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Radiocarbon dating of Sacred Ibis mummies from ancient Egypt

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ABSTRACT

Sacred Ibis (*Threskiornis aethiopicus*) were widespread in Egypt until the eighteenth century. Today the species is extinct in modern Egypt but millions of mummified specimens are scattered geographically in dedicated Ibis burial sites throughout the country. Ibises were regarded as physical manifestations of the god Thoth and worshiped by the ancient Egyptians. A small number of Sacred Ibis were chosen as 'sacred animals', based on physical markings, and were reared for the temples. However, the majority of the mummified Sacred Ibis were 'votive animals' that were given as offerings to the deities by pilgrims, and then buried in catacombs associated with the temple. Their supply became an industry that is thought to have flourished from the Late Period, well into the Roman Period (c. 664 BC to AD 350). Dating of the Sacred Ibis mummies, as well as other mummified animal specimens, has been based on archaeological evidence such as the age of catacombs, the design of enclosures and the shape of the mummy containers (pottery jars, wooden chests or stone boxes). Here we present the first ages of a selection of Sacred Ibis mummies using ^{14}C methods in order to establish how closely they match the archaeological chronology. Dates are reported from museum samples provenience from Saqqara, Roda and Thebes. Our ^{14}C radiocarbon results date the Ibis mummies between c. 450 and 250 cal BC and represent a short period of time. Those dates are falling from the Late Period to the Ptolemaic Period at maximum. Surprisingly, none of the samples were dated to the Roman era.

1. Introduction

The ancient Egyptians' phenomenal success in preserving bodies was not only practiced on humans, but on a wide range of animals as well. Many attempts were made to understand and explain the cultural and religious significance behind the mummification of different animals (e.g. Ikram, 2005). For the ancient Egyptians, animals, or at least animals kept in the temple, were considered ethically in much the same way as humans. This was exemplified by a text from the first millennium BC: "*I have given bread to the hungry, water to the thirsty, clothing to the naked. I have given food to the ibis, the falcon, the cat and the jackal*" (Bergmann, 1879). The Egyptians believed that both humans and animals were equivalent forms of living beings. Therefore, the gods could be represented in any of those forms, or as a hybrid (Te Velde, 1980).

Animal mummification is thought to have occurred for varying reasons. Sometimes it was because the individuals were 'beloved pets', interred with or near their owners. Others, known as food or 'victual mummies', were served as funerary food supplied for the deceased in the afterlife, and formed part of the grave goods. Still others were 'sacred animals' that represented the presence of gods in the temple. These mummies were buried in elaborate containers and placed in designated catacombs. Many animals were mummified as 'votive animals' and offered by pilgrims to the gods to secure a prayer (Ikram, 2005), and then buried in catacombs or in pit-tombs by the god's priests. The latter were the most numerous type of animal mummy. Animal catacombs form one part of a complex sacred landscape, and were typically placed adjacent to temples or shrines of a specific god (Ikram, 2005; Ray, 2001).

The large number of different animals offered to the Egyptian gods indicates the significance of animal mummies to the ancient Egyptians. Literally millions can be found in many geographically separate catacombs (Ikram, 2005, 2012). The use of birds and other animals in cultic activities is thought to have reached its zenith in the Twenty-Sixth Dynasty (664–525 BC), lasting into the Graeco-Roman Period (ending about AD 350 or slightly earlier, with the advent of Christianity and the banning of paganism) (Ikram, 2005). The most popular of these cults

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was that of Thoth, with burials of ibises scattered throughout Egypt (Bailleul-Le Seur, 2012; Ikram, 2012).

Sacred Ibis (*Threskiornis aethiopicus*) are the most plentiful animal mummies found in the dedicated burial sites in Egypt. They were associated with Thoth (Fig. 1), the god of wisdom, writing, moon and magic, the heavenly body that was equivalent to the sun at night, and known as the 'silver Aten' (silver disc) in the Late Period (Kurth, 1986). The ibis, as the human hybrid form of Thoth occurs in two- and three-dimensional representations throughout Egyptian history. Ibis were not only key to cultic activities associated with Thoth, but they also played a significant role in daily life by both recycling refuse and helping to keep water clean by consuming bilharzia-carrying snails. Although it has been suggested by a variety of scholars that the practice of offering animal mummies was popular from c. 664 BC until approximately AD 350, to date no 14C dates have been published, although this technology has been used on human mummies (Dunand and Lichtenberg, 2006). This article presents the results of ^{14}C tests carried out on Ibis mummies coming from Saqqara, Roda and Thebes (Fig. 2). We also consider the textual and archaeological evidence for the likely chronology of the practice of offering animal mummies.

2. Material, methods, and locations

For research purposes, samples of Sacred Ibis mummy bone, tissue, and feathers were obtained from museum collections for both radiocarbon dating and molecular evolutionary studies (to be published elsewhere). Additionally a sample of textile wrapping was collected to assess the potential scale of the radiocarbon freshwater reservoir effect. The mummification materials surrounding the Ibis mummies were sampled to assess whether bitumen-containing ancient carbon was used during the embalming process.

2.1. Sampling

A total of six samples were taken from collections curated by European museums. The samples were collected (Table 1) either in zipped plastic bags or Eppendorf tubes. Gloves and masks were used during the sampling process.

Fig. 1. Thoth, the Egyptian God of Wisdom and Writing who is often depicted as a man with the head of an Ibis.

2.1.1. The necropolis at North Saqqara

Saqqara on the west bank of the Egyptian Nile, lies approximately 30 km south of the capital city Cairo and is the location of the famous Step Pyramid (c. 2600 BC). The area of North Saqqara contains one of most important archaeological locations for animal mummies in Egypt: the Sacred Animal Necropolis (SAN) (Fig. 2). This comprises two Ibis catacombs and a Main Temple complex with cult chambers and catacombs for mummified baboons, cattle, and raptors (Nicholson, 2005; Martin, 1981; Smith, 1974; Davies and Smith, 1997). The catacombs consist of a number of main arterial passageways with galleries along either side. These functioned as the burial places for the mummy pots, which were stacked carefully, with a layer of sand separating each row of vessels. In addition, some of the galleries had a series of 'niches' cut into the walls, to store small limestone chests housing mummified birds. This type of burial may indicate a special offering from a high-ranking person or a Sacred Animal burial (Nicholson, 2005). Two bone samples (Fig. 3) were dated from the collection of the Musée des Confluences, Lyon, France.

2.1.2. Thebes

Thebes contains several burial places for Ibis, and in most cases the ancient Egyptians made use of pre-existing human tombs for the burial of birds (Ikram, 2009). The Theban cult pairs Thoth with Horus and hence it is common for the Ibis to be found in conjunction with raptors. In Thebes such burials have been identified at the tomb of Ankh Hor (Boessneck and von den Driesch, 1982), while they have also been reported near TT 141 (Bekenkhons) (Northampton et al., 1908). Another concentration occurs in the area of TT 156 (Pennesuttaui), and in the environs of TT 11/12 (Ikram, 2009 and personal observation Ikram et al., in preparation). Many ibises were extracted from these venues and sold to private collectors, particularly in the 19th and early 20th centuries. Only one museum bone sample was available for dating from Thebes (Fig. 3). This was obtained from the British Museum collections.

2.2. Methods

In total, collagen was extracted from six samples of Ibis bone (Table 1). The bone was physically cleaned with a scalpel, subjected to a series of solvent washes to remove possible fats and resins before acid–base-acid washes to demineralise and remove secondary carbonates and to remove humics, gelatinisation and filtration to extract gelatin, and ultrafiltration to collect the largest fragments of protein following a protocol similar to Brock et al. (2010). Details of pre-treatment protocols are given in (Supplementary Material).

Stable isotope analyses were also undertaken, additionally providing atomic C:N ratios and %C contents. Carbon and nitrogen stable isotopes were measured in a second aliquot of gelatine in an elemental analyser (ANCA-GSL) that was connected to an isotope ratio-mass spectrometer (IRMS, Sercon 20–22) operating in continuous flow mode. Samples were measured against an in-house gelatine reference and corrected against USGS-40 and USGS-41.

Sacred Ibis eat foods from both terrestrial and freshwater environments (Marion, 2013) and their radiocarbon age could be affected by a freshwater radiocarbon reservoir effect, where ancient carbon, for example from limestone, is dissolved in water and incorporated into the aquatic food chain (Lanting and van der Plicht, 1998; Keaveney and Reimer, 2012). Despite the extensive limestone deposits in the Nile river catchment, particularly north of Luxor (Bauer, 1974; Arnold, 1991), few have investigated this effect in the Nile. However, from an analysis of two modern shells Burleigh (1983) suggest a radiocarbon reservoir of approximately 500 ^{14}C years. To test whether Ibis were affected by a freshwater radiocarbon reservoir, a mummy wrapping provenanced from Saqqara (Sample1) was dated after cleaning with a series of solvents and an acid base acid pre-treatment protocol (Supplementary Material).

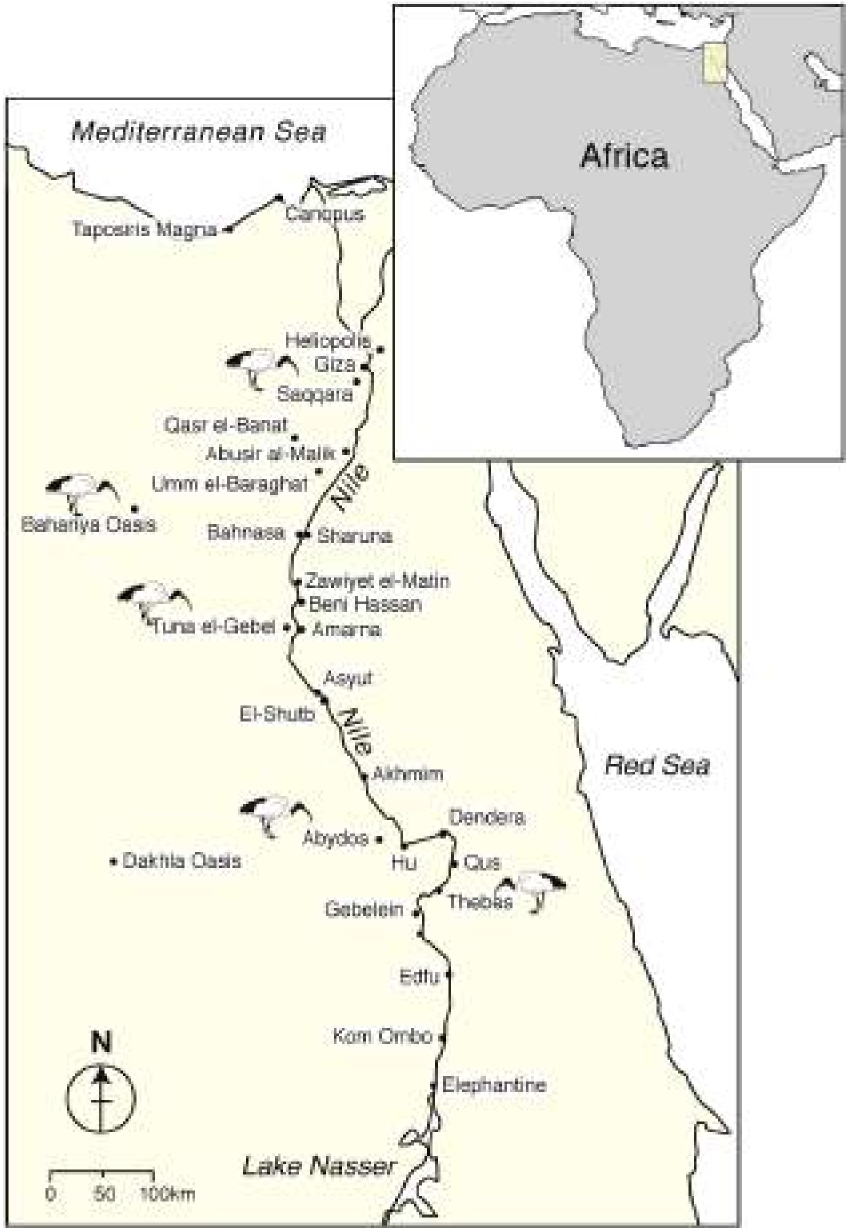

Fig. 2. The location of the main archaeological sites of Ancient Egypt. The ibis symbol indicates the location of the main Sacred Ibis catacombs

The fabric was dated using an acid–base-acid method. As part of the laboratory quality assurance protocol, where c. 1 in 20 dates are duplicated, the sample was treated and dated twice. Using the same series of solvent washes that had been applied to bone material, the sample was treated with 1 M hydrochloric acid for 30 min at 80 °C, then 0.2 M sodium hydroxide for 1 h at room temperature, and finally 1 M hydrochloric acid for 1 h at 80 °C. After each treatment the sample was rinsed with ultrapure water. The cleaned sample was combusted, graphitised, and dated using the methods described for bone. Stable isotope analysis was not undertaken for this sample.

A second possible difficulty in dating mummified material arises when bitumen or tree resin is used during the embalming process. Solvent washes were used in an attempt to remove resinous material, as well as lipids originally derived from the bone and flesh, from the samples. However, those materials are exceptionally difficult to fully remove from samples (Dee et al., 2010) and bitumen consists of ancient carbon. Although, thus far there is no evidence that bitumen was used in the embalming of these ibises. The black resinous material usually found surrounding and in ibis mummies is more often a mixture of resin and oil, sometimes with beeswax added into the mixture (Buckley et al., 2004; Clark et al., 2013; Ikram, 2013) Hence dates may appear erroneously old (Dee et al., 2010). To assess whether large amounts of resin were used during the embalming procedure, a sample of the embalming materials attached to the sample 1 from Saqqara was dated. This sample was dated at the ANU after a gentle acid–base-acid procedure (Supplementary Material).

Radiocarbon dates were calibrated against IntCal13 (Reimer et al., 2013) in OxCal v4.2 (Bronk et al., 2009). The inter-tropical convergence zone lies over Egypt during the growing season bringing air depleted in $^{14}CO_2$ from the southern hemisphere northward. Hence, a regional reservoir effect of 19 ± 5 ^{14}C years was applied to all dates (Dee et al., 2010; Ramsey et al., 2010) (Table 1). Dates from Saqqara and Roda were then modelled (4) as single *Phases* using Bayesian procedures in OxCal v.4.2, assuming that all dates have a 5% prior probability of being an outlier within the *General t-type Outlier Model* (Bronk et al., 2009).

Table 1
Radiocarbon results. $\delta^{13}C$ values measured on the AMS were used to correct the conventional radiocarbon dates for isotopic fractionation, but they are not accurate or precise and cannot be used for dietary reconstruction. $\delta^{13}C$ values obtained with IRMS are used for dietary information. Errors for IRMS $\delta^{13}C$ are ±0.1 and $\delta^{15}N$ ±0.1 at 1σ. For a reliable date, collagen yield should be >1% and C:N ratio should be between 2.9–3.4 (Van Klinken, 1999). Dates are calibrated against IntCal13 (Reimer et al., 2013) with a 19 ± 5 ^{14}C year reservoir (Dee et al., 2010) in OxCal v4.2 (Bronk et al., 2009).

Sample name	Sample source	Material	Analysis code	^{14}C age (BP)	Error	$d^{13}C$ (AMS)	Error	Collagen yield (mg)	Collagen yield (%)	IRMS results			
										$\delta^{13}C$ (deltaPDB)	$\delta^{15}N$ (deltaAIR)	%C	C:N
Saqqara_sample1	Musée des Confluences, Lyon, France	Bone	SANU-40233	2320	25	−26	1	19.68	10.5	−18.2	12.2	43.7	3.3
Saqqara-wrapping	Musée des Confluences, Lyon, France	Wrapping	SANU-40235	2220	25	−19	1			−24.4		42.5	
Saqqara-resin	Musée des Confluences, Lyon, France	Resin	SANU-40232	6895	25	−20	1			−26.0		58.5	
Saqqara_sample2	Musée des Confluences, Lyon, France	Bone	SANU-40906	2430	20	−21	1	8.5	7.1	−17.7	10.8	45.1	3.5
Saqqara_sample3	Musée des Confluences, Lyon, France	Bone	SANU-40907	2365	20	−16	1	25.1	9.6	−17.8	13.0	44.2	3.4
Roda_sample1	Musée des Confluences, Lyon, France	Bone	SANU-40227	2325	25	−23	1	15.64	7.8	−19.1	10.2	45.6	3.4
Roda_sample2	Musée des Confluences, Lyon, France	Bone	SANU-40231	2320	25	−29	1	11.05	7.1	−19.7	13.3	44.0	3.6
Thebes	British Museum	Bone	AAR-19860	2345	25	−18.85	0.64	–	6.6	−19.1	11.88	–	4.0

3. Results

In total one textile, one resinous substance and six bone samples were dated (Table 1) and have been calibrated and/or modelled (Fig. 4 and Table 2). The dates on textile and bone are consistent, with no samples identified as outliers by the model. All bones contained more than 1% collagen, suggesting adequate collagen preservation (Van Klinken, 1999) (Table 1).

Two potential difficulties in radiocarbon dating the ibis mummies were identified and tested. Both contamination from resin within the embalming mixture and a freshwater reservoir effect could cause the collagen to appear inaccurately older. We see no indication of a radiocarbon reservoir effect, and with the possible exception f AAA-19,860, it is unlikely that the collagen is significantly affected by the presence of old carbon contaminants.

3.1. Contamination from the embalming mixtures

Although $\delta^{13}C$ values appear reasonable for collagen, the C:N ratios are towards the higher end expected for collagen (Van Klinken, 1999). Although most are less than 3.4, SANU-40231 has a C:N of 3.6 whilst AAR-19860 has a C:N of 4.0. Despite the use of a series of solvent washes, these samples may still contain substantial quantities of lipids (up to 4% of the sample), some of which may be a different age to the collagen.

To investigate how much of an effect contamination from this source might have, a sample of the embalming materials attached to Saqqara 1 (SANU-40232) was dated. With an age of nearly 7000 BP, it does suggest that some resinous material has been used during the embalming process. This sample had a C:N of 23 and 58 %C. Although a high C:N ratio of collagen in well preserved bone can result from the inclusion of lipids derived from the bone, we will consider the worst-case scenario where all of the excess carbon is derived from exogenous resin. If we make the assumption that the resin added to all of the mummies had a similar age and C:N ratio as SANU-40232, the age of the collagen would only extend beyond a typical quoted 2 sigma error range if the C:N exceeded 3.7 (Table 3). We are therefore concerned only with the accuracy of date AAR-19860 from Thebes.

Of course, the embalming recipes may have varied. If we were to assume the resin contained only fossil carbon and had an age >55,000 BP, i.e. be entirely formed of resin mixed with very little bitumen, the age of collagen with a C:N of 3.5 would be considered inaccurate. Buckley et al. (2004) found that balms used during the preparation of animal mummies were complex mixtures of e.g. beeswax, sugar gum, coniferous and *Pistacia* resins, as well as little or no bitumen. Therefore, although possible, it is highly unlikely that contaminating carbon is fossil in age. This conclusion is supported by the consistency of dates from all three sites.

3.2. A radiocarbon freshwater reservoir effect

It is unlikely that the dates are affected by a radiocarbon reservoir. First, radiocarbon dates from the Ibis bone and wrapping from a single mummy at Saqqara, are identical, with calibrated dates overlapping at 95.4% probability. Second, the radiocarbon dates on bone within each site are highly consistent. A characteristic of the freshwater reservoir is its large variability, even within a single lake (Ascough et al., 2010; Keaveney and Reimer, 2012). Therefore, the consistency of the dates can be very tentatively used to suggest a large reservoir is not affecting the results at sites where textile could not be dated.

Because ibis eat both freshwater foods and terrestrial foods (Marion, 2013), it is unclear whether these results can provide any information on the presence and possible size of a radiocarbon reservoir effect in the Nile. The enriched $\delta^{13}C$ and $\delta^{15}N$ values of the collagen may indicate that some freshwater foods were eaten (Schoeninger and Deniro, 1984; France, 1995; Post, 2002), but these may also reflect the warm arid

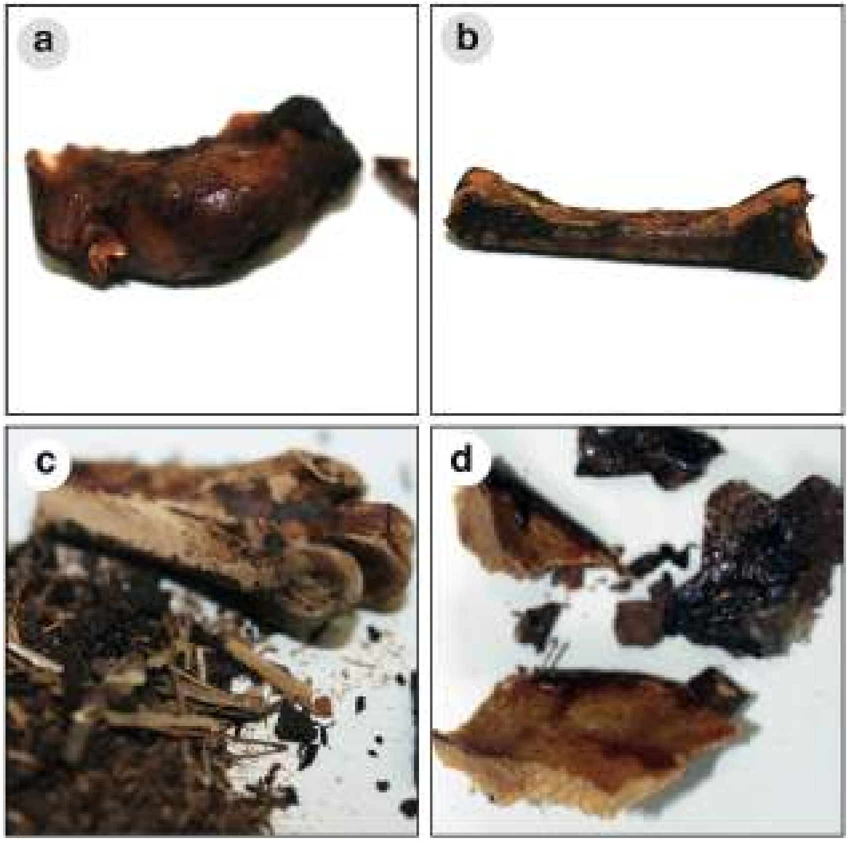

Fig. 3. Ancient mummified Sacred Ibis bone fragments covered with resin from (a) Roda, (b) Saqqara, and (c, d) Thebes.

climate and the presence of some C4 plants at the base of the foodchain (Touzeau et al., 2014). Without an in depth study into the isotopic signature of Sacred Ibis from this period, a more detailed interpretation of the stable isotopes is not possible.

3.3. Bayesian analysis

Bayesian models could be built using radiocarbon dates from Saqqara and Roda. Although the small number of samples means that the modelled Boundaries are imprecise, they demonstrate that the radiocarbon dates are consistent with a short period of activity. Samples from Saqqara, Roda, Thebes are all of a similar age, falling between c. 450 and 250 cal BC and represent a short (<500 years, 68.2% probability) period of time (Fig. 5). None of the raw dates returned any probability later than the 2nd century BC; although, upon Bayesian modelling the end boundaries tapered into the early Roman Period.

4. Discussion

The ^{14}C radiocarbon results date the Sacred Ibis mummies to a range from the Late Period to the Ptolemaic Period. None of the samples were dated to the Roman era. This might, of course, be due to the samples

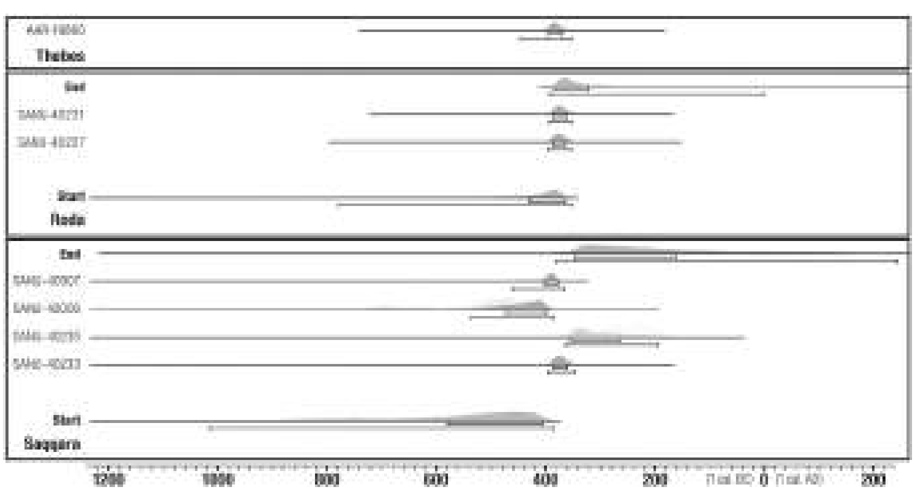

Fig 4. Bayesian model of radiocarbon dates on bone and textile from Saqqara and Roda, calibrated against IntCal13 (Reimer et al., 2013) in OxCal v.4.2 (Bronk et al., 2009) and modelled in OxCal v.4.2 assuming each date has a 5% prior probability of being an outlier within the General t-type Outlier Model (Bronk et al., 2009). The single dates from Thebes are not modelled, and calibrated dates are given

Table 2
Details of calibrated and modelled dates of Sacred Ibis material investigated in this study.

Name	Calibrated date (cal BC/AD)				Modelled date (cal BC/AD)			
	68.2% probability		95.4% probability		68.2% probability		95.4% probability	
	From	To	From	To	From	To	From	To
Thebes	−400	−374	−453	−356				
Roda end					−388	−324	−399	10
Interval Roda					0	113	0	722
SANU-40231	−390	−365	−400	−352	−390	−367	−398	−356
SANU-40227	−392	−368	−401	−353	−391	−368	−399	−357
Roda start					−435	−368	−792	−355
Saqqara end					−347	−317	−356	−223
Interval Saqqara					52	106	32	215
SANU-40907	−408	−380	−472	−371	−402	−382	−415	−367
SANU-40906	−514	−412	−725	−398	−421	−391	−441	−343
SANU-40235	−346	−204	−355	−193	−359	−331	−377	−273
SANU-40233	−390	−365	−400	−352	−390	−365	−398	−353
Saqqara start					−425	−394	−457	−379
SANU-40232	−5779	−5720	−5826	−5707				

Table 3
The impact of contamination from resin, as represented by a high C:N ratio, on the age of a collagen sample (C:N of 3.2 and 44 %C) with a measured age of 2300 BP. The resin from Saqqara, SANU-40232 6895 BP (C:N ratio 23, 58 %C), was taken as the contaminant.

Measured C:N of collagen	% resin in the sample	% carbon in the sample derived from resin	Actual age of the sample (BP)
3.2	0.0	0.0	2300
3.3	0.5	0.7	2275
3.4	1.0	1.3	2255
3.5	1.5	2.0	2230
3.6	2.0	2.6	2205
3.7	2.5	3.3	2180
3.8	3.0	4.0	2155
3.9	3.5	4.6	2135
4.0	4.0	5.3	2110

chosen, but might also indicate that the practice was declining at a time prior to that suggested previously by archaeologists (Bailleul-Le Seur, 2012; Ikram, 2012). Quite possibly the habit of mummifying animals and offering them to deities had ceased or declined by the 2nd or 3rd centuries AD.

Our dating results also show that there was no detectable influence of a freshwater reservoir effect. This was particularly well demonstrated by the Saqqara sample. This seems to be contradictory to previously published results for the ^{14}C dating of a Sacred Ibis and wrapping by Gove et al. (1997), as our results show that the ages of the Ibis bone sample and mummy wrapping from Saqqara are almost identical, with calibrated dates overlapping at 95.4% probability. A characteristic of the freshwater reservoir effect is its large variability, even within a single lake (Ascough et al., 2010; Keaveney and Reimer, 2012). The fact that we have recorded very low variability among dates recorded this suggests that the freshwater radiocarbon reservoir effect is negligible.

On the whole, the 14C dates of the samples and the majority of the archaeological and textual evidence fit well together. Interestingly, none of the dates from these samples extend into the Roman era. Thus far, the results of our work indicate that the zenith of activity for these sites might well have ended by the 1st century BC, rather than carrying into the 4th century AD, as others have suggested (Bailleul-Le Seur, 2012; Ikram, 2012; Kessler, 1986). Certainly, the textual evidence for the Roman period is negligible. Perhaps a renewed focus on this time period in terms of artefacts and texts, as well as an increased number of samples analysed, will elucidate the temporal range of the practice of offering animal mummies.

5. Conclusion

The remarkable Sacred Ibis mummies, which are found in their millions in the ancient catacombs of Egypt represent a unique reservoir for scientific studies. This material is not just important for studies of the traditions and customs of ancient Egypt, but also for investigations into ornithology and evolutionary biology. The supply of Ibis mummies became an industry and is thought to have flourished from the Late Period, well into the Roman Period (c. 664 BC to AD 350), with evidence for the care and upkeep of 'supply' flocks even coming from textual records of the Ptolemaic era (Ray, 1976).

Thus far, most of the dating of the Sacred Ibis mummies, as well as other mummified animal specimens, has been based merely on archaeological evidence such as the architecture of the catacombs and the shape of the mummy containers such as the pottery jars, wooden chests or stone boxes. Being the first to apply the ^{14}C analysis methods to the Sacred Ibis mummified remains, we were able to present the first ages and investigate the archaeological chronology of the animal mummification practice.

By using radiocarbon dating methods, we show that these mummies date to approximately 2220–2430 yr. BP, which may indicate that, the most of the Ibis mummy production happened from the Late Period to

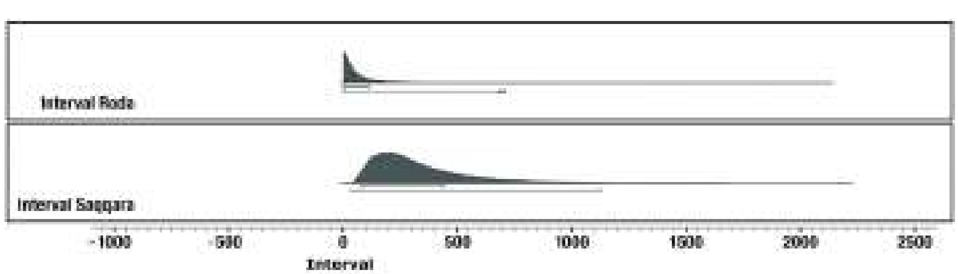

Fig. 5. Duration of burial activity at Saqqara, and Roda, calculated using the Interval function in OxCal.

the Ptolemaic Period. Still those dates maybe restricted to the samples that have been used which provenience from Saqqara, Roda and Thebes.

This suggests that archaeologists might have to re-evaluate their dating of animal catacombs, perhaps with an earlier terminus of the practice of animal mummification than hitherto thought.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jasrep.2015.09.020.

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