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REVIEW ARTICLE

Radiocarbon dating: a scientific overview

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ABSTRACT

The review provides scientific and basics view on radiocarbon dating. However, his presentation, calibration and interpretation of radiocarbon ages are misleading in some cases, and important wide applications for age determining process. Radiocarbon dating is a radiometric dating method that uses the naturally occurring radioisotope carbon-14 (^{14}C) to estimate the age of carbon-bearing materials up to about 58,000 to 62,000 years.

Key words: Radiocarbon dating

INTRODUCTION:

The term Radiocarbon is commonly used to denote ^{14}c, an isotope of carbon which is radioactive with a half-life of about 5730 years ^{14}c is produced by cosmic rays in the stratosphere and upper troposphere. It is then distributed throughout the rest of the troposphere, the ocean, and Earth's other exchangeable carbon reservoir. In the surface atmosphere, about one part per trillion (ppt) of carbon is ^{14}c.[1]

All organisms absorb carbon from their environment. Those that absorb their carbon directly or indirectly from the surface atmosphere have about 1 ppt of their carbon content as ^{14}c.

When an organism dies, carbon stops being absorbed. Hence after 5730 years, about half of its ^{14}c will have radioactively decayed (to nitrogen): only about 0.5 ppt of carbon of the organisms remains will be ^{14}c. And if the carbon of the remains is found to 0.25 ppt ^{14}c, then the organism would be assumed to have died about 11460 years ago. Thus, a simple calculation can find the age, since death from any ^{14}c concentration. (Remains older than about 50,000 year however have a ^{14}c concentration that is in practice too small to measure; so they cannot be dated via ^{14}c.)

Although a tree may live for hundreds, even thousands, of years, each ring or a tree absorbs carbon only during the year in which it grows. The year in which a ring was grows can be determined exactly (by counting); so radiocarbon dating can be tested by measuring the ^{14}c concentration of ^{14}c in old tree rings. It turns out that the concentration of ^{14}c in the carbon of the surface atmosphere has not been a constant 1 ppt, but has varied with time.[2]

The concentration of ^{14}c in the carbon of organism's remains can be compared with the concentration in tree rings; the rings that match, within confidence limits, give the years in which the organism could have plausibly died. Ages determined this way are called 'calibrated ^{14}c ages' others are called 'uncalibrated ^{14}c ages' or simply "^{14}c ages" and continue to be reported as "^{14}c BP" (calibration via tree rings though, does not extend for 50,000 years, only several thousand).Calibrated ^{14}c ages are generally greater than uncelebrated ^{14}c ages, with differences increasing with age. [3]

History:

Carbon dating was developed by American scientist Willard Libby and his team at the University of Chicago. Libby calculated the half-life of carbon-14 as 5568 ± 30 years, a figure now known as the Libby half-life. Following a conference at the University of Cambridge in 1962, a more accurate figure of 5730 ± 40 years was agreed upon based on more recent experimental data (this figure is now known as the Cambridge half-life).

The chairman of the Cambridge conference, Harry Godwin, wrote to the scientific journal Nature, recommending that the Libby half-life continue to be used for the time being, as the Cambridge figure might itself be improved by future experiments.[4]

Laboratories today continue to use the Libby figure to avoid inconsistencies with earlier publications, although the Cambridge half-life is still the most accurate figure that is widely known and accepted. However, the inaccuracy of the Libby half-life is not relevant if calibration is applied: the mathematical term representing the half-life is canceled out as long as the same value is used throughout a calculation.

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Calibration:

The need for calibration:

A raw BP date cannot be used directly as a calendar date, because the level of atmospheric ^{14}C has not been strictly constant during the span of time that can be radiocarbon dated. The level is affected by variations in the cosmic ray intensity which is in turn affected by variations in the Earth's magnetosphere[5]. In addition, there are substantial reservoirs of carbon in organic matter, the ocean, ocean sediments (see methane hydrate), and sedimentary rocks. Changes in the Earth's climate can affect the carbon flows between these reservoirs and the atmosphere, leading to changes in the atmosphere's ^{14}C fraction.

A side from these changes due to natural processes, the level has also been affected by human activities. From the beginning of the industrial revolution in the 18th century to the 1950s, the fractional level of ^{14}C decreased because of the admixture of large quantities of CO_2 into the atmosphere, due to the excavated oil reserves and combustion production of fossil fuel. This decline is known as the Suess effect, and also affects the ^{13}C isotope. However, atmospheric ^{14}C was almost doubled during the 1950s and 1960s due to atmospheric atomic bomb tests[6].

Calibration methods:

The raw radiocarbon dates, in BP years, are calibrated to give calendar dates. Standard calibration curves are available, based on comparison of radiocarbon dates of samples that can be dated independently by other methods such as examination of tree growth rings (dendrochronology), deep ocean sediment cores, lake sediment varves, coral samples, and speleothems (cave deposits).

The calibration curves can vary significantly from a straight line, so comparison of uncalibrated radiocarbon dates (e.g., plotting them on a graph or subtracting dates to give elapsed time) is likely to give misleading results. There are also significant plateaus in the curves, such as the one from 11,000 to 10,000 radiocarbon years BP, which is believed to be associated with changing ocean circulation during the Younger Dryas period.

Over the historical period from 0 to 10,000 years BP, the average width of the uncertainty of calibrated dates was found to be 335 years, although in well-behaved regions of the calibration curve the width decreased to about 113 years while in ill-behaved regions it increased to a maximum of 801 years. Significantly, in the ill-behaved regions of the calibration curve, increasing the precision of the measurements does not have a significant effect on increasing the accuracy of the dates[7].

The 2004 version of the calibration curve extends back quite accurately to 26,000 years BP. Any errors in the calibration curve do not contribute more than ±16 years to the measurement error during the historic and late prehistoric periods (0–6,000 yrs BP) and no more than ±163 years over the entire 26,000 years of the curve, although its shape can reduce the accuracy as mentioned above[8].

In late 2009, the journal Radiocarbon announced agreement on the INTCAL09 standard, which extends a more accurate calibration curve to 50,000 years[9, 10].

Methods:

1)1st Method:-

Various parchment and papyrus manuscripts found in caves in the area of Qumran and at other sites the Judean desert are know generously as the Dead Sea scrolls. In some cases, scrolls suggested as important for dating had insufficient material available in the margins or the margins were too beautiful to be harmed. These sample were not taken and they account for missing numbers in the list (eg.DSS-2)

Samples types and treatment:

Small samples of 5-15 mg.of material were removed. Samples were studied under a binocular microscope and were divided in to 3 types:

1-NSF Arizona accelerator mass spectrometer facility, the University of Arizona, Tucson, Arizona 85721 USA

2-Shrine of the book, israe museum, Jerusalem 91710 israel

3-Dead sea scrolls publication project, department of the bible, Hebrew university, Jerusalem, Israel

Type 1: parchment samples that appeared to be relatively clean –

Piece of ca.2-10mg. were pretreated using procedure based on those reported by Bonani et.al. (1991, 1992) with some modifications.

Samples were washed in 1 N Hcl for 10 min.,rinsed in distilled water, washed in 0.1% NaOH for up to 10 min., rinsed again in distilled water, and finally reacidified with Hcl, cleaned with distilled water. Sample were dried in a vaccum oven and were removed as soon as were dry. We found that some partially gelatinized samples were very easily dissolved by NaOH solutions (as previously reported by Bonani et.al.1991 and 1992), and all samples monitored during this process. Samples that started to dissolved in NaOH were removed from the solution as quick as possible.

Type 2: parchment samples with glue contamination-

These samples were contaminated with Perspex glue, as they had been stuck to rice paper as a backing material. They include DSS-1,-5,-11,-22,-23 and -24. DSS-4 was

difficult to clean, as it had been attached to be a silk backing material and also appeared to be impregnated with a glue like material. Pieces of 2-8mg. with adhering glue were washed in acetone in an ultrasonic bath for 30 min. these procedure worked well for most samples, but in the case of two samples pieces(DSS-23 and -24), this process had to be repeated for 3 hrs.

Type 3: Papyri-

Papyrus samples (DSS-10,-25,-52,-53) were generally very clean. Pretreatment was carried out easily using the standard methods of type1, above. Dried samples were combusted with Cuo to make ca using the standard techniques at Arizona (Donahue,jull and toolin 1990). For most samples, sufficient CO2 samples was available, and a split of up to 0.2 ml was taken for stable isotope analysis of the δ13 c of the carbon. This parameter is important to make accurate corrections to the 14C age, which are all quote as normalized to-25%. The remaining CO2 was converted to graphite using standard procedures.

The graphite powder so produced was pressed in to an accelerator target holder, and the target was then analyzed by accelerator mass spectrometry (AMS).we loaded 24 samples targets with 8 standard targets[11].

2)2nd methods:-

i) Radio carbon dating method:

One of the most widely used and well known absolute dating techniques is carbon-14 (or radiocarbon), this is radiocarbon techniques since it is based on radioactive decay.

Carbon 14 moves up the food chain as animals eat plants and as predators eat other animals. With death, the uptake of carbon 14 stops. Then this unstable isotope starts to decay into nitrogen-14. It takes 5,730 years for half life carbon-14 to change to nitrogen; this is the half life of carbon-14. After another 5730 years only one quarter of original carbon-14 will remain. After yet another 5730 years only one eight will be left. By measuring the proportion of carbon-14 in organic material scientists can determine the date of death of the organic matter in an artifact or ecofact [12].

Limitations:

Because the half life of carbon -14 is 5730 years carbon dating is only reliable about up to 40,000 years, radiocarbon is less useful to date some recent site. This technique usually cannot pinpoint the date of a site better than historic records[13].

ii) potassium- argon dating:

One of the most widely used is potassium- argon dating, (K-Ar-Dating.)Potassium-40 is a radioactive isotope of potassium- 40 is 1.3 billion years, for longer than that of carbon 14, allowing much older samples to be dated. Potassium is common in rocks and minerals, allowing many samples14[14].

Argon a noble gas, is not commonly incorporated in to such samples except when produce in situ through radioactive decay. The date measured reveals the last time that the object was heated pass the closure temperatures at which the trapped argon can escape the lattice. K-Ar dating was used to calibrate the geomagnetic polarity time scale.

iii) Thermo luminescence:

Thermo luminescence testing alsodates items to the time they were heated. This technique is based on the principle that all objects absorb radiation from the environment. This process frees electrons within minerals that remains caught within the item. Heating an item to 500 degrees Celsius or higher release the trapped electron, producing light. This light can be measured to determine the last time the item was heated[15].

Limitations:

Radiation levels do not remain constant over time. Fluctuating levels can skew results for examples, if an item went through several high radiation eras thermoluminescence will return an older date for the item.

Many factors can spoil the samples before testing as well, exposing the sample to heat or direct light may cause some of the electrons to dissipate, causing the item to date younger, because of these and other factors, Thermoluminesence is at the most about 15% accurate. It cannot be used to accurately date a site on its own. However, it can be used to authenticate an item as antiquity[16].

Other factors affecting carbon dating:

The amount of cosmic rays penetrating Earth's atmosphere affects the amount of 14C produced and therefore the dating system. The amount of cosmic rays reaching the Earth varies with the sun's activity, and with the Earth's passage through magnetic clouds as the solar system travels around the Milky Way galaxy. The strength of the Earth's magnetic field affects the amount of cosmic rays entering the atmosphere. Stronger magnetic field deflectsmore cosmic rays away from the Earth. Overall, the energy of the Earth's magnetic field has been decreasing.[17] so more 14C is being produced now than in the past. This will make old things look older than they really are.

Also, the Genesis Flood would have greatly upset the carbon balance.

The Flood buried a huge amount of carbon, which became coal, oil, etc.,lowering the total 12C in the

biosphere (including the atmosphere—plants regrowing after the Flood absorb CO2 which is not replaced by the decay of the buried vegetation).[18] Total 14C is also proportionately lowered at this time, but whereas no terrestrial process generates any more 12C, 14C is continually being produced, and at a rate which does not depend on carbon levels (it comes from nitrogen). Therefore the 14C level relative to 12C increases after the Flood. So the 14C/12C ratio in plants/animals/the atmosphere before the Flood had to be lower than what it is now.

Unless this effect (which is additional to the magnetic field issue just discussed) were corrected for, carbon dating of fossils formed in the Flood would give ages much older than the true ages.

Creationist researchers have suggested that dates of 35,000–45,000years should be recalibrated to the biblical date for the Flood.[19] Such are calibration makes sense of anomalous data from carbon dating—for example, very discordant 'dates' for different parts of a frozen musk ox carcass from Alaska and an inordinately slow rate of accumulation of ground sloth dung pellets in the older layers of a cave where the layers were carbon dated.[20]

Also, volcanoes emit much CO2 depleted in 14C. Since the Flood was accompanied by much volcanism fossils formed in the early post-Flood period would give radiocarbon ages older than they really are.

In summary, the carbon-14 method, when corrected for the effects of the Flood, can give useful results, but needs to be applied carefully.

It does not give dates of millions of years and when corrected properly fits well with the biblical Flood.

Application of carbon dating:

1)^{14}C dating of the Iceman:

The AMS laboratories in Zürich and Oxford performed the first ^{14}C measurements on milligram amounts of bone and tissue from the Iceman[20,21]. In Figure 2 the determination of the calibrated date from the measured radiocarbon age is depicted. It is apparent that the calibrated date covers a much larger time range than the uncalibrated radiocarbon age, which is obtained directly from the results of the AMS measurements.Libby's original assumption, the ^{14}C content of the atmosphere was not constant in time, and thus cannot be inferred for the past by measuring present-day ^{14}C. We now know that both the earth and the solar magnetic field change with time. This has a varying shielding effect on the cosmic rays impinging on the atmosphere, and thus on the ^{14}C production rate. In addition, climatic effects can also change the atmospheric ^{14}C content by variations in the exchange of ^{14}C between the global reservoirs of ^{14}C (see below). For the past 12,000 years, a ^{14}Co calibration was obtained by measuring ^{14}Ct in tree rings whose absolute age (calendar year) was determined from dendrochronology (tree-ring dating) [22]. For earlier times, other objects such as corals, stalagmites, and lake sediments can be used.[22, 23.]

2) In human body:

Carbon-14 can be used as a radioactive tracer in medicine. In the initial variant of the urea breath test, a diagnostic test for Helicobacter pylori, urea labeled with approximately 37 kBq (1.0 µCi) carbon-14 is fed to a patient (i.e. 37,000 decays per second). In the event of a H. pylori infection, the bacterial urease enzyme breaks down the urea into ammonia and radioactively-labeled carbon dioxide, which can be detected by low-level counting of the patient's breath.[24] The 14-C urea breath test has been largely replaced by the 13-C urea breath test which has no radiation issues.

3) In fossil fuels:

Most man-made chemicals are made of fossil fuels, such as petroleum or coal, in which the carbon-14 should have long since decayed. However, such deposits often contain trace amounts of carbon-14 (varying significantly, but ranging from 1% the ratio found in living organisms to amounts comparable to an apparent age of 40,000 years for oils with the highest levels of carbon-14).[25] This may indicate possible contamination by small amounts of bacteria, underground sources of radiation causing the ^{14}N(n,p) ^{14}C reaction, direct uranium decay (although reported measured ratios of ^{14}C/U in uranium-bearing ores[26] would imply roughly 1 uranium atom for every two carbon atoms in order to cause the^{14}C/^{12}C ratio, measured to be on the order of 10^{-15}), or other unknown secondary sources of carbon-14 production. Presence of carbon-14 in the isotopic signature of a sample of carbonaceous material possibly indicates its contamination by biogenic sources or the decay of radioactive material in surrounding geologic strata. In connection with building the Borexino solar neutrino observatory, petroleum feedstock (for synthesizing the primary scintillant) was obtained with low ^{14}C content. In the Borexino Counting Test Facility, a ^{14}C/^{12}C ratio of 1.94×10^{-18} was determined;[27] reactions responsible for varied levels of ^{14}C in different petroleum reservoirs, and the lower ^{14}C levels in methane, have been discussed by Bonvicini et al[28]

4) Application of Radiocarbon Dating to the Sample from the Shroud of Turin:-

This sample was provided, unidentified, together with several other control samples of linen textile whose age was known (though not divulged to the participating laboratories). The main question facing the laboratories was the best way to decontaminate the cloth[29]. Most methods used were similar, although Oxford used an additional step of a lipid extraction in order to remove any grease or candle wax, as well as oxidatively removing lignins from the basic cellulose structure of the cloth[29,30]. The method of measurement used, accelerator mass spectrometry (AMS), was necessary because of the small sample size available. Although at that time AMS was a less well-developed technique than that used for the majority of radiocarbon dates, the participating laboratories had already measured several thousand dates by the AMS method, and its accuracy, both then and subsequently, has been shown to be comparable to the best of the laboratories using conventional methods[31,32,33].

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