



A Brief Overview on Chemical and Physical Aspects of Archaeological Dating Techniques and Their Applications in Dating Construction Materials and Buildings

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Authors' contributions

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ABSTRACT

This review is devoted to answering the important question of physical and chemical aspects of dating archaeological remains, particularly, ancient structures. Basically, stratigraphy and typology are considered relative dating techniques while radiocarbon dating, dendrochronology and thermoluminescence are absolute dating techniques. Radiocarbon dating is particularly used to estimate the age of living beings subsequent to their death where radioactivity of ¹⁴C isotope is used which is the longest-lived radioisotope of carbon with a half-life of 5,700 years. Dendrochronology is the science or technique of dating events, environmental change, and archaeological artefacts by using the characteristic patterns of annual growth rings in timber and tree trunks. Thermo-luminescence is a technique based on measuring luminescence of material that has been constructed by subjecting to high temperatures. Archaeological dating is very important in structural engineering as well as in archaeology and we now review the applicability of above techniques in dating engineering materials.

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1. INTRODUCTION

Located in Thiriyaya, Girihadu Seya [8°52'13.0"N 81°00'27.0"E, Altitude 10.11 m or 33.17 feet] is considered the first Sri Lankan Temple built by Thapassu and Balluka merchants. This eye enshrining the hair relic of the Lord Buddha which they received upon their request to worship something, the request made after offering the first Alms Giving to the Lord Buddha, the following day after the Seven Weeks spent just after the enlightenment. The temple comprises of remains of rich architectures of Sri Lankan ancient culture (Fig. 1). As illustrated in this figure ancient stone columns with their typical architectures, ancient bricks, stone bridge, circular stone (chakra gala which was located on top of the stupa), stone tank and so on add tremendous value to the archaeological values of the location.

It has been reported that The Maduru Oya (Fig. 2) Sluice [7°38'53.2"N 81°12'51.7"E, Altitude 88.24 m or 289.50 feet] made up of stone slabs and bricks, is about 30 feet (9.1 m) high, 30 feet (9.1 m) wide and 219 feet (67 m) long with salient features of its twin inlet conduits, dressed with stone slabs enclosed in a massive corbelled arch-shaped brickwork. It is believed that this corbelled arch-shaped brickwork is unique to this sluice gate [1]. It is a classic proof for the Sri Lankan ancient hydraulic civilization and major irrigation works constructed since 3rd century AD.

2. ARCHEOLOGICAL DATING TECHNIQUES

The question now arising is how one would date such archaeological treasures. This review is devoted to answering this important question of dating archaeological remains, particularly, ancient structures. Basically, there are two types of archaeological dating [2]: Relative dating and absolute dating. Stratigraphy and Typology are considered relative dating while Radiocarbon Dating, Dendrochronology and Thermo-luminescence are absolute dating techniques. We will examine these techniques separately.

2.1 Relative Dating Techniques

2.1.1 Stratigraphy

Stratigraphy is a branch of geology concerned with the order and relative positions of strata

(rock layers) and their relationship to the timescale. This method can be used for the analysis of the order and position of layers of archaeological remains. When soil or other materials deposit they deposit in a chronological order with the oldest layer on the bottom. [3] it not very common to observe perfect horizontal layers along the vertical axis in archaeological sites due to various actions that have been subsequently taken place. However, during excavation, one can observe complex changes of colour, texture and content of these layers of the sample being examined. The archaeologists then record them horizontally in planes and vertically in sections. The order in which the layers were created is then predicted by the process known as sequencing which is done by examining cuts and fills when soil was removed or filled. By examining the sequencing archaeologists can predict the actions that took place on the site in the right chronological order. These relationships are recorded in the form of Harris Matrix. [4] an archaeological relationship is a position in space and by implication, in time, of an object or context with respect to another. There are basically seven relationships: Cuts, Overlies, Above, Below, Butts, Contemporary with and same as, respectively. Fig. 3 explains these relationships. These relationships are converted to a Harris Matrix which is a tool used to depict the temporal successions of archaeological contexts. This gives a sequence of depositions and surfaces of a dry-land archaeological site which is called stratigraphic sequence. The matrix, therefore, represents the relative position and stratigraphic contacts of observable stratigraphic units, or contexts. Using these matrices the ages of different layers can be recognized [5].

2.1.2 Typology

Topology is based on classifying things according to their physical appearance. The products of classification are called types and hence the name typology is used to describe these types. These types can be related to their chronology [6]. As can be seen from Fig. 1, the bricks used to build Girihadu say in the 3rd century AD are different in size and shape to the new bricks we use today. Antiquaries have realized in the late 16th century that monumental effigies represented with their legs crossed were likely to be older than those with straight legs [7]. In the late 17th century, John Aubrey worked out

crude evolutionary sequences based on typological distinctions in medieval architecture, handwriting, shield-shapes and costumes [8]. Reading and interpretation of stone inscriptions (see lipid) by an expert of archaeology and estimating time-based on them also belongs to typology. There are about 4000 stone inscriptions available in Sri Lanka which belong to different types [9,10]. They can be classified by considering their locations and physical appearances into four categories; namely, cave inscriptions, rock inscriptions, slab inscriptions and pillar inscriptions. The inscriptions found in Mihintale, Wessagiriya, Sithulpawwa, and Ritigala are of cave typed while those found in Gadaladeniya and Alawwa are rock types. Slab inscriptions are found in Polonnaruwa, Thonigala and Mihintale whereas Badulla inscription and Katugahagalge inscription are classified under pillar inscriptions [6,7]. Shown in Fig. 4 are (a) Polonnaruwa Glapotha Slab inscription (b) a Pillar inscription and (c) Girihadusaya inscription. These inscriptions belong to different Era and hence identifying them would give a way of estimating their age. These inscriptions are invaluable in finding out information on many different subjects. They provide information about the economy of ancient Sri Lanka, old trade methods, occupations and the economic stability of people, ownership of lands, types of

taxes which cannot be extracted from the literary resources and so on.

2.2 Absolute Dating Techniques

2.2.1 Radiocarbon dating

Radiocarbon, or carbon 14, is an isotope of the element carbon that is unstable and weakly radioactive. The stable isotopes are carbon 12 and carbon 13. Carbon 14 is continually being formed in the upper atmosphere by the effect of cosmic ray neutrons on nitrogen 14 atoms. It is rapidly oxidized in air to form carbon dioxide and enters the global carbon cycle. Plants and animals assimilate carbon 14 from carbon dioxide throughout their lifetimes. When they die, they stop exchanging carbon with the biosphere and their carbon 14 content then starts to decrease at a rate determined by the law of radioactive decay. Radiocarbon dating is essentially a method designed to measure residual radioactivity. [11] by knowing how much carbon 14 is left in a sample, the age of the organism when it died can be known. It must be noted though that radiocarbon dating results indicate when the organism was alive but not when a material from that organism was used [12].

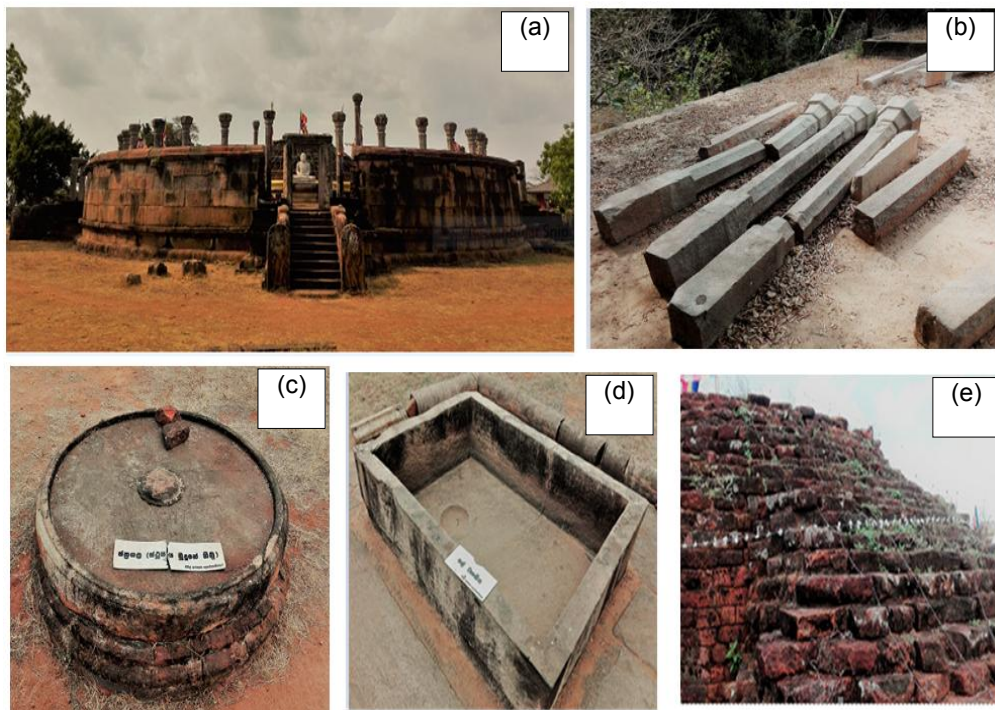
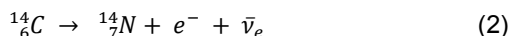


Fig. 1(a-e). Archeological remains of Thiriyaya, Girihadu Seya

Radiocarbon dating is particularly used to estimate the age of dead living beings where radioactivity of ^{14}C isotope is used which is the longest-lived radioisotope of carbon with a half-life of 5,700 years. Its natural abundance is trace, with an approximate ratio of ^{14}C to ^{12}C of 1.5 parts to 1012 parts. In the lower stratosphere and upper troposphere neutrons that are generated by cosmic rays react with ^{14}N to produce ^{14}C according to the nuclear reaction;



Where n and p stand for neutron and proton, respectively. Thus ^{14}C produced reacts with atmospheric oxygen producing $^{14}\text{CO}_2$. This carbon dioxide is dissolved in the sea water and also absorbed by plants through photosynthesis. Some animals eat plants and some others eat those animals fed by plants and some others eat both and hence ^{14}C gets distributed throughout the biosphere. The decay of ^{14}C radioisotope takes place according to the nuclear reaction:



The amount of ^{14}C is constant in living beings due to equilibrium between its takings up and decay. When the system is dead ^{14}C only decays at first order kinetics following exponential decay.

$$a = a_0 \exp(-kt) \quad (3)$$

Here, a , a_0 and k are activity of ^{14}C at time t , initial activity and first-order rate constant, respectively, and when a , a_0 and k are known, t can be calculated. The rate constant k is inversely proportional to the mean life of ^{14}C which is 8,267 years. Rearrangement of the above equation then gives

$$t = 8267 \ln\left(\frac{a_0}{a}\right) \text{ years} = 19035 \log\left(\frac{a_0}{a}\right) \text{ years} \quad (4)$$

Since the activity of ^{14}C present in the dead sample is equal to the activity of e^- which are β rays emitted by the sample in radiocarbon dating the activity of β rays emitted is measured. As such, the measurement of a buried piece of wood [13] or fossil provides a measurement of the time elapsed since it was living to the date of analysis [14].

The change of β rays emitted with time is shown in Fig. 5.

The exchange of carbon dioxide is a complicated process and the 14C:12C ratio can vary in the different parts of the carbon-exchange reservoir. As such, this method of dating is associated with various errors originating from (a) variations of the 14C:12C ratio in the atmosphere both geographically and over the time, (b) isotopic fractionation [15] (c) variations of the 14C:12C ratio in different parts of the reservoir and (d)



Fig. 2. A photograph of sluice gate (Sorowwa) of the dam of the tank fed by Maduru Oya believed to be built in 4th millennium BC

([Online image]. Retrieved November 28, 2017, from <http://amazinglanka.com/wp/maduru-oya-ancient-sluice/>)

Examples of relationships

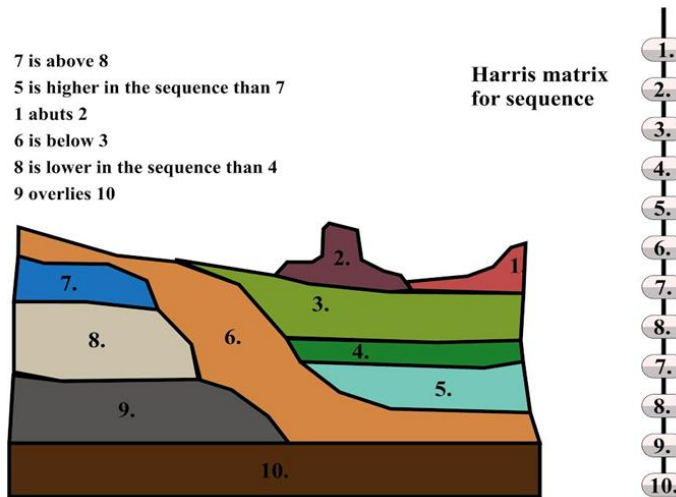


Fig. 3. Examples of relationships in the form of Harris Matrix

([Online image modified]. Retrieved April 04, 2018, from <http://www.wikiwand.com/en/Relationship/archaeology>)

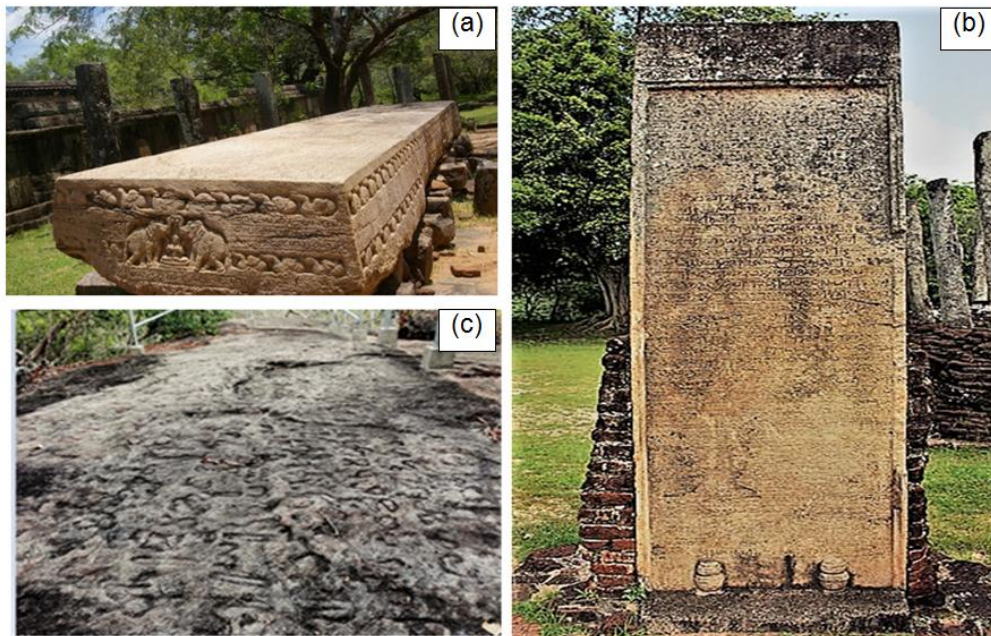


Fig. 4. (a) Polonnaruwa Galpotha slab inscription (b) A pillar inscription and (c) Girihadusaya inscription

contamination as such, radiocarbon dating has to be calibrated by another independent analysis such as dendrochronology [16]. Despite these obstacles, the development radiocarbon dating contributed to a profound impact in archaeology and hence, in 2016, the development of radiocarbon dating was recognized as a National Historic Chemical Landmark for its contributions

to chemistry and society by the American Chemical Society. Interactions with cosmic rays produce other isotopes such as ^3He , ^{10}Be , ^{21}Ne , ^{26}Al and ^{36}Cl . The use of radioactivity of these isotopes began since the 1980s and they are quite suitable for dating rocks. There are other systems such as potassium-argon dating, argon-argon dating, and uranium series dating.

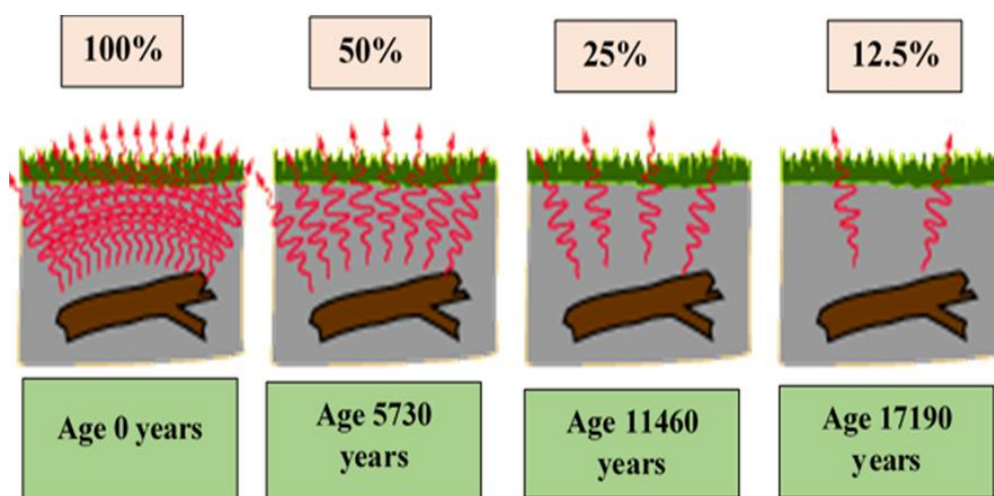


Fig. 5. An illustration of the β decay activity of a buried piece of wood as a function of time

These methods are used in geochronology and archaeology [17].

It is interesting to note that Kullman et al. have discovered the Planet's longest-lived identified plant, the lone Norway spruce which is of the species traditionally used to decorate European homes during Christmas, found in the Dalarna Province of Sweden, which has a root-system of 9550 years old. It is also intriguing to note that the spruce's stems or trunks have a lifespan of around 600 years, and the root system has survived for over 9550 years because as soon as a stem dies, a new one emerges from the same root stock as explained by Kullman. As such, the live plant survives for a very long life-time. The age of the root-system of the live plant has been determined by Radiocarbon Dating [18].

2.2.2 Principal methods of measuring radiocarbon

There are 3 principal techniques used to measure carbon 14 content of any given sample namely gas proportional counting, accelerator mass spectrometry and liquid scintillation counting. Gas proportional counting itself is a conventional radiometric dating technique that counts the beta particles emitted by a particular sample. Beta particles are one of the products of radiocarbon decay [19]. In this method, the carbon sample is initially converted to CO_2 gas before measurement in gas proportional counters takes place. Accelerator mass spectrometry (AMS) is one of the most efficient modern radiocarbon dating methods of measuring radiocarbon content of a sample. By this method, the carbon 14 content is directly measured

relative to the carbon 12 and carbon 13 present. The method does not count beta particles but the number of carbon atoms present in the sample and the proportion of the isotopes is measured. Liquid scintillation counting is another radiocarbon dating technique which liquid samples are used and a scintillator is added in addition [20]. This scintillator produces a flash of light once it interacts with a beta particle generated. A container with a sample is passed between two photomultipliers, and only when both devices register the flash of light that a count is made.

2.2.3 Radiocarbon dating standards

The radiocarbon age of a particular sample of unknown can be determined by measuring its carbon 14 content and comparing the result to the carbon 14 activity in modern and background samples. The principal modern standard used by radiocarbon dating is Oxalic Acid I obtained from the National Institute of Standards and Technology in Maryland. This oxalic acid derived from sugar beets in 1955. Around 95% of the radiocarbon activity of Oxalic Acid, I is equal to the measured radiocarbon activity of the absolute radiocarbon standard a wood in 1890 unaffected by fossil fuel effects. When the stocks of Oxalic Acid I were almost fully consumed, another standard was made from a crop of 1977 French beet molasses. The new standard, Oxalic Acid II, was proven to have only a slight difference with Oxalic Acid I in terms of radiocarbon content. Over the years, other secondary radiocarbon standards have been made [21]. Radiocarbon activity of materials in the background is also determined to remove its contribution from

results obtained during a sample analysis. Background radiocarbon activity is measured, and the values obtained are deducted from the sample's radiocarbon dating results. Background samples analyzed are usually geological in origin of infinite age such as coal, lignite, and limestone.

2.2.4 Dendrochronology

Dendrochronology is the science or technique of dating events, environmental change, and archaeological artefacts by using the characteristic patterns of annual growth rings in timber and tree trunks (Fig. 6).

Before the discovery of Kullman et al., the world's oldest continuously standing trees are considered to be Bristlecone pines in the western United States where the oldest is dated to around 5000 years. The ages of Bristlecone pines are determined by counting tree rings, which form annually within their trunks [22-25].

2.2.5 Thermo-luminescence

Thermo-luminescence is a technique based on measuring luminescence of material that has been constructed by subjecting to high temperatures, such as ceramic, tiles, bricks etc., after sometime when it is excited by heat or gamma rays [26]. This is a technique used to dating ancient ceramics and other artefacts. Crystalline materials, particularly natural ones, have lattice imperfections due to the presence of impurity ions, stress dislocations, and other phenomena that disturbs the regularity of the electric field holding ions together in crystalline solids [27]. This results in the creation of humps and dips (electron traps) in the electric potential of the crystal. Free electrons are attracted to these dips and get trapped in them. When crystalline solids are exposed to ionizing cosmic radiation or ionizing radiation derived from natural radioactivity, some electrons of the atoms of the crystals can get excited to conduction bands. Electrons in the conduction band can move freely. However, most of these excited electrons immediately get recombined with lattice ions, but some can get trapped in lattice imperfections, storing a part of the energy of the radiation absorbed as a trapped electric charge. The energy required to release these electrons from their traps depends on the depth of the traps. Therefore, the storage time of trapped electrons depends on the depth of their traps and some traps are sufficiently deep that they can store electrons for hundreds of thousands of years.

These electrons can be excited by exposing to high energy radiation or heating to high temperatures. The excited electrons will recombine immediately and during this process excess energy is released as a radiation signal and is proportional to the number of trapped electrons present in the crystalline material [28].

This technique is particularly useful for dating objects such as ceramics that have subjected to high temperatures during their manufacturing. The radiation dose is then suddenly bleached and when the substance is buried the radiation dose gradually and linearly accumulates with time in the spans of thousands of years. By measuring the current radiation level the time lag can then be estimated (Fig. 7).

2.2.6 Optically stimulated luminescence (OSL)

Optically stimulated luminescence is another important dating technique that can be used to date materials with certain crystalline structures such as those of quartz and feldspar. These are very large band gap insulating materials and electrons in their valence bands can be excited to conduction bands by ionizing radiation with sufficient energies leaving positively charged lattice sites known as holes in the valence band. Those electrons excited to conduction bands are trapped in various trap levels which located between the valence and conduction bands. Holes are also get trapped in hoe traps. These trapped electrons can be excited to the conduction band by illuminating with radiation having sufficient energy. When these electrons recombine with trapped holes the excess energy is emitted as luminescence. As such, this technique is called optically stimulated luminescence. The luminescence intensities can be measured using a photomultiplier tube and that corresponds to the doses of radiation absorbed by the materials. The original radiation used could be either gamma rays or X-rays. For these radiations, the optically stimulated dosimeter (OSL Dosimeter) gives a reasonable sensitivity. In carrying out OSL dating coarse mineral grains of 100-200 μm or fine grains of 4 -11 μm are extracted from the samples and their OSL dosimetric measurements are made. This technique is particularly suitable for dating ceramics and other materials that contain minerals such as quartz and feldspar.



Fig. 6. An example of the characteristic patterns of annual growth rings in timber and tree trunks from Hillsborough forest

(Wikimedia Commons [Online image]. Tree rings, Hillsborough forest - geograph.org.uk - 1506824.jpg, Retrieved March 19, 2018, from <https://pixabay.com/en/photos/tree%20rings/>)

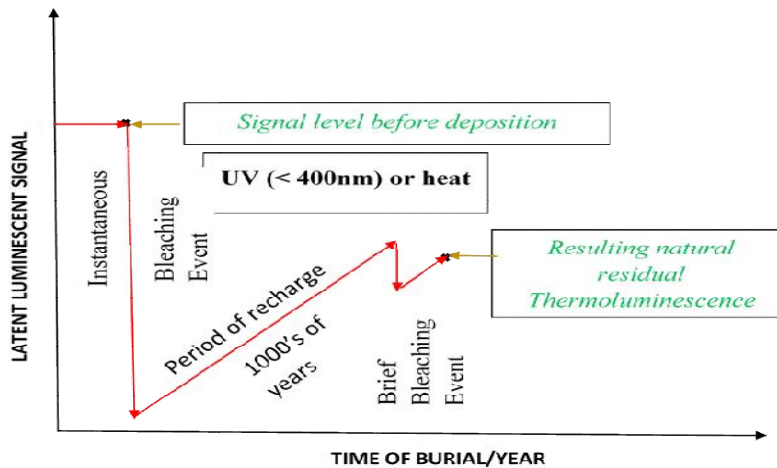


Fig. 7. A plot of latent luminescence signal versus time of burial for objects that have been manufactured by exposing to high temperatures or energetic radiation such as UV

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2.3 Computed-radiology

This is relatively a new technique utilizing phosphor imaging plates instead of radiographic films to enable digitation of images to store in a computer. The imaging plate is placed in a standard cassette with lead screens, in a rigid plate cassette, or in a plastic packet. The plate is exposed and processed through the plate reader.

The image is generated using a standard radiographic practice but imaging plates containing barium fluorohalide and europium doped phosphor. The trapped electrons in the crystalline materials form a latent image on the phosphor imaging plate. The plate is then exposed to a helium-neon laser in the plate reader, which releases the electrons from their traps to the conduction band of the material. The

recombining of the electrons into their former lower orbit shells causes energy in the form of light to be emitted. This phenomenon is known as photo-stimulable luminescence (PSL) [29]. The resultant light energy is collected by a light guide and is quantified by assigning grey scales to the various intensities emitted and converted to an electrical signal. The information is then processed by the reader and transferred to a digital format on the computer. The resultant data can then be viewed on a high-resolution monitor, stored on the hard drive, on the optical disk, on a CD, imaged on laser film similar to a radiographic image, or on to paper [30].

2.4 Archaeo-magnetic Dating

Archaeomagnetic dating is the study and interpretation of the signatures of the Earth's magnetic field at past times recorded in archaeological materials [31]. Archaeomagnetic dating is a method of dating iron-bearing sediments that have been superheated. For example, the clay lining of an ancient hearth [32,33]. Archaeomagnetic dating works because the earth's magnetic field wanders continually changing its position in response to changes in the flow of liquid iron in the planet's core. Scientists use this concept for dating archaeological sites. Certain clays have a naturally high iron (Fe) content including mainly iron oxides, sulphides ($\text{Fe}_2\text{O}_3/\text{Fe}_3\text{O}_4$, FeSO_4 , CuFeS_2 , FeS_2) [34]. As the clay chills, the alignment of the iron "fixes," preserving a record of the magnetic field at a specific time in the past. At archaeological sites, hearths constructed of iron-bearing clays are ideal for archaeomagnetic sampling because they were subjected to repeated hot firings [35]. The iron in the clay realigned with every sufficiently hot fire, so it is the last hot fire in a hearth that archaeologists are able to date. At archaeological sites, hearths constructed of iron-bearing clays are ideal for archaeomagnetic sampling because they were subjected to repeated hot firings. The iron in the clay realigned with every sufficiently hot fire, so it is the last hot fire in a hearth that archaeologists are able to date (Fig. 8 (b)).

When ferromagnetic materials such as magnetite are cooled below their Curie points, the magnetic moment of the material is frozen in the direction of the local magnetic moment at that time [36]. The direction and the magnitude of the Earth's magnetic field vary with time and hence paleomagnetic signatures can be used to

determine the age of the material. Archaeomagnetic dating together with radiodating methods can be used to construct and calibrate the geomagnetic polarity time scale. This is a very important dating method used to age sites within last 10,000 years [37].

2.5 Dating Construction Materials and Buildings

Construction materials used in ancient and historical buildings are usually mud, wood and rock among other things. Archaeological and physiochemical analyses of these materials are done to acquire information on construction materials used and their phases and ages [38]. Building Stratigraphy is a common technique used in ageing ancient buildings. This is a non-destructive technique used to reconstruct the history of ancient buildings by using direct observations of features such as materials, building techniques, continuousness and gaps, demolition tracks and the way a specific element sticks to the next one, etc. as significant traces of the passage of the monument throughout the different historical periods. These stratigraphic techniques enable estimation of the approximate ages of buildings though there can be significant errors and uncertainties associated with the technique since the identification of features depends merely on the talents and capabilities of the archaeologist and the existing knowledge and databases of the stratigraphic information. Another issue is the inability to inspect data that may be available in the interior of walls etc. As such, stratigraphy is used in conjunction with other techniques. Chrono-typology which is a dating method based on different architectural features during historical periods is another such non-destructive relative dating technique that can be used to estimate the ages of structural buildings [39]. Here again, the databases available and the ability and talents of the observer are important factors determining the accuracy of the technique. One sub-branch of chrono-typology is the measure-chronology where dimensions of characters are used in estimating age. It has been predicted that this technique has a tolerance of 20 years which in archaeological terms is a very small error margin. It is amazing to realize that the wall bricks measure-chronology curve defined for Genoa, including also the ancient Genoa Republic territory, ranges from the XIIth to the XIXth century, and in better cases allows dating with a five years tolerance. Since buildings invariably

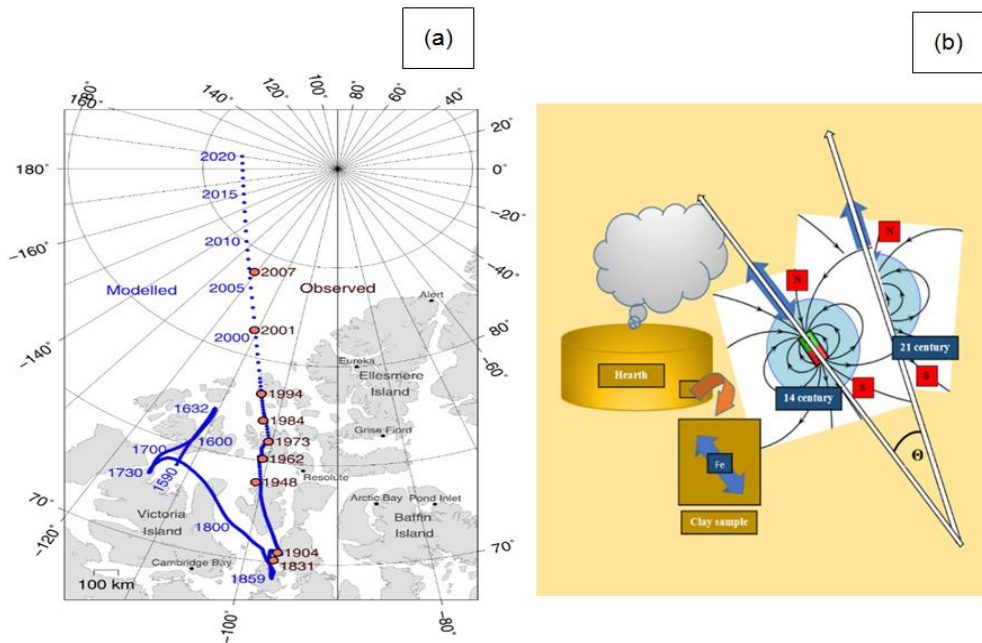


Fig. 8.(a). Magnetic north pole positions changes due to the flow of liquid iron in the planet's core

(Magnetic North Pole Positions 2015.svg. (2016). Persepolis [Online image]. Retrieved December 03, 2017, from https://en.wikipedia.org/wiki/Earth%27s_magnetic_field#/media/File:Magnetic_North_Pole_Positions_2015.svg)

(b) Alignment of iron of an archaeomagnetic sample collected from ancient hearth corresponds to a specific dated position on the reference curve

contain woods and wooden parts dendro-chronology can successfully be used in estimating age [37].

If the construction material or building contains crystalline minerals heated at high temperatures during their construction, such as glass, then computer-radiology of thermo-luminescence is a reliable method for estimating their ages. Elemental composition is usually determined by X-ray Fluorescence Spectroscopy (XRF) though XRF involves exposure to X-rays which may result in sample damage due to storage of radiation. An alternative method that does not require external radiation is the measurement of radiation emitted by natural born radioactive nuclides primarily due to uranium or thorium and only a few other nuclides like 40K with very long half-life times. Usually, 462 keV-line of 40K is used as identification line. Measurements are usually done in a well-shielded HPGc-Detector spectrometer with extremely low background radiation in an energy range from 40 to 1800 keV with a detector resolution of 1.3 keV with respect to the 1.33 MeV 60Co g-line. Due to the low intensity of natural radioactivity, a measuring period of ~100 h is required to eliminate statistical errors.

Ceramic materials used in constructing buildings are usually fired bricks, tiles and less frequently pavements and pipes whose age can be determined by thermo-luminescence. However, there are three important issues with regard to the use of thermo-luminescence in ageing ceramic materials used to construct engineering structures. These include: (i) If the bricks have been exposing to high temperatures due to accidental fires occurred after constructing the structure then the “zeroing” of the luminescence signal takes place at that time and hence there can be an underestimation of the real age, (ii) architectural modifications can distort the dose rate and subsequent age due to changes in the surrounding radioactivity received by the brick and (iii) reused bricks will provide overestimated ages as the firing occurred some time ago [40].

There is a possibility to use radiocarbon dating for ageing ceramic materials and bricks. There can be organic matter present in the original clay or added to it could remain in the brick core even after firing if the temperatures of the brick core do not reach highly elevated values. Remnants of organic matter in the ancient potteries have been observed and used to date the pottery using radiocarbon dating [41,42]. Secondly, carbonates

(e.g., calcite and shells) are normally added to the raw clay paste and shells can be used for dating [43]. Carbonates (usually calcium or magnesium carbonates) are converted to their oxides and carbon dioxide during firing and oxides can recapture carbon dioxide thus making the carbonates. Some old calcium carbonate has been found in bricks [44]. Thirdly, soot and smoke can be adsorbed to the brick surface during firing under reducing conditions. This soot and smoke have been derived from fire woods and hence their 14C content is equal to the 14C content of the dead wood. Therefore, carbon dating can be used to detect the age of such bricks [45].

Archaeomagnetic dating is an important technique in determining ages of historic buildings. It has been reported that the data obtained by the archaeomagnetic dating demonstrated that the buildings of the Pequeña Acrópolis were constructed within a range of approximately 100 years (AD 422–531) with the southern building being the latest of all. Following the chronology proposed by Martin and Grube and Velásquez (by Epigraphy), the buildings that coronate the Pequeña Acrópolis would have been completed (the plasters at least) during the rulings of the kings of the Kaan dynasty before Testigo Cielo (AD 561–572), Yuknoom Ch'e'n I (AD 636-686), and Tuun K'ab' Hix (AD 520–546) [46].

It is of great interest to note that civilizations since pre-historic times used straw-reinforced clay as building materials. There are reports to give evidence to the fact that Egyptians, several hundred years B.C., used clay-like deposits of the Nile Valley with reinforced grass plant fibres to make sun-baked mud bricks to make temple walls, tombs and houses [23]. In fact, the watchtowers of the far western Great Wall of China are supposed to be built with straw-reinforced bricks during the Han Dynasty (about 200 years B.C.). Even today, natural fibre-reinforced clay is used as one of the primary housing materials in the rural sectors of many third world countries. Early Egyptians (1500 B.C.) used laminated wood furniture in which high-quality wood veneers were bonded to the surfaces of cheaper woods. It is believed that Chinese have made the first paper using plant fibres in 108 A.D. The bows used by the warriors under the Mongolian Chief Djingiz Chan in 1200 A.D. are believed to be made with the adhesive-bonded laminated composite consisting of buffalo or anti-lope horns, wood, silk and ox-neck tendons. These laminated composite bows were

able to deliver arrows with an effective shoot in a range of about 740 m. Since all of these contain materials coming from plant or animal origin, they can be dated quite accurately by ¹⁴C radio-carbon dating.

3. CONCLUSION

In this review, we explained both relative and absolute archaeological dating methods in detail. Wherever possible we tried to tie into Sri Lankan archaeological treasures though those of prime interest in global perspectives were also presented. More importantly, archaeological ageing of ancient engineering structures was discussed. Archaeological dating is an important topic that is usually not handled by chemists and physicists though most of the analytical techniques have their fundamental roots in chemistry and physics. As such, in this publication, we discussed fundamentals related to archaeological dating techniques. We have included both relative and absolute dating techniques where we began with stratigraphy and typology as relative dating techniques. In absolute dating techniques, we described radiocarbon dating, dendrochronology, thermoluminescence, computed-radiology and archeomagnetic dating. Finally, we have discussed the importance of these techniques in dating construction materials and buildings.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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