SCIENTIFIC DATING IN ARCHAEOLOGY

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1. AGE DETERMINATION IN ARCHAEOLOGY

- Relative Age: stratigraphy, typology
- Absolute Chronology: historical data
- Age Determination by (natural) Scientific Methods:
  Numerical age (*or* chronometric *age*)
  Relative age

2. AGE DETERMINATION BY SCIENTIFIC METHODS

2-1. Numerical Methods

- Radiometric Dating Methods

  Radioactive Isotope: radiocarbon, potassium-argon, argon-argon, uranium series

  Radiation Damage: fission track, luminescence, electron spin resonance

- Non-Radiometric Dating Methods

  Chemical Change: amino acid, obsidian hydration

2-2. Relative Methods

- Archaeomagnetism & palaeomagnetism, dendrochronology, fluorite

3. RADIOMETRIC METHODS

3-1. Radioactive Isotopes

The dating clock is directly provided by radioactive decay:

e.g. radiocarbon, potassium-argon, and the uranium-series.

- The number of a nuclide (**N_t**) at a certain time (**t**) decreases by decaying into its daughter nuclide. The number of a nuclide (**dN**) that decays within a short time (**dt**) is proportional to the total number of the nuclide at time (**t**) (**N_t**):

$$d N_t / dt = - \lambda N_t \qquad (1)$$

where λ: decay constant.

Then, **N_t** is derived from **(1)** as

$$N_t = N_0 \exp(-0.693t/T_{1/2}) \qquad (2)$$

…Where **N_0** is the number of the isotope at **t = 0** and **$T_{1/2}$** is its half-life.

Thus, the equation from this is: **$t = (T_{1/2}/0.693)\exp(N_0/N_t)$**

- When the values of **$T_{1/2}$** and **N_0** are known, we get **t** by evaluating the value **N_t**. The radiocarbon technique is the typical one in which the decrease of the parent nuclide is the measure of dating. On the other hand, the decrease of the parent nuclide and increase of the daughter nuclide, or their ratio, is the measure of dating in potassium-argon and the uranium-series. In principle, some other radioisotopes, e.g., **^{26}Al (half-life;730ka), ^{36}Cl (300ka), ^{10}Be (1600ka), ^{32}Si (0.1ka)** *and* **^{41}Ca (100ka),** could be available for dating, but are not yet practical methods.

1) Radiocarbon Dating (C-14)

Natural carbons consist of **^{12}C, ^{13}C** and **^{14}C**. Among these, only ^{14}C is radioactive and decays into stable nitrogen **14N** with a half-life of 5730 years. Carbon 14 (^{14}C) is produced in the upper atmosphere (at a maximum of circa 15,000m) by a nuclear reaction with **^{14}N** with cosmic rays combined with stable oxygen to form carbon dioxide (**CO_2**). Since the radioactive and stable CO_2 are mixed uniformly and distributed throughout the atmosphere, the ratio of ^{14}C to ^{12}C (as well as ^{14}C to ^{13}C) is approximately constant at any location in the world. The chemical characteristics of radioactive CO_2 and stable CO_2 are the same, therefore their ratio in the biosphere (plants and animals) and the ocean is close to that in the atmosphere. After the death of plants, animals or shells *et al*., the exchange of CO_2 between them and the atmosphere stops, resulting in a decrease in their ^{14}C content, with a half-life of 5730 years. Thus, if we know how much the ratio of carbon isotopes decrease in excavated organic materials, then we can *estimate* how much time has passed since their death.

Conventional Methods and the Accelerator Mass Spectrometer (AMS) Method

Beta particles emitted from ^{14}C are measured with a proportional counter or a liquid scintillation detector using conventional methods. One gram of carbon contains about 50 billion ($5x10^{10}$) ^{14}C, emitting beta particles of about 68, 42, 23 and 7 particles per hour, 1000, 5000, 10000 and 20000 years after the death of an animal or plant, respectively. It may take many long hours (even days) to get statistically sufficient data using this conventional method. Carbon isotope ratios must be independently evaluated with a mass spectrometer.

In the late 1970's, accelerator mass spectrometry in which ionized atoms were directly counted atom-by-atom was utilized as a dating tool. Now, the significantly improved efficiency of the AMS technique allows the use of sample sizes several orders of magnitude below that of conventional methods, as well as a reduction in time spent measuring a sample. Furthermore, the AMS method can simultaneously measure the isotope ratio.

C-14 Dating **- Important Points to Remember:**

- *Statistics*
- *Half-life of Radiocarbon*
- *Isotope Fractionation*
- *Contamination*
- *Global Variation of the Relative Radiocarbon Concentration*
- *Regional activities*
- *Reservoir Effect*

2) Potassium-Argon (K-Ar) and Argon-Argon (Ar-Ar) Datings

3) Uranium-series

3-2. Radiation Damage

Radioactivity plays an essential part, however, the actual dating signal is a secondary effect of radioactivity: e.g., luminescence, electron spin resonance & fission track.

Radiation accompanied by the decay of radioactive elements and cosmic rays constantly accumulate electrons in the defects of minerals (e.g. quartz and feldspar). The minerals show luminescence and electron spin resonance (ESR) signals in proportion to the amount of accumulated electrons, thus the time when the accumulation began can be obtained by evaluating the intensity of luminescence, otherwise known as an ESR signal. Fission fragments due to the spontaneous fission of ^{238}U cause microscopic tracks in the volcanic glass and zircon that are proportional to the time of the eruption of the volcano.

1) **Luminescence Dating (TL, OSL, IRSL)**

Luminescence dating is another radiometric dating method that can be a strong tool for assessing the age of archaeological sites. The process is as follows: radiated crystals with impurities or dislocations accumulate unpaired electrons in proportion to the amount of the absorbed dose of radiation. These electrons are evicted and emit visible light when they are heated or exposed to light. The intensity of emitted light is, in many cases, proportional to the amount of trapped electrons, or the accumulated dose. If the annual dose which the mineral absorbs at the burial location is known, the luminescence age can be obtained by dividing the accumulated dose by the annual dose.

The thermoluminescence (TL) technique is mainly applied to heated materials such as pottery, burned stone and tephra. The technique of Optically Stimulated Luminescence (OSL) can be used for samples exposed to sunlight (as opposed to heated samples as in the TL technique) such as loess and dune sand. The IRSL technique is a type of OSL dating in which the stimulation of samples occurs through the use of infra-red light.

2) **Electron Spin Resonance Dating (ESR)**

The principle of ESR dating is the same as the TL and OSL methods in that the amount of trapped electrons is measured with ESR signals.

3) **Fission Track Dating (FT)**

3-3. Non-Radiometric Methods

1) **Obsidian Hydration**

2) **Amino Acid**

4. RELATIVE DATING METHODS

The methods in this category refer to the preparation of a standard pattern prior to obtaining the age of an unknown sample. The standard pattern is made by the data that are obtained using samples of known age.

1) Archaeomagnetism and Palaeomagnetism

Archaeomagnetism and palaeomagnetism are both based on the same principle: The direction of magnetic minerals is oriented in the same way as in geomagnetism when they are carried by water (fluvial deposits) or cooled after heating for a particular length of time. Furthermore, the direction and the geomagnetic intensity of them are preserved if they are not heated up to the Curie point, an extremely high temperature. If it is possible to measure the secular variation in declination and inclination in a given area using archaeological or geological samples of known age, the measured declination and inclination of a sample with an unknown age may suggest the numerical age compared to the secular variation. To ascertaian the numerical age using this method, an accurate secular variation of declination and inclination should be prepared prior to the measurement of a given sample; this also holds true for dendrochronology.

The direction of geomagnetism has changed drastically today compared to some periods in the past. This phenomenon is called an “event” or “excursion”. Since the “event” observed in a stratum is identified at many locations around the world, it is a daunting undertaking to determine the age of a stratigraphic layer in prehistoric sites and in an older period such as the Quaternary (2 million to 10 000 years ago). In this case, the age of the events has to be known prior to the measurement of the layer.

2) Dendrochronology

3) Fluorite

5. GENERAL NOTES

Careful consideration is required when applying the results of scientific dating to determine the age of archaeological remains. One of them is concerned with the sample used and the other deals with the problems associated with the principle and techniques peculiar to each dating method.

The most important, and critical, matter when we use any type of scientific dating technique is whether the age of the measured sample represents the age of an archaeological event or sample of interest. For example, charcoal is the most suitable sample for the C-14 method but samples can be easily contaminated, for example, they can be transported by water or landslides and sometimes fall into a small pit made by insects or small animals (i.e. burrowing rodents). In some cases, stone artifacts or ceramic sherds may move vertically up to 1 m or more. In these cases, the C-14 age obtained for a charcoal sample in association (next to) an artifact will not accurately reflect the age of the archaeological context (cultural material. In otherwords, this kind of contamination will give an incorrect assessment of the age of a site or archaeological context.

Every scientific dating method is based on a particular principle. The sample used in a measurement, archaeological object (materials) and age ranges covered by each method are listed in Table 1; the limitations of each technique are not shown here. For example, the age obtained by TL, ESR or Archaeomagnetism shows the latest time when the sample was heated. Therefore, if a ceramic sample was accidentally heated *after* firing, the age obtained is not that of the firing but the latest heating. In the case of C-14 dating, the result is expressed by calibrated (cal.) B.P. or uncalibrated B.P. Even when the data is presented with cal.B.P., it is essential that this result be verified as to whether the data is calibrated for isotope fractionation and reservoir effect.

Finally, it is desirable, indeed necessary, to use more than two scientific dating methods in order to acquire accurate ages and to arrive at an acceptable result considering all data and archaeological contexts.