Radiometric Dating

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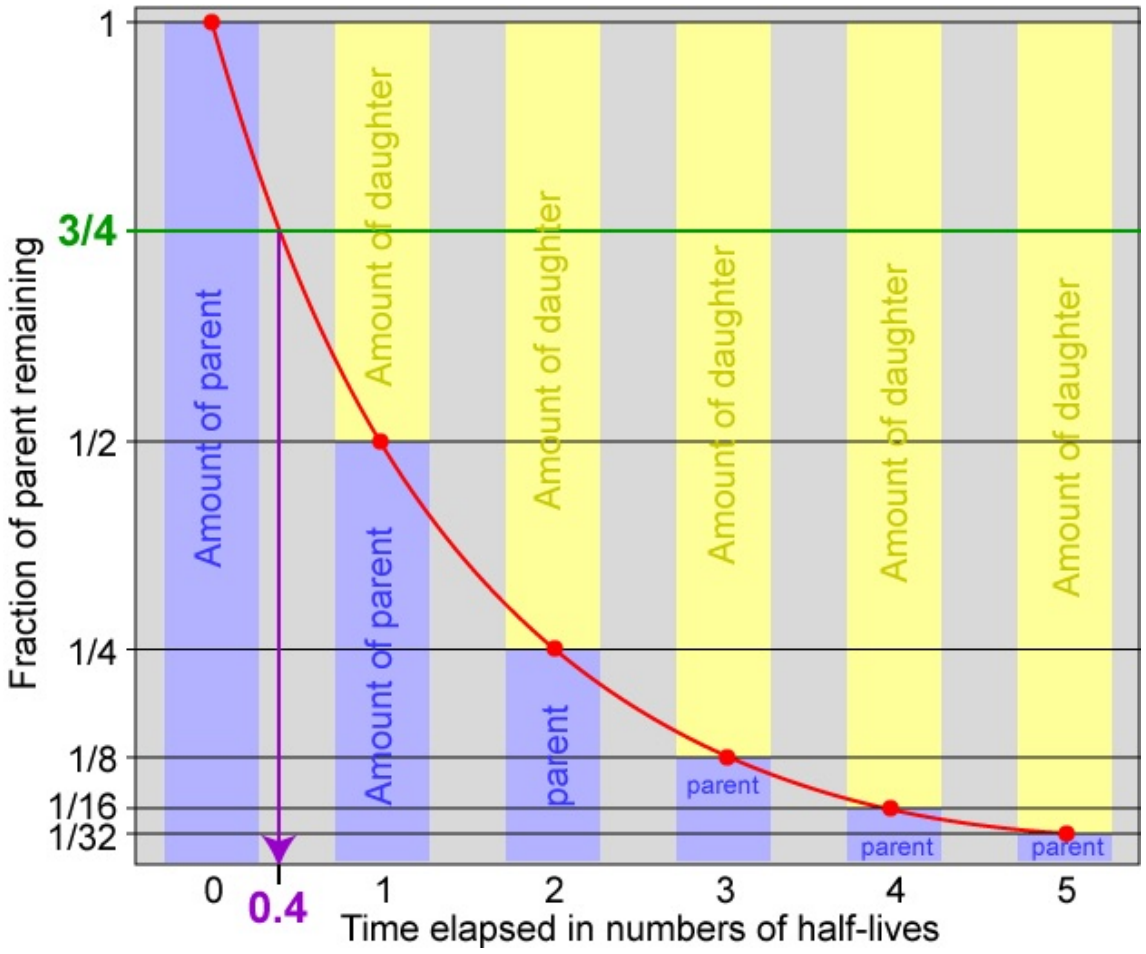
Fundementals

- Suggested by Rutherford in 1905 in his lecture in Yale University.
  - If we know the content of original parent products and the content of the daughter products now, using the half-life, we can find how long the decay had been happening.

$$t = \frac{1}{\lambda} \ln\left(\frac{N_D + N_P}{N_P}\right)$$

  - Rutherford's experiment with uranium containing minerals and helium gas content inside (Rutherford didn't know alpha ray was helium atoms).

- Half-life of the decay determines the range of dates we can tell.



Radiocarbon Dating

- Carbon-14 has half-life of 5,730 years.
- Martin Kamen's photosynthesis experiment in 1940
- It was theorized that Carbon-14 might be produced by cosmic rays

$$n + {}^{14}N \rightarrow {}^{14}C + p$$

- In late 1940's, Willard Libby devised a plan to exploit the fact that ratio of Carbon-14 content should be constant in all organic beings on Earth to date any deceased organic materials

- Carbon dating was hard in 1949
  - for about a gram of carbons, there are about 60 billion carbon 14 isotopes out of billions of billions of other carbons, and only about 14 atoms go off every minute
  - Lots of noises
  - Even a few false positive or false negative reading would create significant error
  - Ernie Anderson's Anti-coincidence counting
- Libby and his student researcher Jim Arnold dated the first Egyptian artifact successfully
- The anecdote about the fake artifact dating and the continues publication of accurately dated known ancient artifacts and materials made the method very popular.
- Libby got Nobel Prize in 1960 for development of this method.

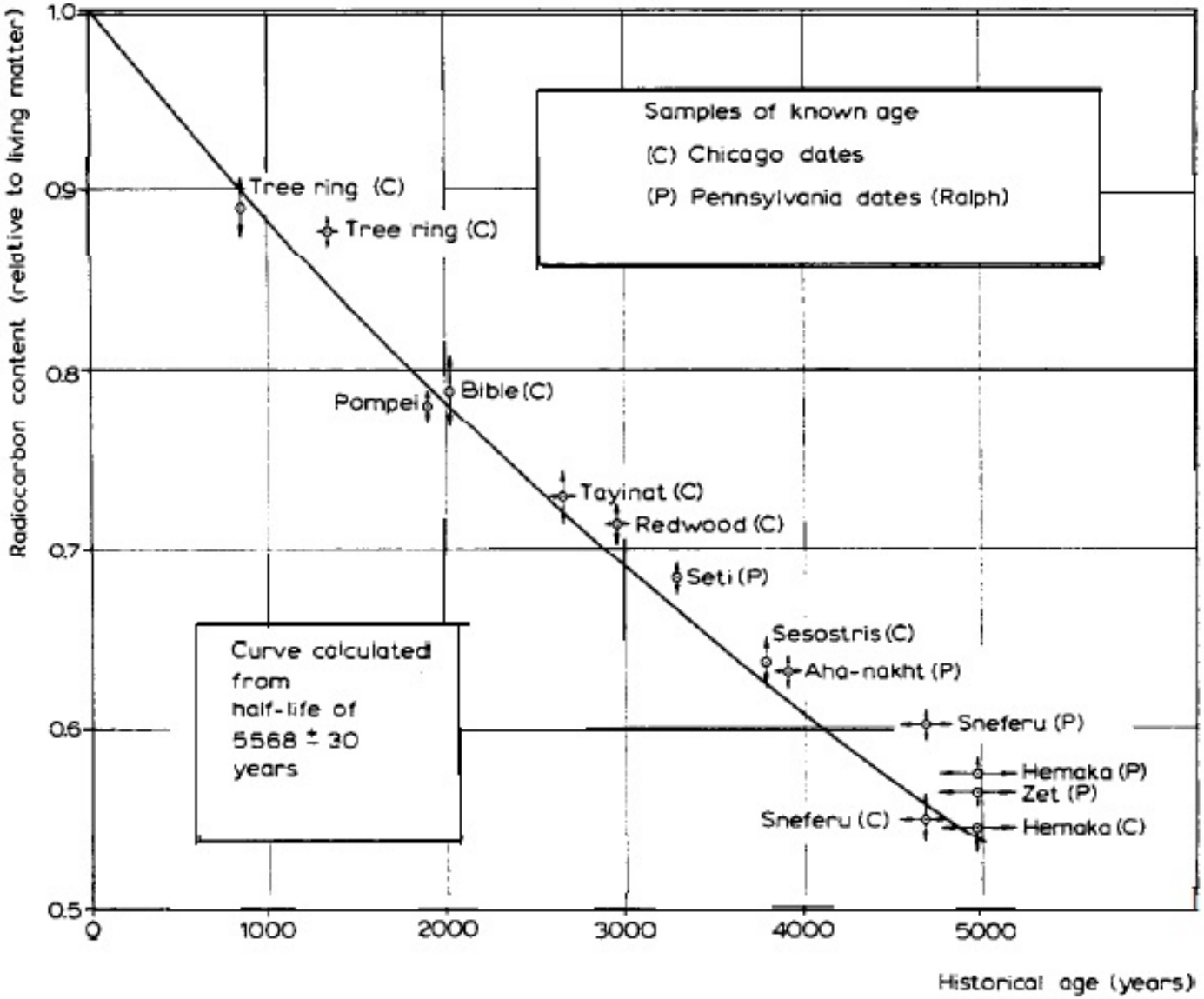


Fig. 3. Curve of Knowns.

- De Vries Effect
  - In late 1950's Hessell de Vries found a crucial discrepancy between real dates and dates calculated via carbon dating
  - Each ring in a tree only contains carbons from the year that the ring is formed. Carbon dating on the rings should give the date when that ring is formed.
  - de Vries killed himself without digging further.
  - Hans Suess who studied under Libby calibrated the method using the tree rings
  - Resolution: Earth/Sun magnetic field fluctuations

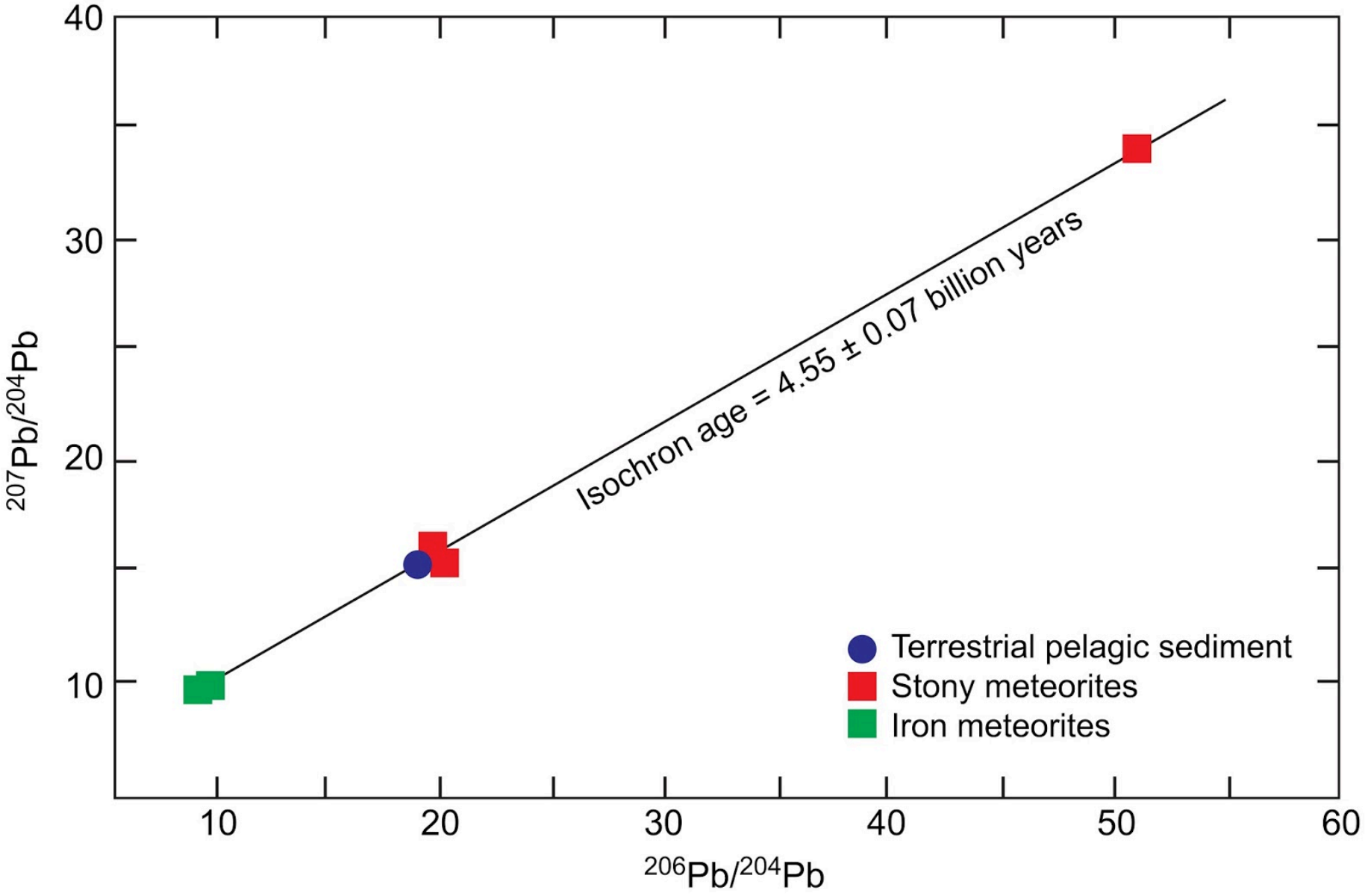
Uranium-Lead Dating

- Uranium-235 has half-life of 703.8 mi years and Uranium-238 has half-life of 4.468 bi years.
- Oldest and most refined method used to date various rocks.
- In 1907, Bertrant Boltwood found that the lead is the stable daughter atoms down the decay chain of Uranium. He suggested the dating method.
- In 1911, Arthur Holmes, a geologist, with realization that this can be come the most accurate way to date rocks, continued the development of the method, but both Boltwood and Holmes assumed that all lead found in rocks are the results of the uranium's decay, so their results were inaccurate.

- The Quest to date Earth
  - Harrison Brown and his student Claire Patterson tried to develop a way to accurately date zircon minerals.
  - Patterson could not measure lead in zircon accurately because of the high contamination level no matter how clean the lab is. This exposed the industrial lead scandal.
  - After a extreme clean lab was setup, zircons were accurately dated using mass spectrometer.
  - Rather unusual property of U-Pb dating - that there are two sets of isotopes decaying into the other two sets of isotopes at different rate (U-238 to Pb-206 and U-235 to Pb- 207)

$$\frac{(\frac{^{207}Pb}{^{204}Pb})_P}{(\frac{^{206}Pb}{^{204}Pb})_P} - \frac{(\frac{^{207}Pb}{^{204}Pb})_I}{(\frac{^{206}Pb}{^{204}Pb})_I} = (\frac{^{235}U}{^{238}U})_P(\frac{e^{\lambda_{235}t}-1}{e^{\lambda_{238}t}-1})$$

- One missing information: primordial lead amount.
- Resolution: Date the iron meteorite (Canyon Diablo) because meteorites are formed the same time Earth was formed and this meteorite cannot have contained any uranium.
- Patterson's isochron graph method

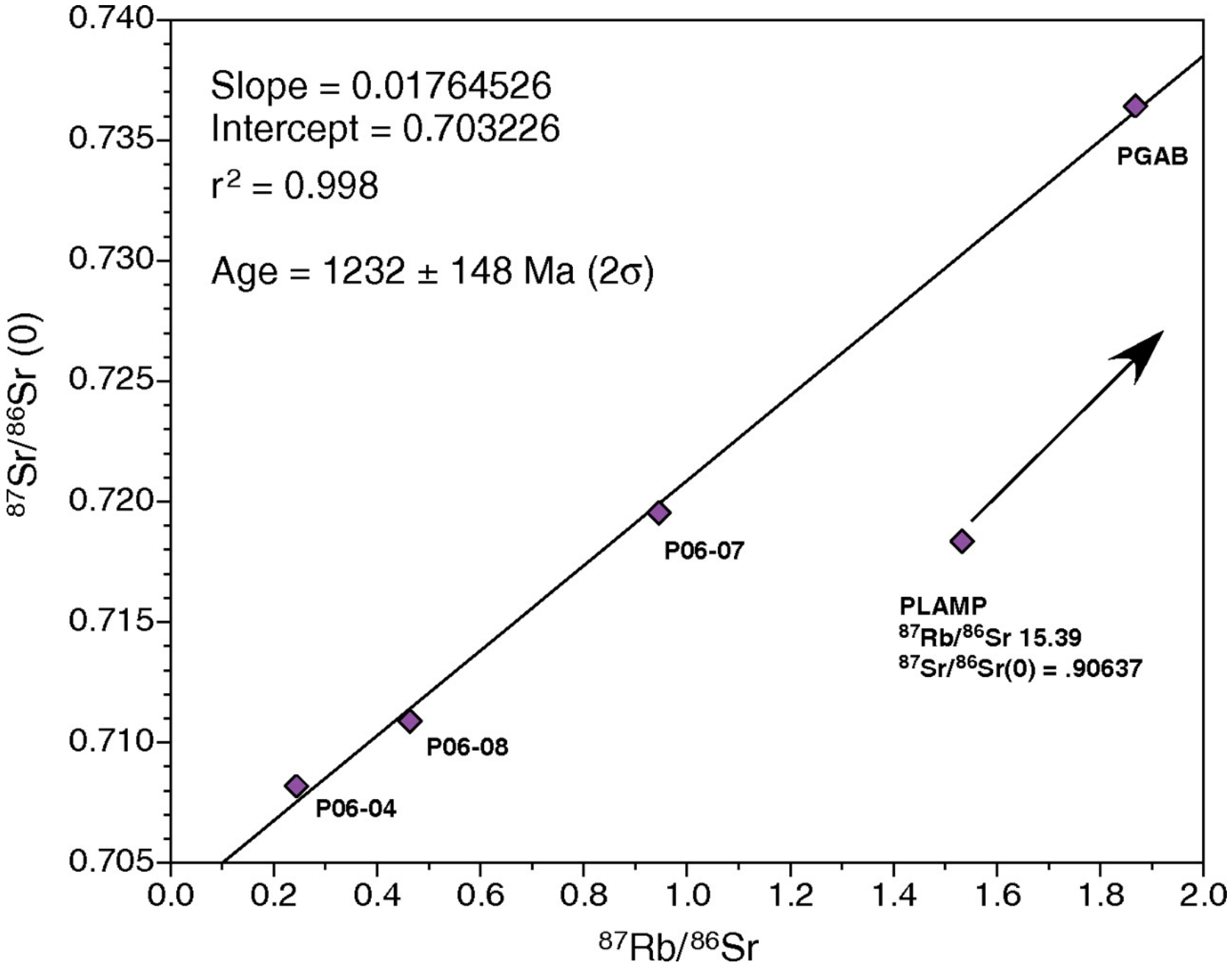

40
30
20
10
$^{207}Pb/^{204}Pb$
10
20
30
40
50
60
$^{206}Pb/^{204}Pb$
Isochron age = 4.55 ± 0.07 billion years
Terrestrial pelagic sediment
Stony meteorites
Iron meteorites

Potassium-Argon Dating

- Potassium-40 has half-life of 1.248 bi years.
- 0.0117% of all potassium atoms on Earth is K-40
- Two daughter atoms: argon-40 (11%) and calcium-40.
- Used to date igneous rocks
  - Argon gas leaves the lava before cooling
  - Radiogenic argon atoms are trapped in the rock after cooling
- Difficulty arises because K is metal and Ar is gas
  - We used heat the mineral to extract gas and weigh Ar and K separately.
  - In 1960s, UC Berkley proposed Ar-Ar method, which improved the accuracy significantly. Make K-40 -> Ar-39 in nuclear reactor.

Rubidium-Strontium Dating

- Rubidium-87 has half-life of 48.8 bi years.
- Beta decays into Strontium-87
- When a part of Earth's mantle melts, rubidium-87, highly incompatible with the crystalized structure goes to the melted part. This allows us to date when the rocks lasted melted.
- We also have Rb-85 and St-86 which are stable, non-radiogenic, naturally occurring isotopes. This means we have another case of isochron.


Slope = 0.01764526
Intercept = 0.703226
r2 = 0.998
Age = 1232 ± 148 Ma (2σ)
PGAB
P06-07
P06-08
P06-04
PLAMP
87Rb/86Sr 15.39
87Sr/86Sr(0) = .90637
87Sr/86Sr (0)
87Rb/86Sr
0.740
0.735
0.730
0.725
0.720
0.715
0.710
0.705
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0

Criticisms

- There is no way to know the original parent and daughter content.
  - The main theme in each method's development is to solve this exact problem.
- The decay rate never has been observed directly
  - We have been directly measuring rates for 40-90 years.
  - Errors are mostly within 2 percent.
- There had been inconsistent results
  - Different results depending on labs / Inconsistent results with materials we already know how old
  - One case that almost always comes up: Volcanic rock in New Zealand.
  - We have overwhelmingly consistent results except for a few cases.