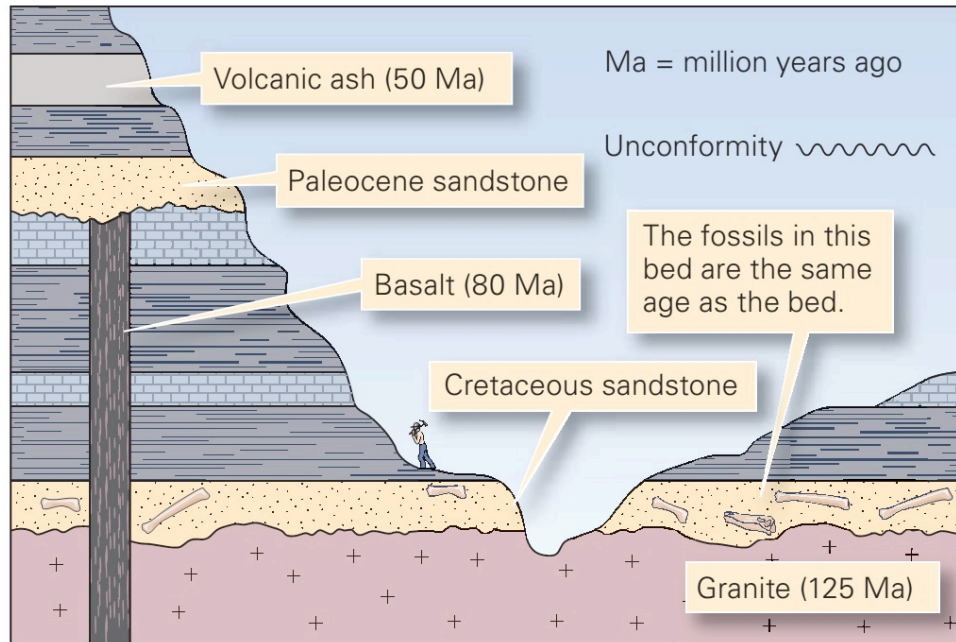


RADIODATING

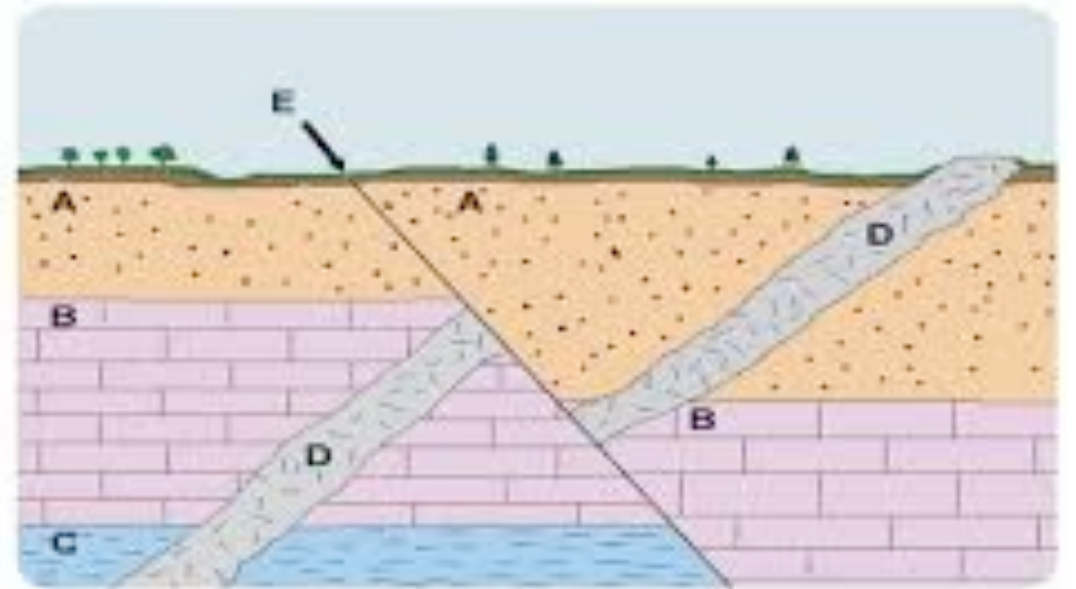
Archeological dating

- Needed to identify time and location of the findings
 - Classification: identification of the presence of common technical aspects among findings
 - Typology: identification of differences among manufacts
- Archeometry (the use of science and modern [technology](#) in [archaeology](#) to [examine](#) and [interpret](#) archaeological remains)
- Geochronology (the science of determining the age of rocks, fossils, and sediments using signatures inherent in the rocks themselves)
 - Absolute geochronology: radioactive isotopes
 - Relative geochronology: paleomagnetism/stable isotope ratios

Geo Chronology

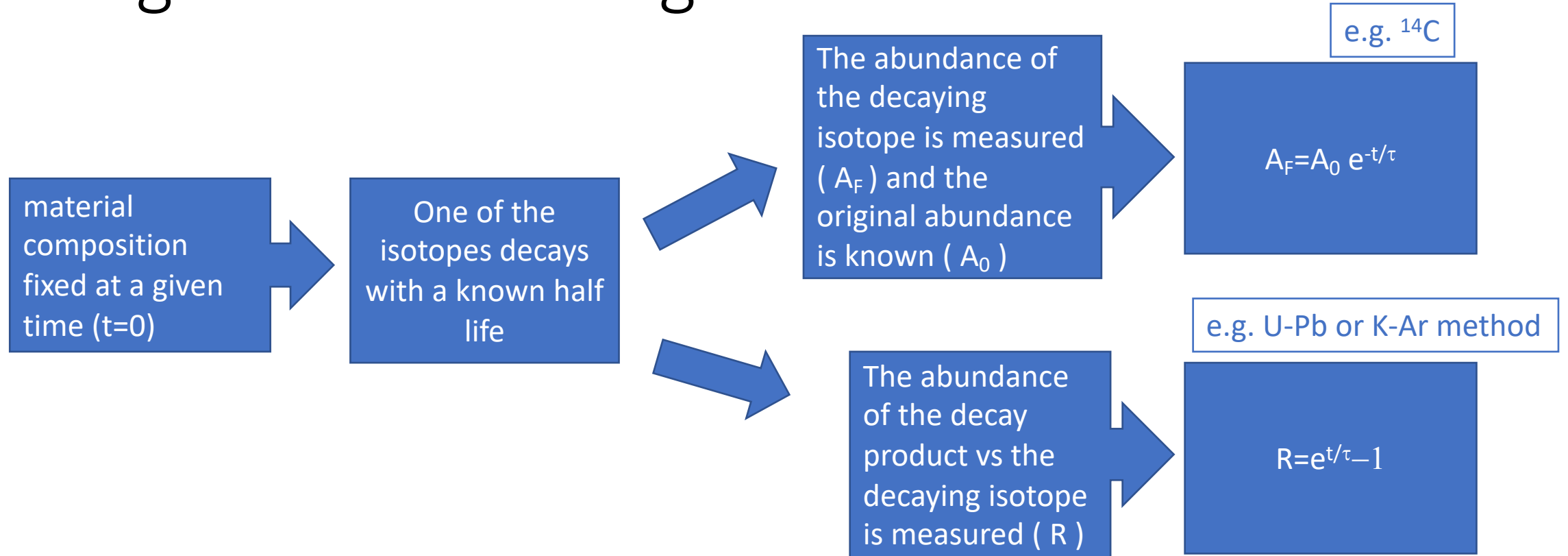


SIMPLE



COMPLEX

Logic of radiodating



Different methods for different materials

Metodi di datazione di interesse archeologico

- Metodo del Potassio - Argon (K/Ar) - Minerali. Rocce ignee e sedimentarie.
- Metodi basati sul disequilibrio delle famiglie radioattive del ^{235}U , ^{238}U e ^{232}Th .

Esempi:

Metodo del Th ($^{230}\text{Th}/^{232}\text{Th}$) - Sedimenti oceanici, vulcaniti recenti.

Metodo del Pa ($^{230}\text{Th}/^{231}\text{Pa}$) - Sedimenti oceanici.

Metodo del $^{230}\text{Th}/^{238}\text{U}$ - Carbonati, conchiglie.

Metodo del ^{210}Pb - Pitture, vernici.

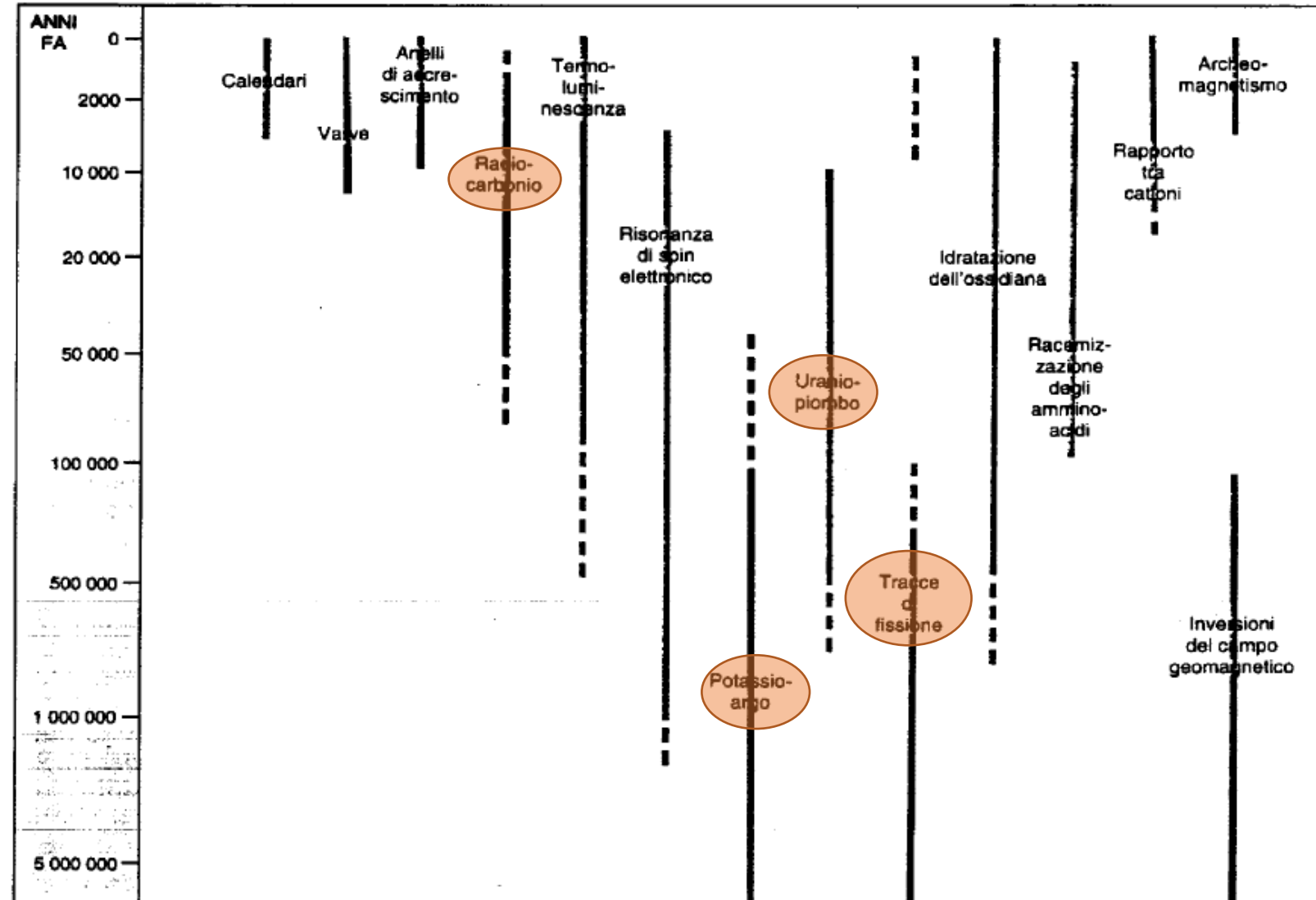
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- Termoluminescenza (TL) - Manufatti di cottura, ceramiche in particolare.
- Metodo del Radiocarbonio (^{14}C) - Resti di organismi.
- Metodo del ^{10}Be - Sedimenti.
- Metodo del ^{36}Cl - Rocce ignee o metamorfiche di superficie.
- Metodo del Trizio (^3H) - Acque.
- Metodo della Racemizzazione degli amminoacidi - Ossa, legno, sedimenti.
- Metodo dell'Idratazione delle ossidiane.
- Metodo del Fluoro o dell'Azoto - Ossa.
- Metodi basati su processi ritmici naturali

Dendrocronologia - Alberi, anche manufatti lignei.

Metodo delle varve - Ritmititi o sedimenti glaciali, lacustri, ecc. varvati

Differenti tecniche per tempi differenti

Tecniche con radiattività



Techniques based on isotopic composition measurements

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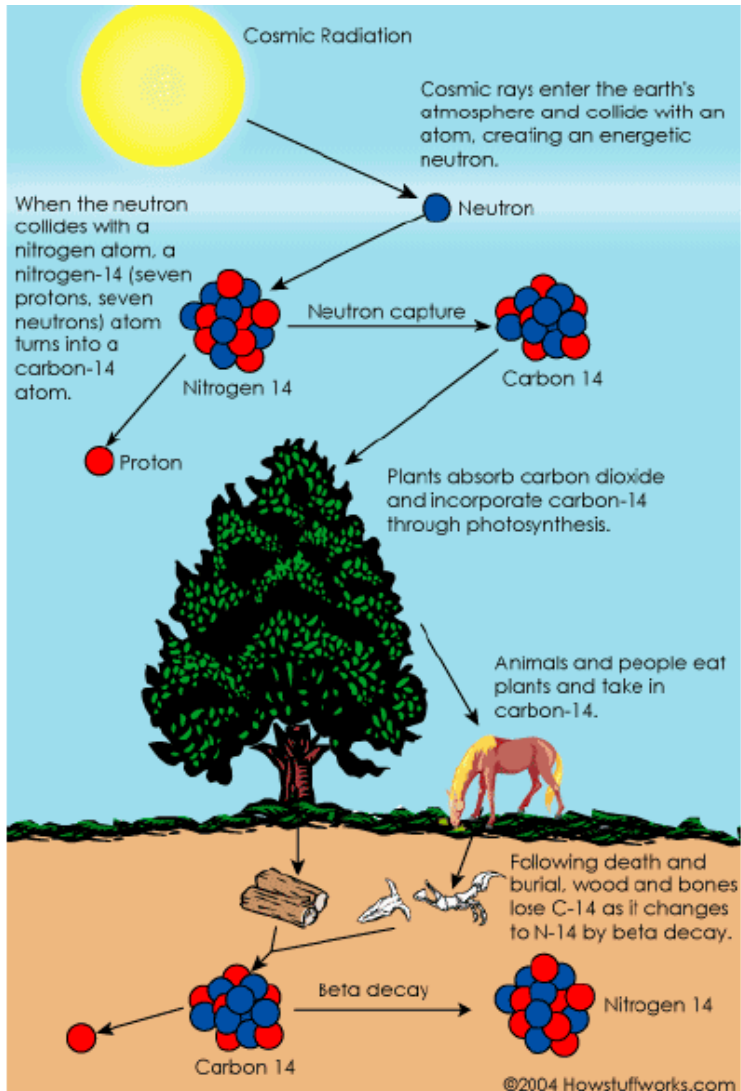
Metodo del ^{210}Pb - Pitture, vernici.

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C14 dating



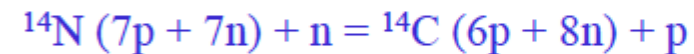
- Typical ratio $R = \frac{^{14}\text{C}}{^{12}\text{C}} = 10^{-12}$
 - Not constant in time \rightarrow corrections
- $\tau_{1/2} = 5730\text{yr}$
- The method works up to $\sim 50,000$ years
 - $R(10 * \tau_{1/2}) \sim 10^{-15}$
- Measurement methods
 - Radiactivity
 - Mass spectrometry

Atmospheric composition and reactions

Nome	Formula	Proporzione
Azoto	N ₂	78,08 %
Ossigeno	O ₂	20,95 %
Argon	Ar	0,934 %
Diossido di carbonio	CO ₂	400 ppm
Neon	Ne	18,18 ppm
Elio	He	5,24 ppm
Monossido di azoto	NO	5 ppm
Kripton	Kr	1,14 ppm
Metano	CH ₄	1 / 2 ppm
Idrogeno	H ₂	0,5 ppm
Ossido di diazoto	N ₂ O	0,5 ppm
Xeno	Xe	0,087 ppm
Diossido di azoto	NO ₂	0,02 ppm
Ozono	O ₃	da 0 a 0,01 ppm
Radon	Rn	6,0×10 ⁻¹⁴ ppm



Il ¹⁴C è prodotto negli strati alti dell'atmosfera dai raggi cosmici (principalmente protoni di alta energia). Questi protoni collidono con i nuclei dei componenti dell'atmosfera (principalmente azoto) producendo neutroni di energia più bassa. Alcuni di questi neutroni a loro volta collidono con nuclei di atomi di ¹⁴N secondo la reazione nucleare:



Notare che in questa reazione si conservano sia la carica (7 e) sia il numero di nucleoni (7 protoni + 8 neutroni).

Gli atomi di ¹⁴C così prodotti vanno a formare molecole di CO₂ che diffondono nell'atmosfera in modo tale da mantenere pressochè costante il rapporto ¹⁴C / ¹²C, nello spazio e nel tempo.

^{14}C – measurement of radioactivity

- 1g of Carbon

- 5×10^{22} atoms of ^{12}C

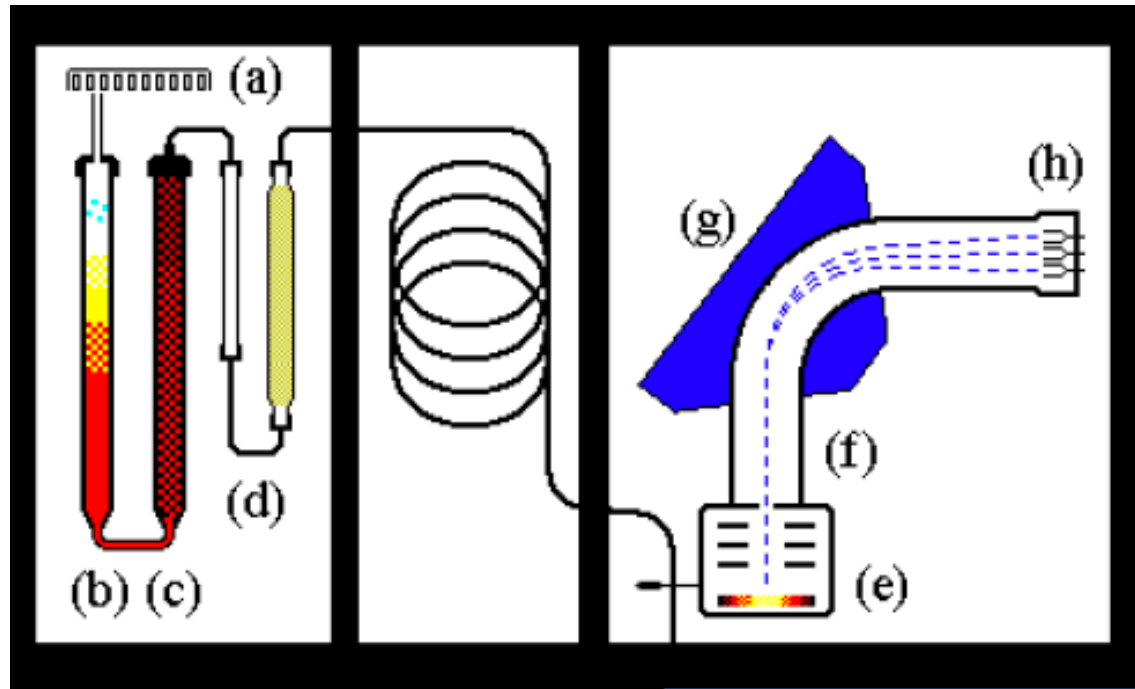
- 6×10^{10} nuclei of ^{14}C

- $\tau_{1/2} = 5700\text{yr}$

- Activity $6 \times 10^{10} / (2.6 \times 10^{11} \text{ s}) \sim 0.23 \text{ s}^{-1}$ (difficult to measure)

- After 10 half-lives (57000 yr) $A(1\text{g}) \sim 0.2 \times 10^{-3} \text{ s}^{-1}$ (unmeasurable)

^{14}C – mass spectrometry



Combustion subsystem

- a) sample dropper
- b) combustion column
- c) reduction column
- d) gas traps (water and optionally CO_2)

Mass Spectrometer

- e) ion beam source
- f) flight tube
- g) magnetic beam deflector
- h) signal detectors

1g of Carbon

→ 5×10^{22} atoms of ^{12}C

→ 6×10^{10} nuclei of ^{14}C

→ After 57000yrs there are
 6×10^7 nuclei of ^{14}C

Mass spectrometry:

$$R = mv/zeB$$

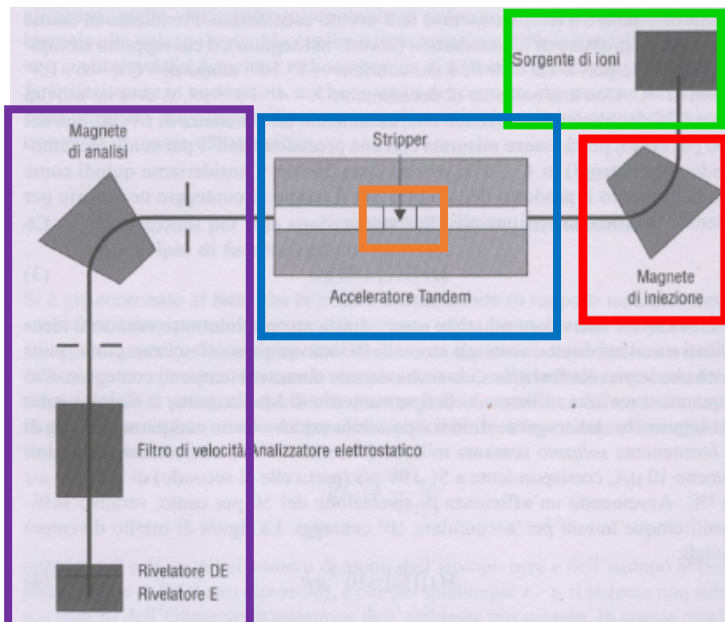
For a fixed m , the relative error
on R is the same as v

Accelerator Mass Spectroscopy

- Increases sensitivity by accelerating the ions
 - $T \sim 30 \text{ MeV}$ as opposed to 100 eV
 - $V \sim \sqrt{T} \rightarrow v$ increases by 200 → $\Delta v/v$ decreases by 200
 - Distinguish ^{14}C from $^{12}\text{C-H}_2$, $^{13}\text{C-H}$, ^{14}N ,



Allows to reach back 50000 yrs



- ION SOURCE (bombardment with Cs --> negative ions)
- FIRST DISCRIMINATOR (mass=12-14)
- ACCELERATOR (Tandem ~ 3 MV)
- STRIPPER (From negative to positive ions)
- PRECISION SPECTROMETER

How well known is the original concentration?

Estimated time from «death»:

$$t = -\tau \log\left(\frac{R}{R_0}\right)$$

And therefore the error on it is

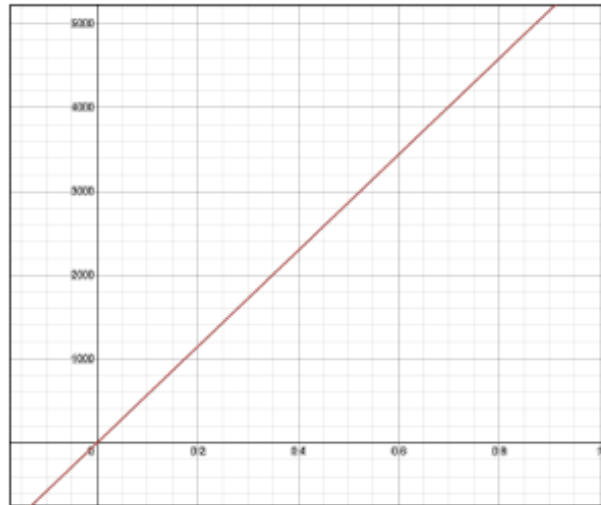
$$\Delta t = -\tau \Delta_r$$

where

$$\Delta_r = \sqrt{\left(\frac{\Delta R_0}{R_0}\right)^2 + \left(\frac{\Delta R}{R}\right)^2}$$

Original concentration needs to be well known

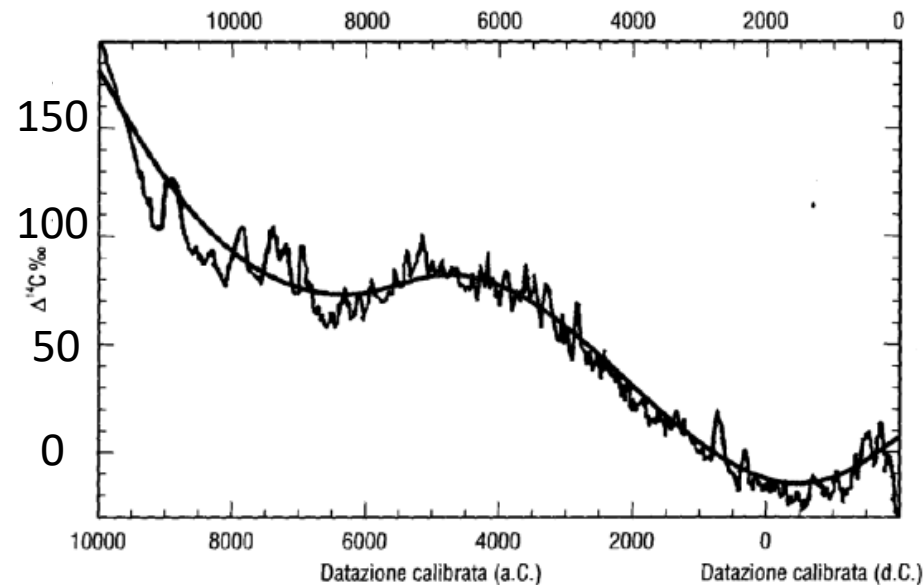
10% \rightarrow 500 yrs error



Dendrocronology

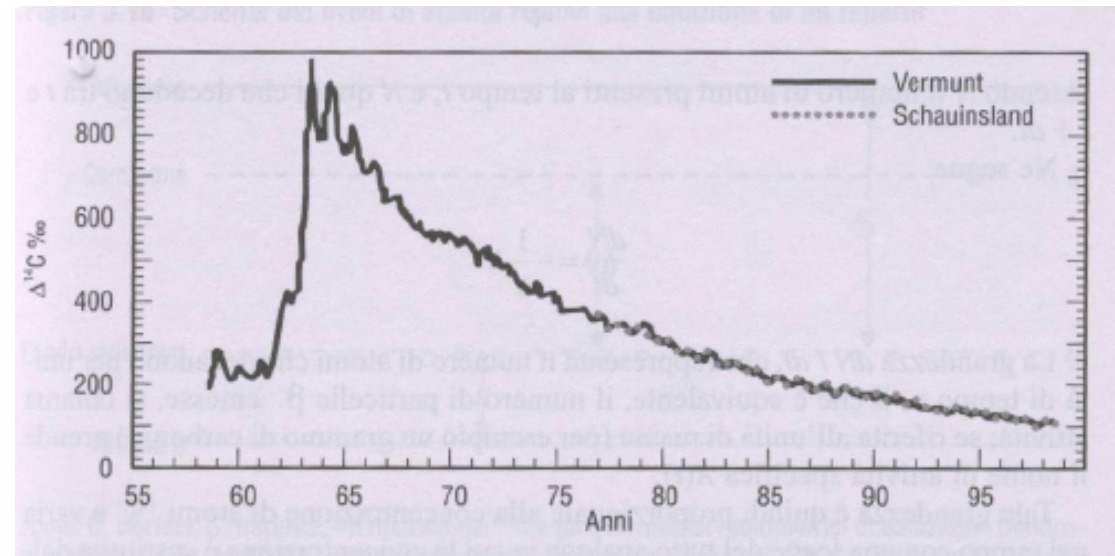
- Measurement of the age of the rings of a tree (Pines, Sequoias, Oaks,...) → up to 12000 anni
- in each ring the C14 concentration is fixed at the moment of formation → correlation C14 and age

10% correction
→ 500 yrs error



Modern Perturbations

- Decrease of R_0 following the Industrial Revolution (combustion of fossiles)
- Increase of R_0 following nucler bomb tests



Techniques based on decay products measurements

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U-Pb Radio-dating

Allows dating rocks between 1 million and 4.5 billion years ago with an accuracy $< \sim 1\%$.

If during the rock formation Zircon (ZrSiO_4) is created, Uranium is incorporated with the isotopic abundance at the time of the rock formation. Since ^{206}Pb is not incorporated, all the detected lead is due to the decay of ^{238}U .

$$N_U = N_0 e^{-t/\tau}$$

$$N_{\text{Pb}} = N_0 (1 - e^{-t/\tau})$$

$$\rightarrow N_{\text{Pb}} = N_U (e^{t/\tau} - 1) \rightarrow t = \tau \log(1 + N_{\text{Pb}}/N_U) \sim \tau N_{\text{Pb}}/N_U$$

By detecting the ratio between lead and uranium the time passed since the rock formation is identified

BLOCKING TEMPERATURES

- The “Blocking Temperature” is an important concept; it refers to processes that result in a “resetting” of the atomic clocks in a rock.
- Essentially, it is possible to heat igneous and metamorphic rocks to high enough temperatures that they no longer behave as “closed systems”. That is some of the daughter products can “leak” out of the primary mineral, giving an erroneous parent/daughter ratio and hence a wrong age.

(Age for what? How could the age be interpreted in a rock in which the blocking temperature has been reached?)

Blocking temperatures for some common minerals and decay series.

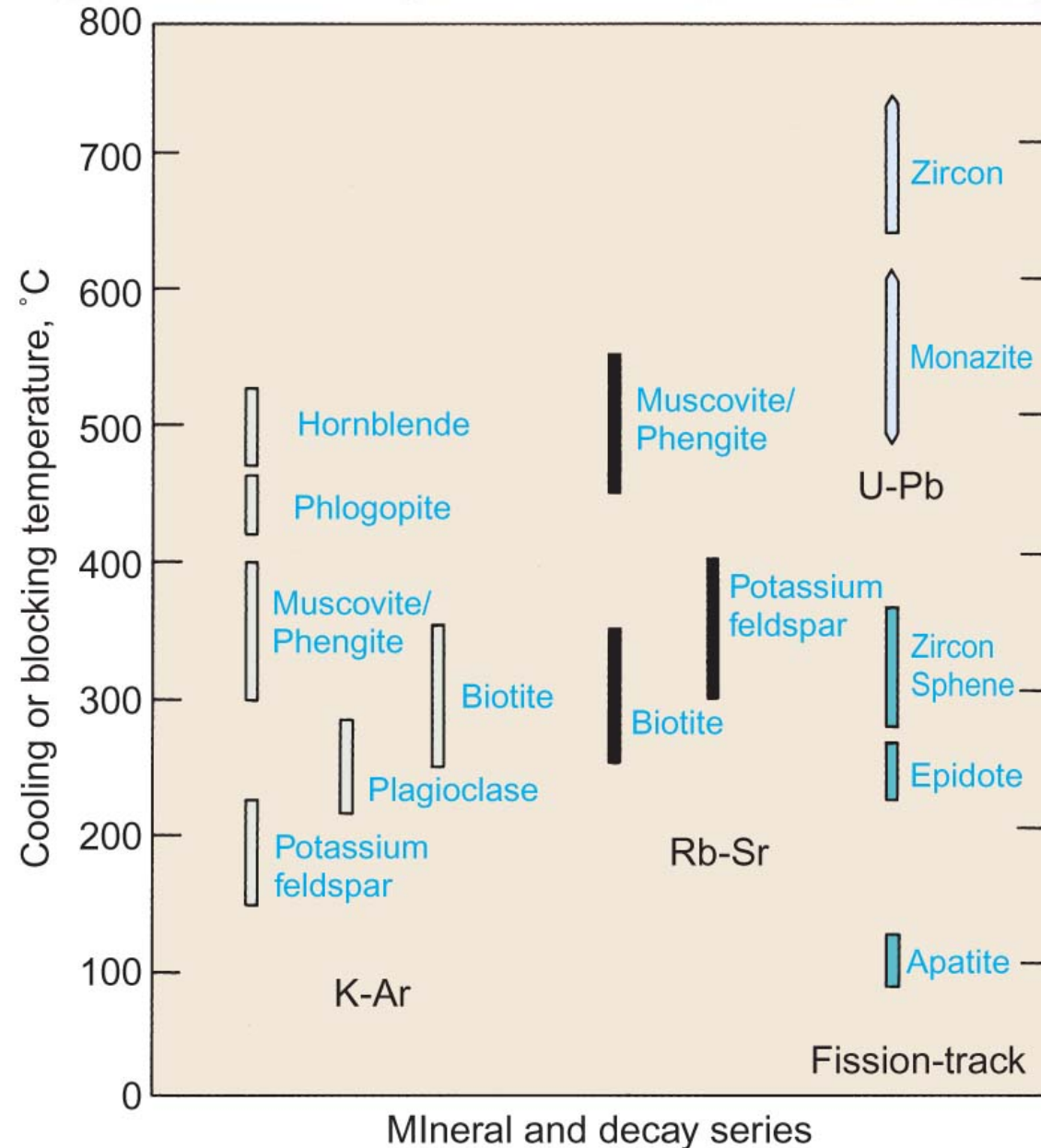
Fig. 5.6

The *blocking* temperature is the temperature above which a mineral or rock no longer behaves as a **closed** system and the parent/daughter ratios may be altered from that due to pure radioactive disintegration.

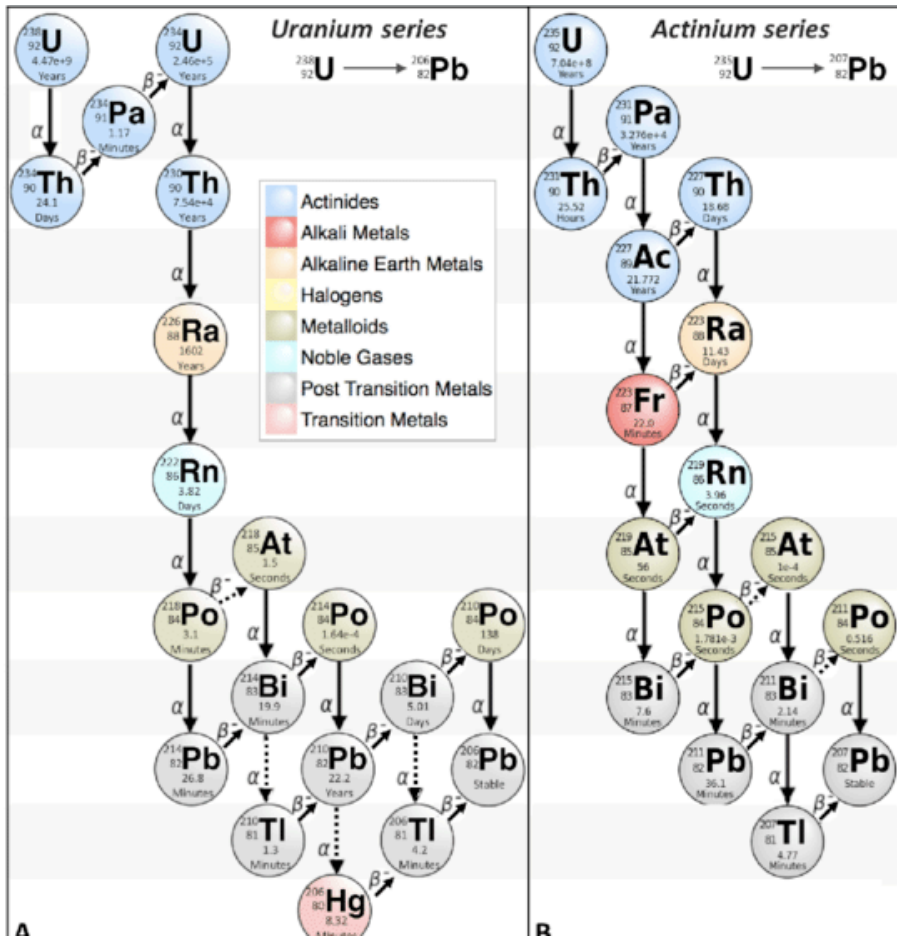
This can result in resetting the isotopic clock and/or give what are called *discordant* dates.

These types of problems have given opponents of the radiometric dating of the Earth ammunition to attack the 4.5 By age geologists cite.

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Different uranium isotopes



Possibility to have simultaneously two measurements of t:

$$t = \tau \log(1 + N_{\text{Pb-206}}/N_{\text{U-238}})$$

$$t = \tau \log(1 + N_{\text{Pb-207}}/N_{\text{U-235}})$$

Agreement between the two allows cross-check

Note: current abundance of U-235 is now 0.72% → at the creation of earth (4.5 billion years ago) it was ~1.6

Note: dating with Uranium meteorites lead to the measurement of the age of the earth: $E = (4.54 \pm 0.05) 10^9 \text{ yr}$

$$T_{1/2}(238) = 4.5 \cdot 10^9 \text{ yr}$$

$$T_{1/2}(235) = 0.7 \cdot 10^9 \text{ yr}$$

K-Ar method

Potassium is a common element found in many materials, such as micas, clay minerals, tephra, and evaporites. In these materials, the decay product ^{40}Ar is able to escape the liquid (molten) rock, but starts to accumulate when the rock solidifies (recrystallizes).

Used for specific rocks

$T_{1/2}(^{40}\text{K})=1.2 \cdot 10^9 \text{ yr} \rightarrow$ allows dating up to billion years

Rb-Sr method

Exploits the $^{87}\text{Rb} \rightarrow ^{87}\text{Sr}$ beta decay

used to date old igneous and metamorphic rocks, and has also been used to date lunar samples. Closure temperatures are so high that they are not a concern. Used for lunar rocks

$T_{1/2}(^{87}\text{Rb}) = 50 \times 10^9 \text{ yr} \rightarrow$ allows dating up to tens of billion years

Thermoluminescence

- Between 50 and 600,000 yr
- Used for ceramics, which are in great majority thermoluminescent
- When manufactured, the heat removes all TL from ceramics → starts new accumulation phase
- When exposed to light, the luminescence starts again



Rilevamento geomorfologico – tecniche

risoluzione: $10^2 \div 10^6$ anni

TRACCE DI FISSIONE (FISSION TRACKS)

✓ *PRINCIPIO: si basa sui danni (tracce) causati dalla disintegrazione del ^{238}U nell'ambito di una reazione di fissione. Il numero di tracce di fissione all'interno di un minerale (ideali sono apatite e zircone) dipende dal tempo trascorso dalla sua formazione (o dall'ultimo riscaldamento intenso in grado di azzerare le tracce preesistenti).*

