

Dating

by

Tony Heyes

Dating

of the non-romantic kind

by

Tony Heyes

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Radio Carbon Dating

Based on the ratio of
radio active Carbon 14
to stable Carbon 12 in
dead organic matter

Carbon Isotopes

- All Carbon atoms have 6 protons
- Differing isotopes have different numbers of neutrons
- Carbon has 15 known isotopes
- Most have very short half lives

ISOTOPES OF CARBON

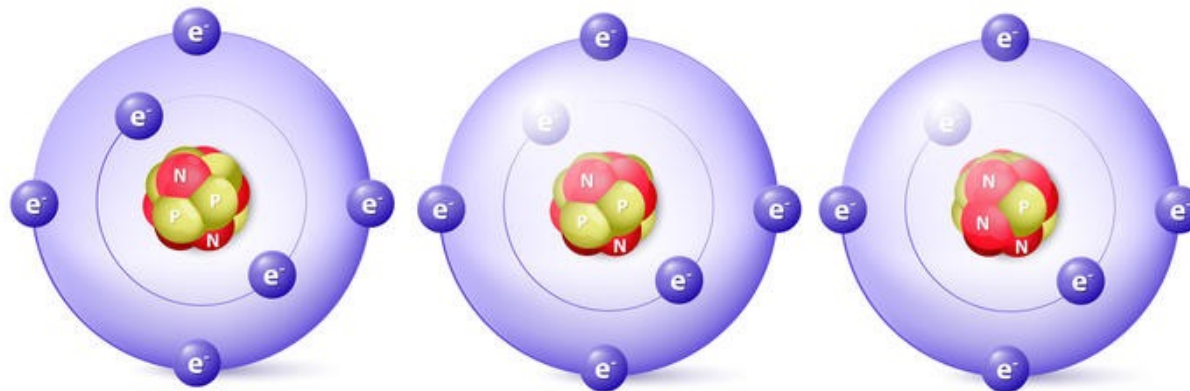
Carbon-12



Carbon-13




Carbon-14



 electron -1 (orbit)

 neutron 0 (nucleus)

 proton +1 (nucleus)

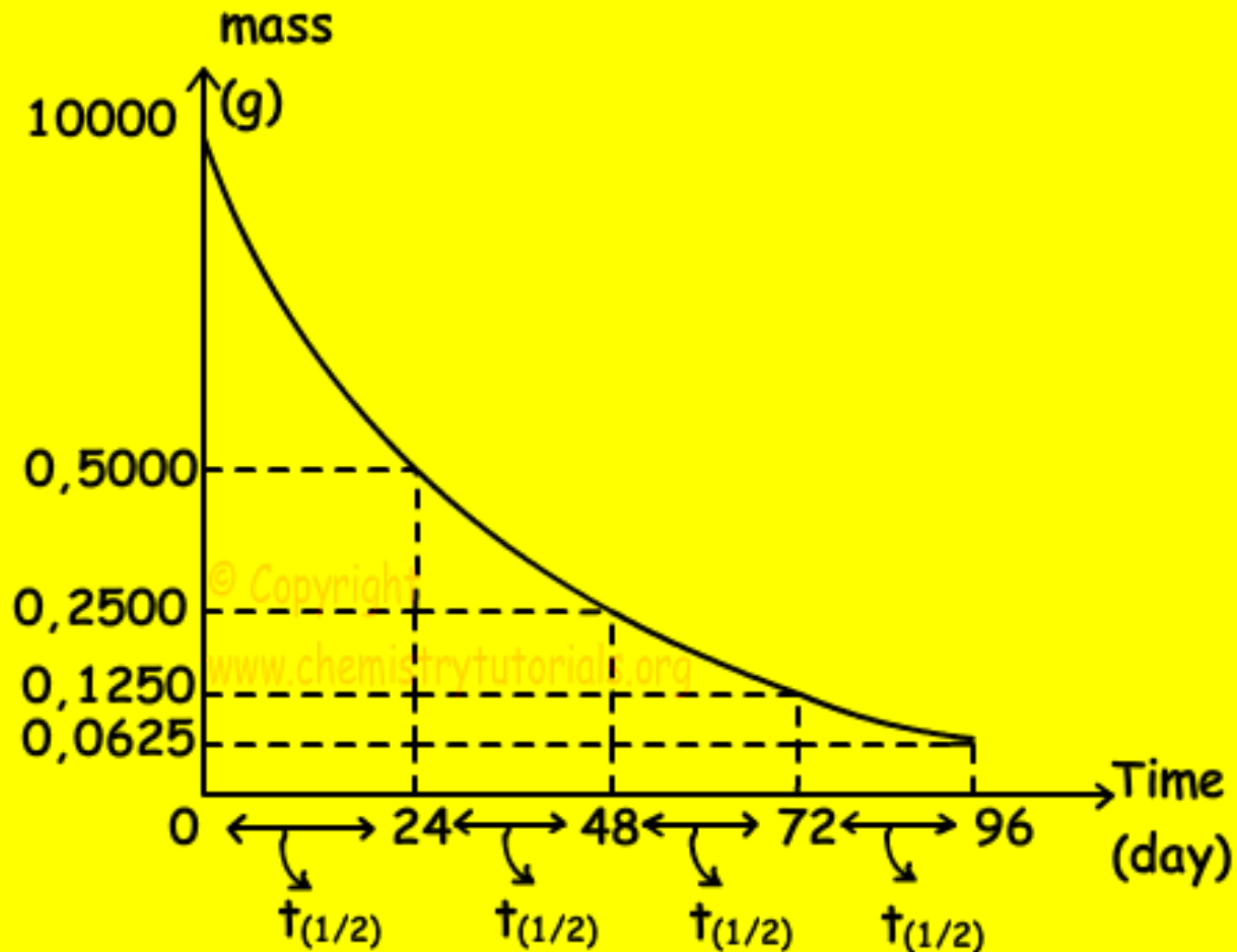
Carbon

- Carbon 12 is stable
- Carbon 13 is also stable
- Carbon 14 has a half life of 5,700 years
- All other isotopes have a half life less than 20 seconds

Half Life

- A characteristic of radio active atoms
- Half the mass of the atom disappears in one half life
- ie. it emits a particle and thereby changes into different atom

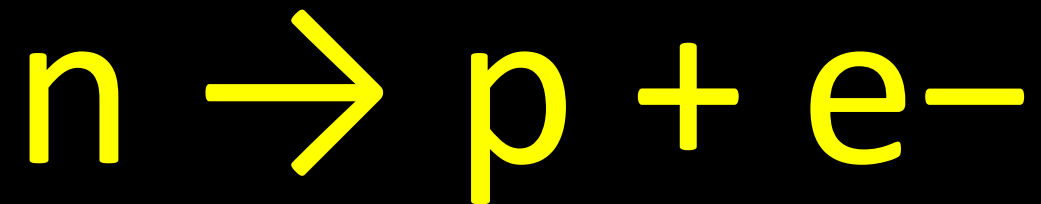
Half Life



Carbon 14

- Decays by emitting a beta particle
- Turns into Nitrogen

Beta Decay



Decay of Carbon 14



Willard Libby

(1908 – 1980)



The idea

Libby read a paper, published in 1939, which suggested that Carbon 14 was formed in the atmosphere when Neutrons, derived from cosmic rays, having been slowed down by interaction with atmospheric gases, interacted with Nitrogen.

The Origin of Carbon 14



- The newly created Carbon 14 would react with Oxygen to form Carbon Dioxide
- The Carbon Dioxide would be taken up by plants by photosynthesis
- Thus radioactive Carbon 14 would enter the biosphere

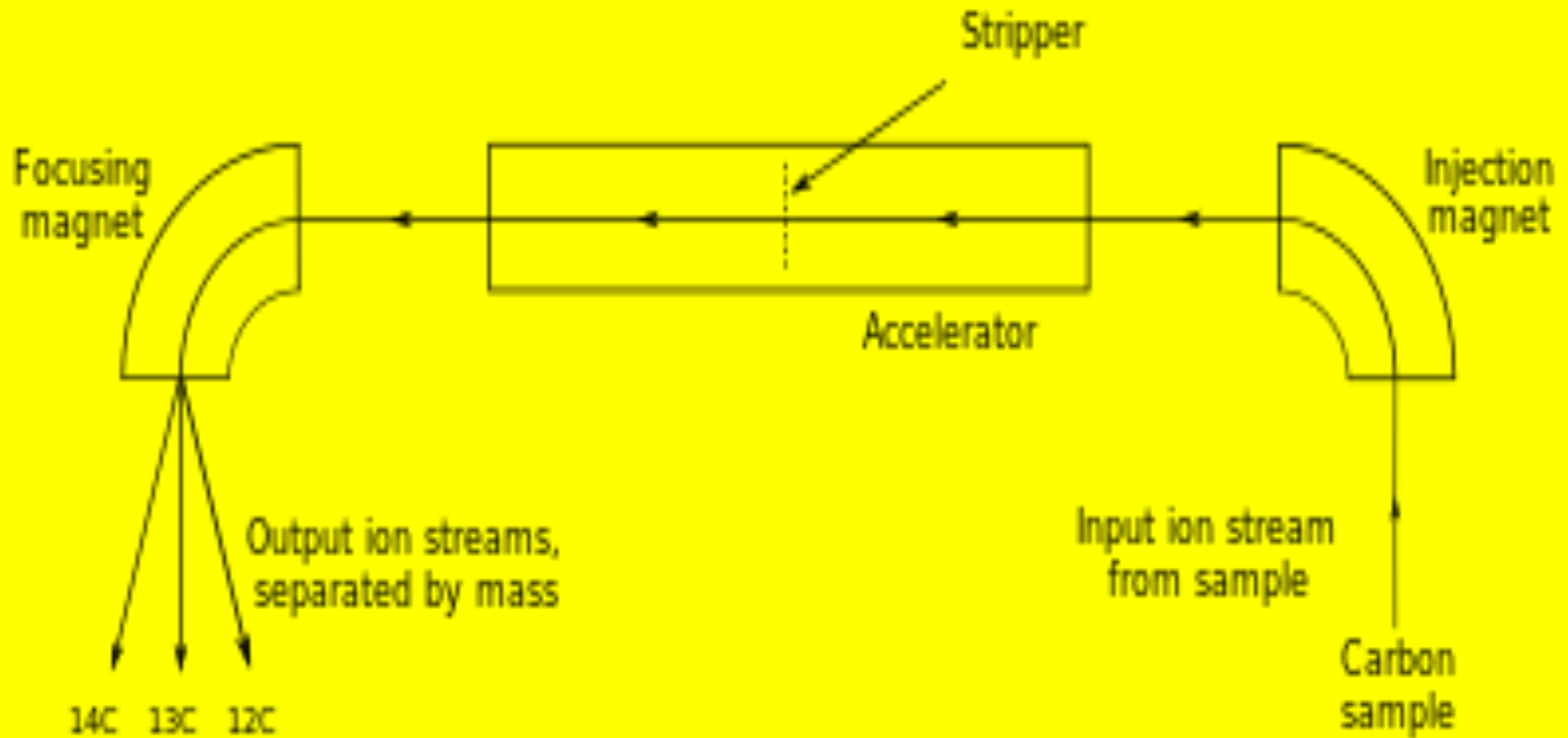
- During its life, a plant or animal is exchanging carbon with its surroundings, so the Carbon it contains will have the same proportion of Carbon14 as that in the atmosphere
- Once the plant dies, it ceases to acquire Carbon. The Carbon14 within the biological material at the time of death will continue to decay
- ie. the ratio of Carbon14 to stable Carbon will gradually reduce

But how much do we start with?

The ratio of Carbon 14 to Carbon 12 in the atmosphere is 1.5 parts of Carbon 14 to 10^{12} parts of Carbon 12

In addition, about 1% of the Carbon atoms are of the stable isotope Carbon13

Mass Spectrometer



Carbon 14

This is an incredibly small amount to start with

After a number of half lives it is considerably less!

After 8 half lives (45,000 years) there is only approximately 1% of the original carbon 14 present

This is about the limit of the technique

Libby's Experiment

In 1949 Libby used Radio Carbon dating to test two samples of wood of a known age

The samples came from the Egyptian tombs of Kings Zoser and Snefer

Libby's Experiment

Libby's result:

2800 BC plus or minus 250 years

The Egyptologists said:

2625 BC plus or minus 75 years

Nobel Prize in Chemistry

Awarded in 1960

Willard Frank Libby

“for his method to use Carbon-14 for age determination in archaeology, geology, geophysics and other branches of science”

But there is a problem!!!!

Can we assume that the cosmic ray flux reaching the earth has remained constant for 45,000 years?

The answer came from a somewhat
unexpected source

Tree rings

Let me introduce you to the
science of

Dendrochronology

Larch



Dendrochronology

- Works well for:
- In temperate regions seasonal changes lead to pronounced tree rings
- Alternate poor and favorable conditions, such as mid-summer droughts, lead to a lack of evenness in the ring pattern

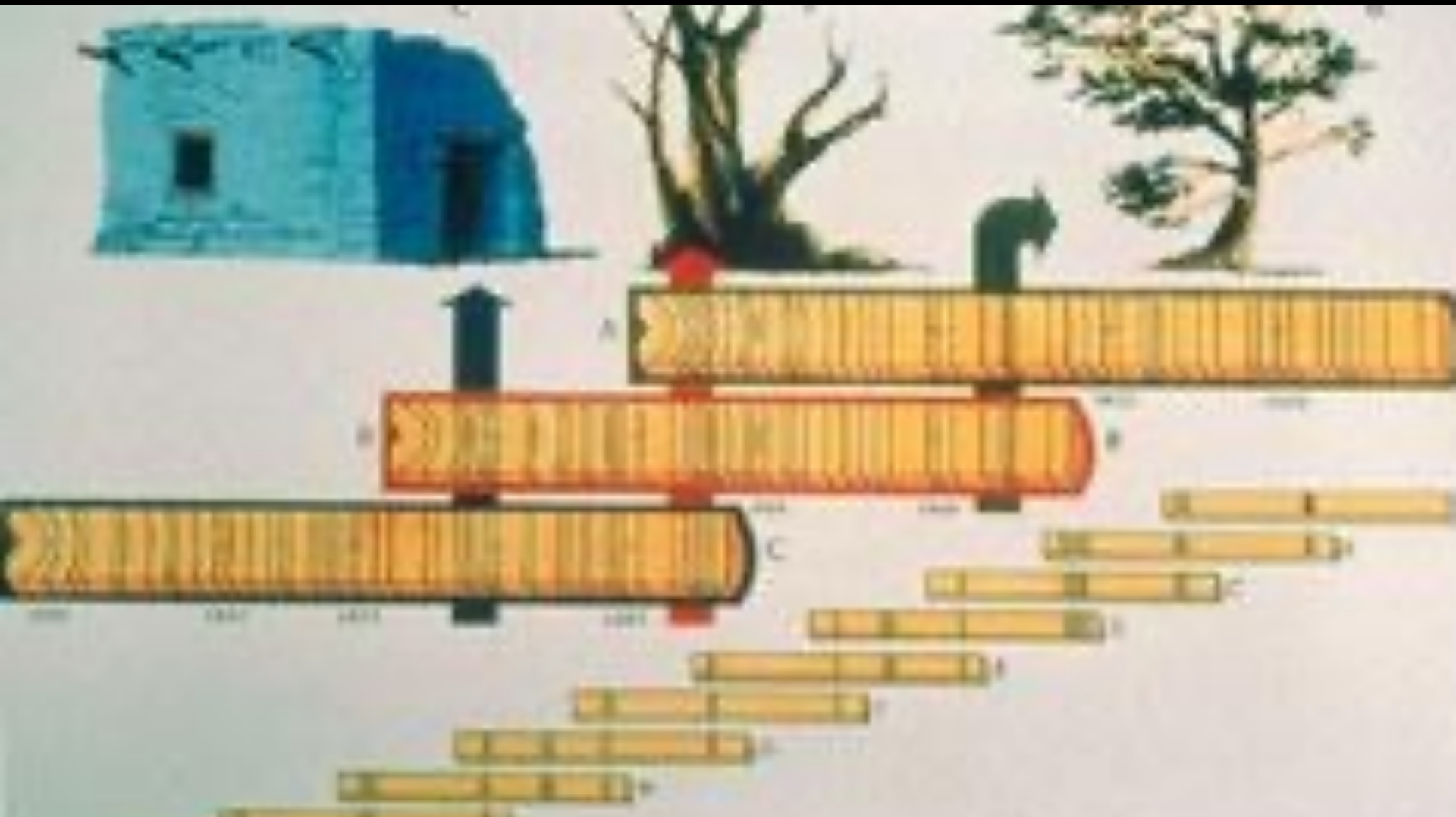
Dendrochronology

- A tree-ring history whose beginning and end dates are NOT known is called a *floating chronology*
- It can be anchored by cross-matching a section against another chronology (tree-ring history) whose dates ARE known

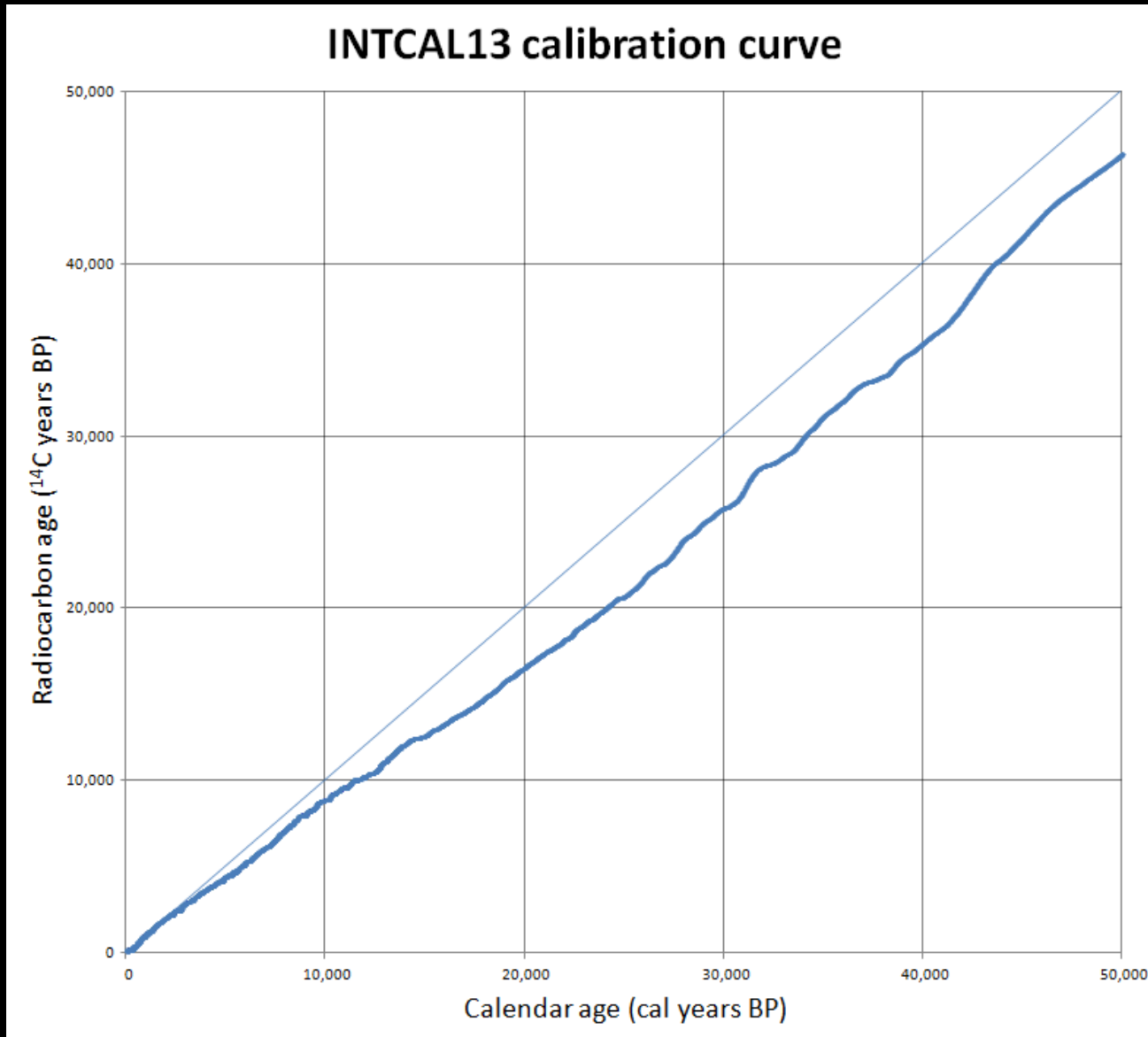
Dendrochronology

- Fully *anchored chronologies* extending back more than 11,000 years exist for River Oak Trees from South Germany (from the Main and Rhine rivers) and for Pine Trees from Northern Ireland.

Going back in time



Radio Carbon Dating Calibration



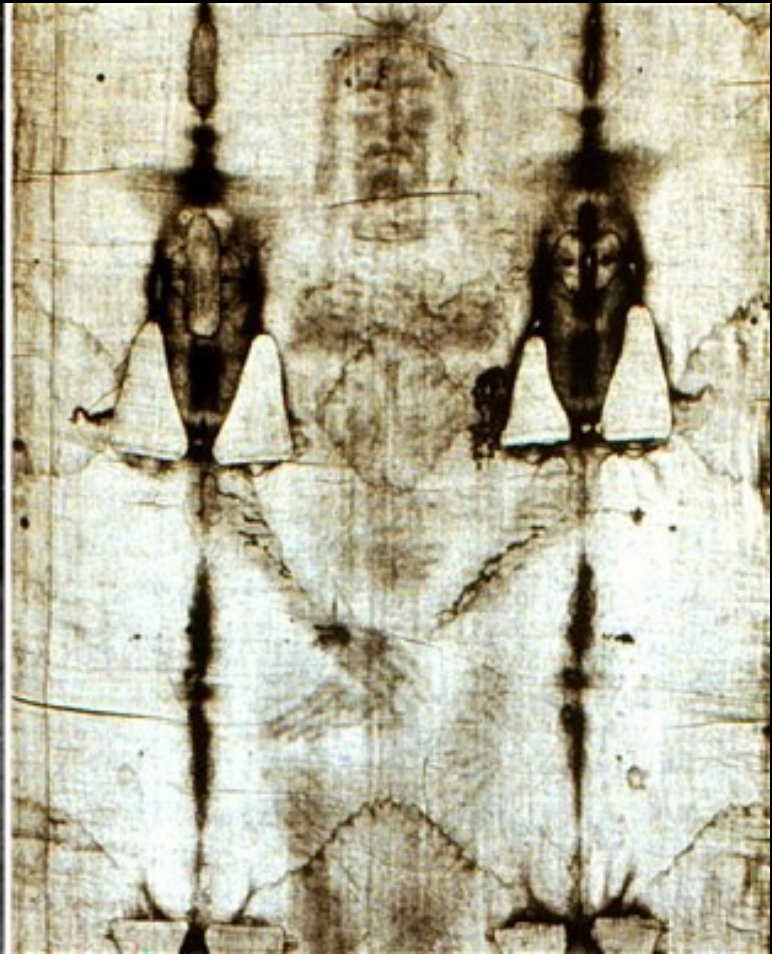
Shroud of Turin

The Shroud of Turin or Turin Shroud is a length of linen cloth bearing the image of a man who appears to have suffered physical trauma in a manner consistent with crucifixion. There is no consensus yet on how the image was created.

Shroud of Turin



Shroud of Turin



Shroud of Turin

A number of features support the shroud's authenticity:

Photographic evidence

Scars on hands

Blood stains

Pollen grains

The Provenance of the Shroud of Turin

The first certain historical record dates from 1353 or 1357

The presence of the Turin Shroud in Lirey, France, is attested in 1390 when Bishop Pierre d'Arcis wrote a memorandum to Antipope Clement VII, stating that the shroud was a forgery and that the artist had confessed

The Provenance

- The history of the shroud from the 15th century is well recorded.
- In 1532, the shroud suffered damage from a fire in a chapel of Chambéry, capital of the Savoy region, where it was stored. A drop of molten silver burnt its way through the layers of the folded cloth. Nuns attempted to repair this damage with patches
- In 1578 Emmanuel Philibert, Duke of Savoy ordered the cloth to be brought from Chambéry to Turin and it has remained at Turin ever since.

The Provenance of the Shroud of Turin

- Repairs were made to the shroud in 1694 by Sebastian Valfrè to improve the earlier repairs
- Further repairs were made in 1868 by Clotilde of Savoy. The shroud remained the property of the House of Savoy until 1983, when it was given to the Holy See.

Shroud of Turin

- After years of discussion, the Holy See permitted radiocarbon dating on portions of a swatch taken from a corner of the shroud
- Independent testing took place in 1988 at the University of Oxford, the University of Arizona, and the Swiss Federal Institute of Technology

Shroud of Turin

- The conclusion from the Radio Carbon Dating was
- with 95% confidence
- that the shroud material was manufactured
- Between 1260 and 1390

Shroud of Turin

Those who were unhappy with this result suggested that:

- the samples tested came from the repairs
- the samples had been contaminated

Shroud of Turin

The most likely explanation:

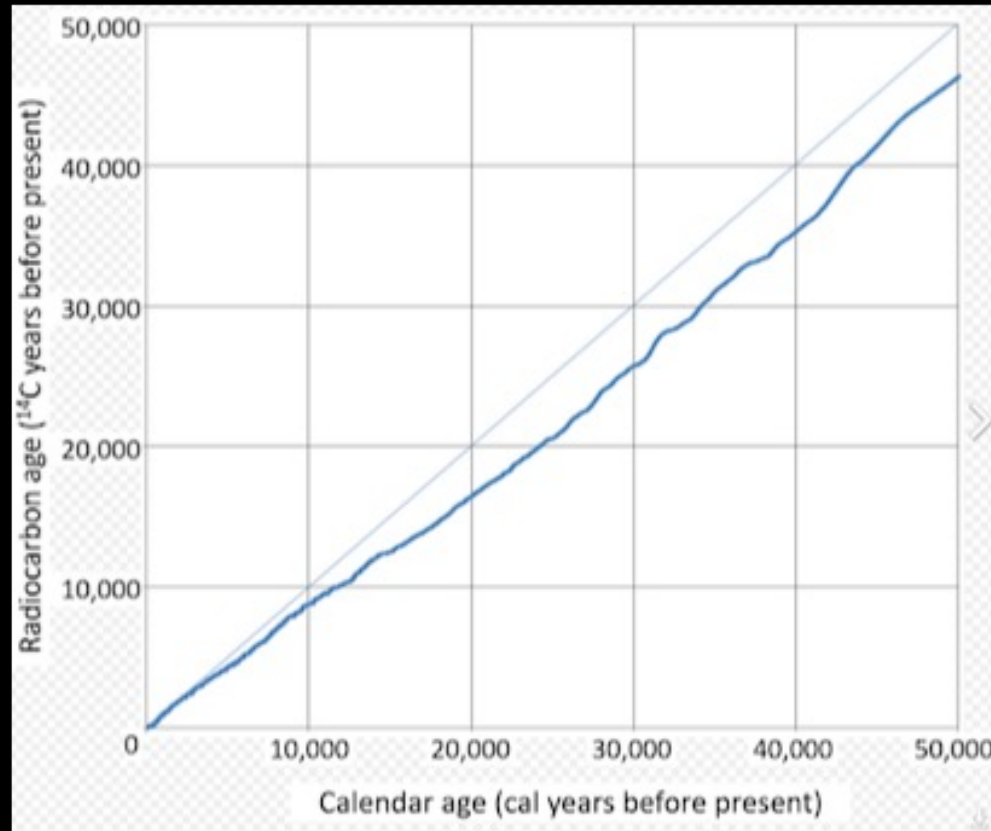
- The shroud was made in the first half of the 14th century
- Its manufacture involved a crucifixion

Dating the Viking settlement in Newfoundland

Radio Carbon Dating

- Has established that the settlement was present in the 11th Century
- Radio Carbon dating relies a constant cosmic ray bombardment
- This maintains the constant ratio of Carbon 14 to Carbon 12 in the atmosphere

Suess Calibration Curve



Radio Carbon Dating

- Detailed examination of this curve shows the 11 year sun spot cycle during which the cosmic ray bombardment increases
- And therefore, so does the production of Carbon 14

Fusa Miyake



Fusa Miyake

- Uses tree rings to study solar activity
- Discovered Miyake Spikes
- Brief 'wiggles' in the graph corresponding to periods of intense solar activity

Miyake Spikes

- 5480 BC
- 660 BC
- 775 AD
- 994 AD

The Vikings

- The Viking settlement at L'Anse aux Meadows in Northern Newfoundland
- Wood cut down 27 years after a Miyake spike
- Thus dating the Viking settlement at

Vikings in the USA

1021 AD

So the first Europeans to reach
the Americas

Not Christopher Columbus in 1492

but

Leif Erikson 1021 AD

And Now

The Adams Event

The Adams Event

- From Douglas Adams book "A Hitch Hiker's Guide to the Galaxy"
- we know that the answer to the question of
- Life, the Universe and Everything is

42

Magnetic Reversals

- Until recently it was thought that a magnetic reversal had never happened during the time that humans have been on earth!
- However, there was a brief but large magnetic excursion some 42,000 years ago and it was recorded in a stone fireplace near Lake Mungo

The Laschamp Excursion

- The **Laschamp Excursion** occurred 41,400 ($\pm 2,000$) years ago during the end of the Last Glacial Period it was first recognised from a geomagnetic excursion discovered c. 1969 in the Laschamps lava flows in the Clermont-Ferrand district of France

The Laschamp Excursion

- From this, and other locations (eg. Sediments in the Black Sea, a NZ tree) we now know...
- The magnetic field was reversed for approximately 440 years, with the transitions lasting approximately 250 years

The most 'recent' excursion

- How do we know such detail?
- Let me introduce you to a tree

Kauri

(*Agathis australis*)



The Kauri

- Native of the North Island of New Zealand
- One of the longest living trees on the planet >2,000 years
- Grow to a height of 60 metres
- With a diameter of 5 metres

The Kauri

- A huge specimen has been found buried in a swamp
- Carbon dating has established that it lived during the period of the last magnetic excursion
- It has been described as
- The Rosetta Stone of Dendrochronology

Kauri

(*Agathis australis*)



Prof Alan Hogg

University of Waikato

- This huge, lonely tree grew for some 1700 years across a remarkable period in our planet's history when the Earth's magnetic field flipped some 42,000 years ago; the Laschamp Excursion
- This period of low magnetic field has been termed the **Adams Event**. During this period, Earth's magnetic field dropped to below 6% of the current level, Carbon-14 production increased, ozone levels decreased, and atmospheric circulation changed. This loss of the geomagnetic shield possibly caused the extinction of the Australian Megafauna, the extinction of the Neandertals, and the appearance of cave art.

A short film

The local copy [Here](#)

The copy on the www [Here](#)

What about the Age of the Earth?

Prior to the discovery of Radioactivity there had been several attempts to come up with a value. These were based on:

- The Bible
- The salinity of the oceans
- The growth of sedimentary layers of rock
- The cooling of the Earth

Biblical Dating

In 1650 James Ussher, Archbishop of Armagh and Primate of All Ireland, published a chronology based on his reading of the Old Testament.

- Ussher calculated
- The first day of creation to have been
- The 23rd October 4004 BC
- Some 6,026 years ago

Ocean Salinity Dating

Almost 200 years ago Edmund Halley suggested that the age of the earth could be estimated from the build up of salts in the oceans.

- 1899 Jolly estimated 97.6 Million years
- Others calculate short times
- All agreed that there were many assumptions
- Few took this seriously

Sedimentary Rocks Dating

In the 19th Century many scientists were fascinated by the new science of Geology.

- Many estimates as to the Age of the Earth were
- based on the time taken to build up layers of sedimentary rock.
- Look at this list for familiar names!

Estimates of the age of the Earth based on rates of sedimentation

Date	Author	Maximum thickness (in feet)	Rate of deposition (years/ft)	Time (millions of years)
1860	Phillips	72,000	1,332	96
1869	Huxley	100,000	1,000	100
1871	Haughton	177,200	8,616	1,526
1889	Croll	12,000	6,000	72
1890	de Lapparent	150,000	600	90
1892	Wallace	177,200	158	28
1893	McGee	264,000	6,000	1,584
1883	Upham	264,000	316	100
1895	Sollas	164,000	100	17
1908	Jolly	265,000	300	80
1909	Sollas	335,000	200	67

Cooling Earth Dating

William Thomson, Lord Kelvin, one of the giants of classical physics calculated the age of the earth based on thermal conductivity and Irradiation, he concluded 100 million years.

The Age of the Earth

- We now accept the Age of the Earth to be
 - 4.543 billion years
 - That is
 - 4.5 thousand million years

And now its time for another long
word.....

Geochronology

the science of determining the age of rocks, fossils, and sediments using signatures inherent in the rocks themselves

Geochronology

- Many radioactive isotopic techniques are used
- Whereas in Radio Carbon Dating we look at the declining amount of Carbon14, in most geochronological techniques one looks at the build up of particular substances

Geochronology

- The oldest, the most commonly used and still one of the most accurate is the
- Uranium – Lead – Lead technique
- Why two Leads?
- All will be revealed.....

Uranium

- Two important isotopes
- Uranium 238 decays, via a long chain of intermediates, to stable Lead 206 with a half life of 4.47 billion years
- Uranium 235 decays to stable Lead 207 with a half life of 704 million years

Uranium

- Naturally occurring Uranium is found in the form of chemically precipitated compounds (eg Pitchblende: U_3O_8) having isotopes in the ratio
- Uranium 238 99.27%
- Uranium 235 0.72%
- Uranium 234 0.005%

(part of the U238 decay chain)

Uranium –Lead - Lead

- Measuring the amounts of the two Uranium isotopes and the two daughter isotopes, Lead 206 and Lead 207, in a sample enables several cross checking methods to be used to estimate the age of the ore sample
- The technique is suitable for an age range of about 1 million years to over 4.5 billion years, and with routine precisions in the range 0.1–1%

But how do we know when the clock started?

- When Zircon (zirconium silicate) crystals form they readily incorporate Uranium atoms in their structure but very little Lead.
- Then if later they are cooked in volcanoes, until.....
- The Closure Temperature

Closure Temperature

- **Closure Temperature** is the **temperature** at which a system has cooled so that there is no longer any significant diffusion of the parent or daughter isotopes out of the system; they are trapped within the crystal lattice.

Closure Temperatures (Uranium – Lead)

- | • Mineral | Closure temperature (°C) |
|------------|---------------------------|
| • Titanite | 600-650 |
| • Rutile | 400-450 |
| • Apatite | 450-500 |
| • Zircon | >1000 |
| • Monazite | >1000 |

Yet another technique for dating volcanoes

- Surface Exposure Dating
- Cosmic ray bombardment transforms
- $^{16}\text{O} \rightarrow ^{10}\text{Be}$ and $^{26}\text{Si} \rightarrow ^{28}\text{Al}$
- Formed during exposure, decaying when covered.

The Isochron Method

- How could we possibly know how many radioactive atoms were present in a given rock when it was formed?
- There is a brilliant way round this
- Brace yourselves for the Isochron Method

The Isochron Method

- Consider the decay of Rubidium-87 (half life 48 billion years) to Strontium-87
- We count the number of ^{87}Rb (parent) and ^{87}Sr (daughter) atoms in our sample of rock
- We also count the number of ^{86}Sr (sibling) atoms present

The Isochron Method

- ^{86}Sr is a stable isotope of Strontium
- In fact the Isochron Method relies on the daughter atom having a stable isotope sibling.

The Isochron Method

- We now have three numbers per rock sample
- $N(^{87}\text{Rb})$, $N(^{87}\text{Sr})$ and $N(^{86}\text{Sr})$
- $N(\text{parent})$, $N(\text{daughter})$ and $N(\text{sibling})$

The Isochron Method

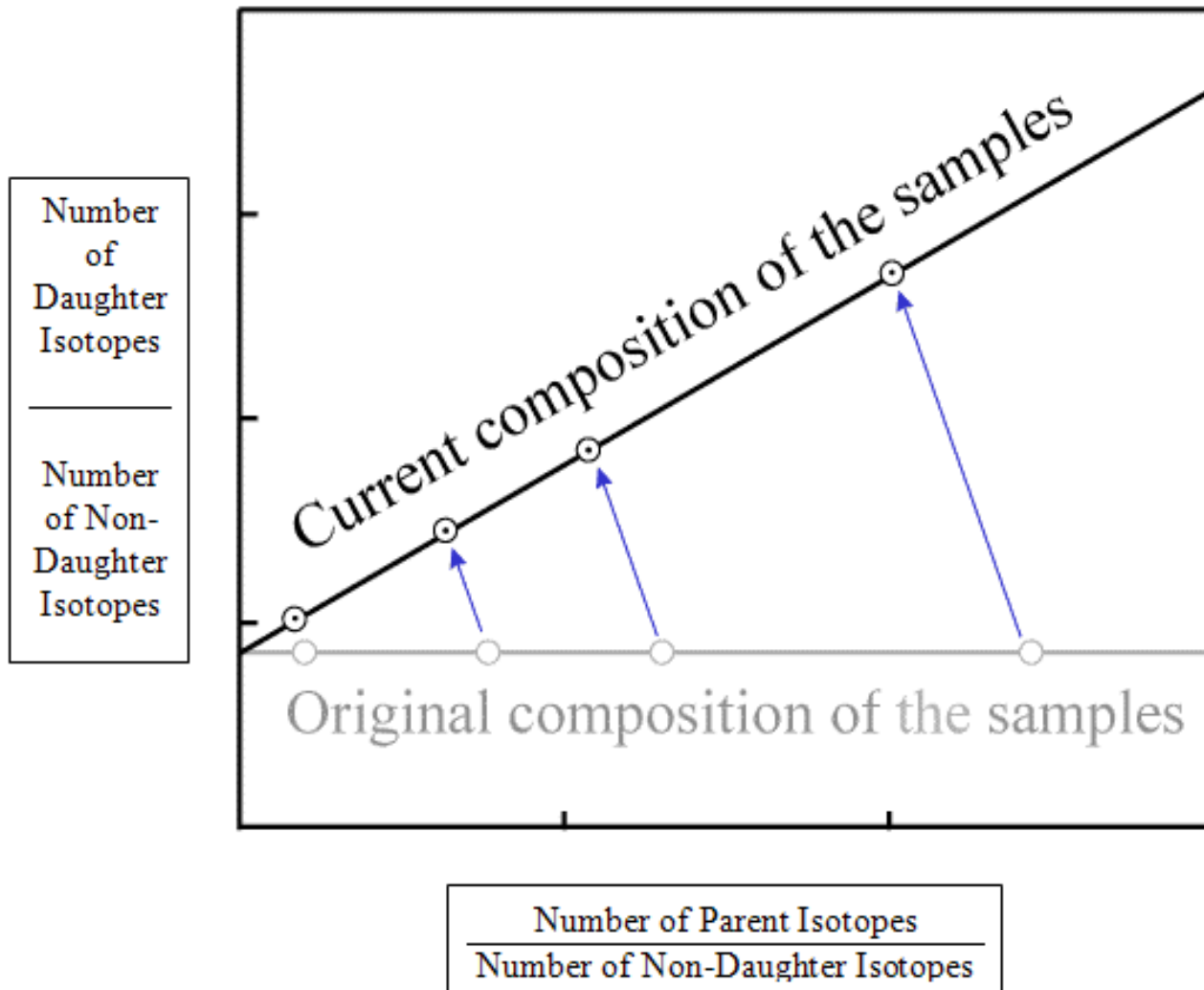
- We calculate two ratios:
- $N(^{87}\text{Sr})/N(^{86}\text{Sr})$ and $N(^{87}\text{Rb})/(^{86}\text{Sr})$
-
- $N(\text{Daughter})/N(\text{Sibling})$ and $N(\text{Parent})/N(\text{Sibling})$

The Isochron Method

- We now examine several rock samples and get ratios for each
- We draw a graph of
- $N(^{87}\text{Sr})/N(^{86}\text{Sr})$ plotted against $N(^{87}\text{Rb})/N(^{86}\text{Sr})$
- $N(\text{Daughter})/N(\text{Sibling})$ against $N(\text{Parent})/N(\text{Sibling})$

Isochrons

Progression of an Isochron, from Stasser 1998.

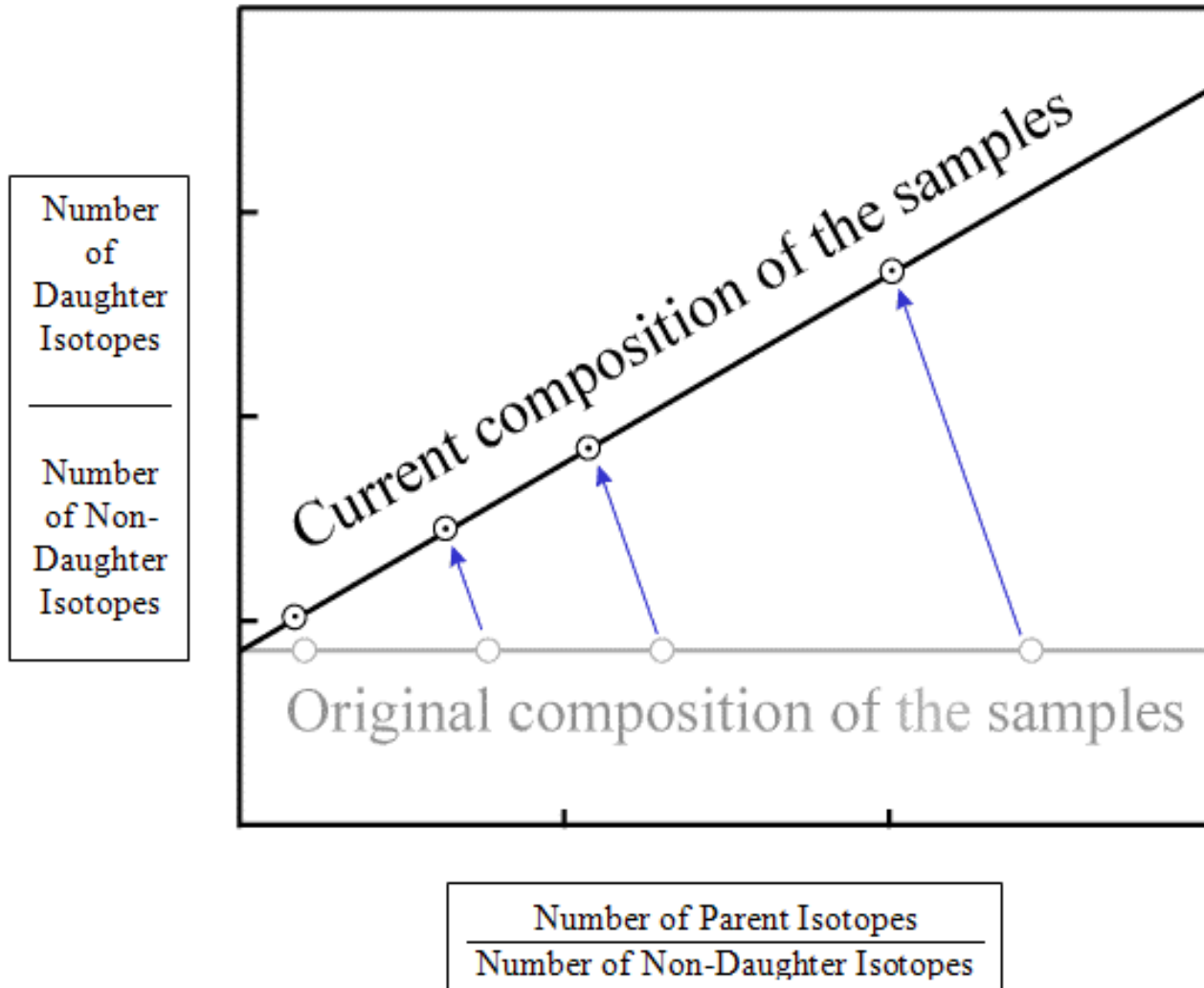


The Isochron

- As time goes by the parent ^{87}Rb decays so the point moves to the left
- At the same time the number of daughter ^{87}Sr atoms grows so the point moves upwards
- The *slope* of the line indicates the time that has elapsed since the rock formed

Isochrons

Progression of an Isochron, from Stasser 1998.



Important to end on an intellectual note

- I found something to send to Prof Alan Hogg, the tree ring man at University of Waikato
- His comment:
- “It made my day.”



I KNEW SHE WAS LYING ABOUT HER AGE.

The End