Radiocarbon Dating: An Introduction

By LYNN FRASER

'When?' is one of the main questions that archaeologists want to answer. To this end radiocarbon dating has transformed our understanding of the past, over a relatively short period of time.

What is radiocarbon?

During World War II, along with fellow scientists, Willard Libby was studying cosmic radiation, the bombardment of the earth by small, high energy sub-atomic particles. He discovered that one of the atomic reactions caused by the particles' contact with the earth's atmosphere is the production of small quantities of radiocarbon in the atmosphere.

Radiocarbon or carbon-14 is a rare *isotope* of carbon i.e. it has a heavier atomic weight than, but behaves in the same way as, the common isotope carbon-12. It therefore combines with oxygen to form carbon dioxide and is taken up by plants during photosynthesis, thus entering the earth's carbon cycle (Figure 1).

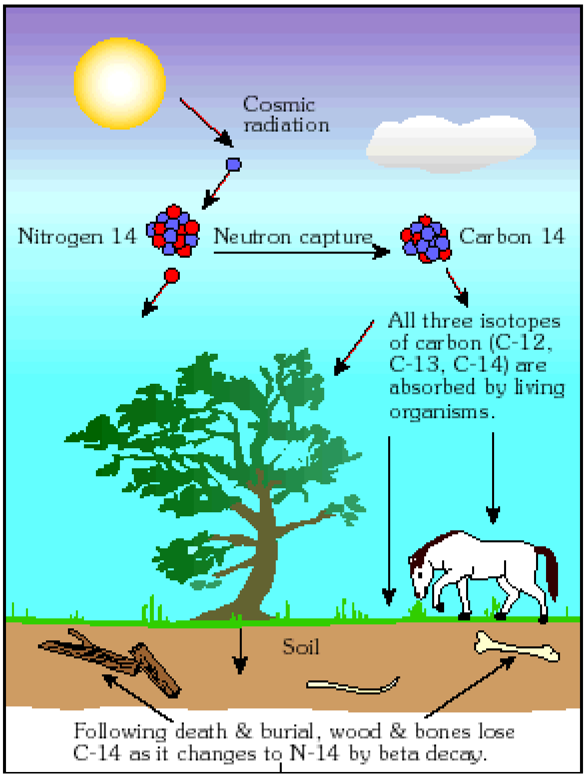

Figure 1: Radiocarbon is produced in the atmosphere and absorbed by plants during photosynthesis as carbon dioxide. It is then absorbed by animals eating plants or other animals. This uptake ceases once an organism dies.
(Image source: www.unc.edu/~tlycan/carbondating.html)

Carbon-14 also differs from carbon-12 in that it is radioactive and, therefore, spontaneously decays at a constant rate unaffected by climate or environment. The length of time taken to lose one-half of its atoms through decay is called a *half-life*. Libby estimated that this took approximately 5568 years, although modern research indicates that the figure of approximately 5730 is more accurate. During its lifetime the amount of carbon-14 within a plant or animal will remain constant; the uptake of new carbon-14 balances the loss of carbon-14 through radioactive decay. However, once an organism dies the uptake of carbon-14 ceases and the amount of carbon-14 declines. After one half-life half the original amount of carbon-14 remains; after two half-lives one quarter remains; after three half-lives one eighth remains and so on.

Trees are slightly different in that carbon-14 decay begins as soon as the cellulose molecules of wood are formed. This means that the inner rings will give an older date than the outer rings, which only correspond to the felling date.

Measuring radiocarbon

Libby's basic premise of radiocarbon dating is to measure the amount of carbon-14 left in a sample, such as charcoal, wood, seeds, plant remains and bone. This relies on the assumption that the levels of carbon-14 in the atmosphere have remained constant through time. However, it is now known that this assumption is incorrect. Carbon-14 levels have fluctuated through time, mainly due to changes in the earth's magnetic field: a weaker field allows increased carbon-14 production and vice versa. The increase in fossil fuel combustion since the Industrial Revolution has had a diluting effect on the amount of carbon-14 in the atmosphere. This has, however, been overshadowed by the production of vast quantities of artificial carbon-14 from atmospheric nuclear weapons testing in the 1950s and 1960s.

In addition to the fluctuation of carbon-14 levels, other factors have to be taken into account when measuring the level of carbon-14 in a sample. Plants normally do not take up carbon-14 as readily as carbon-12; this discriminatory process is called *fractionation* and plants contain an average of 3-4% less carbon-14 than the atmosphere. It is further complicated by species variation, but, if this difference is not adjusted for, ages of 240-320 years older than the true age will be suggested. Plants are also fractionating agents: animals consume them accumulating an unrepresentative carbon signal. Marine organisms also have to be treated with caution as they have apparent ages hundreds of years older than they really are due to carbon's very slow circulation in the oceans.

There are two methods of measuring the amount of radiocarbon in a sample. The first is based on Libby's discovery that carbon-14 releases beta radiation particles as it decays and these emissions are counted. Radioactive decay is a random process so the rate of emission of beta particles is determined by counting them for a set period of time. Statistically, this count is liable to be different from the average that would be determined if the counting time is infinitely longer, introducing an element of inaccuracy. Accuracy can also be affected by counting errors, background cosmic radiation and contamination of the sample. That is why radiocarbon dates are accompanied by the plus/minus term, representing an estimate of probable error. They should not be read as *A* year plus/minus *b* years (Figure 2).

The second method is Accelerator Mass Spectrometry (AMS), which measures the concentration of carbon-14 atoms by counting them directly. This is done in a nuclear accelerator; a more expensive option but giving greater accuracy. AMS has had a large impact on archaeology as smaller samples of material are required for the process, thus opening radiocarbon dating to a new range of finds; the Turin Shroud is a famous example. Contamination by modern carbon is still a problem and can adversely affect results.

Radiocarbon years are shown as BP (before present, where the 'present' is AD1950)

If a radiocarbon date is shown as 2500 ± 100 BP the first figure is the year BP (in this example 2500). The second figure (in this example 100) is the probable error known as the standard deviation.

The standard deviation means there should be a 68% probability (2 chances in 3) that the correct estimated age in radiocarbon years lies between 2600 (2500 + 100) and 2400 (2500 – 100) BP.

To increase the probability of a correct estimate the standard deviation should be doubled. This gives a 95% chance that the age estimate will lie between 2700 (2500 + 200) and 2300 (2500 – 200) BP.

Obviously, the larger the standard deviation, the less precise the dates.

Calibrated dates are shown as Cal BC/AD

Figure 2 Example of how to read radiocarbon dates

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Calibrating radiocarbon dates

Laboratory ages are given in radiocarbon years, which are not the same as ages in calendar years, due to the fluctuations in atmospheric carbon-14 levels. This has been demonstrated through dendrochronology by obtaining precise radiocarbon dates from the long tree-ring master sequences of bristlecone pine and oak; by plotting the radiocarbon ages against the tree-ring ages calibration curves have been produced (Figure 3). Broadly speaking radiocarbon ages diverge increasingly from true ages before 1000BC; by 5000BC in calendar years the radiocarbon age is 900 years too young. The calibration curve is not an infallible conversion tool however, as it contains ‘wiggles’ and plateaux resulting in multiple or an increased span of dates respectively. Complex statistical calculations are required in these situations. The current calibration curve extends to 50,000 years ago and this is, perhaps, the radiocarbon dating limit due to the very small amounts of carbon-14 available to measure after this time.

Conclusion

Radiocarbon dating and its calibration has revolutionised the study of archaeology and has established broad chronologies for many of the world’s cultures. It continues to be the method of choice for dating organic material and the diminishing sample sizes required for a successful result will continue to open new avenues of research.

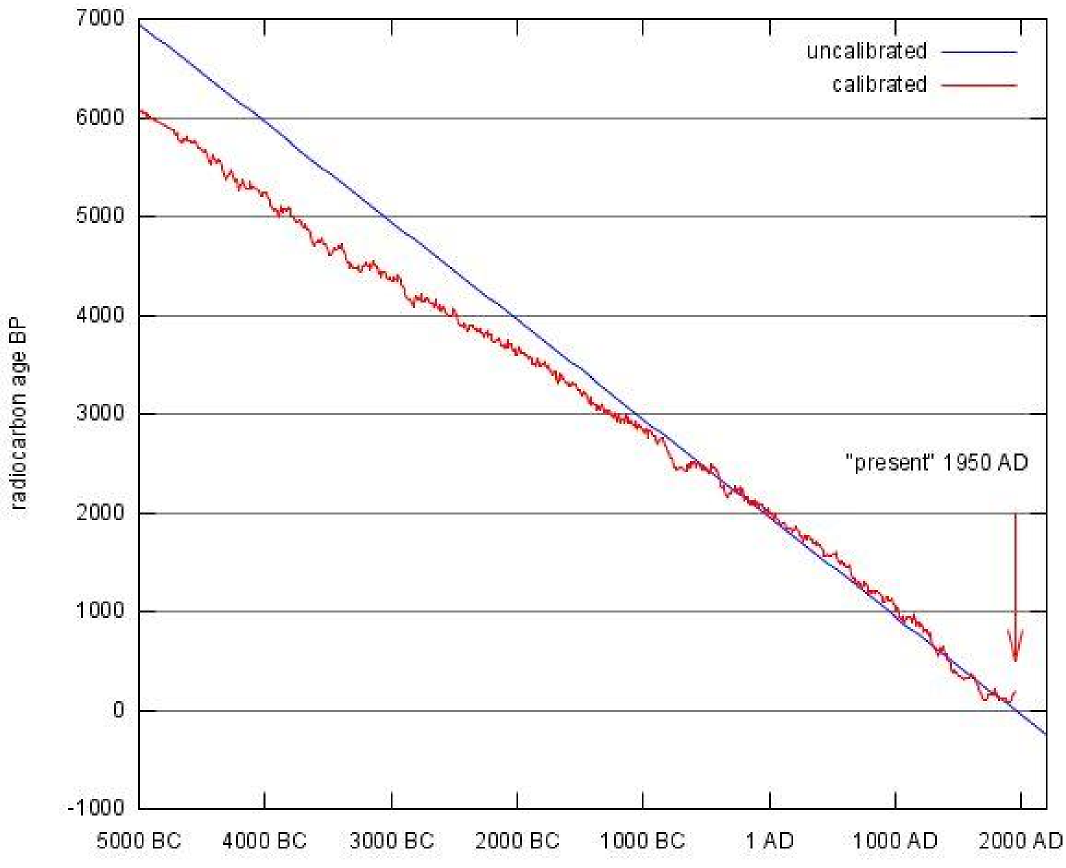

Figure 3: Calibration curve
(Image source: http://proteus.brown.edu/greekpast/4781)

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