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From revolution to convention: the past, present and future of radiocarbon dating

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ABSTRACT

Radiocarbon dates form the basis of many archaeological chronologies that span the last 50,000 years. Since the first studies in the early 1950s the method has changed almost beyond recognition, with the major developments often described as revolutions. Dates are now more likely to be measured in an AMS than a radiation counter. This is allowing ever-smaller samples to be subjected to increasingly robust pretreatment protocols, improving both accuracy and the range of samples that can be directly dated. A terrestrial calibration curve now extends to 50,000 years, allowing more confident calibration throughout the late Pleistocene. Finally, rather than simply dating a single sample, it is becoming increasingly common to combine large numbers of radiocarbon dates to create chronological models designed to test specific hypotheses. Development is continuing along these lines, aiming to expand the types of datable materials and improve accuracy and precision, whilst decreasing sample size and cost. However, the largest and most pressing problem facing the field is appropriate publication of dates. Radiocarbon's long history means a range of methods and approaches exist, but the scant details published alongside the majority of dates means assessment of their quality is impossible, either in terms of association with archaeology or accuracy of the number. Whether this is due to a lack of education, journal guidelines or laboratory reporting, work must focus on improving the situation. If we cannot improve publication, many of the thousands of dates produced every year will be unusable in the future. This would be a terrible waste of what is a valuable resource of increasingly high quality chronological information.

1. Introduction

Before the mid-20th century, the primary objective of many archaeologists was to produce chronological order amongst the rich archaeological records being uncovered. With no chronology the past was “*chaotic*” (Renfrew, 1973) and described as being “*wrapped in a thick fog*” (Nyerup, 1806). In the early 20th century, archaeological chronologies were primarily based on the relative ordering of events through stratigraphies at individual sites, and typologies and seriations between sites. In 1946 Libby proposed that radiocarbon may be produced in the upper atmosphere, and by 1949 a series of known age samples stretching back around 5000 years had been radiocarbon dated (Arnold and Libby, 1949). The potential impact of radiocarbon dating, a method that would enable the construction of independent chronologies for disparate sites, was recognized immediately with the award of the Nobel Prize for Chemistry to Libby in 1960.

The technique has lived up to this early promise. Radiocarbon dates now dominate the vast majority of archaeological and palaeoenvironmental chronologies spanning the past 50,000 years (Bayliss, 2009; Hajdas, 2009; Kuzmin, 2009), as well contributing to study of many other fields, including oceanography (Broecker, 2009), cell biology (e.g. Spalding et al., 2013) and forensics (e.g. Alkass et al., 2010). The research field is well organized, with a dedicated journal (*Radiocarbon*, initially published as *American Journal of Science Radiocarbon Supplement* in 1959) and regular conferences for both methods (e.g. AMS, Radiocarbon) and applications (e.g. Radiocarbon and the Environment, Radiocarbon and Archaeology), whilst international laboratory intercomparisons are regularly undertaken (Scott et al., 2010).

In many circumstances, radiocarbon is ideal for archaeological chronologies. It stretches from *c.*1750 AD to *c.*50 cal kBP. It can often directly date the event we are interested in, such as the death of an individual or the presence of a domesticated grain. Moreover,

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organic materials are frequently abundant on archaeological sites providing ample samples for analysis. Combined with the perceived and real reliability across much of its range, the techniques relatively low cost (typically US\$300–600 per sample), high precision (<5% well beyond 30 cal kBP) and easy access (132 research and service laboratories now exist (Radiocarbon 55 (4), 2073–2096)) have contributed to its wide application today.

Research into radiocarbon is continuing apace, building on the fields' long history and multiple 'revolutions' (Renfrew, 1973; Pettitt et al., 2003; Mellars, 2006; Bayliss, 2009). Many of the key research areas today (Fig. 1) were defined in the 1950s and 60s, namely pretreatment, measurement, and calibration (Godwin, 1954, 1959). The most recent 'revolution', the application of Bayesian statistics, is rapidly gaining momentum and is fundamentally altering the way in which samples are selected and chronologies built (as described in Bayliss, 2009). This review will provide a necessarily brief description of the theoretical basis of radiocarbon, before examining the four key areas of current research. Finally, the persistent problem of inadequate publication will be discussed.

2. The radiocarbon dating method

Space does not permit a comprehensive description of radiocarbon, and the reader is referred to Bronk Ramsey (2008) for a detailed review of the method.

Carbon has three isotopes. ^{12}C and ^{13}C are stable and form *c*.98.89% and *c*.1.11% of the carbon atoms in the atmosphere today respectively, whereas ^{14}C (radiocarbon) is unstable and forms just $c.1 \times 10^{-10}\%$. ^{14}C is primarily produced in the upper atmosphere when neutrons, resulting from spallation reactions caused by cosmic rays, react with ^{14}N. ^{14}C is subsequently oxidized to carbon dioxide, which rapidly mixes in each hemisphere and is incorporated into the food chain through photosynthesis. After photosynthesis the clock used by archaeologists, the decay of ^{14}C back to ^{14}N, starts to tick. When eaten, the ^{14}C from the plant is incorporated into tissue within the animal. If the tissue is turned over slowly, e.g. femoral bone, it will appear slightly older than tissues that are rapidly replaced such as blood or skin. As an extreme case, the tissues making up the inner rings of a tree are not replaced as the tree grows and therefore record the ^{14}C activity in the year of growth.

The proportion of radiocarbon in the atmosphere varies over both time and space, so radiocarbon dates need to be calibrated to produce dates that are comparable to calendar age estimates (Ramsey et al., 2006). It is also possible for an organism to take its carbon from a reservoir other than the atmosphere. In the marine system calibration is more complicated, but still possible for organisms feeding in surface waters. Here carbon is on average *c*.400 years older than the atmosphere because deep water, which cannot exchange carbon with the atmosphere, mixes with surface waters when it upwells (Stuiver and Braziunas, 1993). Local variation from the global marine average is caused by local variations in this upwelling and is termed the ΔR. For accurate marine calibration this value must be known for each location, time (Stuiver and Braziunas, 1993; Ascough et al., 2009b) and species (Petchey et al., 2013). In contrast, it may not be possible to obtain reliable dates from organisms feeding in freshwater systems where multiple sources carbon exist, such limestone or geothermal activity (Lanting and van der Plicht, 1998; Ascough et al., 2010b; Keaveney and Reimer, 2012).

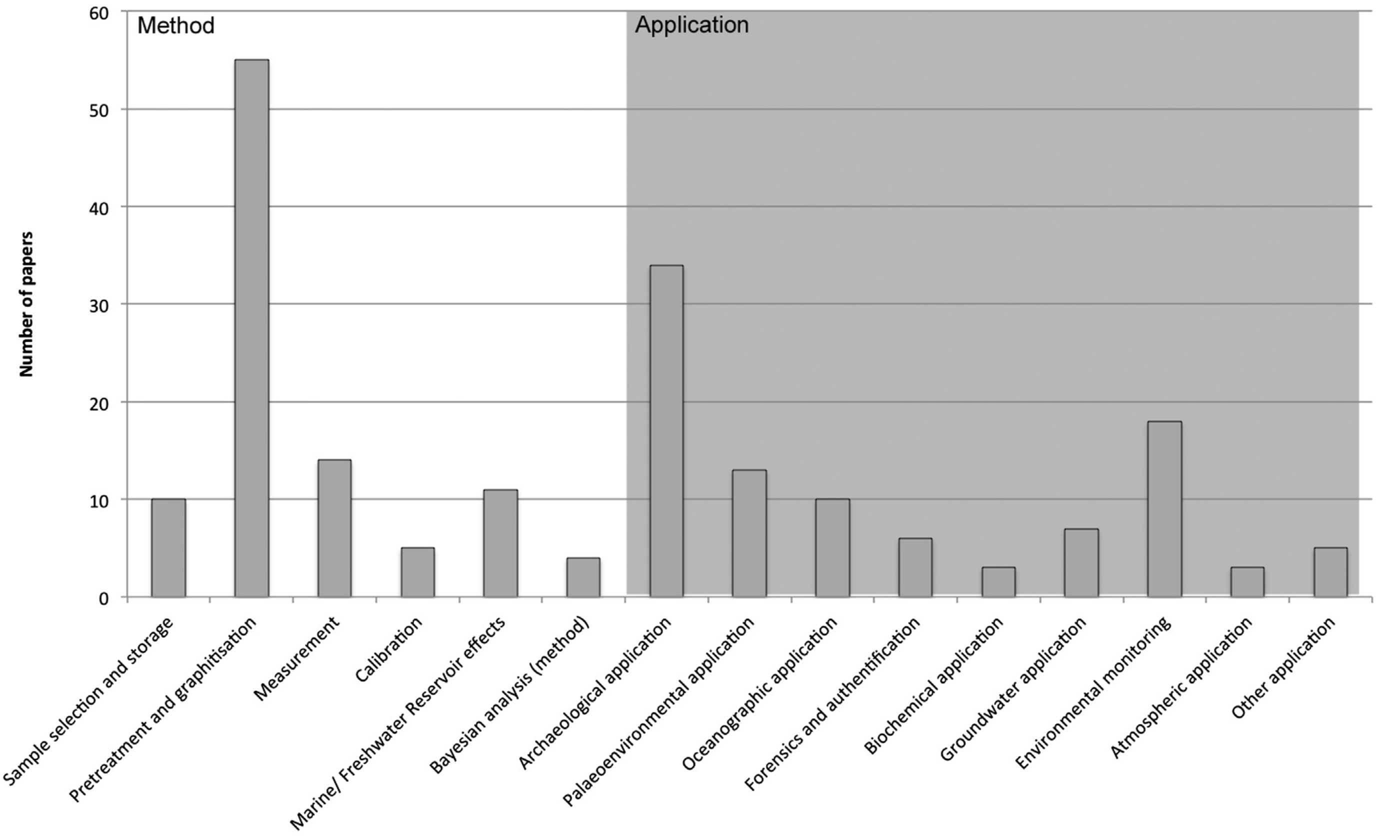

Fig. 1. A comparison of the main areas of research published in the proceedings of the last Radiocarbon conference, Paris, 2012 (*Radiocarbon* 2013 vol 55 (2–3)). 166 papers relating to radiocarbon were published, several falling into two or more categories. Calibration is poorly represented because the following volume of *Radiocarbon* presented the IntCal13 calibration curve.