Absolute Datings in Archaeology

Introduction

In the process of reconstruction of the past, the control over absolute date is necessary to place the historical events in coherent manner. If the dates of the archaeological materials are known, then, it is more convenient to place the human social development in a chronological order. In general, the history is reconstructed based on written documents. The written documents generally appeared very late in human history. Around the world the writing system appeared around 5th millennium BCE. In India, earliest writing systems are the Indus script or graffiti marks datable to the middle of third millennium BCE. However, the human artefacts unearthed at Tikoda, District Raisen, Madhya Pradesh and at Attirampakkam, District Thiruvallur, Tamil Nadu push the date of human appearance in India before 1.50 million years ago. Therefore, the history reconstructed based on written documents narrates only a small part (0.2%) of human history. The major part of unrecorded history (99.98%) is being reconstructed based on material evidences. When the material evidences fail to provide absolute date, the archaeologists forced to seek the help of science to preciously date the historical or archaeological documents through inherent physical, chemical or biological material analysis. Though, we get a quite number of written documents in the form of seals and sealings in Indus valley civilization, it could not be dated due to non-decipherment of the script. The radio carbon dating methods came to the rescue of the archaeologists to date the Indus valley civilization. Thus, the primary sources also basically need certain degree of assistance from the science to fix the chronology. Absolute dates are of particular importance to the archaeologists when they are unable to place the remains in a time-frame due to the non-availability of the datable material like coins, inscriptions or any other written records. In pre-literate societies, particularly, in prehistoric and proto-historic sites, the scientific dates are the only answer to fix the chronology. In many occasions, the absolute dates forced us to drastically revise our conventional ideas of chronology.

All the dating systems could be placed under two broad categories, namely, absolute dating system and relative dating system. In the former system one could achieve almost precise chronological frame whereas in the latter system, a comparative date could be achieved. Till 1950s, the historians and archaeologists mostly obtained absolute dates from datable historical records such as coins, copper plates and stone inscriptions. After 1950s, the physical, chemical and biological sciences contributed a number of dating techniques that had revolutionary effects on archaeology. Among the absolute dating methods listed below the Radio Carbon dating method is considered as one of the best available methods today. However, Radiocarbon dating cannot be used for the sample that goes back beyond

75000 years. Therefore, other absolute dating methods are being vigorously followed. Those are:

Absolute dating techniques

1. Dendrochronology (Tree-ring dating analysis)
2. Thermoluminescence
3. Potassium-argon method
4. Uranium series method
5. Fission-track dating
6. Electron spin resonance (ESR)
7. Tree-ring dating
8. Amino acid racemisation
9. Obsidian hydration
10. Archaeomagnetism
11. Historical dating

Dendrochronology (Tree-ring analysis)

In Dendrochronology, the age of the wood can be determined through the counting of the number of annual rings in its cross section (see figure). It is an approach based on counting the annual growth rings observable in the cross-sections of cut trees. The characteristic feature of the ring reflects the rainfall conditions that prevailed during the years of the tree's life. The variations in the annual rainfall pattern would create a distinct set of ring patterns of a particular region for a particular set of years. By comparing the pattern of tree rings in trees whose lifespan partially overlap with the other trees. By comparing these overlapping tree patterns, one can create a master sequence of tree ring patterns. This master sequence of tree ring patterns could be sequentially dated back in time. The absolute date of the sample could be established by matching the archaeological sample to the master sequence of tree ring patterns. Thus, a master sequence of tree ring pattern of a region is necessary to date an archaeological sample.

It is developed by A.E.Douglass in 1913 and the method completely outlined in 1929. Douglass in his pioneering work developed a master sequence beginning with modern trees and extended it back in time as far as back to 2000 years and now the record spans more than 8,000 years. The sequence of the tree-ring found in archaeological digging is compared with the master sequence and dated.

Scientist outlined four basic requirements for the development of mater sequence of the tree-ring of a particular region. First, there must be trees that produce clearly defined annual rings. Secondly, tree growth must be principally dependent upon one controlling factor. Thirdly, the wood must be well preserved as so that it still retains its cellular structure. Finally, the prehistoric population must have extensive use of wood, particularly in their construction.

The primary archaeological context of the wood specimen is so important in determining the age of the wood or the architectural edifice in which the wood is used. Archaeologist must keep in mind the following possible interpretations while collecting the specimens:

- The wood may be re-used and therefore older in date than the construction in which it was used.
- Replacement of old and weaker beams by new and stronger ones may result in the wood being younger than the original construction.
- The wood piece collected from the artefacts or furniture may be younger or older than the building material.

The above factors clearly suggest that archaeologists must take utmost care in recording the primary context in which the wood is collected. Besides the dating, the tree-ring analysis is extensively used to determine the various environmental factors that controlled its growth.

Fission Track (or Alpha Recoil)

The natural splitting (fission) of uranium-238 (238U) atoms present in obsidian and other glassy volcanic minerals leaves traces called fission tracks. These fission tracks are erased once the mineral is heated above a critical temperature. During volcanic eruption, all fission tracks present in the mineral are removed. This sets the clock to zero. However, the fission track again started appearing once the material cooled down. The density of uranium-238 fission tracks is proportional to the time elapsed since the sample was last heated. So, the date is determined by calculating the presence of the fission tracks. These tracks can be detected by treating a prepared rock sample with hydrofluoric acid and then observing its surface under magnification. To assign an actual date, one should be aware of the uranium238 content of the mineral. This is achieved by bombarding the sample with a known dose of 238U radiation. Once the 238U content are known, and the density of fission tracks determined, the scientist correlates the sample's fission track density with its estimated 238U fission rate to assess its age.

Thermoluminescence or Optically Stimulated Luminescence (OSL).

Thermoluminescence dating (TL dating) is based on the fact that all materials particularly crystalline material such as ceramic traps electrons released by natural radiation present in the material. The original heating of the energy (firing process in the case of ceramic and brick) would release all previously stored TL energy in the clay, thereby setting the clock at zero. Once the firing is over, the process of trapping the new TL energy starts afresh. These trapped electrons accumulate through time. When a sample is heated above a critical temperature (400-500° C for ceramics), the accumulated or trapped electrons will be released as light energy (Thermoluminescence or TL). Thus, one can determine the time elapsed by calculating the accumulated light energy.

When the light (optic) is used instead of heat (thermo) to release the accumulated electrons, then it is called Optically Stimulated Luminescence (OSL).

The application of this technique has greatly increased in recent years. Further, now it is being realised that any heated material made of soil like pottery, fired clay, terracotta, bricks, kilns, furnace and hearths can be used for dating purpose. Therefore, archaeologists are showing much interest in this dating method, as the above sample is easily available in most of the archaeological excavations.

Collection of sample

- The sample should not be smaller than one gram.
- Samples should not be exposed to heat.
- Samples that are powdery or in granular state should not be exposed to bright light.
- It is necessary to send the earth matrix along with the sample as the scientist may need to judge the environmental radiation.

Sampling for Thermoluminescence

Potsherds for thermoluminescence must have been buried for at least two-thirds of their burial time at minimum depth of 30 cm. The materials and the sampled potsherds should be homogenous. Each sample should consist of six or more potsherds with minimum dimensions of 25x25x5 mm and a handful of soil (if there are shell, bone or building material that also be included) surrounding the potsherds. Sample should be collected as soon as possible to avoid evaporation of moisture content. Use an opaque black cloth when collecting the sample to avoid unnecessary exposure to sunlight. Bag your potsherds and surrounding soil in a plastic bag and seal. Then this bag has to be placed in an opaque sunlight-proof cloth or bag and keep it away in sunlight or heat. Never expose samples to ultra-violet, infra-red, x-rays or beta-rays. In addition to the locus positions, the sample should also carry the information like seasonal moisture, content of the soil at the site and any other ecological data.

Potassium-Argon

Potassium-Argon (K-Ar) dating method, developed by the scientists at the University of California in 1950, is based upon decay of the radioactive of a rare isotope of potassium (40K) into argon (40Ar) gas. The decay takes place at known rate. The half-life of 40K is 1.31 billion years. This method can only be used with the rocks that contained no argon gas when they are formed. Obviously, this makes the scientist to choose volcanic rocks. When the rock is super heated like volcano, all the accumulated gases would be released into the atmosphere. This sets the atomic clock to zero. When the rocks solidify again, radioactive potassium proceeds to decay into argon. The argon build-up takes place in the rock at a fixed rate. So, the samples collected from volcanic flow are heated at a high temperature and the accumulated argon that is being released is measured. The date is determined based on the amount of argon gas that had accumulated through radioactive decay.

Uranium-series

Like Potassium-Argon method, Uranium dating method is also based on the process whereby a radioactive isotope of uranium 238U+ decays into 235U+. The date is determined based on the amount of 235U+ that had accumulated through radioactive decay.

It is also called Uranium-Thorium method. The Thorium-230 (230Th) accumulates in the sample through radiometric decay over time. The accumulated ratio of Thorium -230 (230Th) and Uranium-234 (234U) is calculated by comparing with the initial ratio of Thorium -230 (230Th) and Uranium-234 (234U) formed at the time of sample formation. The difference is calculated and measured to calculate the time elapsed since its formation.

It is also known as Uranium-Thorium dating method, Thorium-230 dating method, Uraniumseries disequilibrium dating method or Uranium-series dating method.

Electron Spin Resonance (ESR)

Ikeya and Miki developed this technique in 1980. The ESR is based on the fact that an electron is a charged particle which spins around its axis and this causes it to act like a tiny bar magnet (called magnet moment). If an external magnetic field is impressed on the system (magnetic moment), the electron will align itself with the direction of this field and process around this axis. This behaviour is analogous to that of a spinning top in the gravitational field. Increasing the applied magnetic field will induce the electrons to process faster and acquire more energy of motion called kinetic energy. In this process, the magnetic field divide the electrons into two groups. In one group the magnetic moments of electrons align with the magnetic field (ms = + ½) and it has high energy whereas in another group the magnetic moments of electrons align opposite to the magnetic field (ms = - ½) and it has low energy. These two alignments with two different energies were measured through induction electromagnetic field usually in the microwave range of frequencies. The dating of bovid teeth from Acheulian levels at Isampur produced a date of 1.7 million years (Blackwell et.al., 2001; Shipton et.al., 2014:23-26).

Thus, the Electron Spin Resonance (ESR)measures radiation-induced defects or the density of trapped electrons in bone and calcite materials. The laboratory analysis suggests that tooth enamel particularly with thick enamel layers is the best material for ESR studies. On counting on the amount of electrons trapped in the bone, the date is determined.

Cosmogenic-Nuclide burial dating

It is one of the recently developed dating systems used to date geological samples. In archaeological context, it is more useful to date Palaeolithic tools. The general concept of Cosmogenic-Nuclide burial dating is that a particular pair of cosmogenic nuclides that are produced at fixed ratios in a particular rock or mineral, but having different decay constants could be measured.

If a sample (for example Palaeolithic tools) is exposed at the surface for a particular point of time (no matter how long the exposure), the concentration of two nuclides confirm to the production ratio. The ratio between the two nuclides remains constant as long as it is on the surface. Once the sample (i.e., the Palaeolithic tools in this case) is buried deeply enough into the ground, then the nuclide productions stops. From the time of concealing of sample, the inventories of the nuclides start decay due to radioactive decay. The decay of both the nuclides are not uniform or not at the same rate of decay. Since the rate of decay differs, the actual ratio between the two nuclides gradually differs or diverges over time from the production ratio (i.e., the nuclides produced when it is exposed on the surface). By measuring the ratio difference between the two nuclides, one can measure the length of time the sample has been buried. Otherwise one may say, based on the rate of decay in relation to their half-life period, one can measure the length of time.

So far, Al-26 (aluminium-26) and Ba-10 (Berlyllium-10) pair in quartz is measured as the quartz is the common mineral, generally found in all sedimentary deposits. The pair is always preferred in this method, as the production ratio of Al-26 and be-10 is constant with 6.75 ma. The half-life of Al-26 and Ba-10 is respectively well-established as 0.7 ma and 1.4 ma. Based on the constant value and half-life value, the length of time is measured. If the sample does not carry Al-26 and Ba-10, then other pair like Cl-36 (Chlorine-36) and Ne21(Neon-21) could be measured.

The Attirampakkam Lower Palaeolithic tools have been dated by using this method. For the first time, Cosmogenic-Nuclide burial dating method is applied in Indian context. The dates obtained based on Cosmogenic-Nuclide burial dating, palaeomagnetism, Optically stimulated Luminescence and Electron Spin Resonance for the stone artefacts obtained at Attirampakkam are pooled together that produced a pooled average date of 1.51 million years (Pappu et.al.,2011:1596-1599).

Amino Acid or Aspartic Acid Racemization

Jeffrey L.Bada has developed a new technique for determining the age of bone. This technique depends on cumulative changes in amino acids in bone after animal has died. Among the about 20 kinds of amino acid present in the modern bone, only one kind of amino acid (Aspartic acid) exist in two mirror-image forms. As long as the organism is alive, the amino acid molecules are in left-handed form (or L-isomer form). But at death, they began to change to distinct right-handed form (or D-isomers). This process of change called racemization. If one knows the racemization rate, one could be able to calculate the date of the bone.

Obsidian-hydration

It has long been observed that the surfaces of many geological materials undergo chemical alteration through time. These weathering reactions create a visibly distinct surface layer or patina. When obsidian (a volcanic glass) artefacts are buried, they start absorbing water and form a layer called hydration layer. The thickness of the layer depends on how long the article has been buried, the surrounding temperature condition, long-term change in the soil humidity and the petrographic nature of the sample. By keeping these factors in mind, the sample is dated by measuring the thickness of the hydration layer. Irving Friedman and Robert L.Smith established this age-determination method in 1960.

Archaeomagnetism

Archaeomagnetic dating is based on the fact that the earth's magnetic field varies through time. Therefore, the location of the magnetic north pole changes its position both horizontally (expressed as declination angle) as well as vertically (expressed as dip angle). The course of these shifts over the past few years has been determined from compass readings preserved in historical records. Certain mineral compounds, such as clay, contain iron particles, which are aligned in magnetic north. When the clay is heated to a critical temperature (above 670° C), the iron particles present in the clay align to the present magnetic north by loosing their previous magnetic orientation. When it is cooled, the new magnetic alignment of the iron particles is frozen in the clay. Thus, the sample will preserve the angles of dip and declination from the time when it was last heated. By using the knownage samples of such fired clay, scientist traced the location of magnetic pole into the past and prepared a time scale. This helps to date the newly discovered fired clay samples directly by using the archaeomagnetic data.

This method is widely used now. However, its reliability is based on two factors. First, one should know the magnetic variation of each region separately. Secondly, one should get the sample from its original position.

Thus, the archaeological material unearthed in the excavation and the associated material of non-organic in nature could be dated using various scientific techniques as stated above.