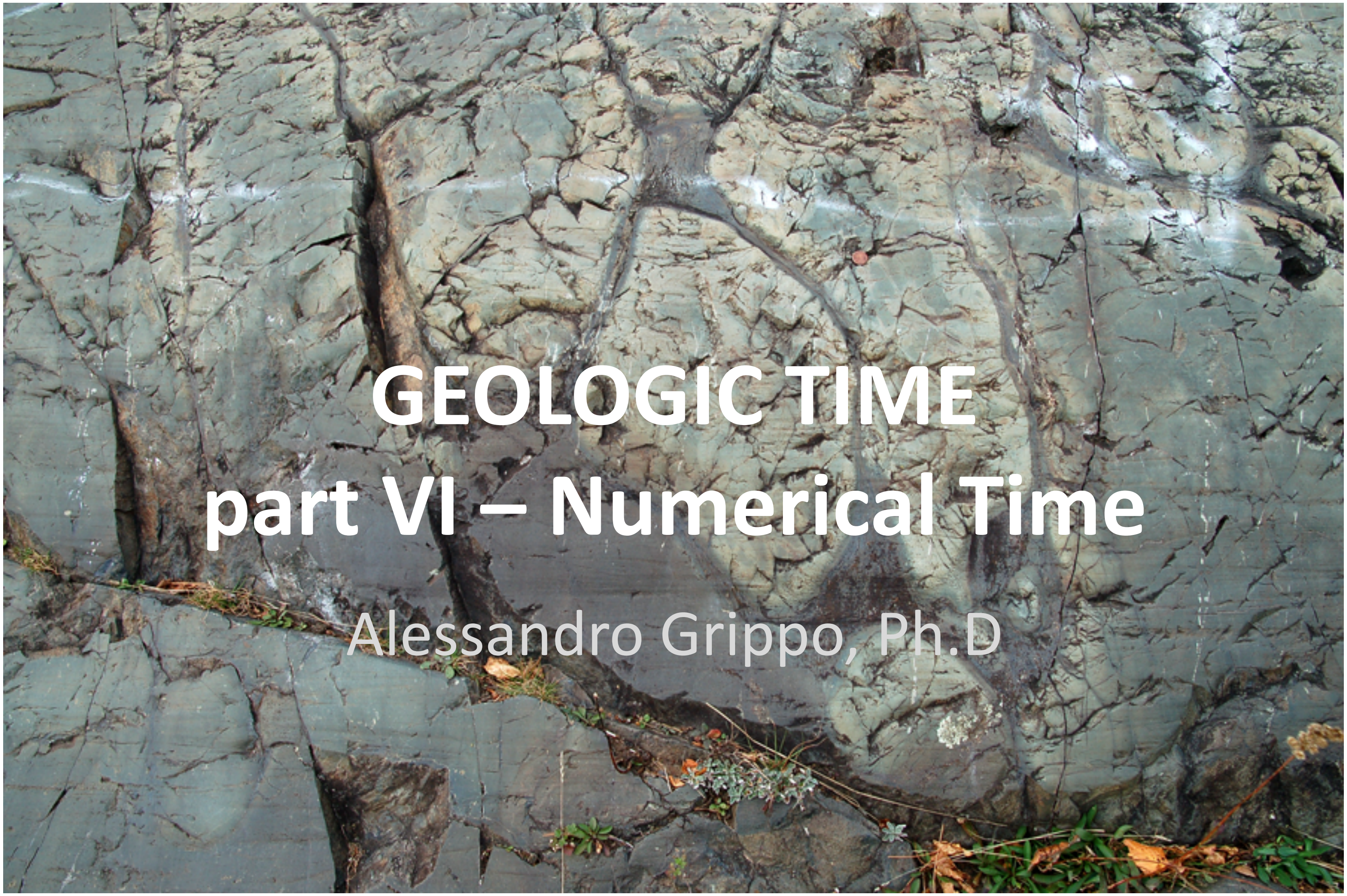


GEOLOGIC TIME
part VI – Numerical Time

Alessandro Grippo, Ph.D

Archean Pillow Basalts (Greenstones)
Gilbert, Minnesota

Numerical Time

- Numerical Time vs. Relative Time
  - we obtain a number (with a margin of error)

- Numerical methods are based on the Radioactive Decay of isotopes

- They work with Igneous Rocks only
  - except for ^{14}C, which works for organic matter only

Isotopes: a review

- Atoms
  - protons, neutrons, electrons
- Isotopes
  - Elements with the same number of protons, but different number of neutrons
  - Can either be stable or unstable (radioactive)
    - Stable isotopes are mostly used in studies of climate change
    - Radioactive isotopes are used in the determination of the numerical age of a rock or, in certain cases, organic matter

Stable vs. Unstable Isotopes: examples

^{16}O
8 protons
8 neutrons
stable

^{18}O
8 protons
10 neutrons
stable

^{12}C
6 protons
6 neutrons
stable

^{13}C
6 protons
7 neutrons
stable

^{14}C
6 protons
8 neutrons
radioactive

Radioactive (or Unstable) Isotopes

- Radioactive isotopes *decay* over time, turning into stable isotopes

- Radioactive isotopes are called the Parent Isotopes (**P**), while the products of their decay are called Daughter Isotopes (**D**)

- So P → D over time

Radioactive Isotopes: from Parent to Daughter

- There are several different couples P → D in nature
  - Examples:
    - $^{238}U \rightarrow {}^{206}Pb$
    - $^{235}U \rightarrow {}^{207}Pb$
    - $^{40}K \rightarrow {}^{40}Ar$
    - $^{87}Rb \rightarrow {}^{87}Sr$
    - $^{14}C \rightarrow {}^{14}N$

the concept of **Half-Life**

- All these couples P → D decay according to the same law

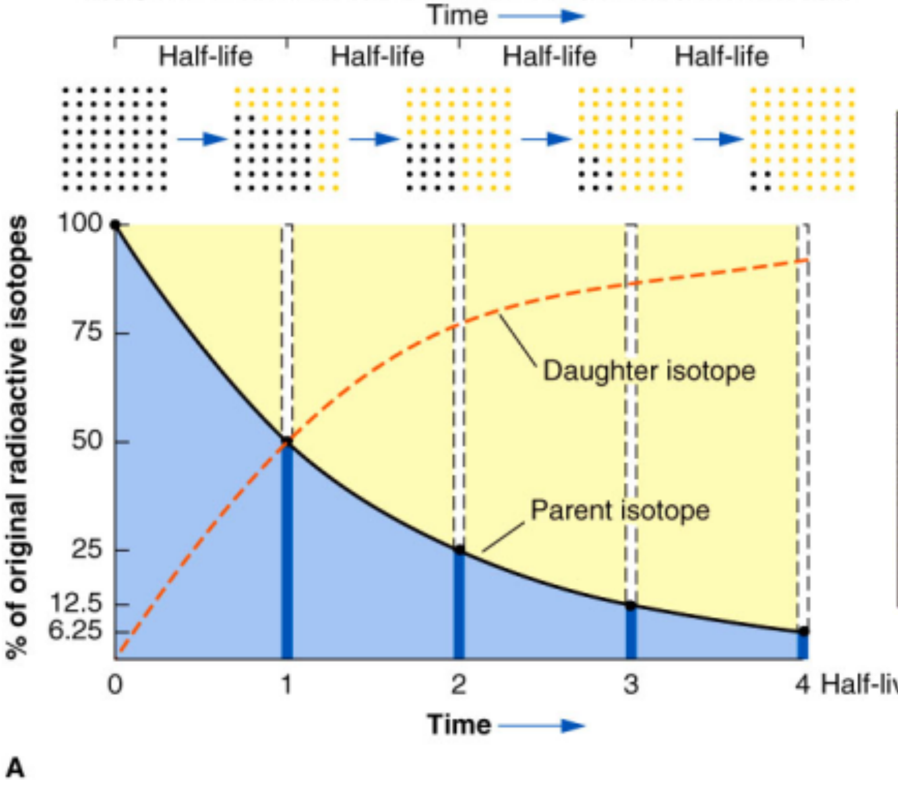
- Concept of “Half-Life”
  - The Half-Life of a radioactive isotope (P) is the amount of time that it takes for one half of it (P) to turn into D
  - That is, the time that it takes for a Parent isotope (P) to be reduced by 50%

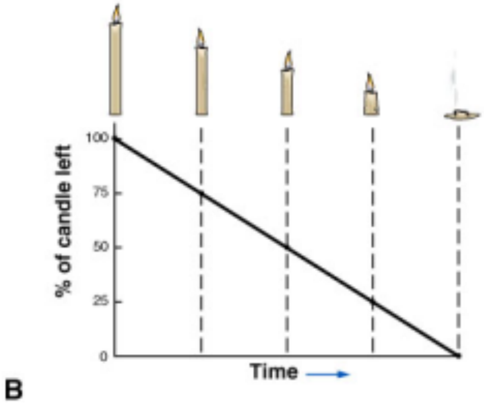
the concept of **Half-Life**

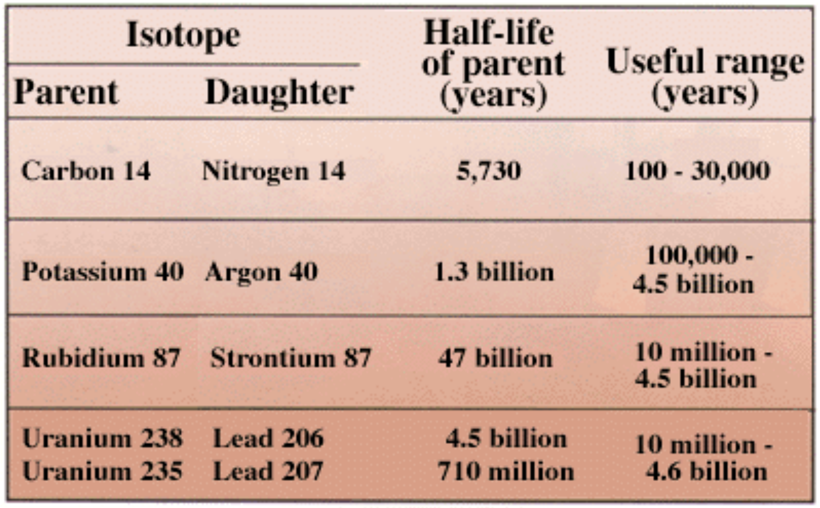
- It does not matter how many atoms of P one starts with: the concept of Half-Life is based on a percentage
  - the time that it takes for 1 million P to decay into 500,000 P is one half life
  - the time that it takes for 4 P to decay into 2 P is still one half-life

  - these two half-lives are identical in duration (for the same couple P → D)

- So, what changes from couple to couple?
- Why do we need different couples?
  - The duration of Half-Life is actually different for every couple P→ D







Isotope		Half-life of parent (years)	Useful range (years)
Parent	**Daughter**		
Carbon 14	**Nitrogen 14**	**5,730**	**100 - 30,000**
Potassium 40	**Argon 40**	**1.3 billion**	**100,000 - 4.5 billion**
Rubidium 87	**Strontium 87**	**47 billion**	**10 million - 4.5 billion**
Uranium 238 **Uranium 235**	**Lead 206** **Lead 207**	**4.5 billion** **710 million**	**10 million - 4.6 billion**

What is the age of a rock that contains 25% of the original ^{235}U?

Go on the y axis of the diagram, locate 25%
From there, go parallel to the x axis and intercept the curve.
From there go down to the x axis and you fill find out that the number of half-lives required is 2.
(It makes sense: it takes 1 half-life to go from 100% to 50%, and another half-life (total of 2) to go from 50% to 25%).

At this point you have to multiply the length of the half-life of the $^{235}\text{U} \rightarrow {}^{207}\text{Pb}$ (710 million years) by two. The rock is 1,420,000,000 years old

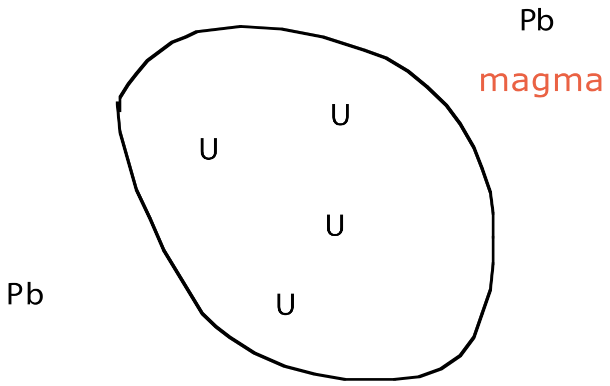
What can I date?

- **Igneous Rocks**
  - When magma cools, igneous rocks can include some P, but not D
    - For instance, when felsic magma cools underground, forming plutons, they originate a rock called granite
    - The common minerals in granite are
      - Quartz SiO_2
      - K-Feldspar $KAlSi_3O_8$
      - Na-Plagioclase $NaAlSi_3O_8$
      - Biotite $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$
    - But other, less common elements (such as Zr, Zirconium, and U, Uranium) can also form minerals
      - Zircon $ZrSiO_4$

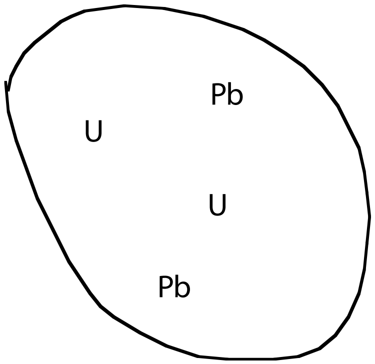
Zircons in igneous rocks

- **Zircon**
  - When magma cools, zircons form as a relatively rare mineral in igneous rocks
  - We have seen how Uranium (U, the Parent isotope) turns in time into Lead (Pb, the Daughter isotope)
  - Zircons would only allow Uranium to enter their structure (as an impurity), but NOT Pb

Both U and Pb are originally found in magm
When magma cools, Zircon crystals can forn
But, only U can enter in a Zircon, Pb cannot

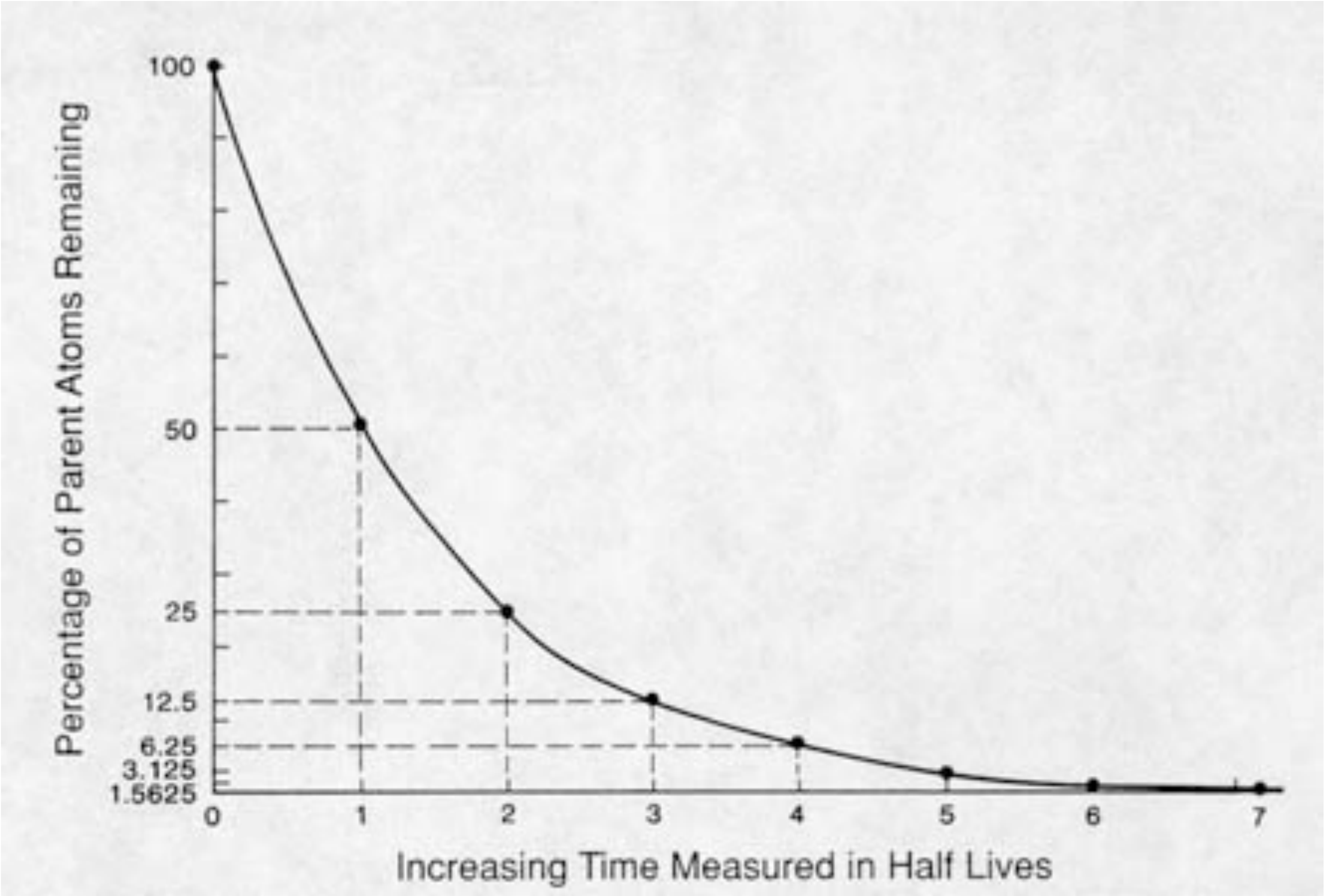


After one-half life, 50% of U has decayed into Pb. We are CERTAIN that Pb comes from decay of U and was not originally in the Zircon, so we know how many original atoms of U we had. That amount will be our 100% Parent



- **Zircon**
  - So, when zircons crystallize, it does not matter how many P are present: whatever their number, they will constitute 100% of isotopes
  - After cooling, P start to turn into D
  - When recovering igneous rocks, the sum of P and D present in it would give us the number of original P
  - So we know how many P we had originally, and how many we have today, and we take that percentage on the radioactive decay curve

Curve of Radioactive Decay



why only Igneous Rocks?

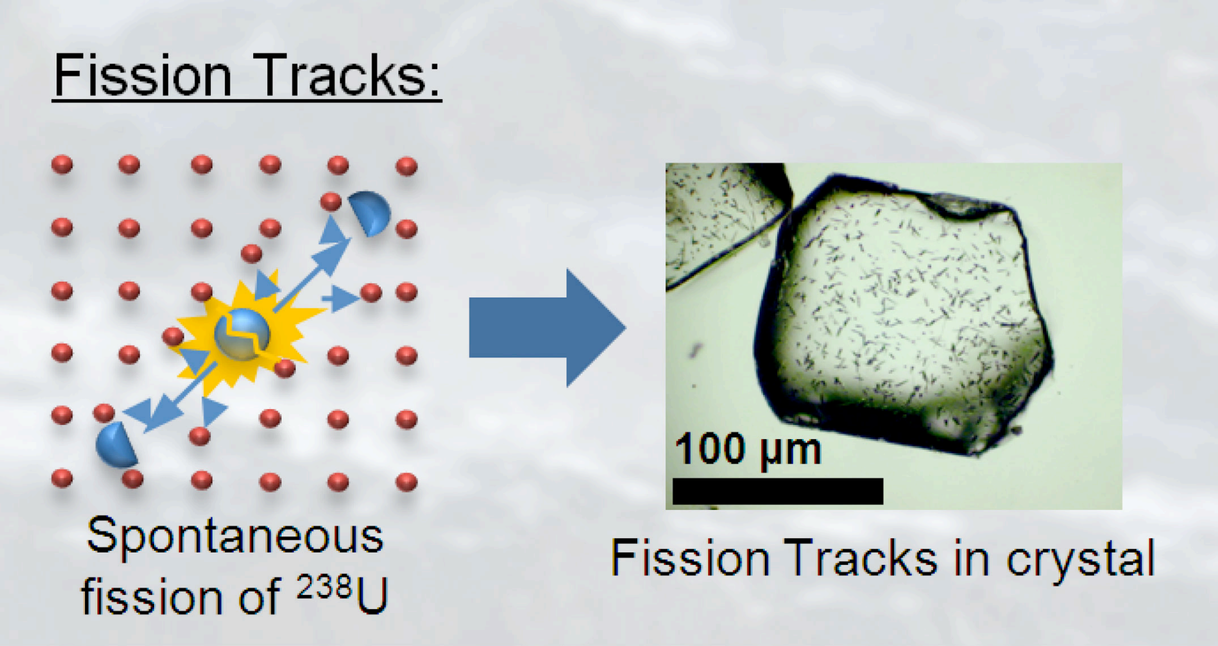
- Igneous rocks are a closed system
  - Metamorphism opens up the system
    - you can date the time of metamorphism, sometimes
    - oldest rock on Earth, Acasta Gneiss (NWT, Canada), dated at 3.96 billion years

  - Sedimentary rocks can be dated for individual minerals but not for the rock itself: still, not a closed system
    - A Mesozoic sandstone (age know through relative methods), still from Canada, contains zircons grains dated at 4 billion years
    - the grain is older than the previous rock, but it is NOT A ROCK

  - It is always a safe bet to date with two different systems P→D: dates should be *concordant*

Fission-Track Dating

- Uranium decay also leaves linear tracks in crystals
- Counting how much uranium is left, and how many fission tracks are present, allows dating
- If the rock gets heated (metamorphism!), tracks are annealed and method does not work



^{14}C methods

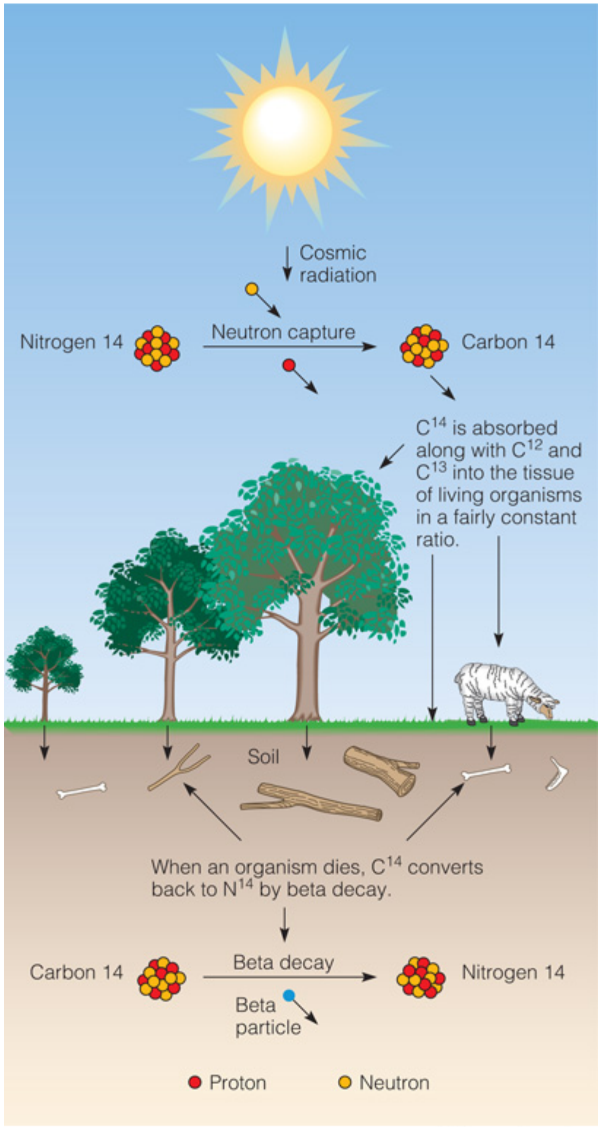
- ^{14}C is produced by high-energy solar radiation in the upper atmosphere: ^{14}N is "excited" and transformed into ^{14}C
- ^{14}C enters Earth's systems, becoming part of atmospheric CO_2
- $^{14}CO2$ is then taken up by algae and plants during photosynthesis
- Plants contain the same amount of ^{14}C of the atmosphere
- Animals eat plants
- Animals contain the same amount of ^{14}C of the atmosphere too

Conifer forest

Medicine Lake
Siskiyou County, California

^{14}C methods

- ^{14}C amounts remain constant in living organisms and also in certain kinds of ceramics (as long as the system is, again, closed)
- ^{14}C is not replaced upon death, so that we can go back in time to the moment of death by knowing its half-life (5730 years)
- Because this half-life is very short, we cannot use the method on organic matter that is older than 50,000 years ago
- So, we CAN date fossils with this method as long as they are < 50,000 years old
  - Human bones: yes
  - Dinosaur bones: no



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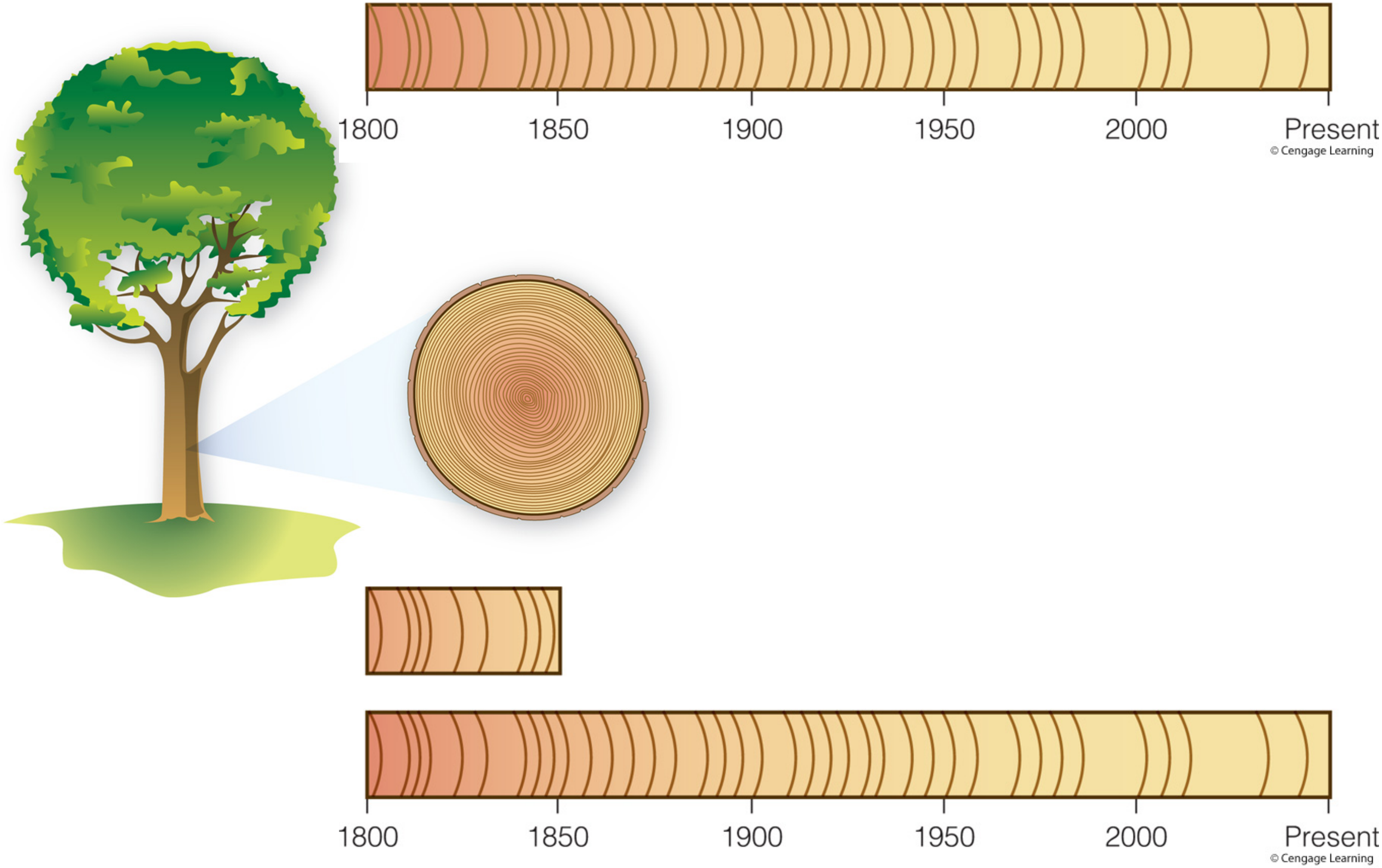
Other Numerical Methods

(not using radioactivity)

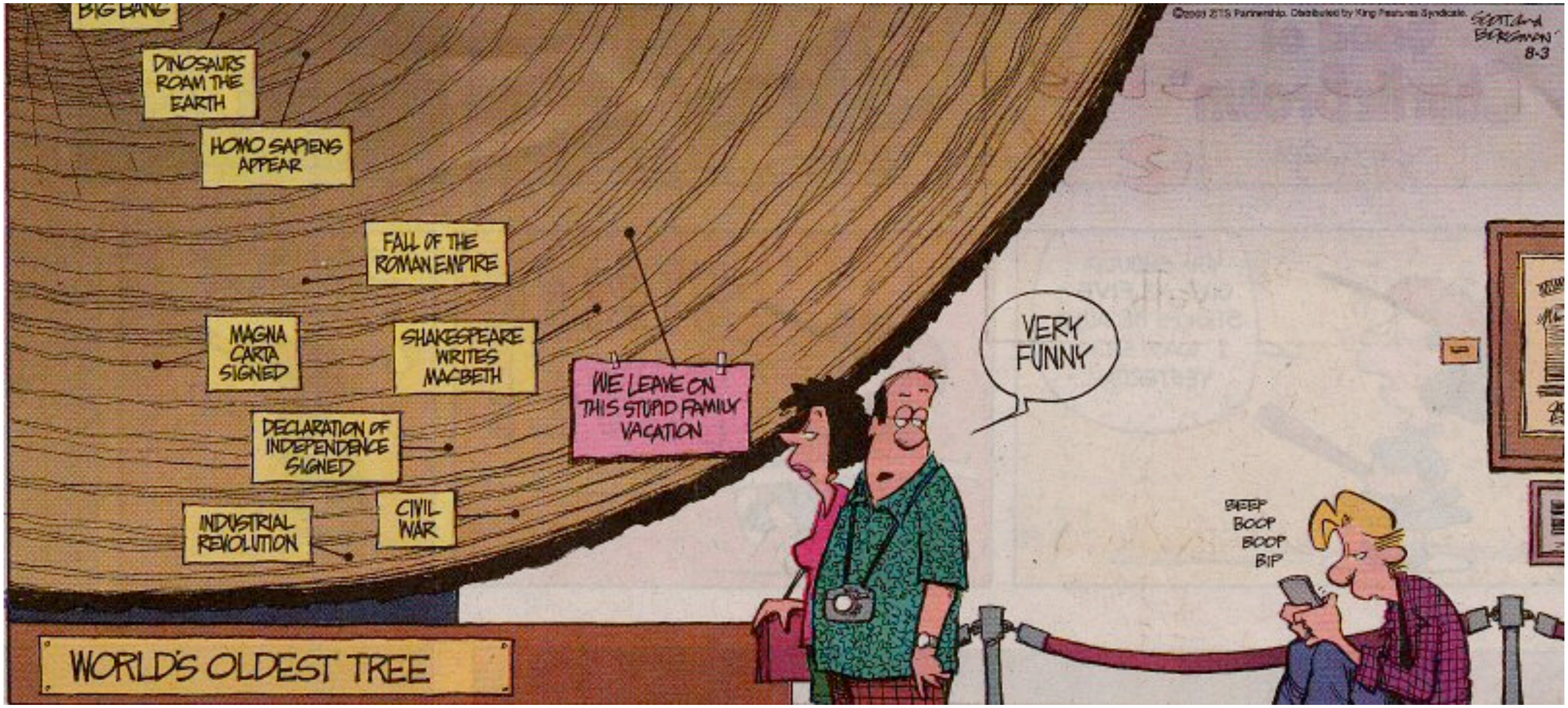
- We have to be able to count, and anchor that count to a known, specific date (otherwise we have so -called “floating chronologies”):
  - Tree Rings
    - yearly rings
  - Varves
    - yearly sediment couples
  - Milankovitch (Astronomical) Cycles
    - astronomical patterns (20,000, 40,000, 100,000, 400,000 years)

Tree Rings


1800
1850
1900
1950
2000
Present
1800
1850
1900
1950
2000
Present

Tree Rings

Lake Como, Hamilton, Montana


BIG BANG
DINOSAURS ROAM THE EARTH
HOMO SAPIENS APPEAR
FALL OF THE ROMAN EMPIRE
MAGNA CARTA SIGNED
SHAKESPEARE WRITES MACBETH
WE LEAVE ON THIS STUPID FAMILY VACATION
DECLARATION OF INDEPENDENCE SIGNED
CIVIL WAR
INDUSTRIAL REVOLUTION
WORLD'S OLDEST TREE
VERY FUNNY
BEEP BOOP BOOP BIP
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SCOTT and BORGMAN
8-3

Varves

- Glacial sediments constituted by a light-colored layer and a dark –colored layer
- Light colored sediment is deposited during warm season
- Dark colored sediment is deposited during cold season
- A varve represents 1 calendar year

Milankovitch Cycles

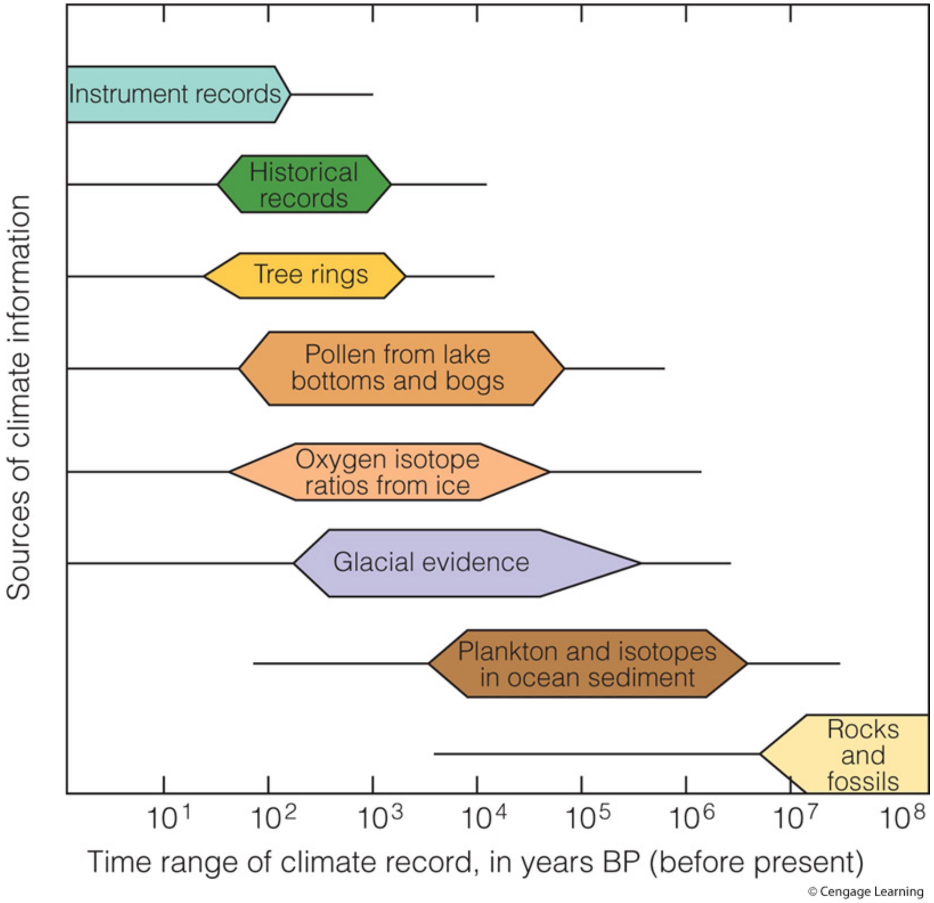
knowing the duration of a layer, and counting the layers

Cretaceous Scaglia Bianca Formation (limestone)

Gubbio, Perugia, Italy

What method should I use?

- It depends on what I have available
- It depends on the age range I need to estimate
- If older than one million years, I will use radioactive methods



NUMERICAL TIME

the end