Journal of Archaeological Science 37 (2010) 687–693

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Investigating the likelihood of a reservoir offset in the radiocarbon record for ancient Egypt

M.W. Dee [a,*], F. Brock [a], S.A. Harris [b], C. Bronk Ramsey [a], A.J. Shortland [c], T.F.G. Higham [a], J.M. Rowland [a]

[a] RLAHA, University of Oxford, Dyson Perrins Building, South Parks Road, Oxford OX1 3QY, United Kingdom
[b] Dept of Plant Sciences, University of Oxford, South Parks Road, Oxford OX1 3RB, United Kingdom
[c] Centre for Archaeological and Forensic Analysis, Cranfield University, Shrivenham, Swindon SN6 8LA, United Kingdom

ARTICLE INFO

Article history:
Received 5 November 2008
Accepted 2 September 2009

Keywords:
Radiocarbon
Egypt
Reservoir Effect
Seasonal Effect
Egyptian Historical Chronology
Nile

ABSTRACT

Some radiocarbon dates for ancient Egypt have been significantly offset from the established historical chronology (see Bonani et al., 2001). In this paper, short-lived plant species collected in Egypt between 1700 and 1900 AD were used to investigate the possibility that the radiocarbon record had been influenced by reservoir effects. AMS radiocarbon measurements were made on 66 known-age samples, resulting in an average offset from expected values of 19 years. The implications of this minor discrepancy on the likelihood of a reservoir process are discussed, and the agreement of the data with recent models of radiocarbon seasonality is also considered.

1. Introduction

Ancient Egypt was dependent upon the annual inundation of the River Nile. The mineral-rich floodwaters from the Ethiopian highlands continually renewed the agricultural fields, fostering the intensive crop growth that underpinned the prosperity of the complex society. Moreover, as Egypt received negligible rainfall,[1] the river was the principal water source for the entire local environment – a reliance exacerbated by the harsh expanses of desert on either side of the Nile Valley. As a result, all indigenous organic material, from cereal crops to the Egyptians themselves, retained a direct connection with the river.

Bio-organic material from Ancient Egypt has been sampled for radiocarbon (^{14}C) dating since the beginnings of the method in the mid 20th century. Indeed, historically-dated Egyptian material was included in Libby's original Curve of Knowns (Arnold and Libby, 1949). As the method was refined, however, disparities between the scientific method and conventional records were uncovered (see Clark and Renfrew, 1973). Recently, the Old and Middle Kingdom Monuments ^{14}C Dating Project (Bonani et al., 2001) produced a number of determinations that were substantially older than expected, particularly for the 4th Dynasty (2613–2498 BC), where some discrepancies were of the order of 200–300 years. Although the significance of these offsets has recently been challenged (Manning, 2006; Dee et al., in press), the effect of a reservoir process has yet to be discounted.

In ^{14}C dating, a reservoir effect occurs wherever an organism incorporates carbon that is depleted in the radioisotope relative to atmospheric levels. The diminished proportion of ^{14}C results in dates that are offset to older ages. Reservoir effects most frequently occur in aquatic environments, either due to the extended residence times of CO_2 in the deep ocean (Mangerud, 1972; Stuiver and Braziunas, 1993; Hogg et al., 1998) or the incorporation of geological carbonate by freshwater molluscs (Yates, 1986; Cook et al., 2001; Ascough et al., 2007). In Egypt, the common agent of any widespread effect is likely to have been the River Nile. However, a vast majority of the ^{14}C dates from Egypt have been made on plant species that obtain their carbon directly from the atmosphere. For example, 98% of the dates from the Old and Middle Kingdom Monuments Project (Bonani et al., 2001) were made on terrestrial trees and shrubs (or charcoal derived from them) and riverbank reeds. Although the routing of carbon in plant tissue is yet to be fully understood, and recent studies (Ford et al., 2007) indicate a fraction (~0.8%) is derived from terrestrial inorganic sources, for such significant discrepancies to have occurred, across such a variety of locations and species, the only plausible explanation is that any depleted supply would have to have been atmospheric in origin.

---

* Corresponding author.
E-mail address: michael.dee@rlaha.ox.ac.uk (M.W. Dee).

[1] Estimates for the onset of the Dynastic period range from about 0–300 mm/year (Kuper and Kröpelin, 2006).

0305-4403/$ – see front matter © 2009 Published by Elsevier Ltd.
doi:10.1016/j.jas.2009.09.003

Plants that photosynthesize atmospheric CO_2 can exhibit localised reservoir offsets. Such anomalies are most often attested at sites exposed to significant volcanic activity (Bruns et al., 1980; Weninger, 1990). Nonetheless, discrepancies the order of centuries have been attributed to the evolution of aged CO_2 from peat bogs (Jungner et al., 1995; Charman and Garnett, 2005). The mechanisms of this process have yet to be defined, but it is probable that CO_2 from the decay of deeply-lying material is trapped for an extended period before it reaches the surface. Alternatively, CH_4 from anaerobic decomposition may be built up and subsequently oxidised before evolution (Svensson and Sundh, 1993). Analogous systems of carbon retention and emission have been published for papyrus swamps in Kenya[2] (Jones and Humphries, 2002). Finally, a number of other mechanisms have been proposed for localised reductions in atmospheric ^{14}C, such as the influence of oceanic upwelling and seasonal variations (see below). However, the magnitude of these offsets (no more than a few decades) is insufficient to account for the chronological discrepancies manifest in the Egyptian record.

2. Materials and methods

2.1. Sample description

To investigate whether reservoir offsets have affected ^{14}C dates from Egypt, the simplest approach is to employ short-lived plant material. As this project was primarily concerned with archaeological material, ideally the sample set should also comprise the sorts of plant remains most frequently selected for dating. These include seeds, reeds, wood, and charcoal. However, no collection from Dynastic times could be independently dated to the levels of accuracy required. In addition, the natural environment of modern Egypt does not provide a good proxy for the growing conditions and hydrology of the country in antiquity. Since the completion of the first Aswan dam (1902) and more especially the High Dam (1970) the cycle of annual inundation has ceased and the local environment been completely transformed. However, historical plant samples are preserved in herbaria and permissions were obtained to sample the collections in the University of Oxford Herbaria (OXF) and the Natural History Museum, London (BM). Crucially, these herbaria included specimens collected before the damming of the Nile. OXF included specimens collected by Augustine Lippi in Egypt at the turn of the 18th century as well as a number obtained by various collectors between 1820 and 1880 AD. Specimens from the BM filled the missing period between the two OXF groups. In all cases, the date of collection (i.e. the “true age”) was known to within ±2 calendar years, and often the dating records were even more precise.

There are several significant plateaux in the calibration curve during the 18th and 19th centuries. This is usually considered problematic for dating studies, but for this work it ensured minimal variability in the ^{14}C data, thereby providing a clear reference level against which any shifts to older ages (higher determinations) could be identified. In addition, it permitted some flexibility in the historical dating of the samples, as the ^{14}C determinations were not expected to vary much from year to year.

A central notion of this study was that the natural processes underlying any reservoir effect in antiquity would have continued right up until damming of the Nile. However, this assumption is not predicated on the riverine environment remaining static over that period. The Nile certainly fluctuated between periods of high and low flow (Bell, 1970; Hassan, 1981; Rampino et al., 1987) but throughout the Holocene its origin and course have remained essentially unchanged (Hassan, 1997). Nonetheless, to ensure the rigour of the programme, the sample set was kept as broad as possible in terms of taxa, geographic location, and preferred habitat. Those plants naturally found close to the river were prioritised, although the availability of wholly aquatic plants was unfortunately extremely limited. Materials that were routinely utilised by the Egyptians themselves were also favoured, and fortunately three samples of the quintessential Nilotic resource, *Cyperus papyrus*, were obtained. A summary of the diversity present in the sample set is shown in Table 1, and a detailed list of all the specimens is included in Table A1 (Appendix A).

2.2. Experimental

In general, the botanical specimens had been stored on paper mounts using glue or adhesive strips. In some cases, mercuric chloride ($HgCl_2$) had been applied as a preservative. Care was taken to obtain samples that were free of such chemical contamination. However, organic additives likely to remain impervious to the aqueous pre-treatment procedure were targeted by a solvent wash, comprising the following steps: acetone (45 min, 45 °C), methanol (45 min, 45 °C) and chloroform (45 min, 20 °C). This procedure was applied to every sample whether contamination was suspected or not.

The cellulosic fraction was extracted using Oxford Radiocarbon Accelerator Unit’s (ORAU) routine pre-treatment process (Hedges et al., 1989), which was developed from the original Jayme and Wise method (Green, 1963). Briefly, the procedure involved four treatments: acid (HCl, 1 M, 80 °C, 20 min), base (NaOH, 0.2 M, 80 °C, 20 min), acid (HCl, 1 M, 80 °C, 20 min) and oxidation (acidified $NaClO_2$, 0–5%, 20–80 °C, 20 min). The strength of the oxidant employed in the

Table 1
The diversity of locations, environments and taxa in the set of 66 botanical specimens obtained from the University of Oxford Herbaria and the Natural History Museum, London.

Category	Detail	Count
Location	Cairo (Greater)	21
	Alexandria	5
	Sinai	4
	Luxor	3
	Rosetta	2
	Other “Near Nile, Egypt”	5
	Other “Egypt”	26
Natural Environment	Terrestrial (wild)	57
	Riverbank	4
	Terrestrial (wild or cultigen)	3
	Terrestrial (cultigen)	1
	Aquatic	1
Plant Family	Asteraceae	17
	Fabaceae	10
	Apiaceae	4
	Cyperaceae	4
	Zygophyllaceae	4
	Geraniaceae	3
	Amaranthaceae	3
	Rutaceae	3
	Aizoaceae	2
	Malvaceae	2
	Molluginaceae	2
	Tamaricaceae	2
	Other	10

---

[2] Papyrus (*Cyperus papyrus*) no longer grows in Egypt (Nicholson and Shaw, 2000) but was widespread in antiquity.