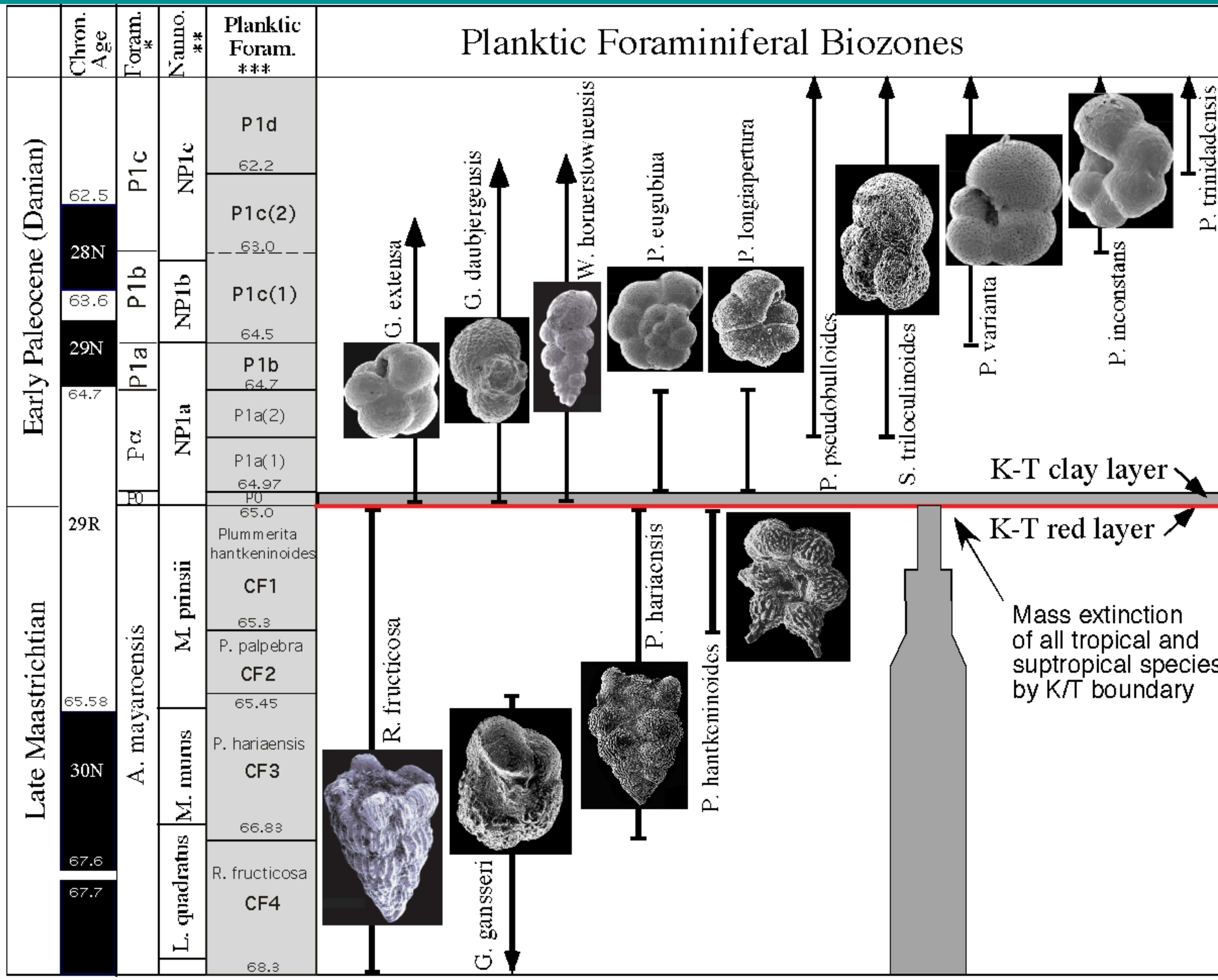
- Original Horizontality
- Superposition
- Lateral Continuity
- Cross-cutting Relationships
- Inclusions: Any rock included in another rock must be older than the rock it is included in (pebbles in a sedimentary rock, xenoliths in an igneous rock)
  - Xenolith: piece of host rock included in an intrusion of igneous rock

Inclusions

In sedimentary rock

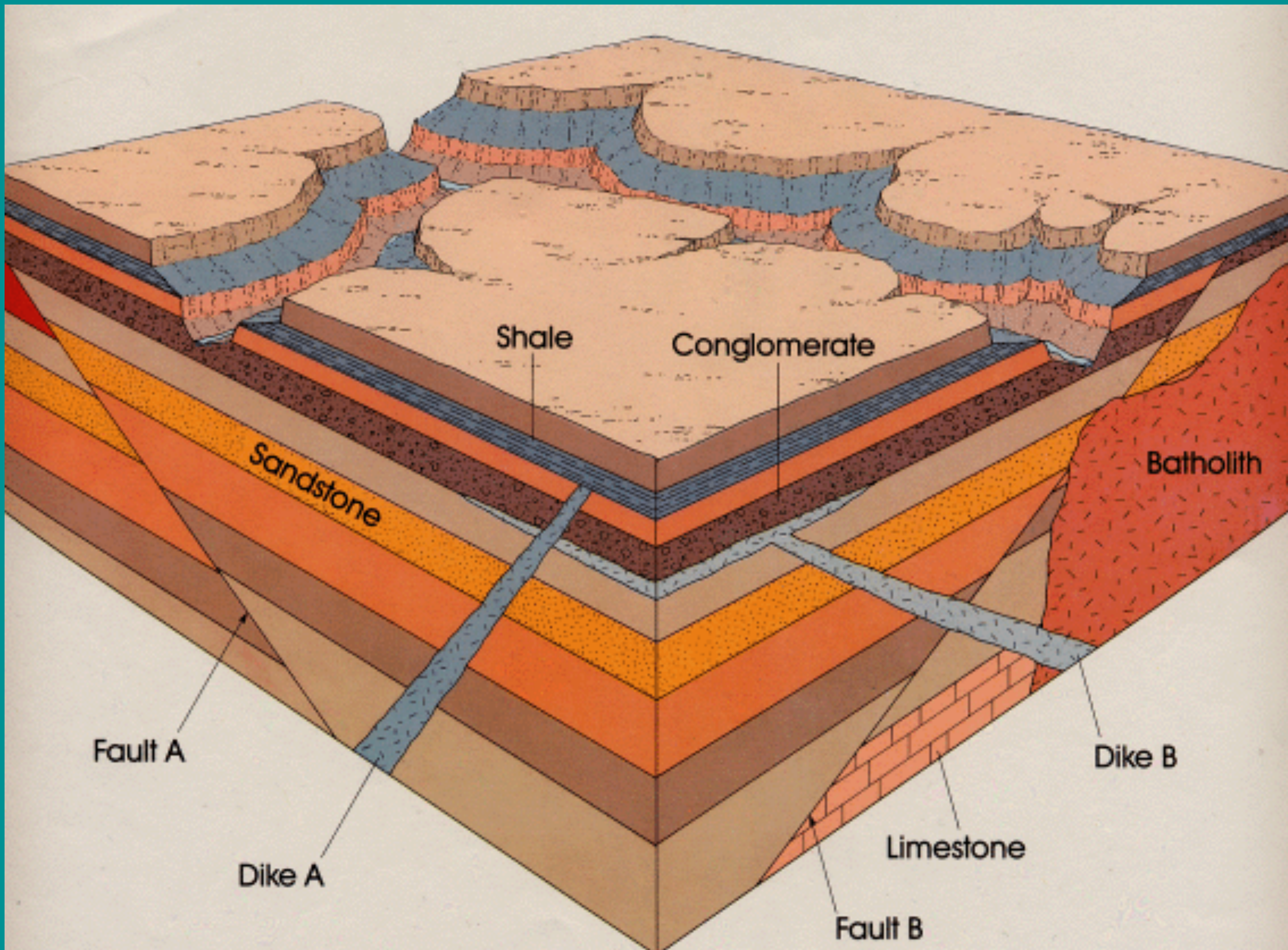
In igneous rock

- Original Horizontality
- Superposition
- Lateral Continuity
- Cross-cutting Relationships
- Inclusions
- Fossil succession: In undisturbed sedimentary rock, the fossils always occur in the same order



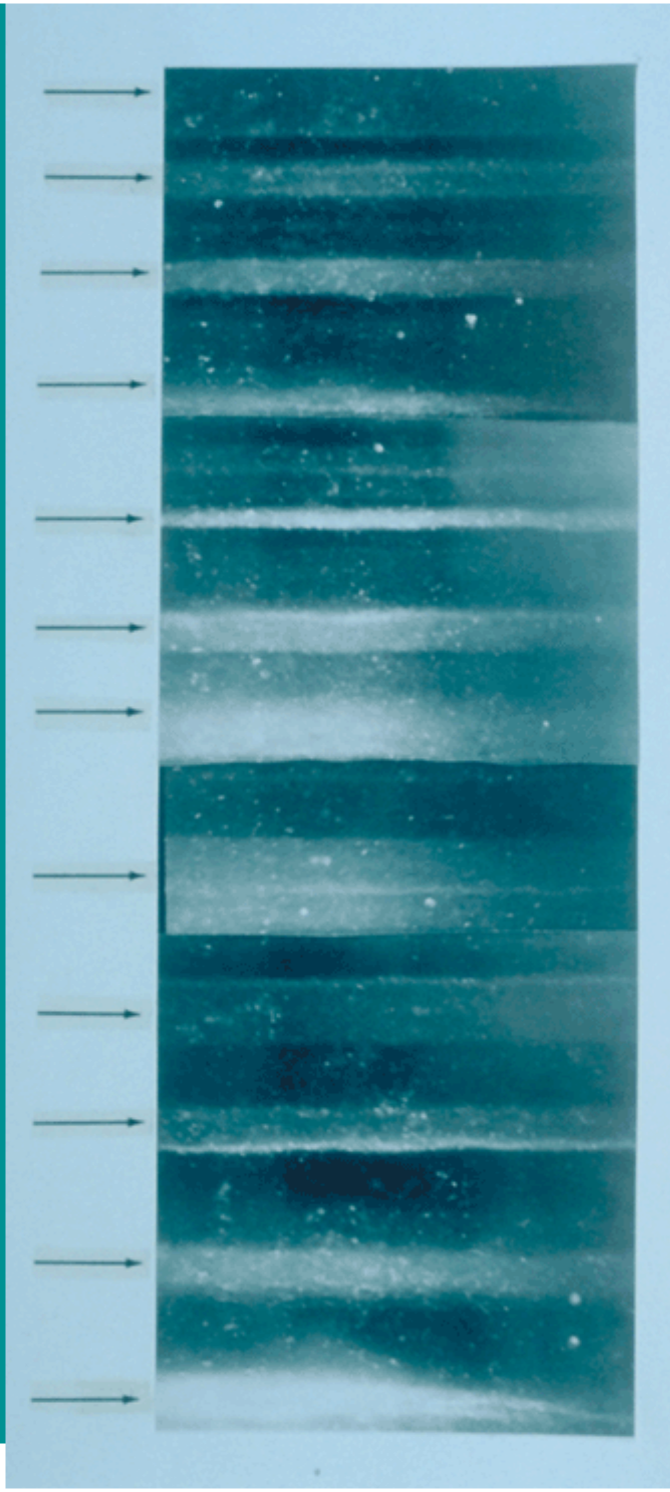
Planktic Foraminiferal Biozones
Chron. Age
Foram. *
Nanno. **
Planktic Foram. ***
Early Paleocene (Danian)
Late Maastrichtian
62.5
28N
63.6
29N
64.7
29R
65.58
30N
67.6
67.7
P1c
P1b
P1a
Pα
P0
A. mayaroensis
NP1c
NP1b
NP1a
M. prinsii
M. murus
L. quadratus
P1d
62.2
P1c(2)
63.0
P1c(1)
64.5
P1b
64.7
P1a(2)
P1a(1)
64.97
P0
65.0
Plummerita hantkeninoides
CF1
65.3
P. palpebra
CF2
65.45
P. hariaensis
CF3
66.83
R. fructicosa
CF4
68.3
G. extensa
G. daubjergensis
W. hornerstownensis
P. eugubina
P. longiapertura
P. pseudobulloides
S. triloculinoides
P. varianta
P. inconstans
P. trinidadensis
K-T clay layer
K-T red layer
Mass extinction of all tropical and suptropical species by K/T boundary
R. fructicosa
G. gansseri
P. hariaensis
P. hantkeninoides

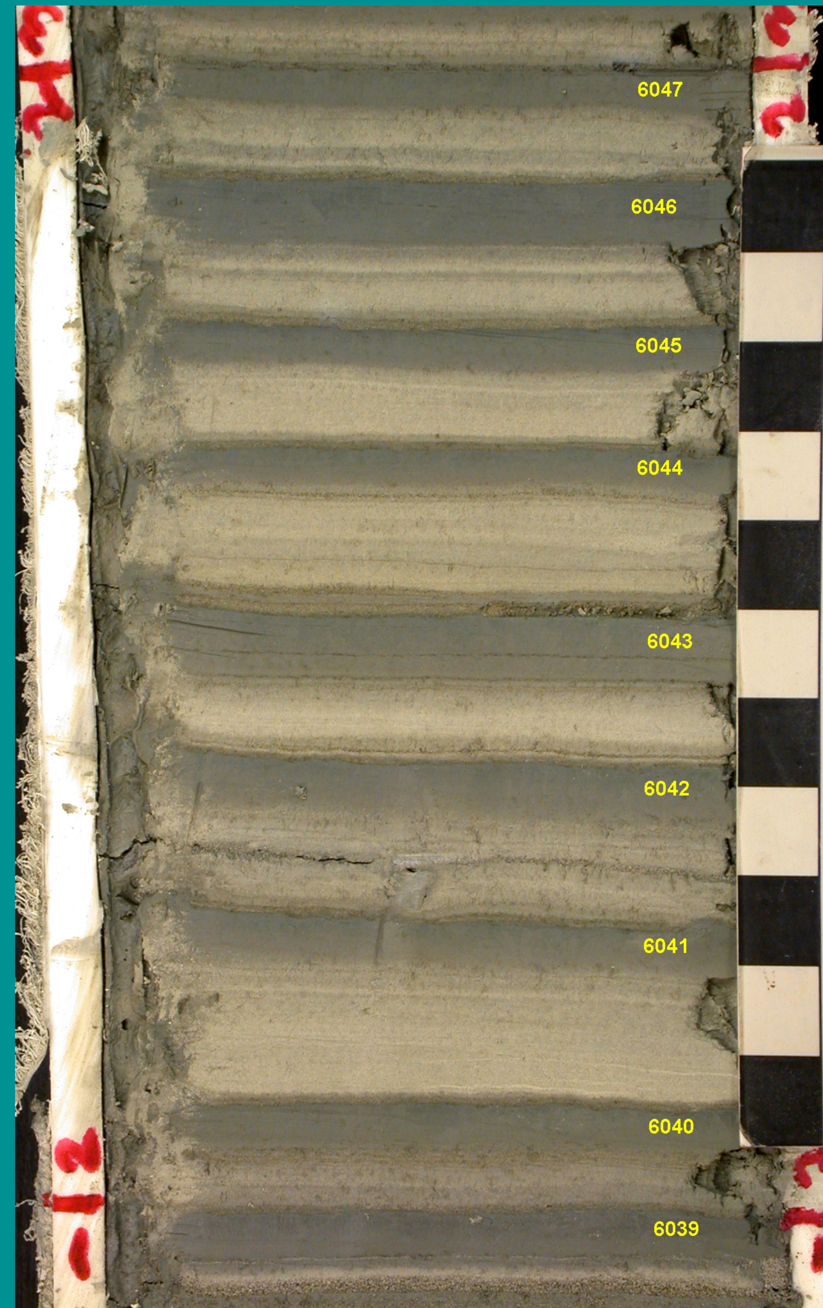
Figure 2


Shale
Conglomerate
Sandstone
Batholith
Fault A
Dike A
Dike B
Limestone
Fault B

- Relative time – order of events

- Absolute time: time in years
  - Does not have to be accurate (could be wrong)
  - Does not have to be precise (could be a range)
- Two methodologies:
  - Counting methods
    - Tree rings
    - Ice layers
    - Varves (glacial deposits)

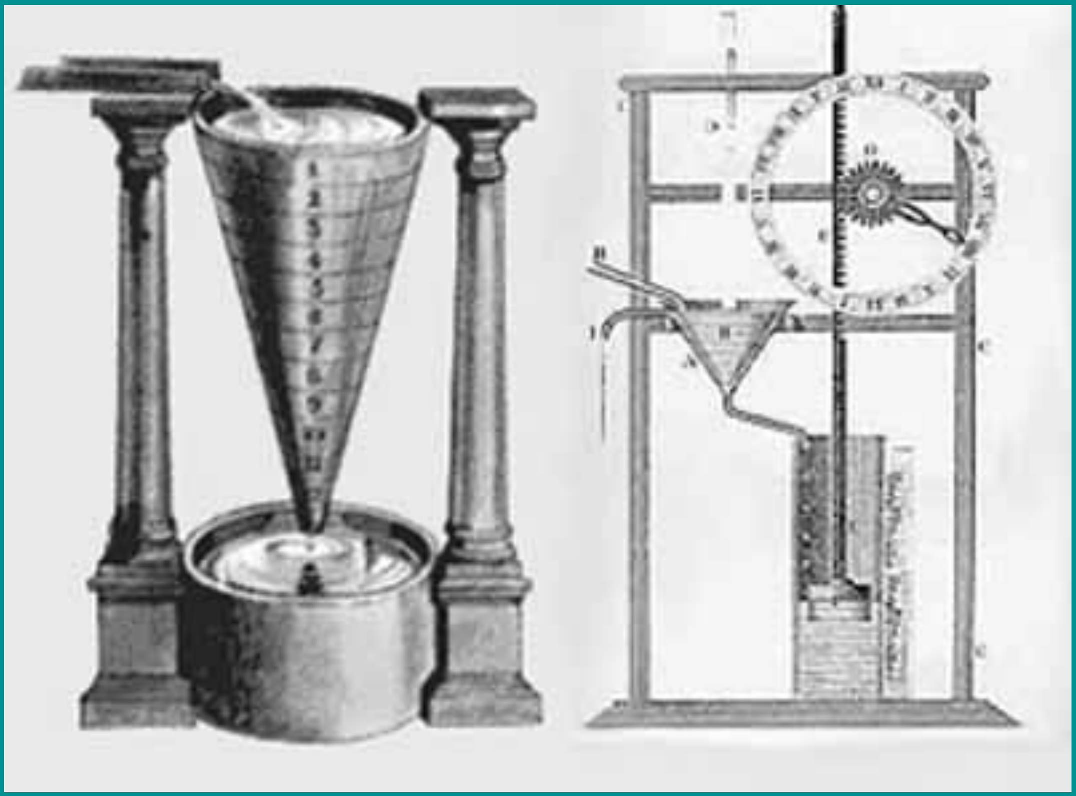



6047
6046
6045
6044
6043
6042
6041
6040
6039

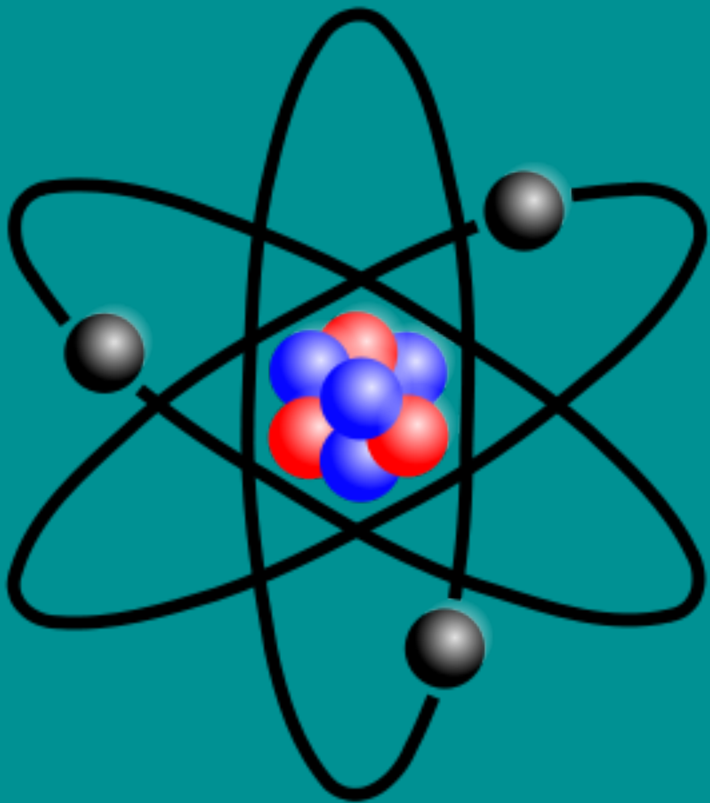
- Absolute time: time in years
  - Does not have to be accurate (could be wrong)
  - Does not have to be precise (could be a range)

- Two methodologies:
  - Counting methods
    - Tree rings
    - Ice layers
    - Varves (glacial deposits)
  - Radiometric clocks

- What's a clock?
- Anything that happens at a predictable rate



http://www.crystalinks.com/clocks.html



What does the number of protons determine?

What kind of atom it is (element)

What does the number of electrons determine?

Charge (with # of protons)

What does the number of neutrons determine?

Atomic mass (with # of protons)

Parts of atom:

In nucleus:
-Proton (+)
-Neutron (neutral)
On outside:
-Electron (-)

Isotopes: atoms of same element with different atomic mass.

Same number of…

PROTONS

Different number of…

NEUTRONS

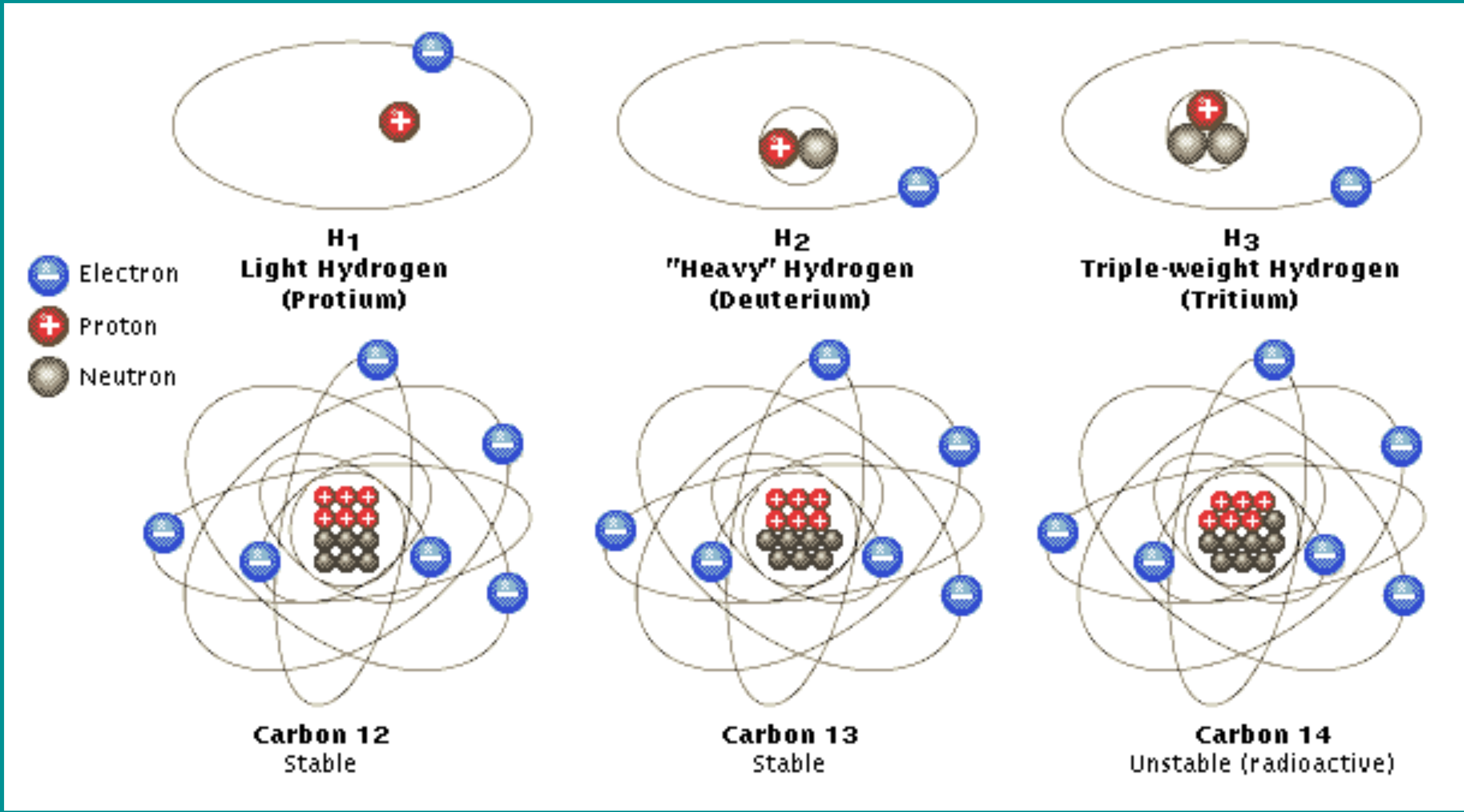
Some isotopes are STABLE.

There can be more than one stable isotope of the same element.

Some isotopes are UNSTABLE.

They spontaneously emit particles to become something else – a different isotope, a different element.

Hydrogen: one stable isotope, two unstable ones



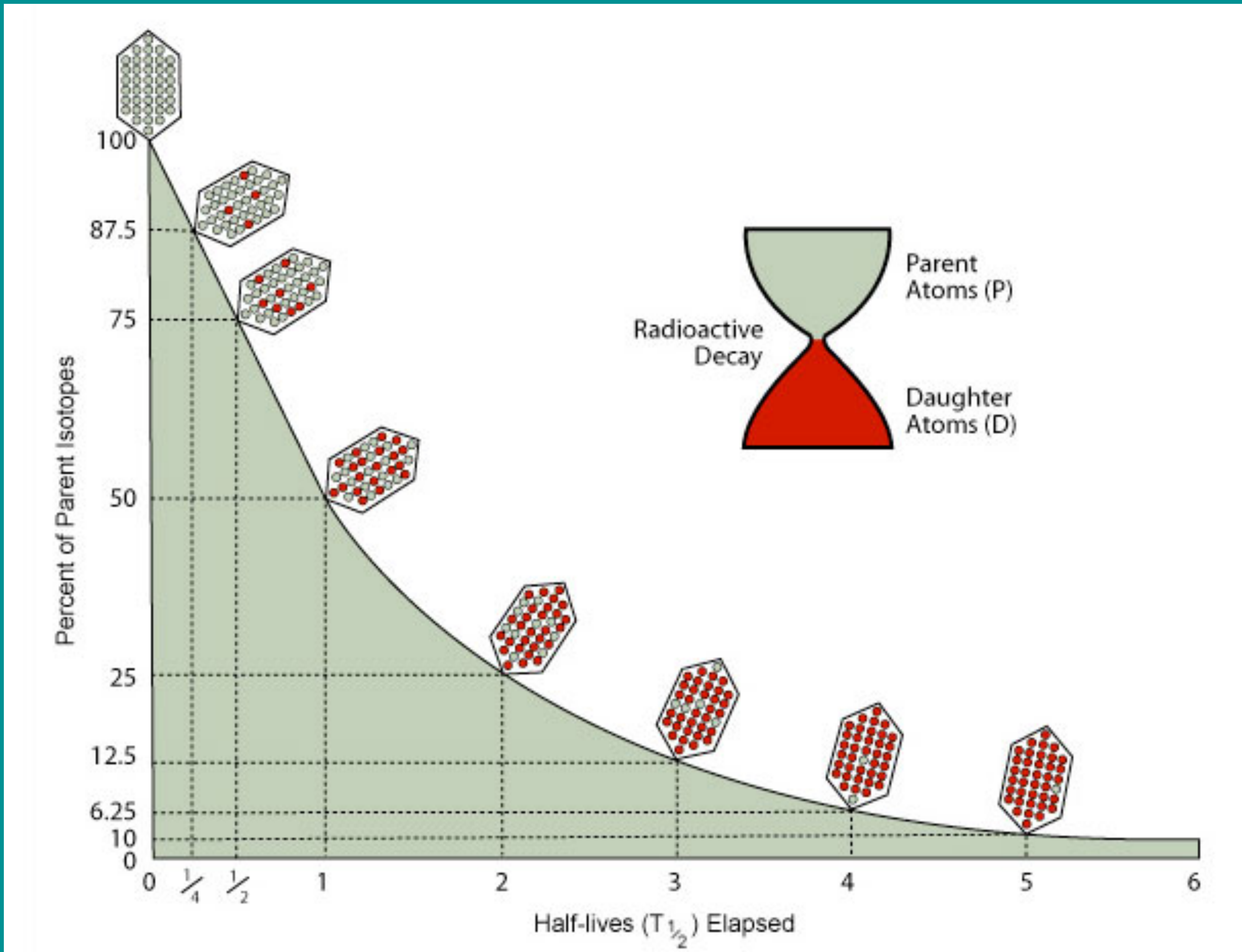
http://lc.brooklyn.cuny.edu/smarttutor/corc1321/nature.html

Carbon: two stable isotopes, one unstable

Half-life:

Time it takes for half of any amount of an element to decay (turn into something else – daughter product).

So how long does it take for the entire amount of the element to decay – 2 half lives?



http://oceanexplorer.noaa.gov/edu/learning/15_seamounts/activities/coral.html

So how do we use radioactive decay to tell time?

- What information do you have to have?

1. Half-life of isotope
2. Amount of parent and daughter isotopes

- What assumptions are you making?

1. That you accurately know the half-life
2. That you have accurately measured all the parent and daughter
3. That you have not lost any of the parent or daughter

- What processes can change the results?
  - Weathering
  - Diagenesis (alteration of rock underground by groundwater)

- How do we control for error?
  - Use many samples.
  - Collect samples from unweathered, unaltered rock.
  - Use multiple dating methods: triangulation

- Main isotopes for dating & half-lives:

- ^{238}U-^{206}Pb: 4.5 GY
- ^{40}K-^{40}Ar: 1.3 GY
- ^{40}Ar-^{39}Ar: 1.25 GY
- ^{235}U-^{207}Pb: 700 MY
- ^{87}Rb-^{87}Sr: 50 MY

What does the date you get actually mean?

- For igneous rocks?

  Time after crystallization when rock cools below blocking temperature.

- For sedimentary rocks?

  For particles: when the rock that particle came from formed.

  For cement: when cement formed, which can be long after the rock lithified.

- For metamorphic rocks?

  Time after crystallization when rock cools below blocking temperature.

How can we be sure we know half-life accurately?

- When does the amount of remaining parent isotope change the fastest?
- So you can observe for a shorter time than you might think to observe the decay.
- Modern methods allow the detection of even a small number of atoms decaying.
- Even in only a milligram of 235U, there are a LOT of atoms.
- Measured about 5000 disintegrations per minute per mg 235U, corresponding to HL of about 700 MY

How can we know the age of the Earth?

- Age of oldest meteorites: 4.5-4.6 GY
- Rocks from the Moon: up to 4.3 GY
- Oldest rocks: about 3.96 GY
- Oldest bits IN rocks: zircon crystals 4.3+ GY (maybe 4.4 GY)
- But it took the Earth some time to settle into stable rock. So when did the Earth actually form?

Age estimate from lead ratios

- There are four isotopes of lead: 204, 206, 207, 208
- Only one – 204 – is NOT formed from the decay of uranium or thorium, so the lead-204 today is the same amount we've had from the beginning, the the amounts of the other 3 isotopes have been increasing due to radioactive decay of uranium & thorium.
- Some meteorites have all four isotopes of lead, but no uranium or thorium. That means that the proportions of lead isotopes in those meteorites has always been the same since the solar system formed.
- We can compare the lead ratios on Earth to those in the meteorites to tell how long it has been since the Earth had that same ratio.