Introduction to Archaeology: Notes 9

Chronology, part 2

- Trapped-charge dating methods
  - Several different kinds, one basic principle
  - All measure
    - the accumulated damage
      - (displaced electrons)
    - to the crystal structure
    - of mineral crystals
    - caused by exposure to radiation
    - since the crystal was undamaged
  - In **Electron Spin Resonance (ESR)**
    - The mineral apatite in teeth is undamaged when the tooth is formed, and accumulates damage from then on
  - In **Thermoluminescence (TL)**
    - Quartz and feldspar crystals in ceramics are "annealed", or allowed to "heal" by being heated when fired or used in a hot cooking fire
  - In **Optically Stimulated Luminescence (OSL)**
    - Quartz grains are "annealed" by exposure to sunlight
  - In all of these, damage to the crystal is then caused by radiation from radioactive elements naturally in the soil
  - So if we measure the total damage
    - and we know the annual radiation dose in the ground
    - we can calculate how long the sample has been exposed to that radiation
      - that is, how long it has been buried since the crystal was undamaged
  - All these methods require measuring the radioactivity of the soil that the the sample was in
    - this is done by placing a **dosimeter** in an unexcavated portion of the same stratum that the sample came from
      - typically by pushing it deep into a sidewall of the excavation
    - you return perhaps 6 months or a year later and retrieve it
    - the dosimeter has accumulated radiation damage during that known period of time
    - allowing us to calculate the annual dose of radiation that the sample was exposed to
  - These methods assume that
    - the sample has been surrounded by the same soil since it was "reset"
    - it was buried soon enough after being "reset" that no significant damage occurred from a different annual radiation dose before burial
  - So these methods should not work on samples found on the surface
    - we can't know whether and for how long they might have been buried
    - or how radioactive the soil around them was
  - They also might not work on samples that were used for a long time before burial
  - What the methods actually date
    - Electron Spin Resonance (ESR) dates

- How long a tooth was buried
- its apatite was undamaged when first formed
- Thermoluminescence (TL) dates
  - How long a piece of ceramic was buried since it was fired or used in a hot fire
  - Or since a piece of chert (a rock) was heated to improve its flaking properties
- Optically Stimulated Luminescence (OSL) dates
  - How long windblown sand has been buried (in the dark)
  - Windblown sand is assumed to have been well exposed to sunlight, so each crystal has been "reset" to an undamaged state
- Thermoluminescence is the oldest and most widely used of the trapped-charge methods
  - Works from present back to an unknown maximum, approaching 200,000 years or more
    - long enough for all archaeology of humans and some of our immediate ancestors
  - In the best cases of single dated samples, ages are +/- 15%
  - In the best cases of multiple samples that have been averaged, +/- 7% to 10%
  - Not as trusted as radiometric methods
  - $600 per sample at U. of Wollongong (Australia)

- Another radiometric method: **Potassium-Argon (K-Ar) dating**
  - **radiometric**: based on radioactive decay
  - How it works
    - Potassium (K) is very common in rocks
    - A small fraction is ^{40}K, which is unstable (radioactive)
      - It has a half-life of 1.3 billion years
    - so the elements in the Earth are not old enough for it all to have decayed away yet
    - ^{40}K decays to ^{40}Ar (Argon)
      - ^{40}Ar is a gas
    - if the rock is molten, deep in the earth or in a volcanic eruption, the argon bubbles away and escapes from the melt
    - when the melt solidifies into mineral grains, each mineral crystal contains some ^{40}K, but no argon
    - from then on, though, as ^{40}K decays, the argon is trapped inside the solid crystal, building up over time
      - every argon nucleus represents a single ^{40}K nucleus that decayed
    - so we measure how much ^{40}K and ^{40}Ar are present
      - the more ^{40}Ar relative to ^{40}K, the longer the material has been solid, trapping the argon
      - after one half-life, for example, half of the ^{40}K has decayed into ^{40}Ar
        - so the mix is half ^{40}K and half ^{40}Ar
        - after two half-lives, ¼ of the ^{40}K is left, and ¾ have decayed to ^{40}Ar: a mixture of 1/3 ^{40}K and 2/3 ^{40}Ar
  - So K-Ar dating gives time since solidification of molten rock
  - Material: Typically lava (basalt, etc.) or volcanic ash or tuff
    - what we are dating is the eruption or lava flow, when the crystals solidified from a melt
  - Sample must be fairly old to get a good reading, since decay is so slow
    - 1 million years old or more generally claimed

    - Geochron lab (a commercial dating lab that serves archaeological, geological, and other customers) won't accept samples expected to be under 2 million years old
  - $400 to $600 per sample
- **Argon-Argon (40Ar-39Ar) dating**
  - A refinement of ^{40}K -^{40}Ar dating
  - Potassium (^{40}K) and argon (^{40}Ar) had to be measured separately in two different samples, typically multiple grains from a single rock
    - introducing lots of measurement error – measuring exactly the same size of samples is impossible
    - also the chance that the grain that the ^{40}K came from had a different starting amount of ^{40}K, or have solidified at a different time from the sample that the ^{40}Ar came from
  - In ^{40}Ar-^{39}Ar dating, one sample is irradiated
    - converting all of the ^{40}K into ^{39}Ar
    - not found in nature
    - so each ^{39}Ar nuclei was once a ^{40}K nucleus
  - now all the argon (both ^{40}Ar and ^{39}Ar) is collected from a single mineral grain, in a single chemical lab process
  - the nuclei are counted in an AMS, similar to radiocarbon
  - the ratio of ^{40}Ar to ^{39}Ar can be measured precisely
    - since they are collected by the same sample in a single chemical process, they automatically come from exactly the same amount of material, and the same particular grain of mineral
    - this eliminates a lot of the uncertainty (error estimate) in K-Ar dating
  - The date is calculated just as in 40K-40Ar dating
    - but with much less measurement error
    - (^{40}K decays to ^{40}Ar. The ^{40}K has all been converted into ^{39}Ar. So the more ^{40}Ar and the less ^{39}Ar, the longer the radioactive decay has been building up ^{40}Ar)
  - Tested on volcanic ash from Pompeii
    - the date came out dead on to the historical date of AD 79
  - so this method works on samples under 2000 years old
  - Again: time since solidification of molten rock
  - Material: Typically basalt or volcanic ash or tuff
  - No set price – you negotiate a research arrangement
- Obsidian hydration dating
  - Gives time since a surface of obsidian was exposed by flaking, typically in making a stone tool
  - Material: obsidian tools or waste from toolmaking
  - How it works
    - most glasses, like obsidian, can absorb humidity – but very slowly at normal temperatures and pressures
    - when a fresh, dry surface of the glass is exposed to humidity, the water slowly moves into the thickness of the glass
      - at a constant rate

- if you cut a cross-section of the glass and use the appropriate microscope, you can see a clear "rind" of hydrated (water-containing) glass on the outside
- you can measure the thickness of this "hydration rind"
- if you know the rate at which water advances into this glass, the thickness of the rind tells you how long it has been exposed to humidity
- When people make tools from obsidian, they break flakes off to shape it
  - this exposes fresh, un-hydrated obsidian to the humidity in the air and ground
  - from that moment on, humidity slowly migrates into the obsidian

- What it dates
  - the time since a fresh surface of the obsidian was exposed by flaking
    - usually, since a tool was made or reshaped
    - so this is one method that directly dates an event that is interesting to us!
- Works on recent material, and back to the Pleistocene
  - that is, to around 15,000 years ago
  - because temperatures were too different before then
  - and this method is affected by the temperature of the soil around the artifact
- Must know the hydration rate of the particular type of obsidian that the artifact is made from
  - there are various methods to establish this rate
  - identify the source
    - (a particular obsidian flow, which will have its unique chemical composition and hydration rate)
    - and use the rate for that source established by a previous project
  - estimate the rate from induced hydration of the sample
    - (a lab process where a sample of the material is exposed to humidity at known high temperature and pressure for a known time, then the resulting "induced" hydration rim is measured)
    - estimate of the effective temperature while buried
    - this can be combined with the experimental induced hydration data to estimate the hydration rate in the burial environment
  - estimate the rate from "intrinsic water" of the sample
    - another lab measurement
    - and estimate of the effective temperature while buried
    - these allow a calculation of what the hydration rate in the burial environment should be
- Results are rarely translated to years, but left as rim thickness for rough absolute or relative dating
- Determining the hydration rate can be expensive
  - chemical identification of the source
  - $700 for induced hydration
  - $50 for intrinsic water lab work, plus placing probes in the site to measure temperature and humidity
- Measuring the hydration rim is cheap
  - $20 - $30 per sample

– Paleomagnetic or archaeomagnetic dating

    - as we saw when we looked at magnetometers for subsurface testing, clays can become slightly magnetic when they have been heated, as by a fire
        - clay contains countless tiny magnetic regions, which are normally all in random orientations, so they cancel each other out, producing no net magnetic field
        - but when heated, these regions can reorient themselves
        - they line up with the surrounding magnetic field of the Earth
        - when the clay cools, the regions are “frozen” into that orientation
        - since they are aligned, the clay now has a slight net magnetic field, in the same orientation as the Earth’s
    - but the Earth’s north pole actually moves around
        - US Geological Survey maps indicate not only magnetic north, but the direction and number of arc seconds per year that the north pole is moving, as seen from a given place
    - so if our clay is fixed in the ground, like the burned soil under a fire, it retains a magnetic field that points in the direction of north at the time of the fire
    - an expert takes a sample in a precisely oriented brass cube
        - takes the sample in its cube to a lab
        - measures the magnetic orientation in 3 dimensions
        - relative to the edges of the brass cube
    - then compares this orientation to a local master sequence built up from hearths dated by radiocarbon or historical information
        - as in the case of Roman kilns in England
    - since the magnetic north pole has wandered around for a long time, sometimes it has passed close to where it was at an earlier date
        - so paleomagnetic dating often gives you several options for the date
        - each is known pretty precisely (to decades or even a few years)
        - but the archaeologist has to have other information about the general age of the site to pick which of the several alternatives is the right one
    - local variations in geology affect the exact direction of magnetic north in any region
        - so, like dendrochronology, paleomagnetism needs a master sequence for every region, and it takes a lot of work to create one

- Dating historical sites
    - By ceramics of known date of manufacture
        - gives a terminus post quem
        - or average the middle date of manufacture of every sherd in the stratum for a “**mean ceramic date**”
    - By colonial clay **pipestems**
        - they were made with narrower holes over time
        - average a bunch of fragments to get an average diameter
        - apply a formula that gives a rough date for that diameter
    - By nail technology
        - from hand-wrought before 1810
        - to machine-cut from sheet iron, various forms, after 1810
        - to wire nails with machine-made heads, early 1900s on