- chronometry = the measurement of time
- direct dating = the assignment of an age to a physical remain based on the direct analysis of that physical remain
- indirect dating = the assignment of an age to a physical remain based on its association with other remains of known age

- absolute dating
  - units and time depth
  - reliability → accuracy, precision
  - resolution

- Potassium/Argon (K-Ar)
  - radioactive decay of $^{40}$K to $^{40}$Ar
  - $^{40}$K half-life = 1.31 billion years
  - “dating gap” and OSL-TL

- stratigraphy & the Law of Superposition = the order of strata from bottom to top represents the temporal order of their deposition from oldest to youngest
  - does not answer question of primary/secondary context

- relative dating
  - only are able to say that something is older than or younger than something else
    - no “dueling banjos” jokes please…

- absolute dating
  - are able to say that something is older than or younger than something else AND you can specify HOW MUCH older or younger using a measured unit of time (e.g., seconds, minutes…millions of years)
the ideal (remember the complexities)

\[ A < B < C < D < E < F \]

‘Layer-cake’ stratigraphy

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“Law of Superposition” still works.

WEATHERING/EROSION

Source-Sink Model

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Stylistic Seriation = ordering of physical remains in a series so that adjacent items in the series are more similar to each other than items farther apart
Frequency Seriation = the ordering of artifacts according to their frequencies so that the distribution conforms to a “battleship-shaped” curve; FUNDAMENTAL ASSUMPTION

- biostratigraphy
  - subdivision of the stratigraphic record into sediments or rocks by means of fossil content
  - process of evolution (change through time) is the basis for biostratigraphic subdivision
    - the development of new species
    - the evolution of the characteristics one particular species
  - can be thought of as analogous to either stylistic seriation or frequency seriation depending on chosen methods

- crossdating (sequence comparison)
- age assignment for a site or sequence of artifacts based on comparisons with a sequence of known relative or absolute age
- assumes that the processes operating at the undated spatial location are the same as that at the dated spatial location, or that the locations are connected (e.g., through trade or population movement)
- Paleomagnetic stratigraphy
  - Earth’s poles decompose and reemerge in opposite positions
    - Normal Polarity = like today
    - Reversed Polarity = opposite of today
  - Happens every ~200 ka
  - Occurs rapidly; 1000 years (?)
  - Measure orientation of iron minerals in sediment samples
    - Iron minerals deposited from suspension align themselves to the ambient geomagnetic field
    - Heating sediments above the ‘Curie point’
  - If independently numerically dated, a resulting magnetostratigraphy can be used to date sedimentary successions

Matuyama-Brunhes boundary 780 kya
- Last time the earth switched polarity
- How do we know the age of this event?

- Archaeomagnetism
  - Magnetic minerals in heated sediments track “wandering” pole
  - Useful over past 2000 years (path crosses too many times to be useful for older ages)
  - May help “refine” ages estimated from relative dating techniques

Some sequences cannot be cross dated based on sedimentary, soil, biostratigraphic or cultural similarities
**absolute (chronometric) dating**

- Time is divided into measurable units
  - Units are arbitrary and fixed
    - 1 standard year always contains 365 days
  - Scale is independent of process of interest
    - We can compare 10 years of soil formation with 10 years of sedimentation

- Principal Units
  - Mya = millions of years ago (10⁶ years)
  - Ka = (Kilo annum) 1000 years ago (10³ years)
  - BP = Years “before present” (by convention 1950)

**key concepts in absolute dating**

- Age range = the time range over which a particular dating technique works (e.g., ¹⁴C age range = ~50 ka to present)

- Reliability = a subjective/objective determination of whether a date is representative of the “true” age

- Accuracy = is a measure of systematic error and refers to the “closeness” of a chronometric estimate to the true age

- Precision = is a measure of random error and refers to how often you arrive at the same answer for repeated dates

- Resolution = (closely related to precision) refers to the smallest unit of time at which two dates can be distinguished

- **High accuracy**
- **Moderate accuracy**
- **Low accuracy**

- High precision
- High precision
- Low precision

- Must have an independent means of assigning age to estimate accuracy (or know if there is a standard systematic error)
- Resolution = shortest interval of time by which two age assays can be distinguished

- My grandfather is an octogenarian. My grandmother is also an octogenarian. Who is older?
  - octogenarian = 80, 81 … 89 years old
  - decadal resolution
  - only able to distinguish between the ages of my grandfather and grandmother if their ages differ by more than ten years

- resolution notation: 15,000 ± 250 BP
  - error term is 1 standard deviation (SD)
  - 1SD = 68% probability that the “true” age is between 14,750 – 15,250 BP
  - 2SD = 95% probability that the “true” age is between 14,500 – 15,500 BP
  - if you wanted to be 68% certain that two dates were different then they dates should be different by at least 250 years...

- for relative stratigraphic dates, resolution is determined the thickness of the layers in the stratigraphic sequence

- high-resolution

- low-resolution

- chronometry =
  - direct vs. indirect dating
  - relative vs. absolute time
  - relative dating
    - stratigraphy
    - law of superposition
    - stylistic seriation
    - frequency seriation (textbook)
    - biostratigraphy
    - paleomagnetism & archaeomagnetism
    - cross-dating
  - absolute dating
    - units and time depth
    - reliability → accuracy, precision
    - resolution

- high-precision techniques
  - calendars
  - dendrochronology
  - radiometric techniques
    - radioactivity and half-life
  - radiocarbon (14C) dating
    - 14C half-life = 5730 years
  - organics, atmospheric equilibrium
  - assume constant production of 14C
  - calibration
  - Potassium/Argon (K-Ar)
    - radioactive decay of 40K to 40Ar
    - 40K half-life = 1.31 billion years
  - “dating gap” and OSL-TL
- high-precision techniques: calendrics
  - only useful in literate times, usually complex societies
    - e.g. historical archaeology, Roman coins, Egyptian hieroglyphs, Mayan stelae, textual sources

- To be used successfully, one must...
  1. understand the date, literally
     - can you decipher it?
  2. understand what it dates
     - what is the literary context? factual or mythical?
  3. be able to translate it to a meaningful date referable to our time system
     - can the calendar be anchored in our calendar system?

- Coin Dating Example

  - patron goddess
  - possible date markings

- high-precision techniques
  - dendrochronology (tree ring dating)
    - based on observation that the annual growth rings of a few tree species vary in width according to differences in seasonal growing conditions (especially water availability)
      - sequence of tree-ring widths is perfectly unique to a sequence of growing seasons
Dow Jones
daily price variation
long-term sequence is
perfectly unique…with
a sufficient sample size!

- dendrochronology limitations
  - if right species, must be
    seasonal variation in growing
    conditions
  - tree rings must be well
    preserved & sample >30 rings
  - dated master sequence
  - sample context
    - direct dating (e.g., wood beam in
      a pueblo may date time of
      construction)
    - indirect dating (e.g., found in a
      deposit where cross-dating can be
      applied)

- radiometric dating techniques
  - based on the systematic decay of unstable isotopes of
    common chemical elements into more stable isotopes
    - $^{14}$C, $^{46}$K, $^{235}$U…
    - radioactive isotopes decay with a characteristic “half-life”
    - half-life = the amount of time it takes for $\frac{1}{2}$ of the radioactive
      isotopes originally present to decay

  \[
  N_t = N_0 e^{-\lambda t} \\
  \lambda = \ln(2)/\text{half-life}
  \]

- radiocarbon ($^{14}$C) dating
  - radiocarbon is produced in the
    upper atmosphere through the
    bombardment of $^{14}$N with
    cosmic and solar radiation
    - $^{14}$N + n $\rightarrow$ $^{14}$C + $^1$H

  - radiocarbon is oxidized to
    CO$_2$ and mixed in the
    atmosphere and oceans very
    quickly

  - all organic life incorporates
    $^{14}$C into their makeup,
    ultimately via photosynthesis
radiocarbon (\(^{14}\text{C}\)) dating

- \(^{14}\text{C}\) half-life = 5730 years
- \(^{14}\text{C} \rightarrow \beta + ^{14}\text{N}\)

- all organic life is in equilibrium with atmospheric \(^{14}\text{C}\)
  - all living organisms (plants, animals, bacteria) contain the same amount of \(^{14}\text{C}\) in them as the atmosphere
  - the amount of \(^{14}\text{C}\) entering the organism through photosynthesis or ingestion equals the amount leaving the organism through decay; total amount does not change until...

- when an organism dies it stops taking up \(^{14}\text{C}\) and the \(^{14}\text{C}\) present in the organism at the time of death begins to decline through decay

- decay will continue until there is no \(^{14}\text{C}\) remaining

- the maximum age range of radiocarbon is determined by the minimum amount of the radioactive isotope that can be measured
  - approximately 9 half-lives (51,570 years)

How is the \(^{14}\text{C}\) Clock Set?

- any organic material (and a few inorganic materials that incorporate organic carbon) can be dated using the radiocarbon method
  - wood, charcoal, bone, pollen, soils...

- critical assumption is that the amount of radiocarbon produced in the upper atmosphere has remained constant over time
  - It has not!!!
  - variability in solar radiation = variability in production rates
  - radiocarbon years are “elastic” and not the same thing as calendar years, which are “inelastic”
In general, there was more $^{14}$C in the atmosphere in the past compared with the present (1950); radiocarbon ages are usually too young compared with calendar ages.

**Radiocarbon ($^{14}$C) dating**

- radiocarbon calibration = application of a correction equation to convert radiocarbon years into calendar years
- most reliable calibration based on:
  - dating of annual tree rings (but only goes back to ca. 13 ka)
  - dating of varved sediments
  - dating of fossil coral reefs using U-Th
- other absolute dating techniques are in calendar years!!!!
  - need to calibrate radiocarbon dates to be able to compare with other dating results!

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**$^{40}$K-$^{40}$Ar → Ar$^{40}$-$^{39}$Ar Dating**

- only viable radiometric technique for dating very old archaeological materials
- successfully dated rocks as much as 4 billion years old

**$^{40}$K-$^{40}$Ar Reaction**

- based on the fact that the radioactive isotope $^{40}$K decays to the gas $^{40}$Ar
- $^{40}$K has a half-life of 1.31 billion years
  - starting with 100 atoms of $^{40}$K, you will have 50 remaining after 1.31 billion years, 25 remaining after 2.62 billion years, 12.5 remaining after...
- only 11.2% of $^{40}$K atoms decay to $^{40}$Ar, remainder to $^{40}$Ca
  - starting with 0 atoms of $^{40}$Ar, you will have 5.6 atoms after 1.31 billion years, 8.4 atoms after 2.62 billion years, 9.8 atoms after...
- The technique is based on measuring the ratio $^{40}\text{Ar}/^{40}\text{K}$ in a sample.
- Assuming that there is no $^{40}\text{Ar}$ present at the beginning.
- The ratio increases as age increases; $^{40}\text{Ar}$ increases and $^{40}\text{K}$ decreases as $^{40}\text{K}$ decays.
- Note: $^{40}\text{Ar} - ^{19}\text{Ar}$ method provides a different way of measuring $^{40}\text{K}$.

- Can we assume that there is no $^{40}\text{Ar}$ present?
- $^{40}\text{K}$ is abundant almost everywhere (e.g., soil, clay, salt, bananas)...
- K is one of the most abundant elements in the Earth's crust (2.4% by mass).
- One out of every 100 K atoms is radioactive $^{40}\text{K}$ (19 protons and 21 neutrons).

**Age Range:** beginning of the universe to ~100 ka.

**How is the $^{40}\text{K} - ^{40}\text{Ar}$ Clock Set?**
- When rocks are heated to the melting point, any $^{40}\text{Ar}$ contained in them is released into the atmosphere.
- When the rock recrystallizes, it becomes impermeable to gases.
- As the $^{40}\text{K}$ in the rock decays into $^{40}\text{Ar}$, the $^{40}\text{Ar}$ gas is trapped in the rock.

**Limitations to K-Ar Dating**
- Works well for most volcanic rocks (especially basalt), provided the rock has not subsequently been heated and recrystallized.
- When is it useful to archaeologists?
Limitations to K-Ar Dating

- Standard deviations for K-Ar dates are large
  - 10^4 to 10^6 years (e.g., 1.2 ± 0.015 mya = 15,000 year resolution!)

- At 100 ka, only 0.0053% of the ⁴⁰K in a rock would have decayed and only 11.2% of this is ⁴⁰Ar
  - Too little ⁴⁰Ar to measure!!!
  - K-Ar dating is not useful for “young” archaeological contexts
  - Dating range for K-Ar = >4.5 billion years to ~100 ka

The dating “gap”

- ¹⁴C dating range: 50ka to present

- K-Ar dating range: 4.5 billion to 100 ka

- Several key human evolutionary events occurred in this “gap”

Filling the dating “gap”

- Thermoluminescence (TL) and Optically Stimulated Luminescence (OSL)

  - Certain mineral crystals (e.g., quartz, feldspar) have minor crystalline flaws that operate as “electron traps”

  - If these crystals are bombarded with high energy radiation at a constant rate, then electrons will be “trapped” at a constant rate until all of the traps are filled

  - One can count the total number of trapped electrons by either heating a sample (TL) or stimulating it with light (OSL); in both cases the mineral crystal will emit light (luminesce) in proportion to the number of trapped electrons

How is the TL/OSL clock set?

- The TL/OSL clock is set to “zero” when all of the electron traps are empty

  - Electron traps are completely emptied if the crystal is heated to a high enough temperature (TL) or exposed to bright light (OSL)

  - If the material is then buried in a context where it receives a constant dose of cosmic and nuclear radiation—radioactive U and K are reasonably common in most sediments—then the material begins to accumulate “trapped” electrons

  - The event dated by TL/OSL is the last time the object was heated, or exposed to light

    - Wind deposited sand dune (OSL) overlying an archaeological site
    - Fired ceramic vessels
    - Burned flint stone tools (heat treatment, discarded in fire pit)

- Age range: 250 BP to 1 mya
direct vs. indirect dating
what exactly are you dating?

14C date on fossil?

K-Ar date on basalt stone tool?