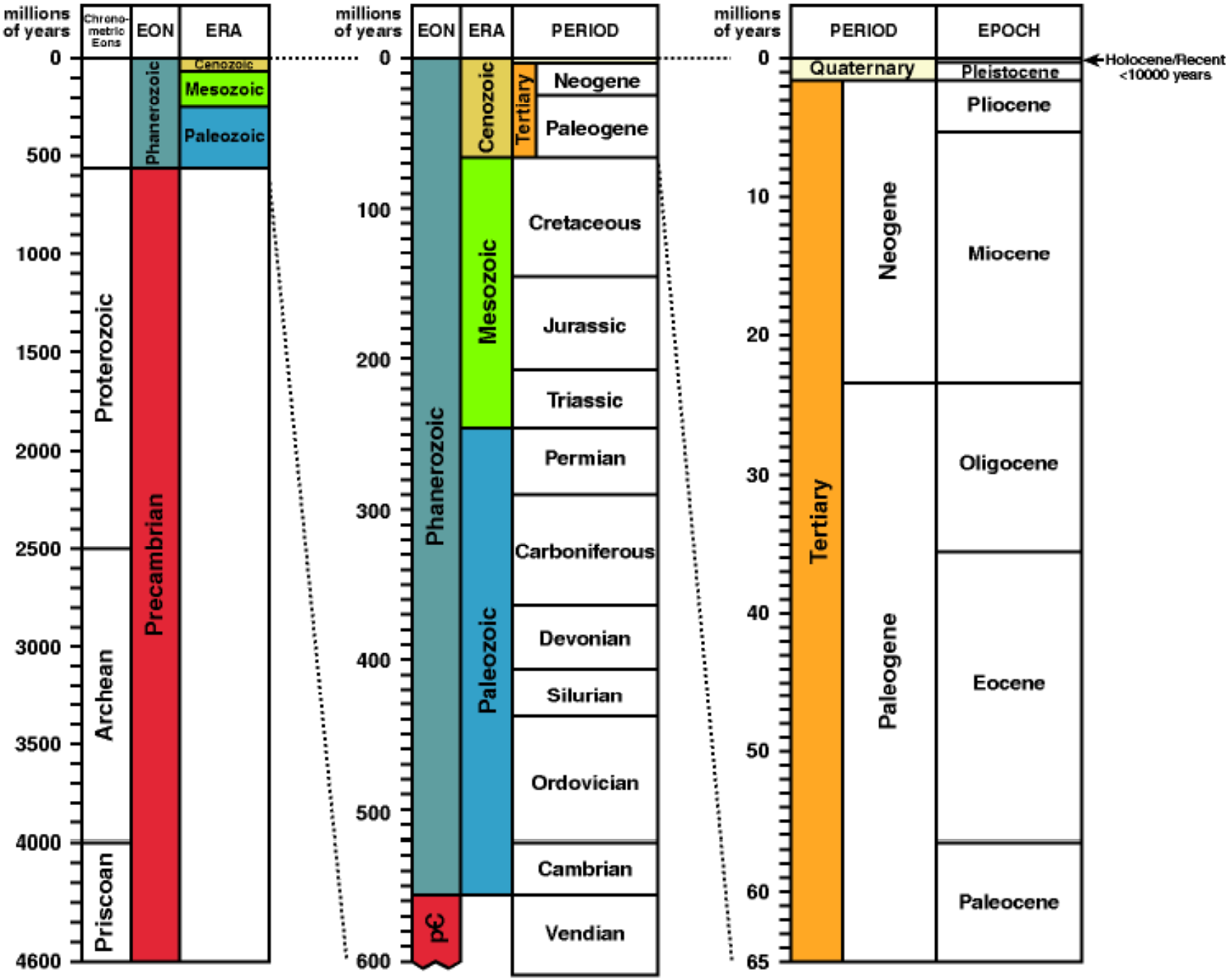
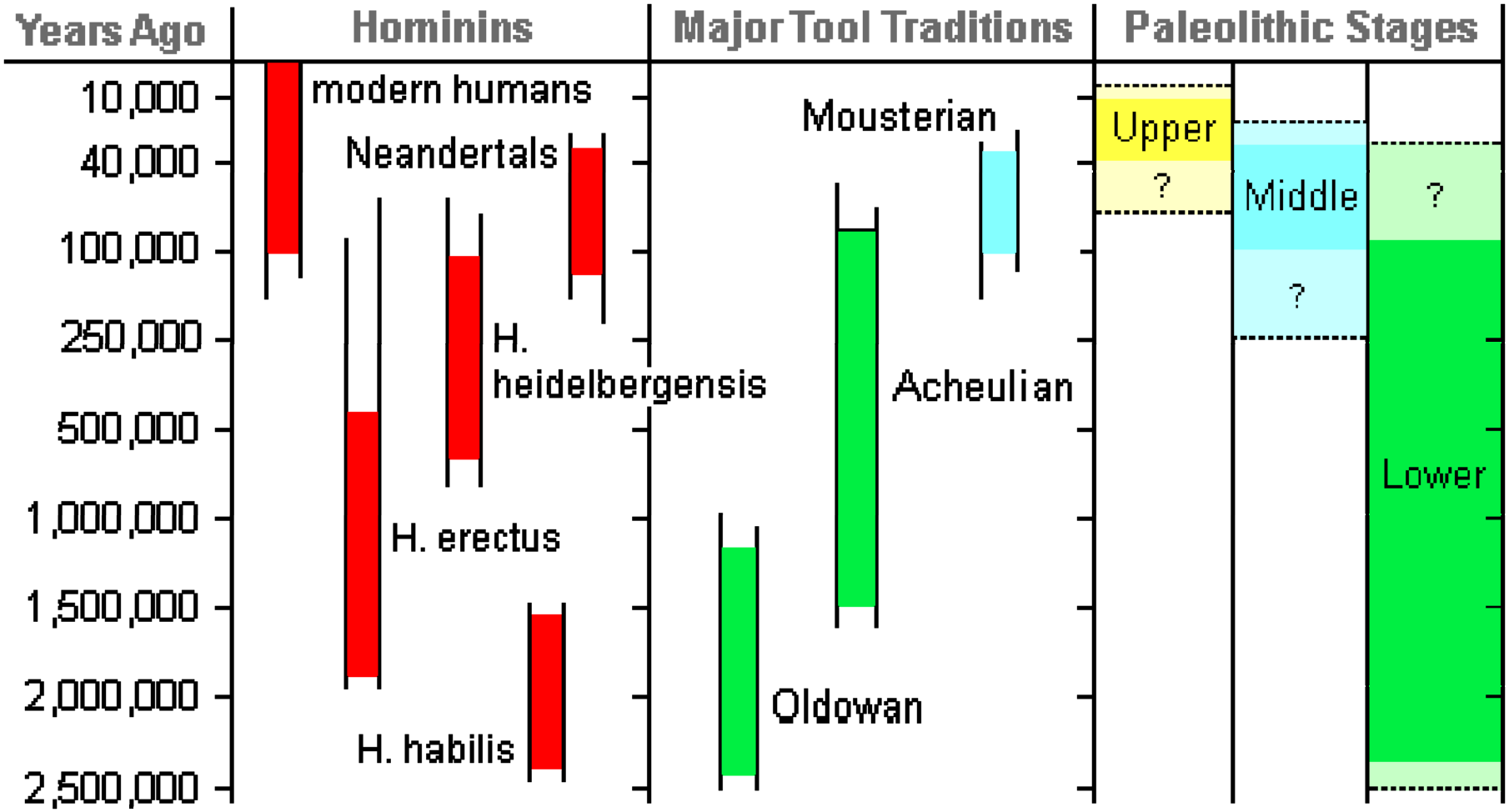
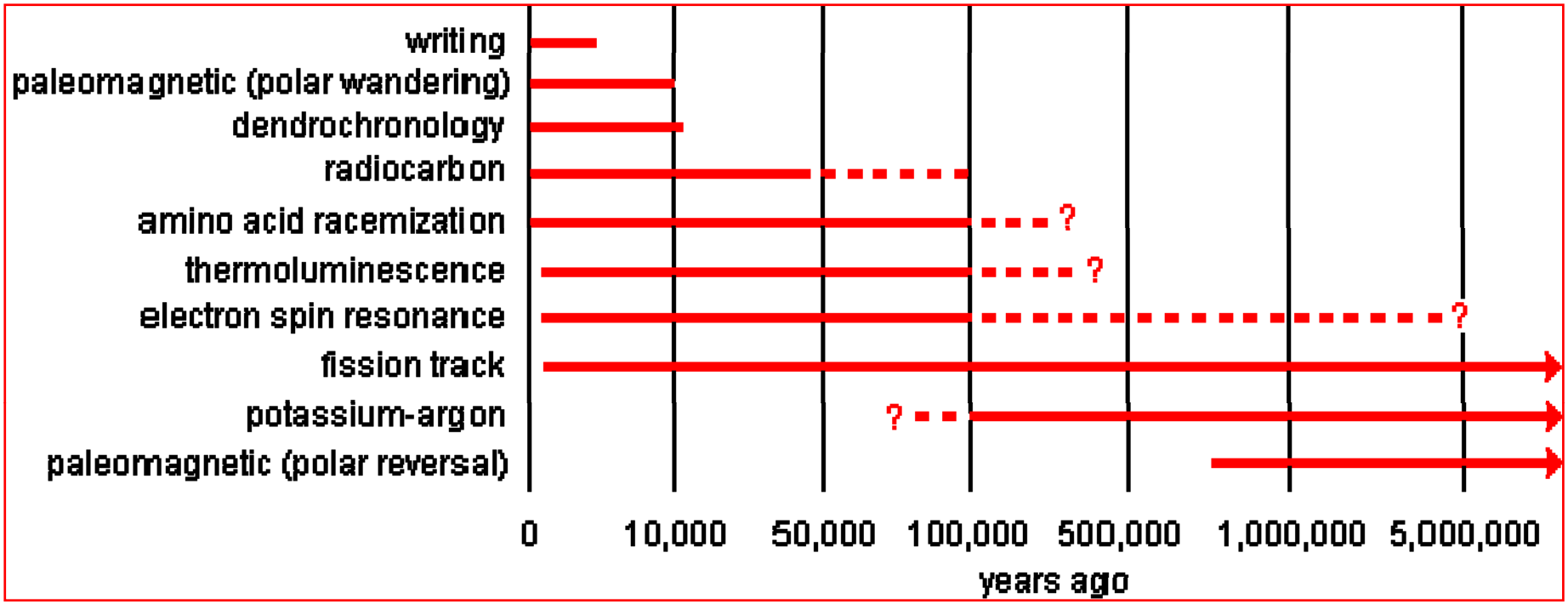
Dating: Chronometric Techniques (a.k.a. ‘Absolute Dating’)


millions of years
Chrono-metric Eons
EON
ERA
0
500
1000
1500
2000
2500
3000
3500
4000
4600
Cenozoic
Mesozoic
Paleozoic
Phanerozoic
Proterozoic
Archean
Priscoan
Precambrian
millions of years
EON
ERA
PERIOD
0
100
200
300
400
500
600
Cenozoic
Tertiary
Neogene
Paleogene
Mesozoic
Cretaceous
Jurassic
Triassic
Phanerozoic
Paleozoic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
Vendian
pЄ
millions of years
PERIOD
EPOCH
0
10
20
30
40
50
60
65
Quaternary
Pleistocene
Holocene/Recent <10000 years
Pliocene
Neogene
Miocene
Tertiary
Oligocene
Paleogene
Eocene
Paleocene

Timeline of early humans



Which Chronometric Technique?



‘Absolute’ or Chronometric Techniques

- Absolute dates are not absolute!
- All chronometric techniques except dendrochronology produce **estimates** of age, along with a statement about the precision and accuracy of the estimate
- The techniques are based on physical processes that <u>on average occur at a fixed rate</u>
- Random noise in that rate (in any individual specimen), along with technical difficulties in making the necessary measurements, mean that the ‘result’ is only a more or less reliable estimate of the true age
- Whenever you see a date produced with a chronometric technique, remember that ***it is only an estimate***, and think of it not as a specific year but as a range of time around that year

Which Chronometric Technique?

- The methods that are used depend on the presumed age of the site and artifacts excavated
- For instance, if a site is believed to be over 100,000 years old, dendrochronology and radiocarbon dating could not be used
- However, potassium-argon, fission track, amino acid racemization, thermoluminescence, electron spin resonance, and paleomagnetic dating methods would be considered
- In addition to the likely time range archaeologists must select dating techniques based on the kinds of datable materials available

Radiometric and Chemical Dating Techniques

Basic Principals

In order to use these techniques certain criteria are needed:

1. A ‘product’ which is detectable
   (the clock)

2. The rate of production of that ‘product’ must be know
   (the ticking clock)

3. The ‘product’ amount is 0 (or known) at age 0
   (clock set to zero)

Trapped charge dating

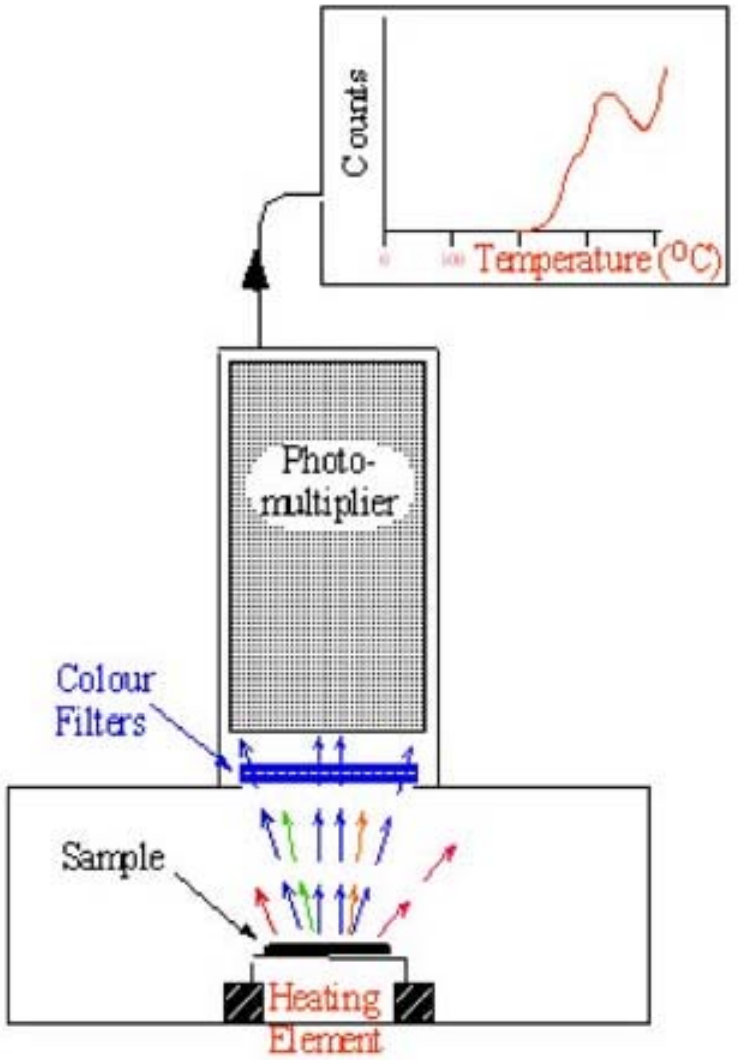
There are three principal techniques which operate on the basis of measuring trapped electrons in certain minerals, such as quartz and feldspar in sediments

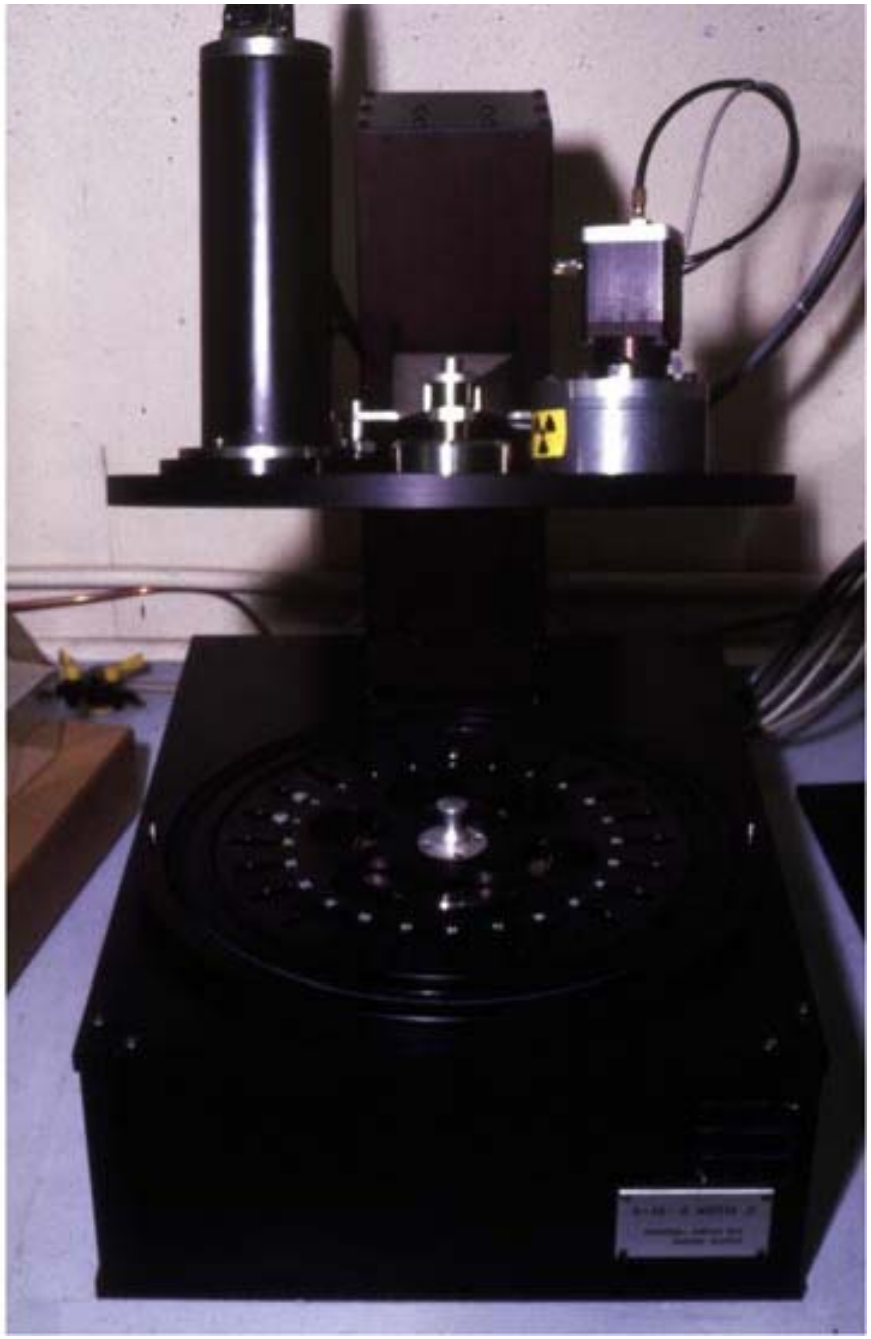
- thermoluminescence
- optically stimulated luminescence
- electron spin resonance

How does it work

- Over time, background gamma radiation in sediments cause these electrons to build up at a constant rate in the crystal structure of the minerals
- Electrons trapped in these minerals, escape when they are heated over 500 degrees C, or by exposure to sunlight
- The application of the heat or sunlight sets the clock back to zero, and the electron trapping process begins again
- So the trapped charge dating identifies *the last time the specimen had its electron trap emptied*
- In order to measure the trapped electrons a number of techniques are used which are distinguished by the methods used, ***and*** the type of material they date

Thermoluminescence





Thermoluminescence (TL)

- This technique is used largely to date pottery, and since pottery is one of the most abundant artifacts in most archaeological sites this can be quite a useful technique
- Since pottery is made by ‘firing’ or heating clay minerals and associated inclusions (often quartz sand), this firing acts as the ‘resetting event’ for TL dating
- As pottery sits in soils, the minerals in the pottery will begin to reabsorb electrons
- It is this ‘re-absorbtion’ since firing which is measured in TL dating, and this method can therefore tell you when the pottery was made
- MOST ancient pottery had relatively short life spans, so this can help to pin down a date, more or less.

Thermoluminescence (TL)

- In order for this information to be useful, you need to measure the radioactivity of the soil from which the sample came, usually through burying a ‘dosimeter’ in the site for a year
- Sometimes a radiation counter can be used on site for a faster assessment of radioactivity in the soil, or soil samples can be taken to be measured by the lab analyzing the pottery
- If the background radiation can not be determined, this is a less accurate method of dating
- This is particularly true for objects for which there is no provenience, such as many museum objects

Thermoluminescence (TL)

- In order to measure the TL level of pottery, it is irradiated with a calibrated radioactive source, and the TL given off is measured

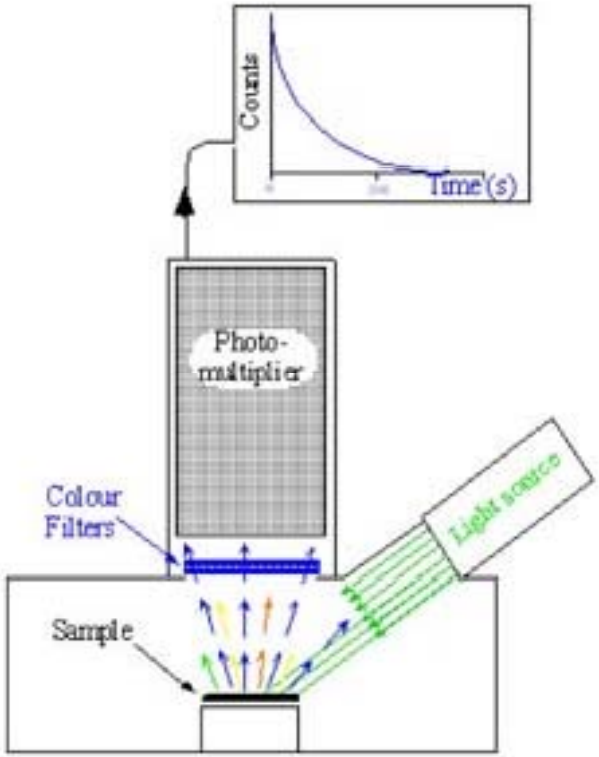
The formula used to determine age is:

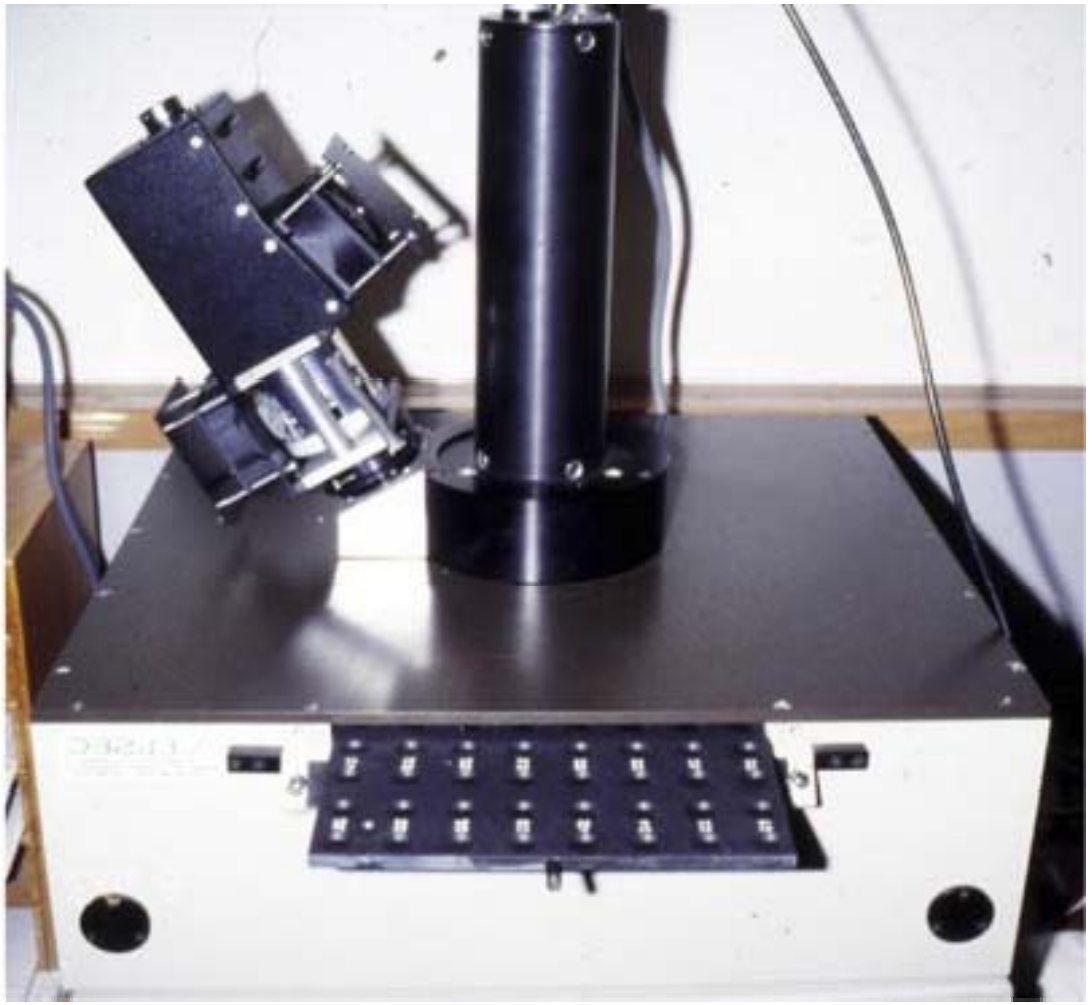
$$\textbf{Age} = \frac{\textbf{accumulated dose} \text{ (pottery)}}{\textbf{dose rate} \text{ (soil background)}}$$

Dose Rate = dose accumulated each year (background radiation)

- In addition to pottery (for which this is the only way to obtain an absolute date), in theory this method would work on other types of materials such as fired hearths, or heated rocks, including flint and chert

Optically Stimulated Luminescence





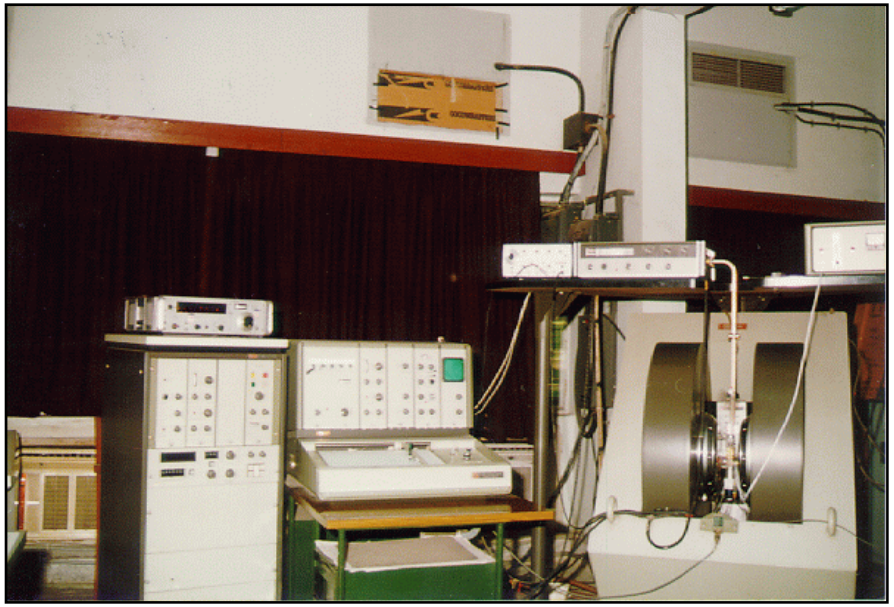
Optically stimulated Luminescence

- OSL is based on the fact that minerals in sediment grains are affected by prolonged exposure to light
- Specifically, light causes electrons of the mineral atoms to be progressively dislodged during ‘transport’ of the sediment
- This ‘bleaching’ of electrons provides a natural clock, since once they are deposited, they begin to accumulate once more
- The OSL technique has been used to date silty or sandy water deposited (sedimentary) deposits that are 1/2 million years old or younger

The Uffington Horse, carved into a chalk hillside in southern England has been dated using this method to suggest a Late Bronze Age date instead of the presumed Iron Age date

Electron Spin Resonance

- Technique is based on the fact that background radiation causes electrons to dislodge from their normal positions in atoms and become trapped in the crystalline lattice of the material.
- When odd numbers of electrons are separated, there is a measurable change in the magnetic field (or spin) of the atoms.
- Since the magnetic field progressively changes with time in a predictable way as a result of this process, it provides another atomic clock, or calendar, that can be used for dating purposes.



ESR Spectrometer

Electron Spin Resonance

- Unlike thermoluminescence dating, however, the sample is not destroyed with the ESR method, which allows samples to be dated more than once.
- ESR is used mostly to date calcium carbonate in limestone, coral, fossil teeth, mollusks, and egg shells.
- It also can date quartz and flint.
- The method has been used to date samples from the last 300,000 years
- It could potentially date much older samples

Dendrochronology (Tree chronology)

- Dendrochronology relies upon our ability to count the growth rings of a tree
- Because we know that a tree makes a new ring every year, if we have the entire diameter of a tree we can establish the exact age of the tree

Dendrochronology (Tree chronology)

- Although a tree makes a new ring every year, not every annual ring is the same and these will vary according to annual cycles in the environment producing variations in the size of annual growth rings
- This irregular pattern is expressed in a ‘dendrochronological curve’
- If we plot the thickness of the ring along the vertical axis and the years along the horizontal axis, it allows us to count backwards for very long periods

Dendrochronology

- The trick is to find ancient wood, and to fit this to an already existing series of rings
- For several regions (e.g., California and northwestern Europe) it has already been possible to make a chronology reaching back for thousands of years
- Using series like these we can date wood from archaeological sites by comparing and matching it ring for ring with the known curve

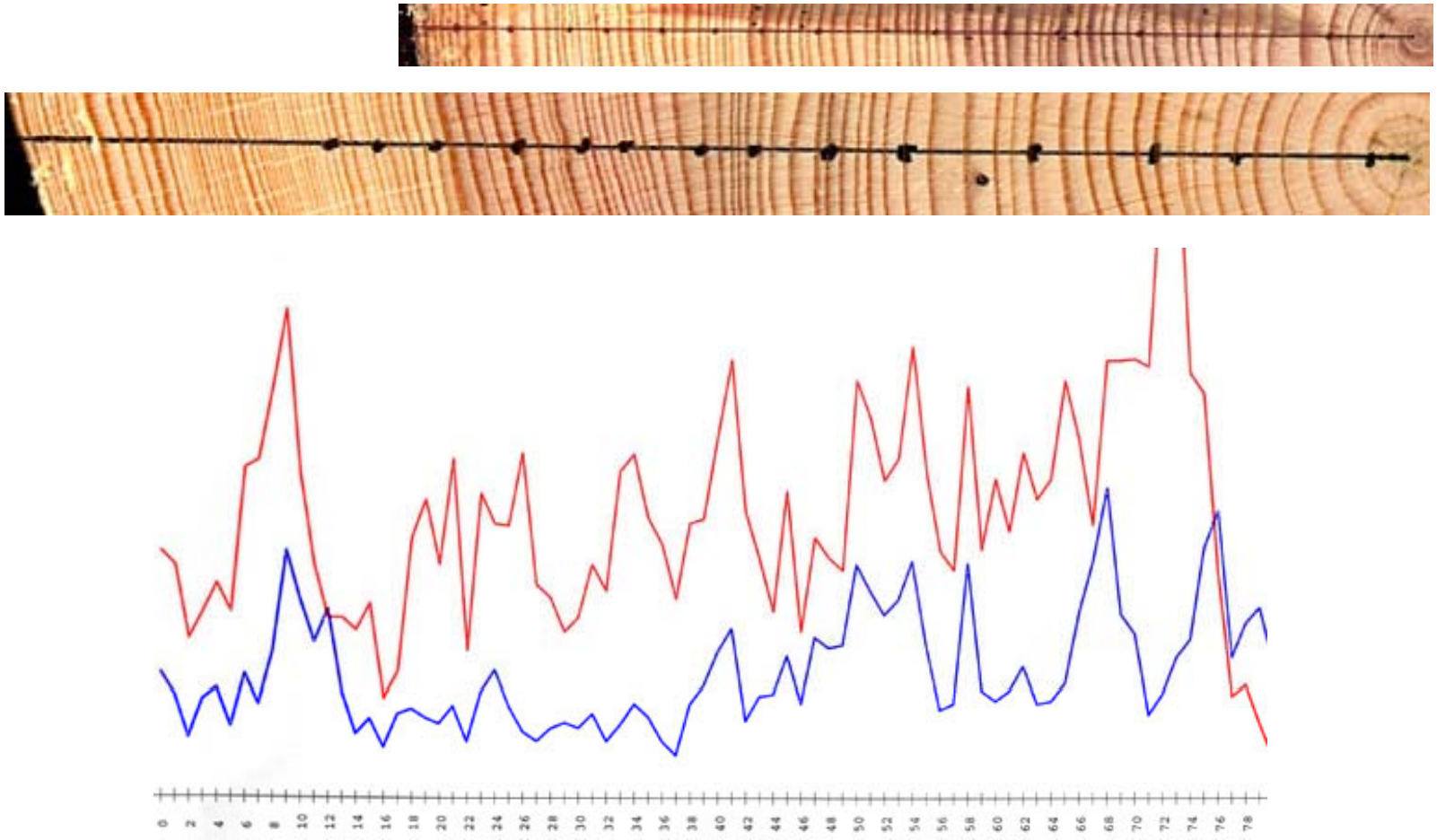
Dendrochronology

The accuracy depends on three factors:

1. the piece of wood to be dated it must have at least forty rings
2. the tree rings can only be compared to a dendrochronological curve from the same climactic region (American Southwest, Northern Europe etc.)
3. if the border between the sapwood and the heartwood is still present, the moment of the cutting of the tree can be dated exactly, otherwise, we find a *terminus post quem*

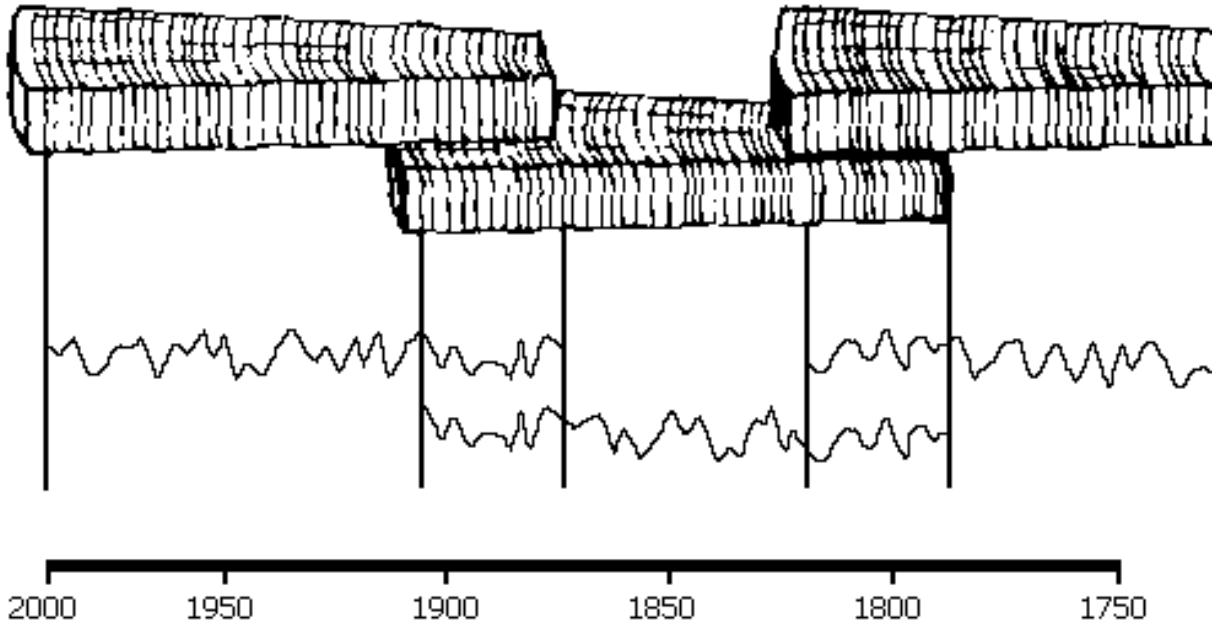
Dendrochronology

- two samples are 21 centimeters and 16 centimeters long
- they are taken out of two different logs in the house



Dendrochronology

- In the example below, the first tree was cut down in 2000, and it is possible to count backwards to 1870
- The second piece of wood is taken from a supporting beam in a house built at the beginning of the twentieth century
- There is an overlap for the years 1870-1910: both trees have the same pattern of thick and thin annual rings
- More or less the same can be said for the third part of our series, found in a windmill built in 1820

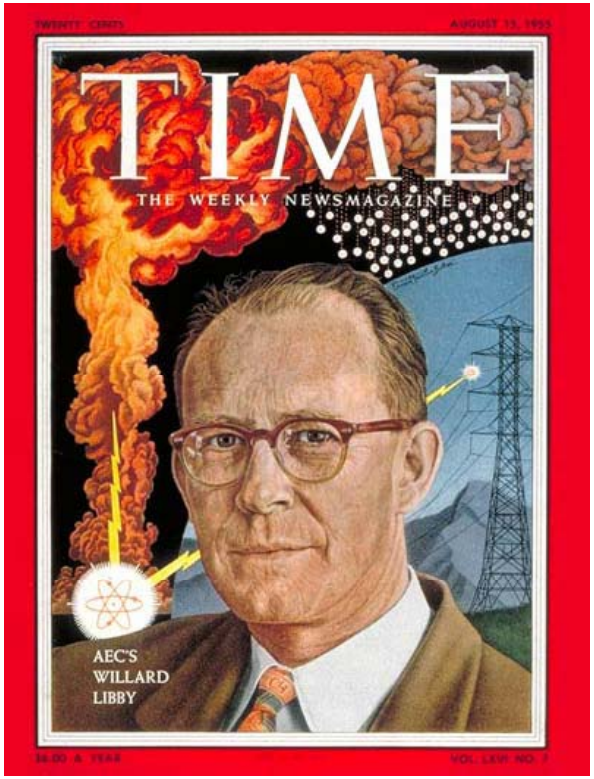


Dr. Gretal Boswijk, Director of the Tree Ring Lab at the School of Geology, Geography and Environmental Science, Auckland University describes dendrochronology work undertaken in New Zealand to extend the dating of the modern kauri tree record back to 1724BC, using data from logging relics, building timbers and sub-fossil kauri.

http://www.youtube.com/watch?v=TfZnp09lkHk

Radiocarbon Dating (C14)

- The first use of radiocarbon dating was by Willard Libby
- Libby's original measurements on 14C were done by counting the decays of 14C, using samples of several grams of carbon-black powder
- Libby found that after 5568 years, half the C14 in the original sample will have decayed and after another 5568 years, half of that remaining material will have decayed, and so on
- The *half-life* is the name given to this value which Libby measured at 5568±30 years. This became known as the *Libby half-life*



Radiocarbon Dating

Isotopes: elements with the same atomic number but different atomic mass

atomic number: number of protons in nucleus, e.g., 6-Carbon 7-Nitrogen, 19-Potassium

atomic mass: number of protons + neutrons, e.g., Carbon 12, 13, 14; Potassium 39, 40

- Some isotopes **unstable** 40K, 14C; while others are stable
- Unstable isotopes decay to another stable or unstable isotope
- Decay is expressed as 'half-life', which is the time in which ½ of radioisotopes decay

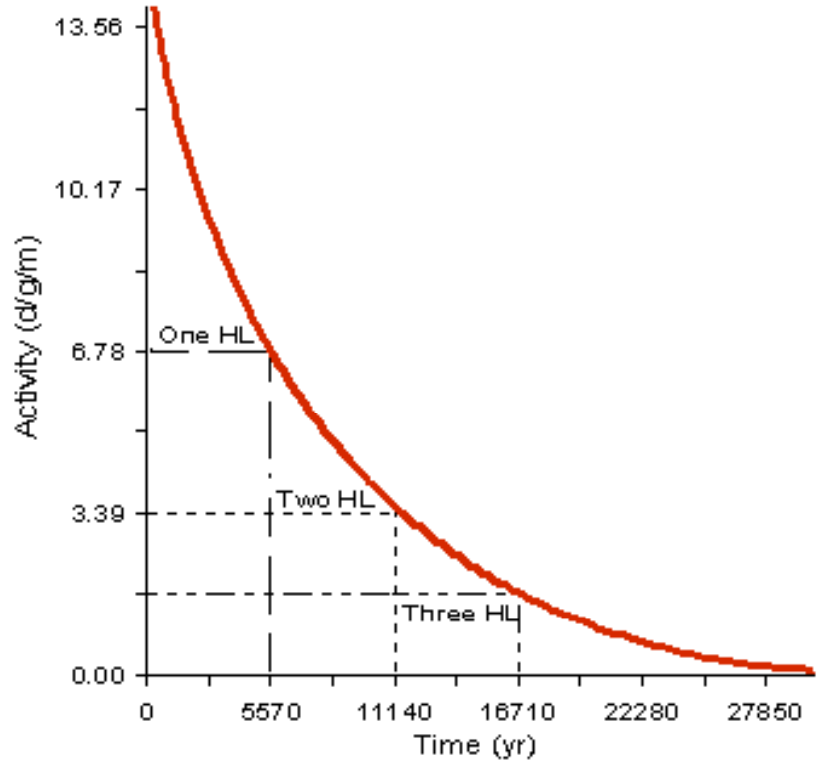
examples: 14C / **5730** yr (5570, Libby)
40K / 1.31 X 109 yr

Radiocarbon Dating

- Plants and animals which utilize carbon in biological food chains take up C14 during their lifetimes
- They exist in equilibrium with the C14 concentration of the atmosphere
- When a plant/animal dies they stop taking up carbon
- By measuring the C14 concentration of a sample whose age is not known, it is possible to obtain the count rate or number of decay events per gram of Carbon
- Comparing this with modern levels of activity (1890 wood corrected for decay to 1950 AD) and using the measured half-life it becomes possible to calculate a date for the death of the sample
- The advantage of the radiocarbon method is that any material which is composed of carbon may be dated
- All living organism contain carbon, so this method is used for wood, charcoal, seeds, bone, shell, etc.

Radiocarbon Dating

- Unfortunately, in the 1950s, due to atmospheric nuclear testing, this method was subject to errors due to nuclear contamination
- More accurate methods were developed using gas-proportional counters and liquid-scintillation counters
- These methods relied on the observation of a decay of the radioactive carbon atoms



Radiocarbon Dating

- When a 14C atom decays, it emits a beta-particle, which can be counted in a gas by the electrical pulse it generates.
- In a liquid-scintillation counter, the beta-particle excites the emission of light from a complex organic molecule or ‘scintillant’
- Because only about 13.5 decays per minute occur in one gram of modern carbon, it was necessary to use fairy large samples of *several grams of carbon*
- As this is a destructive method, this means the destruction of the archaeological sample being tested

Radiocarbon Dating

- Once the radiocarbon sample is measured, statistical analysis is necessary to attain a date.
- Two factors are important here:

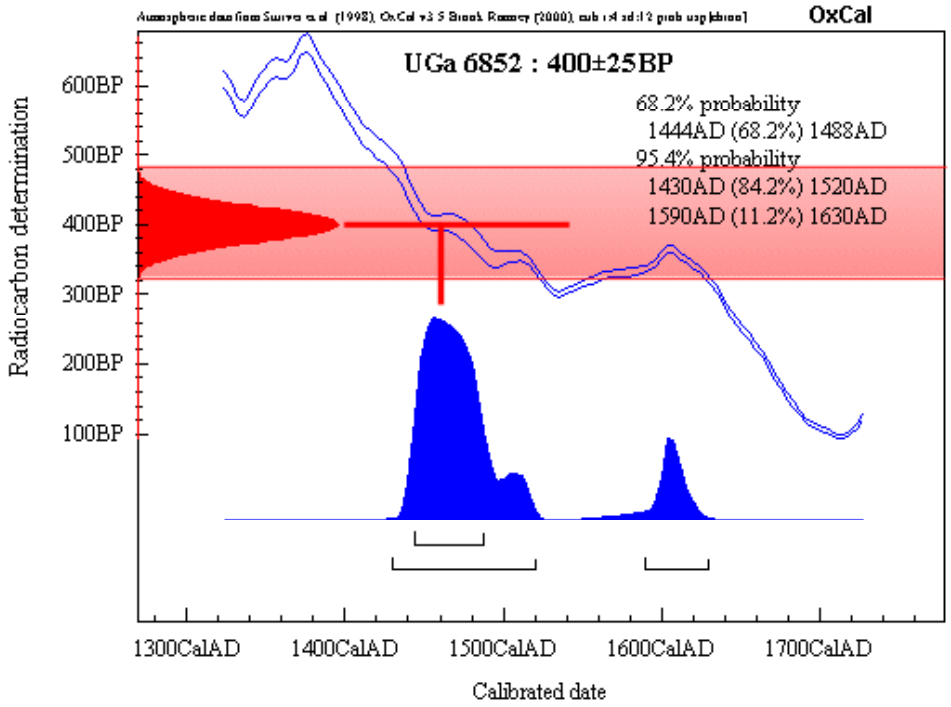
1. the decay of C14 although constant, is spontaneous
2. It is therefore not possible to measure all of the radioactivity in a given sample, hence the need for some kind of statistical analysis of counted data

- The distribution of counted C14 decay events will, over time, yield a pattern
- The pattern is termed a ‘normal distribution curve’
- A normal distribution describes the symmetrical bell shaped cluster of events around the average or mean of the data

Radiocarbon Dating

- In a normal distribution, 2 out of 3, or 68% of the values or counts observed will fall within one standard deviation of the average of the data
- At two standard deviations, 95% of the observed counts will fall within the range
- And at three standard deviations, 99% of the counts which comprise the normal distribution will fall within this region

- Each radiocarbon date is released as a conventional radiocarbon age with ‘standard error’
- This is the '±' value and by convention is ± 1 sigma



Accelerator Mass Spectrometer Dating (AMS)

Accelerator Mass Spectrometer Dating (AMS)

- Eventually it was recognized that direct measurement of the number of 14C atoms in the sample would greatly enhance the sensitivity
- Following some unsuccessful attempts using conventional mass spectrometry, a particle accelerator was added to a mass spectrometer to produce an *accelerator mass spectrometer* (AMS)
- This technique has allowed the measurement of radiocarbon in samples of much less than a milligram, or over a thousand times less material than is needed from the older counting methods

Accelerator Mass Spectrometer Dating (AMS)

- Radiocarbon dating using Accelerator Mass Spectrometry (AMS) differs from the decay counting methods in that the amount of 14C in the sample is measured directly, rather than by waiting for the individual radioactive decay events to occur
- This makes the technique 1,000 to 10,000 times more sensitive than decay counting
- The enhanced sensitivity is achieved by accelerating sample atoms as ions to high energies using a particle accelerator, and using nuclear particle detection techniques.

Accelerator Mass Spectrometer Dating (AMS)

Size limits (prior to any pretreatment) for AMS ^{14}C dating of archaeological samples:

Sample Type	Optimum Size	Minimum Size
Charcoal	50 mg	10 mg
Wood	50 mg	10 mg
Shell	100 m g	25mg
Peat	250 mg	100 mg
Bone/Antler	5 g	1 g
Cremated Bone	5 g	1 g
Soil/Silt/Sediment	500 mg	100 mg

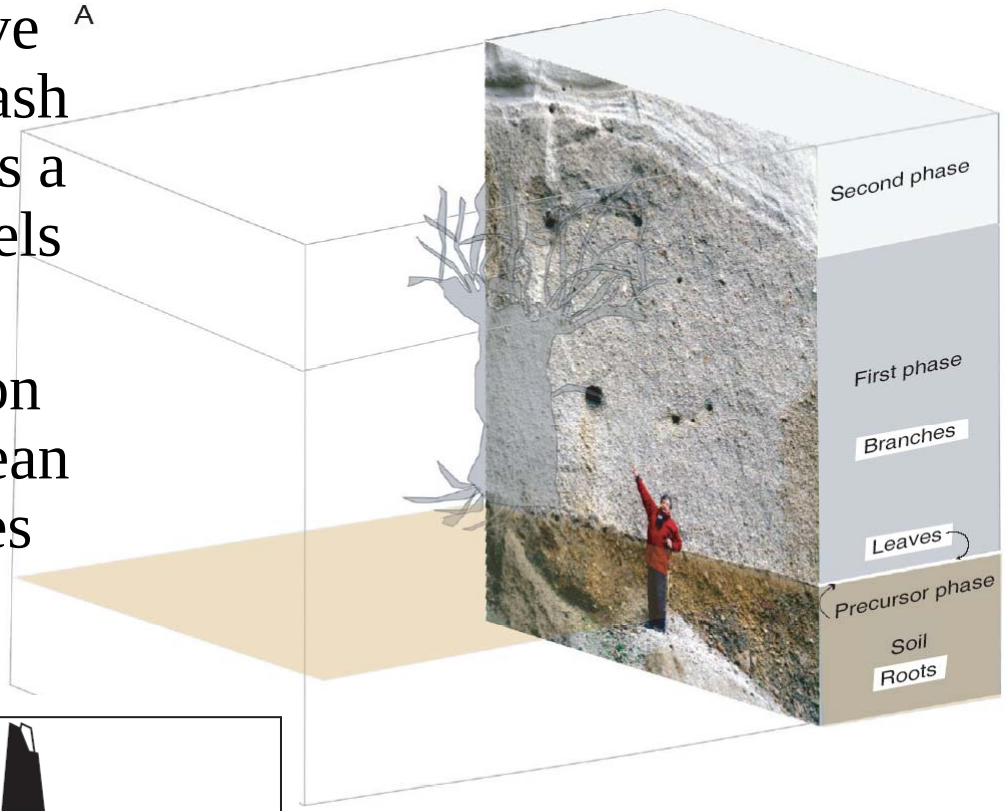
AMS ANALYSIS costs approx. $500 per sample and takes between 1-4 months to process

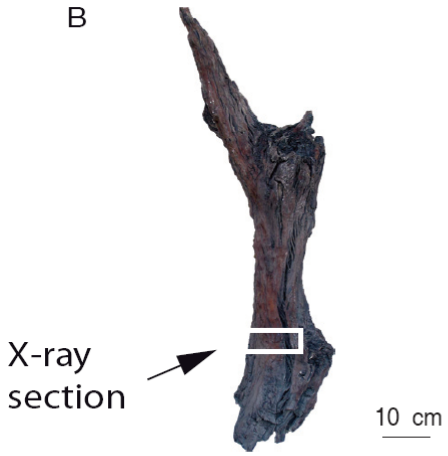
Volcanic eruptions at Thera

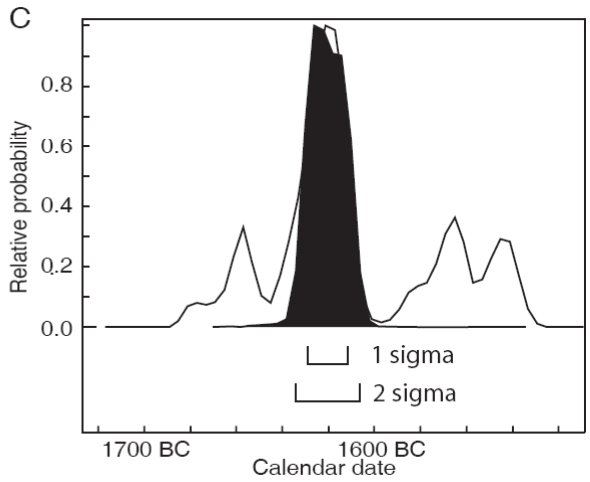
- Important for the dating of the phases of the Minoan civilization
- Implications for Aegean and Near Eastern chronologies
- For generations there have been competing dates (high and low chronologies)

The volcanic eruptions at Thera

- Radiocarbon dating of an olive tree, covered in the volcanic ash of the Thera eruption provides a direct way to date the ash levels
- This allows us to resolve the problem of dating this eruption and has implications for Aegean and Near Eastern chronologies





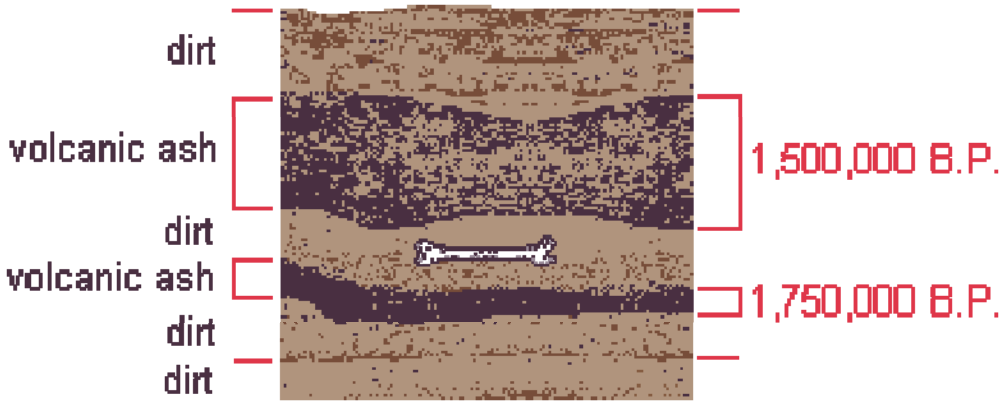


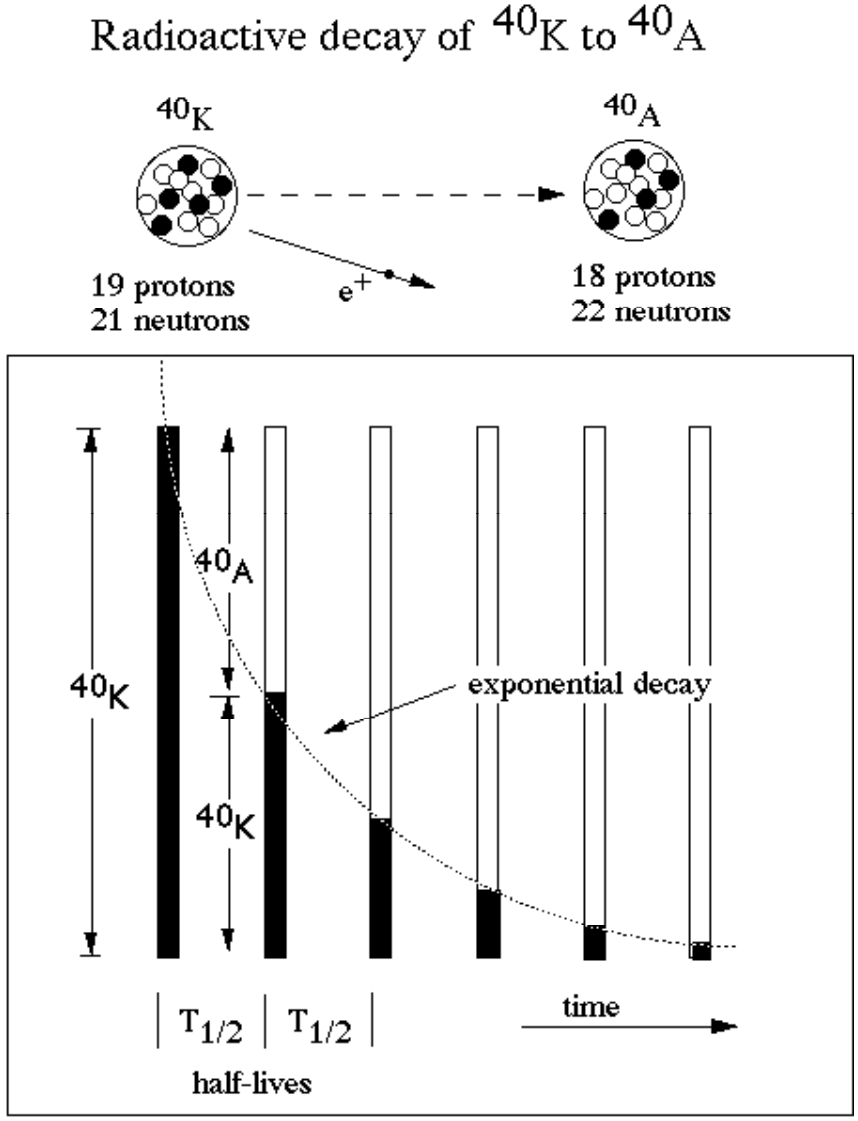
Potassium-Argon Dating (K/Ar)

- The Potassium-Argon (K-Ar) dating method is the measurement of the accumulation of argon in a mineral
- In contrast to radiocarbon dating, which measures the disappearance of a substance, K-Ar dating measure the accumulation of argon in a substance from the decomposition of potassium
- This is relatively easy because argon, being an inert gas, usually does not leech out of a mineral and is easy to measure in small samples
- The date achieved for the sample indicates the time since it was formed from molten/heated minerals
- The K-Ar method would give you the date that piece of rock was ‘reset’ by the changing of it’s chemical structure
- Heating, weathering and many kinds of alterations will reset this time

Potassium-Argon Dating (K/Ar)

K/Ar dates are based on ratio of the isotopes 40K / 40Ar trapped in the sample, heating drives off argon gas, re-setting clock.

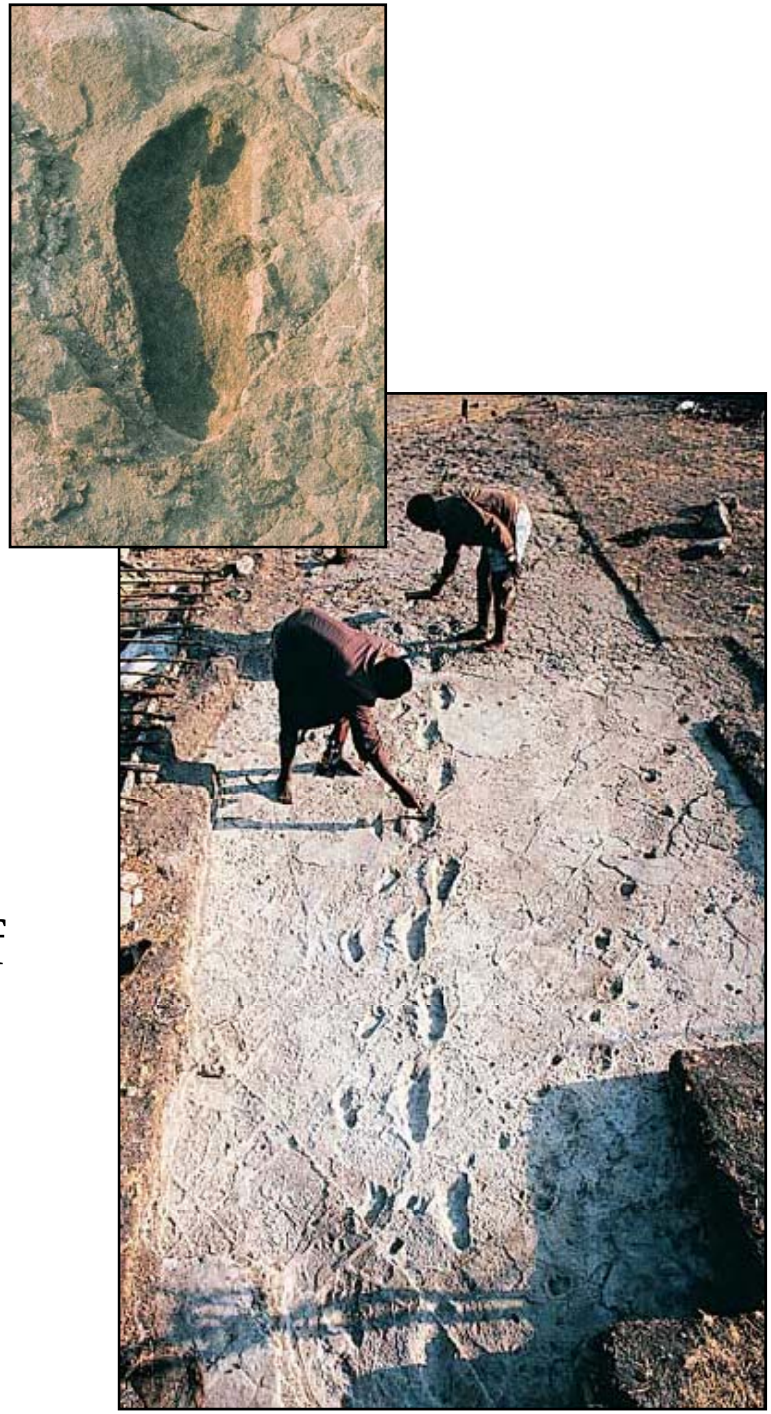




For $^{40}K \rightarrow {}^{40}A$ decay, the half-life is 1.3×10^9 years

Laetoli footprints

- This sites is located in Northern Tanzania, and in 1978 Mary Leakey and Tim White found 59 footprints of bipedal hominids (australopithecines) hardened in volcanic ash layer
- Two individuals walked in two close parallel tracks across volcanic dust from a recent eruption, which had been turned to mud from rainfall
- In addition, there are a child's footprints within those of the larger adult
- The footprints look almost like those of modern humans
- Using the K/Ar technique the volcanic eruption was dated to at least 3.5 million years ago



Finally....

It is vital to remember that the several techniques provide estimates of the age of different events.

Those events, however, may not be the same time as the human behavior you actually want to date. For example:

- Dendrochronology tells you the year(s) that part of the tree grew
- C-14 dating estimates the time when the sample tissue died
- Obsidian hydration dating estimates when an obsidian surface was exposed, such as when an obsidian tool was made
- K/Ar (and Ar/Ar) dating estimates when molten rock crystallized
- TL dating estimates when the sample last was heated above a certain temperature