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RADIOCARBON-BASED MODELING OF THE REIGN OF KING DEN (1ST DYNASTY, EGYPT) AND THE START OF THE OLD KINGDOM

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ABSTRACT. This study focuses on the chronology of King Den's reign, the fifth ruler of the 1st Egyptian dynasty. A series of radiocarbon (^{14}C) dates were established on archaeological material from several tombs at the Abu Rawash site, near Cairo, which comprises a complex of 12 monumental mud-brick mastabas. Modeling the ^{14}C results enables us to estimate the date of King's accession and to link this to the beginning of the 3rd Dynasty, i.e., to Egyptian state's structuration. Through the application of OxCal software, sets of ^{14}C results obtained from the same archaeological context have been summarized and compared with the precise state of our knowledge on the historical duration of this reign. These results place King Den's accession between 3104 and 2913 BCE (2σ), with the more likely date being 3011–2921 BCE (1σ). The modeled temporal density thus obtained is based both on new contextualized ^{14}C dates and on an updated reading of the historical information on his reign. This is a dynamic result, which can be refined as soon as we have more data to integrate into the model. Above all, this resulting model becomes a crucial chronological point to better determine the beginning of the Egyptian Old Kingdom.

KEYWORDS: Abu Rawash, ^{14}C modeling, Early Dynastic, Egyptian chronology, King Den, Old Kingdom.

INTRODUCTION

Fixing the absolute timeline of ancient Egypt is a crucial issue for understanding the history of the Mediterranean basin in the third millennium BCE. If more recent periods can be linked to our calendar by synchronisms with other civilizations and/or astrochronological hazards, restoring the times of the Old Kingdom (OK) is a very singular challenge. This is due to the scarcity of textual sources and the limited availability of contextualized archaeological material. Museums display exceptional collections of objects related to the OK, however frequently little is known about their acquisition or the archaeological context from which they were excavated. This is the reason why only 17 radiocarbon (^{14}C) dates were available for the OK in the Oxford Chronology published by Bronk Ramsey et al. (2010), and these are associated with only a small number of rulers. Furthermore, the large plateau-age around 2800–2600 BCE corresponds to the first dynasties of the OK, and increases the difficulty of modeling an accurate chronology. This highlights the need not only for analysing well-contextualized samples, but also for gathering large data sets on which statistical tools can be applied.

The only way to go further in our understanding of the absolute time of the OK is to study archaeological materials recently uncovered during ongoing excavations in Egypt, and to carry out sampling at the site in conjunction with the archaeologist responsible for the mission. By discussing the reliability of the samples to fix the chronology of a single ruler to a site, we maximize the chances of producing consistent results and our ability to establish an accurate chronology for the OK.

This study focuses on the reign of King Den, fifth ruler of the 1st Dynasty. In the Abu Rawash site, near Cairo, the so-called Cemetery M comprises a complex of 12 monumental

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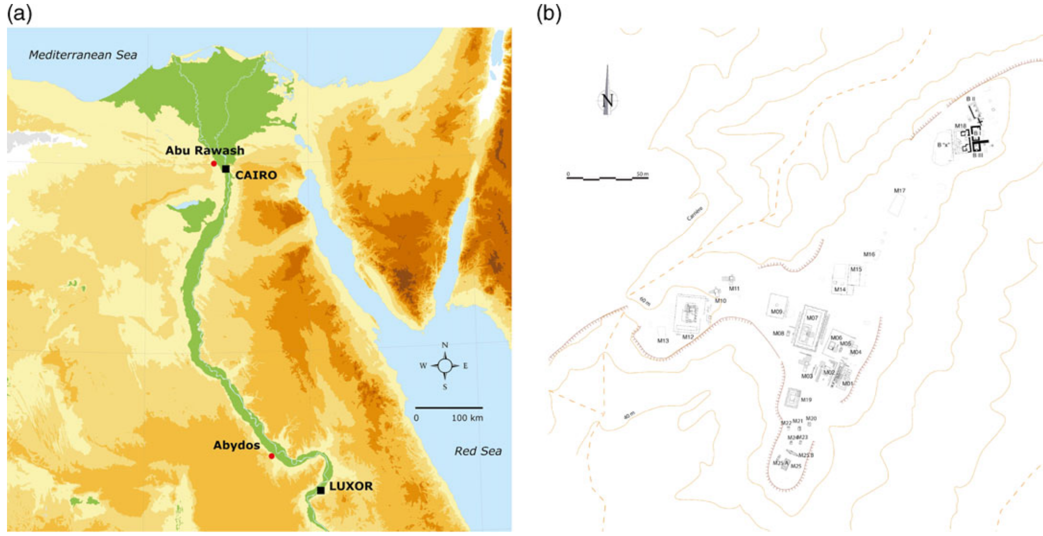

Figure 1 (a) Localization of the Abu Rawash site and Abydos site in Egypt; (b) map of the Abu Rawash cemetery and localization of tombs in which samples were collected.

mud-brick tombs (*mastabas*), some of which contained impressive funeral boats (Tristant et al. 2014). All mastabas can be dated to the reign of King Den (Tristant 2008). A series of ^{14}C dates were carried out on archaeological material from several tombs in order to model King Den's accession date, and to seek to link this to the beginning of the 3rd Dynasty, i.e., the structuration of the Egyptian state.

MATERIALS AND METHODS

Abu Rawash Site—Archaeological Context

At the northern end of the Memphite necropolis, 8 km northwest of the Giza plateau, Cemetery M of Abu Rawash is located on top of a small hill, clearly visible in Antiquity from the Nile flood plain. The cemetery was excavated before the First World War by Pierre Montet (Montet 1938, 1946) who only partially published the results of his work; then by Adolf Klasens (Klasens 1957) for the area located at the southern end of the cemetery. Since 2008, the Institut français d'archéologie orientale (Ifao) has been involved in the reappraisal of the cemetery, combining both the resumption of excavation on site and the study of the material distributed in museum collections in and outside Egypt. The objective is to better understand the place of Cemetery M, and the role played during the life of its occupants, in the general framework of the Memphite region during the 1st Dynasty (Tristant 2008, 2016, 2017, 2019).

Twelve mud-brick mastabas, with underground chambers dug into the natural bedrock, were built there in the middle of the 1st Dynasty, during the reign of King Den (Figure 1). Both the architecture and the grave goods (wine jars, stone vases, ivory figurines, copper tools, etc.) of these extravagant monuments reflect the social status of their owners. The elite nature of these monuments is further emphasized by the presence of subsidiary graves (Tristant et al. 2021) and of wooden boats deposited at the north of the mastabas—the oldest examples excavated in Egypt (Tristant et al. 2014).

From a chronological perspective, the Cemetery M of Abu Rawash functioned for only a very short period of time at the beginning of the reign of King Den, fifth ruler of the 1st Dynasty. Apart from a few residual sherds related to the nearby Cemetery F dated to the 4th Dynasty, the ceramic material is dated only to Naqada IIIC2 (mid-1st Dynasty) phase. Unlike most of the cemeteries in Egypt, the tombs have never been reused, and no activity was recorded among the mastabas groups after the 1st Dynasty. Inscribed material, specifically mud stoppers with seal impressions closing wine jars, relates only to King Den, and more precisely to the beginning of his reign, due to the mention of Ankh-ka, the first of the three chancellors attested during Den's reign (Tallet and Resk Ibrahim 2008).

Sampling

A set of 22 samples has been collected during the excavation work carried out in 2012 and 2014. They have been selected based on their archaeological contexts, environmental soil conditions, and because they succeeded providing enough material for carrying out conventional ^{14}C dating. Eight are wood samples obtained from five individual tombs and a wooden floor of a mastaba (Table 1). Thirteen others are charcoal collected in two distinct areas of the Mastaba 17's ground (IFAO_0723 to IFAO_0735). IFAO_0736 are vegetal fibers collected from the sieving of destroyed mudbrick at tomb 1522 (Table 1). The whole provides a representative description of the frequentation phases at the Abu Rawash site during the reign of King Den.

Conventional Liquid Scintillation Counting

Samples were subjected to ^{14}C analysis using the routine protocol running at the Ifao lab (Quiles et al. 2017). After physical cleaning, around 20 g of samples are chemically pre-treated by AAA protocol [HCl, 8% (80°C); NaOH, 0.1–0.5N; HCl 8%] and then rinsed and cleaned using an automated ultrapure water system based on sand, bacteria, UV and resin filters. Combustions are performed using a combustion bomb. Samples are placed in a stainless-steel cup inside the bomb, in contact with tungsten filament and in a stream of around 10 bars oxygen, under an accurate vacuum ($\sim 10^{-1}$ mbar). The CO_2 gas is then purified using ethanol traps (–80°C) and collected in liquid nitrogen cooled traps (–196°C). A sub-sample of the purified CO_2 is collected to measure the $\delta^{13}C$ value by IRMS on a Thermo Delta V Plus at the Stratochem laboratory in Cairo. CO_2 is then slowly released into a furnace in presence of molten lithium in stoichiometric quantity with an excess of 1 g to form lithium carbide (Li_2C_2). Once the lithium carbide is cooled, it is then slowly hydrolysed into acetylene gas (C_2H_2) using tritium-free water. The acetylene gas is purified by passing successively through ethanol (–80°C) and orthophosphoric acid (H_3PO_4) bubble traps, and finally trimerized to benzene using an alumina-vanadium-chromium catalyst. Liquid benzene at atmospheric pressure is finally stored in glass vials in the fridge prior to being measured.

A cocktail of Bis-MSB and butyl-PBD scintillators dissolved in equal ratio in 4mL benzene solution is then prepared to be measured on two Perkins Elmer Tricarb 3100 liquid scintillation counters. Each sample is measured around eight 1000 min-run times. The ^{14}C activity is calculated in percent relative to the activity of an international standard of oxalic acid NIST SRM 4990C (OxII), using the Libby half-life (5568 yr) and taking into account the isotopic fractionation normalized to –25‰ (versus VPDB) (Stuiver and Polach 1977; Mook and van der Plicht 1999). ^{14}C densities are converted into calendar ages using the

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Table 1 Results of the 26 ^{14}C analyses carried out at the IFAO lab on 22 wood species.

Lab code	Material	δ^{13}C	Age (BP)	σ (BP)	Site reference	Tomb – associated Mastaba
IFAO_0660	Wood	–27.87	4275	30	N°36–1428	Tomb S1427 – M02
IFAO_0660-0*	Wood	–27.87	4279	30	N°36–1428	Tomb S1427 – M02
IFAO_0662	Wood	–24.00	4417	31	N°38–1440	Tomb S1439 – M02
IFAO_0662-0*	Wood	–26.81	4377	30	N°38–1440	Tomb S1439 – M02
IFAO_0663	Wood	–27.10	4301	30	N°39–1442	Tomb S1441 – M02
IFAO_0663-0*	Wood	–27.10	4400	30	N°39–1442	Tomb S1441 – M02
IFAO_0664	Wood	–26.60	4423	30	N°40–1444	Tomb S1443 – M02
IFAO_0664-0*	Wood	–26.60	4475	30	N°40–1444	Tombe S1443 – M02
IFAO_0665	Wood	–26.77	4338	30	N°41–1402a	Mastaba M03 boat
IFAO_0665-0*	Wood	–26.77	4448	30	N°41–1402a	Mastaba M03 boat
IFAO_0666	Wood	–26.10	4449	33	N°42–1402b	Mastaba M03 boat
IFAO_0667	Wood	–26.50	4542	30	N°43–1409	Mastaba M02 boat
IFAO_0668	Wood	–26.45	4257	30	N°44–1426	Tomb S1425 – M03
IFAO_0723	Charcoal	–23.20	4419	31	N°15, US 1568	Mastaba M17
IFAO_0724	Charcoal	–27.48	4359	30	N°16, US 1574	Mastaba M17 – South floor
IFAO_0725	Charcoal	–28.01	4351	30	N°17, US 1575	Mastaba M17 – South floor
IFAO_0726	Charcoal	–27.36	4387	30	N°18, US 1575	Mastaba M17 – South floor
IFAO_0728	Charcoal	–24.70	4487	30	N°20, US 1570	Mastaba M17 – North floor
IFAO_0729	Charcoal	–23.30	4401	31	N°21, US 1570	Mastaba M17 – North floor
IFAO_0730	Charcoal	–23.90	4386	30	N°22, US 1570	Mastaba M17 – North floor
IFAO_0731	Charcoal	–24.60	4403	31	N°23, US 1566	Mastaba M17 – North floor
IFAO_0732	Charcoal	–24.30	4427	30	N°24, US 1566	Mastaba M17 – North floor
IFAO_0733	Charcoal	–25.30	4400	30	N°25, US 1566	Mastaba M17 – North floor
IFAO_0734	Charcoal	–23.70	4398	31	N°26, US 1566	Mastaba M17 – North floor
IFAO_0735	Charcoal	–26.10	4278	32	N°28, US 1566	Mastaba M17 – North floor
IFAO_0736	Vegetal fibers	–21.40	4347	31	N°29, US 1522	Tomb S1522

*Replicate samples.

IntCal20 calibration curve (Reimer et al. 2020) using the OxCal4.4 software (Bronk Ramsey 1995, 2009a).

Bayesian Modeling

For nearly 30 years the Bayesian approach has become increasingly important in the analysis of ^{14}C dates, because it offers the possibility of proposing plausible reasoning in the presence of uncertainties. While ^{14}C densities are represented in the form of probability laws, archaeological information is mostly expressed in a non-probabilistic basis. Thus, it is necessary to translate the various cases of archaeological *a priori* into the form of probability laws so as to build high-resolution Bayesian chronological models.

Regarding historical issues, textual, archaeological and field data are generally the most common constraints on absolute dating and mainly expressed as phrases. The main difficulty is to faithfully reproduce the quality of this spoken information in the form of probability laws, which can then be integrated as statistical *a priori* within the model. Modeling has been built using the OxCal4.4 software (Bronk Ramsey 1995, 2009a, 2009b), with the IntCal20 calibration curve (Reimer et al. 2020). Historical priors used in the models have been described based on the available information and down-weighted by identified error sources.

Bayesian modeling has been applied to constrain the frequentation of the Abu Rawash site during the reign of King Den and to estimate his accession date. To achieve this, historical information was firstly used to estimate the duration of Den's reign. Archaeological data was then used to specify when these mastabas were built.

RESULTS

^{14}C Results

Twenty-seven analyses were carried out on the 22 samples, 5 having been replicated (Table 1). Result of sample IFAO_0727 has not been validated because of a bad yield during the combustion. The set of others provide results ranging from 4542 ± 30 BP to 4257 ± 30 BP, thus the standard deviation of the full set of results was 75 yr. The replicates give good consistency for three of them, whereas two others are slightly less accurate but still remained validated due to the measurement method involved (χ_2 test failed at 5% (3.8), reaching 5.227 for IFAO_0663 and 6.722 for IFAO_0665).

$\delta^{13}C$ values spread from –28.01‰ to –21.40‰, consistent with C3 vegetation. The higher value is for the vegetal fibers, which could be a mix of plant remains used for the manufacturing of bricks. Calibrated densities are ranging from 3369 to 2706 cal BCE (2σ), the large interval range being partly due to the plateau-age between 3250 and 2950 cal BCE (Figure 2).

In addition, series of samples collected in the Mastaba 17 (North and South) provide two sets of consistent results except IFAO_0728 a little older but still in the 2σ range. They can be combined, giving two constrained densities of 4400 ± 14 BP and 4366 ± 20 BP (Figure 3b, c), thus calibrated ranges of 3026–2910 BCE (93.6%) and 3093–2927 BCE (95.4%). These two densities are also consistent with IFAO_0723 estimate from charcoals resulting from the fire of the northern part of the wooden floor from the burial chamber and clearly show that Mastaba M17 occupation is focused on the younger part of the plateau-age (Figure 3).

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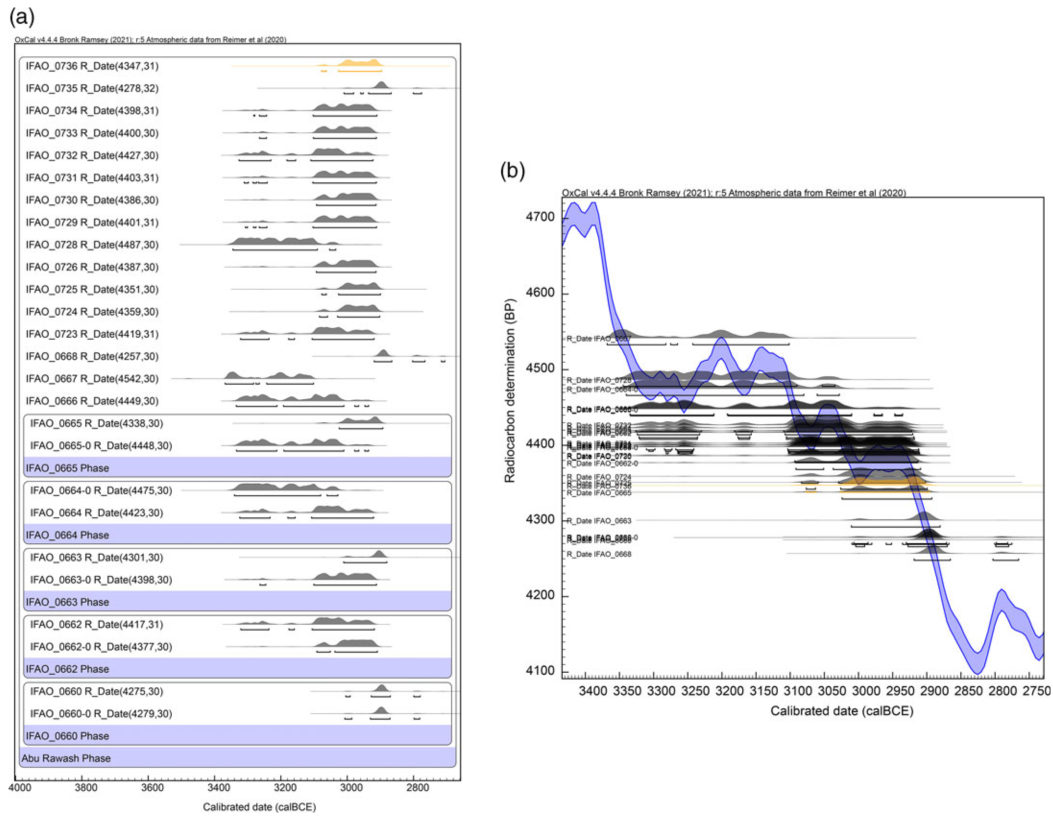

Figure 2 (a) Calibrated temporal estimates for the 26 analyses carried out on Abu Rawash archaeological samples from tombs associated with the reign of King Den. Short-lived material is in yellow whereas wood and charcoal are in black. The five replicates are gathered in corresponding Phase. (b) Temporal densities on the IntCal20 calibration curve centred on the 3250–2950 BCE plateau-age. (Please see online version for color figures.)

In addition, these estimates are contemporaneous to the ones obtained from samples from tomb S 1522, S 1441, S 1439, S 1427, S 1425 and from the boat of Mastaba M03, whereas the estimates from Mastaba M 02 boat could be slightly older as well as those from tomb S 1443 (Figure 4). However, such discrepancies could not really be interpreted from an archaeological point of view as statistics obtained for each building are considerably weak, and very small discrepancies can be strongly enlarged by the plateau-age. Because all the tombs are clearly linked to the reign of King Den, it is safer to proceed by considering this set of data on a whole, and to estimate Den's frequentation in the Abu Rawash site. A sequence of M17 has been modeled using Start and End boundary surrounding a Phase occupation in which all the ^{14}C results were integrated (Figure 3b).

Within the set of samples, only one is from short-lived organic remains, whereas all others are wood or charcoal. It is indeed really challenging and rare to find organic remains like seeds or plant fiber in a well-understood archaeological context in order to proceed with the conventional method. Consequently, results obtained on this set of long-lived samples should only be considered as a *terminus* to the site frequentation and should therefore be modeled according to this restriction.

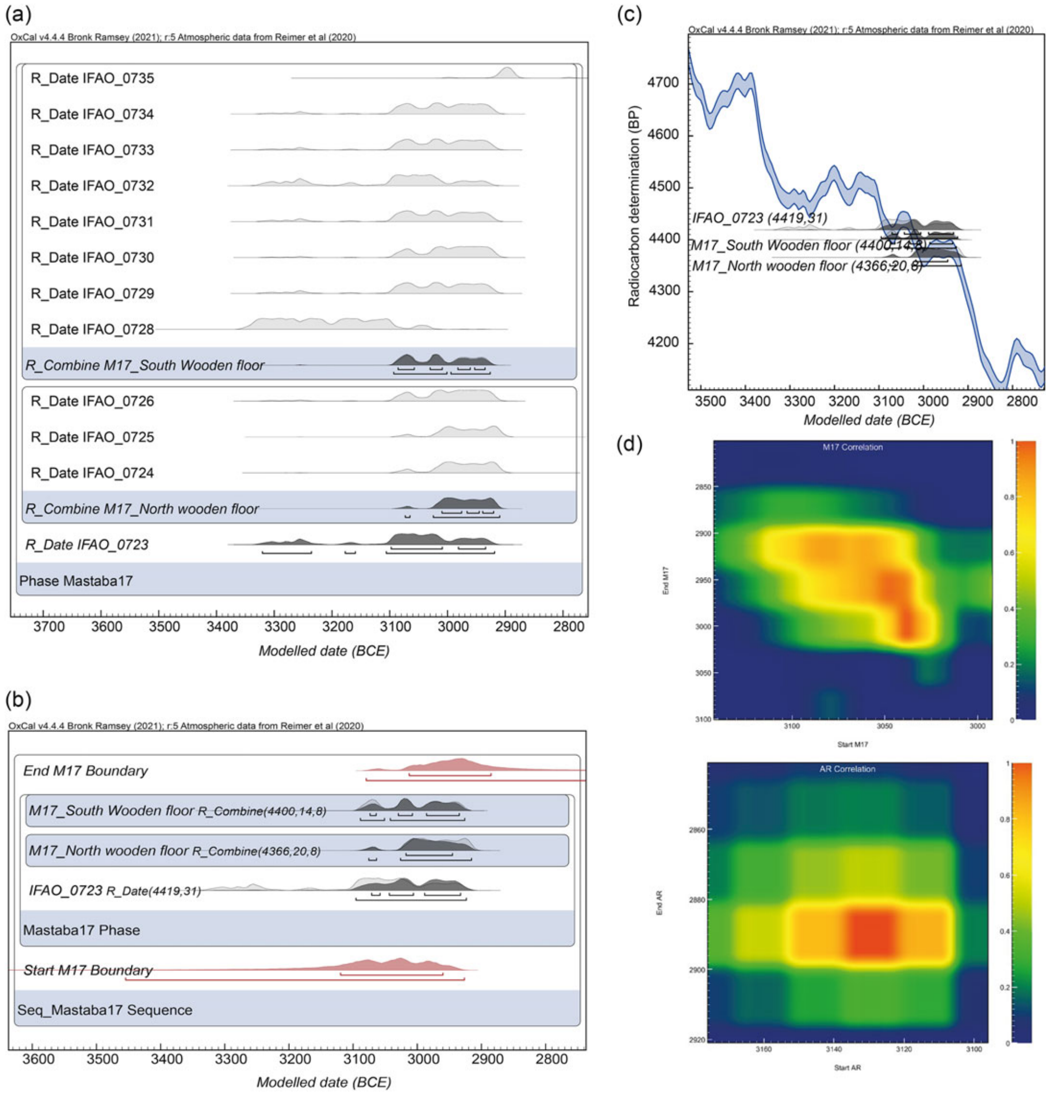

Figure 3 (a) Mastaba 17, R_Combine densities associated with the set of analyses carried out on samples from respectively the South and the North of the Mastaba floor. Comparison with the single charcoal dating results excavated close to a pot. (b) Modeling of the M17 occupation linked with the M17 R_Combine densities, using Boundary tools. (c) View on the calibration curve. (d) Correlation matrix between the end and the start boundaries got from the modeled sequence for M17 (up) and Abu Rawash occupation (down).

Length of Den’s Reign

The reign of King Den is a pivotal stage in the development of the pharaonic state, with numerous changes and innovations in terms of administration, economy, religion and kingship (Wilkinson 1999:63–65). This reign is also one of the best documented from an archaeological and epigraphic perspective, even if its length is still debated.

The tomb of King Den is located in the royal necropolis of Abydos (Upper Egypt). It is the first tomb with a staircase leading to the burial chamber, an architectural innovation that was soon

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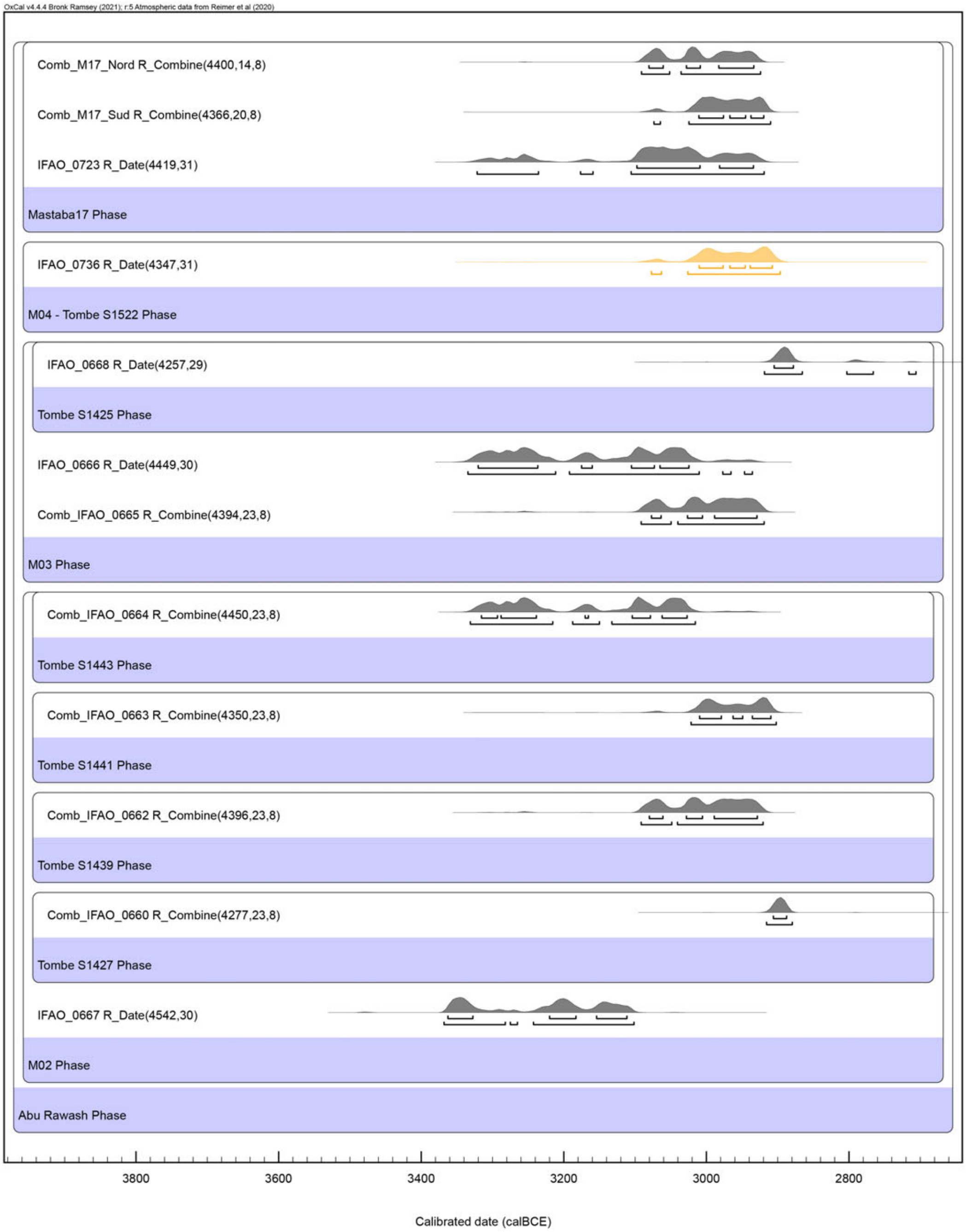

Figure 4 Calibrated densities obtained on charcoal and wood samples (black) as well as short-lived sample (orange) from Abu Rawash site. The distributions are organized according to their buildings and associated mastabas in the cemetery M.

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copied by the nobles of Saqqara. From the tomb comes a jar stopper with a seal imprint giving the succession of the rulers of the 1st Dynasty (Dreyer 1987). Unfortunately, no indication is given about the length of each reign. This succession order is confirmed by another seal, this time from the tomb of Qa'a, with the mention of all rulers of the 1st Dynasty including the successors of Den (Kahl 2006:96–98). The absence in this second inscription of Meret-Neith, mother of King Den, has led to the assumption that she played only a subordinate role in the destiny of the country. However, other documents indicate that she did rule Egypt as regent and played a role in political affairs (Pätznik 2017).

On the Palermo Stone—a fragmentary basalt stela that comprises the list of the kings from the five first Egyptian dynasties with significant events for each year of their reigns—the section concerning King Den is only partially preserved. This document indicate that Den reigned for at least 16 years (Godron 1990:106; Kahl 2006:99–101), perhaps even 34 depending on the interpretation of the gaps (Hornung et al. 2006:23–24). However, considering the number of innovations of his reign (first attestation of the title *nswt-bỉty*, invention of the double crown, major changes in the administrative organisation of the country, etc.), the quantity of private elite tombs known for his reign at Saqqara—more than 30—Abusir, Helwan, and Abu Rawash, or the fact that the king had at least three different chancellors (Strudwick 1985; Tallet and Resk Ibrahim 2008:172; Moreno Garcia 2013), suggests that his reign was considerably long. The discovery of a fragment of a limestone vessel near his tomb mentioning "the second occasion of the Sed festival" (Dreyer 1990:80) confirms that if the king did indeed celebrate two Sed festivals, he had a very long reign. The most recent analysis of the Palermo Stone, combined with the study of other documents mentioning events related to the reign of Den, has led T. Wilkinson (1999) to allocate at least 32 years to the reign of King Den. We can therefore confidently subscribe to Gérard Godron's view that Den reigned between 33 and 65 years, and more probably between 35 and 40 years (Godron 1990: 195).

^{14}C Modeling

Twenty-six ^{14}C determinations were integrated within a Bayesian model to evaluate the Abu Rawash occupation, and then to suggest a time range for the accession date of King Den. Dee et al. (2010) suggests a variation of ^{14}C activity of 19 ± 5 ^{14}C yr to the IntCal04 curve for the Nile valley due to a seasonal effect, which has been revised by Manning et al. (2020a, 2020b) to 16 ± 4 ^{14}C yr, using IntCal20 curve. More investigations currently in progress are corroborating this offset for plants having grown up close to the Nile (Quiles et al. 2021). This correction has been integrated. As the two series of Mastaba M17 samples are clearly associated with the same archaeological context, we can first model this occupation. The two *R_Combine* densities were integrated within a *Phase,* ordered within a *Sequence* surrounded by two *Boundaries* (Figure 3b). The correlation matrix reporting the *End* to the *Start* boundaries highlights a scarce occupation, this being approximately 3100–3020 to 3020–2850 BCE. The same modeling performed on the whole AR set of data provides us with a more centred occupation with a medium focus at 3130 and 2890 BCE (Figure 3c).

Tests have been run to determine the most suitable tools for summarizing the whole set of AR data. A kernel density estimate *KDE_Model* (Bronk Ramsey 2017) has been tested with a Normal distribution N(0,1), spreading over 100 yr U(0,1) and compared to the result of the Sum function (Figure 5a). It has first been tested on Mastaba M17, then on all Abu Rawash data integrated as single dates or within R_Combine tools when suitable

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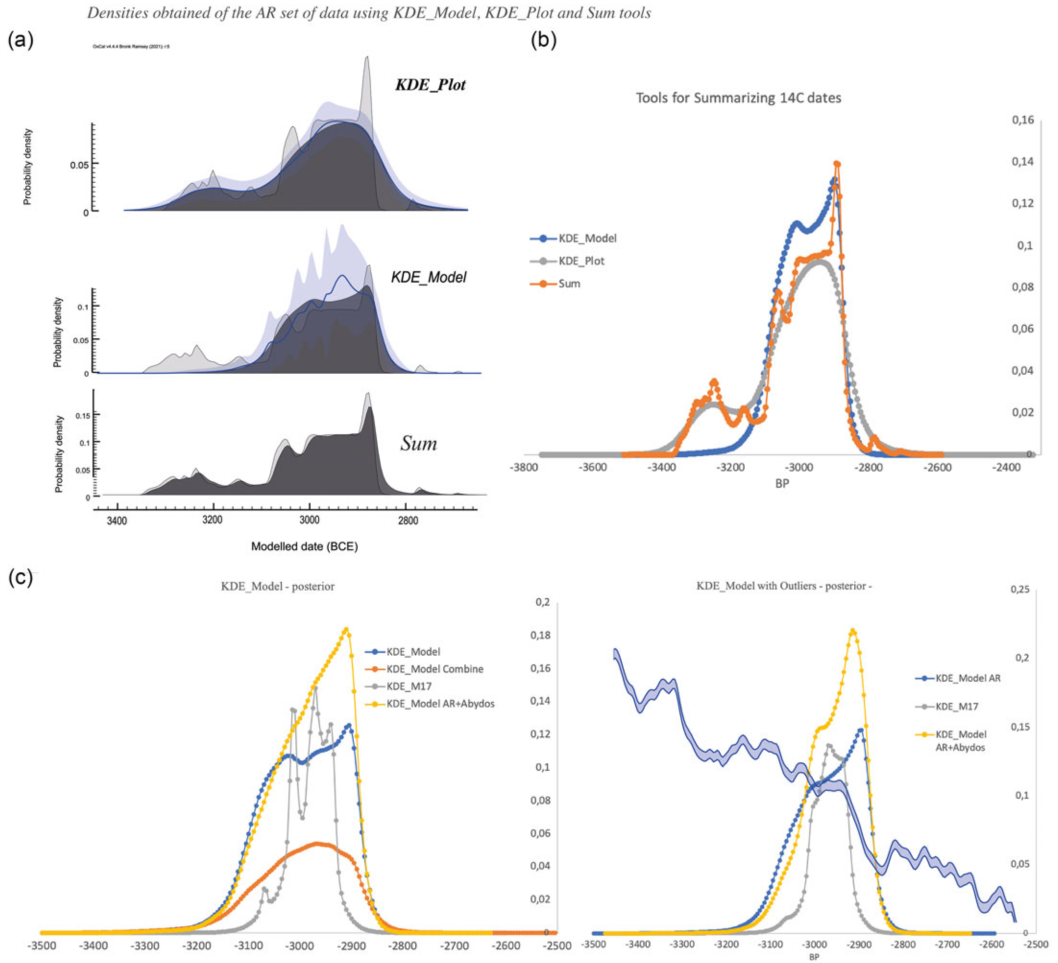

Figure 5 (a) Comparison of modeled KDE_Plot, KDE_Model and Sum densities got on the whole set of data from Abu Rawash (AR). (b) Comparison of densities obtained on the whole AR set of data using KDE_Model, KDE_Plot and Sum functions, each single density being downweighted by Charcoal and General Outlier Models. (c) Comparison of a posteriori KDE_Model got on several data sets: AR (blue), AR with R_Combine densities (orange), M17 (grey) and AR+Abydos (yellow) left) without Outlier-Model right) with "Charcoal" Outlier-Model for all except IFAO_0736 short lived sample which estimate is down-weighted using the "General" Outlier-Model.

(Figure 5b, c). *KDE_Model* enables the suppression of noise and provides more robustness compared to the *Sum* densities.

Outlier probabilities were then assigned to the ^{14}C dates according to the nature of the sample. Except IFAO_0723, all are long-lived samples which significance can possibly be restricted by inbuilt-age effect (Dee et al. 2014). These samples can be wood pieces coming from the inner tree rings of large specimens, whilst other wood specimens could have been reused for several years. Both can strongly bias towards older ages than the investigated archaeological age. To take into account this possible offset, such ^{14}C estimates were modeled using a *Charcoal* outlier density as defined in Bronk Ramsey (2009b), whereas the only short-lived sample was down-weighted using a symmetric Student's t-distribution with 5% probability (*General* Outlier model). *KDE_Model* were also tested by integrating *Outliers* densities in the calculation (Figure 5c).

KDE_Model is not a Bayesian model framework and has to be used on its own, whereas a *KDE_Plot* provides a KDE distribution of the events without affecting the Bayesian model (Figure 5b). As such, this tool was used with modeling. Aside from historical and archaeological inferences, we can suggest king Den's reign lasted at least 30 years, but could have been of 45 years or up to 65 yr.

First, we can consider that the whole occupation in Abu Rawash cannot be longer than 65 yr, the maximum estimated length of King Den's reign. By integrating in a *Sequence* the *KDE_Plot* surrounded by two *Boundaries* Start and End, the whole being in a *Phase* together with a *Span* function restricted to be of maximum 65 yr (65+10*T(5)), we can model the start of the Abu Rawash occupation to be between 2968 and 2907 BCE (95.4%), such modeling integrating *Delta_R* and *Outliers* parameters. However, to more precisely model our state of knowledge on the length of Den's reign, we have to build a density function which gives an equiprobability for the first 30 years (as it is certain that he was king), then decrease from 30 to 60, each additional year of rule being less likely than the one before it. To ensure accurate probability distribution several runs of the model were tested. By combining a step function from 0 to 30 years to a *student t* function centred on 35 yr with *t* of 5, a probability distribution was obtained that seems to be a good compromise to represent the current state-of-knowledge about the length of Den's reign.

Finally, because the construction of the tombs and mastabas from which the samples have been collected have occurred any time during the reign of King Den, but more probably at the start of his reign judging by the mention of Ankhka, known as the first of king Den's three viziers, it can be suggested that his reign started 1 to 30 years before the first burials on Cemetery M, the first 15 years being more plausible whereas the last being less. Several runs were tested. By combining tools *After()* and *Before()*, the second integrating a flexible student law centered on 15 yr:

*Interval("Den Length of reign", After(0)&Before(15+10*T(5)));*

We get a distribution law fairly standing for our current knowledge about the length of Den's reign (Figure 6a, left).

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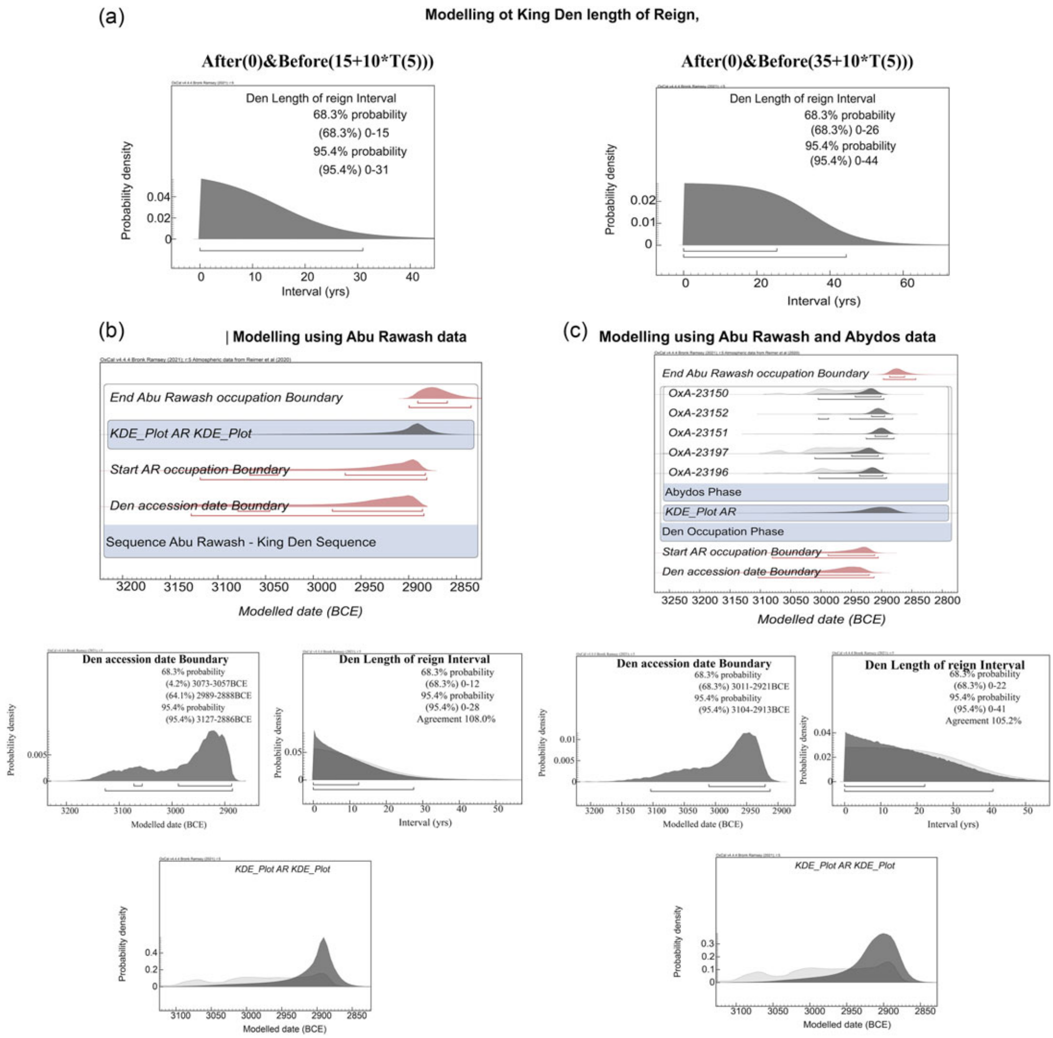

Figure 6 (a) Modeling of the King Den's length of reign: (b) modeled estimates for the King Den's accession date using the Abu Rawash data (c) and combining the Abu Rawash and Abydos, Umm el-Qaab data (from Dee et al. 2013).

The model was run within a *Sequence( )* ordering:

- first, a *Boundary* standing for the accession date of King Den,
- second, the simulated Interval
- third, the KDE_Plot estimate of the whole set of ^{14}C dates surrounded by *Boundary "start/ end of AR occupation"*,
- the whole being down-weighted by outlier distributions.

The resulting model shows that the start of the AR occupation is modeled from 3116 to 2883 BCE (95.4%), thus the King Den accession date is from 3127 to 2886 BCE (2σ) and more probably occurring between 2989 and 2888 BCE (64.1%; Table 2, Figure 6b).

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Table 2 Result of the simulated Den accession date modeled using Abu Rawash data. Interval 1 is expressed as After(0)&Before(15+10*T(5)), whereas Interval 2 is After(0) &Before(30).

Modeled estimate	Interval1, BCE (2σ)	Interval2 BCE (2σ)	Interval1, *No Delta_R,* BCE (2σ)	Interval1, *No outlier,* BCE (2σ)
Den accession date	**3127–2886**	3137–2888	3177–2892	3165–3039
Modeled interval	0–28 yr	0–28 yr	0–29 yr	0–29 yr
Start AR occupation	3116–2883	3121–2884	3161–2888	3151–3032

DISCUSSION

King Den's Accession Date

The modeled estimate for King Den's accession date (Table 2) is slightly wider than the first one suggested by Dee et al. (2013) of 2945–2904 BCE (2σ). This is easily understandable as the current model only focuses on one reign and is not constrained at the beginning and end of the model, which results in more flexibility than the Dee et al. model, hence the larger time range. At the same time the large set of data integrated in the Kernel density function ensures the robustness of the model. As shown in Figure 5c, the more data we have, the more accurate and smooth the Kernel posterior density is. Mastaba M17 *KDE_Model* provides us with a posterior density with several maxima, whereas the *AR_R_Combine* is smoother but very large. This is because these two kernels were run with only around 10 temporal densities because the *R_Combine* densities are treated as a single event, whereas the two others integrated more than double. This highlights the need for a large set of data to carry out modeling with *KDE_Plot*, but when available it definitively gives a more robust *a posteriori* density.

In addition, to test the convergence of the model, we have run it again by changing several parameters. As expected, the most impacting parameters are the Outlier-Model which strongly extend the *a posteriori* time-range, but fairly take into account that we are mostly dealing with long-lived materials. The Delta_R correction affords for a translation on all the ^{14}C estimates. If the offset is set to 0 ± 10 ^{14}C yr, we do not bias the model, and Den's accession date estimate is 3177– 2892 BCE (2σ).

Several distributions for simulating Den's length of reign were then tested. The model run using a restrictive U(0,30) function, standing for a reign of 30 years and no more, provides a time range for Den's accession date of 3137–2888 BCE (2σ), which is very close to that which was previously suggested.

This new set of ^{14}C dates for the reign of King Den can be compared with the previous ones published in Dee et al. (2013). Tarkhan dates were excluded because of insecure associated archaeological contexts (from Naqada IIC2 to Djer-Den kings) as well as Mastaba 3504 of Saqqara North dates, as we cannot decide on their historical attribution between king Djer and king Den. Contrastingly, the five short-lived samples from the Abydos Umm el Qaab Tomb T (two hair and three short-plants samples), are clearly associated with king Den's reign. They were collected at the Pitt-Rivers Museum in Oxford and analyzed at the Oxford lab using the AMS method. The comparison of such temporal densities to the ones obtained from the Abu Rawash site are clearly consistent (Figure 7a, b). Some of the Abu

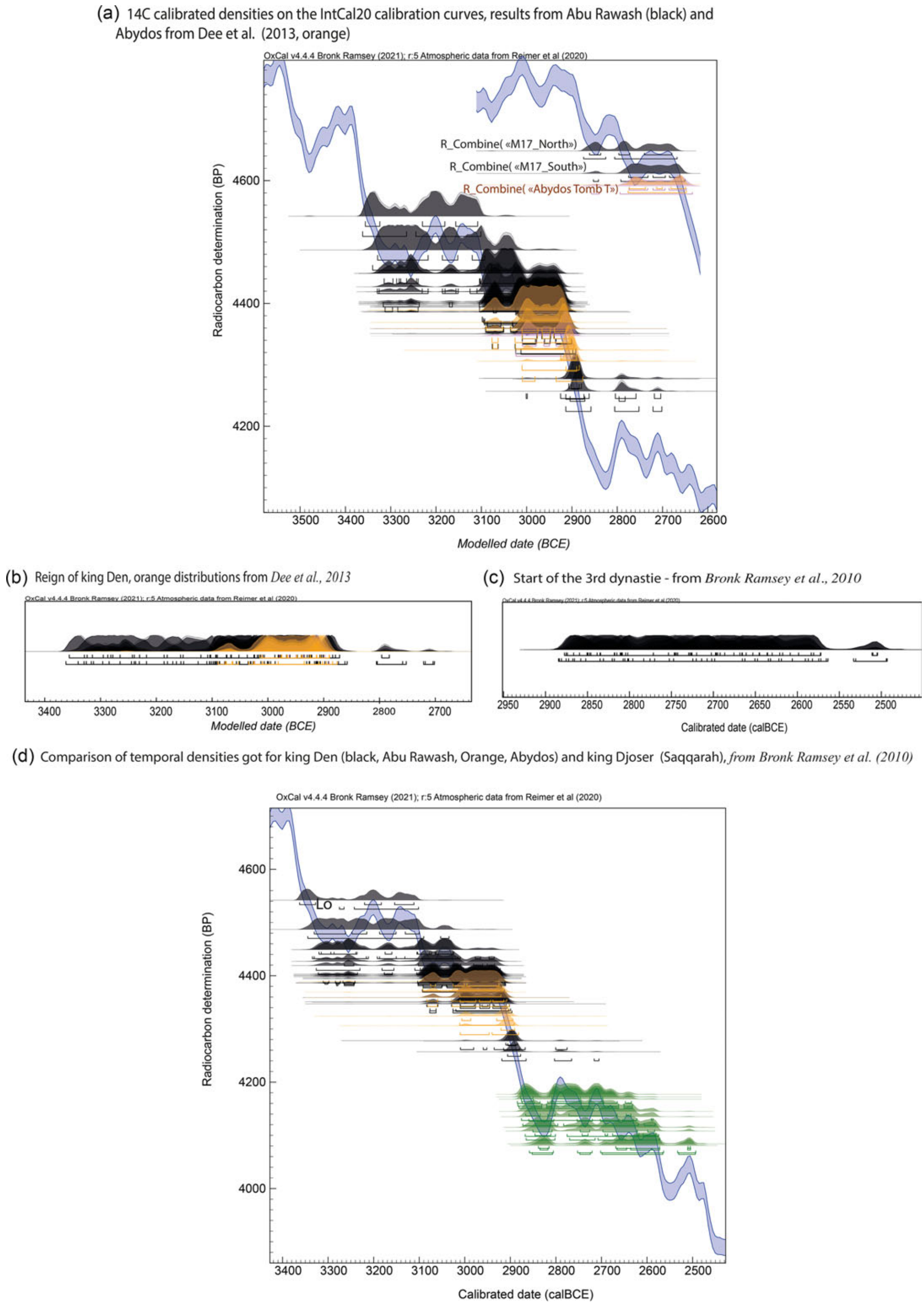

Figure 7 Comparison of the ^{14}C results for Abu Rawash samples (black) to the Abydos, Umm el-Qaab short-lived samples (from Dee et al. 2013): (a) on IntCal20, (b) stack densities, (c) stack density of Djoser samples from Bronk Ramsey et al. 2010), (d) comparison of the three sets of data (Djoser samples in green).

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Table 3 Modeled estimates for the start of the 3rd Dynasty.

Modeled estimates	1σ	2σ
Span "*End 1st Dyn-2nd Dyn*"	14–73 (57.3%) 188–223 (11.0%)	0–79 yr (63.6%) 116–248 yr (31.9%)
Start 3rd Dynasty	2873–2818 (58.5%) 2698–2669 (9.8%)	2883–2813 (62.7%) 2777–2639 (32.7%)

Rawash samples provided a slightly older age, which is expected as they are long-lived wood and charcoal samples, which accounts for the wider discrepancy.

Even if these new dates are closely associated with the reign of Den, there is no direct relationship between the archaeological context of this set of data, and the one of Abu Rawash. Furthermore, they are not as clearly associated with the first half of King Den's reign as were the AR dates. Therefore, to ensure that the data was not over-interpreted, these new densities were integrated within an independent *Phase* instead of the *KDE_Plot* of the previous model, with both tools being integrated in the same Phase ("Den Occupation"). Regarding Abydos data, *Phase* has been preferred to another *KDE_Plot* because of the weak number of analyses (n=5) and the less well-documented archaeological contexts. The simulated Interval was extended to cover the entire possible length of king Den's reign using *After(0)&Before(35+10*T(5))* distribution. Thus, the model was re-run by integrating the Delta_R correction and downweighting ^{14}C determinations using Outlier models. The accession date of King Den is modeled to 3104–2913 BCE (2σ), with this more probably being 3011–2921 BCE (1σ; Figure 6c).

2nd Dynasty Length

Results so far obtained could also be used to better estimate the gap between the end of king Den's reign and the start of the 3rd Dynasty, which stands for the structuration of the Egyptian state. Nine previous analyses were based on samples from Saqqarah in the framework of the Oxford project (Bronk Ramsey et al. 2010): four seeds and short-lived plants associated with Khasekhemuwy/Djoser period and held at the Medlhabsmuseet in Stockolm, two short-lived plants from the Royal Botanic Gardens in Kew and a wood (three samples) located at H.Haas associated with King Djoser. These analyses were integrated in a *Phase* associated with the start of the 3rd Dynasty. This tool was preferred to the use of a *KDE_Plot* because this set of data is not very large and above all, not associated with the same archaeological context, thus it would have biased the modeling by integrating more information than what we really have.

To estimate the time span of the period "*End 1st Dyn.- 2nd Dyn.*", the whole Sequence linked to the reign of Den—gathering a Boundary Start, the KDE_Plot and the Phase Abydos data—was integrated in a Phase of which the span was constrained to be of 65 yr maximum, the estimated maximum length of Den's reign (Table 3). Then, an additional *interval* with a null-distribution prior was integrated between the *Boundary* standing for the *end of the 1st Dynasty* and the one for the *start of the 3rd Dynasty*. The estimation of the gap between both boundaries will provide us with an idea on the length of the 2nd Dynasty. The final model scheme is as follows:

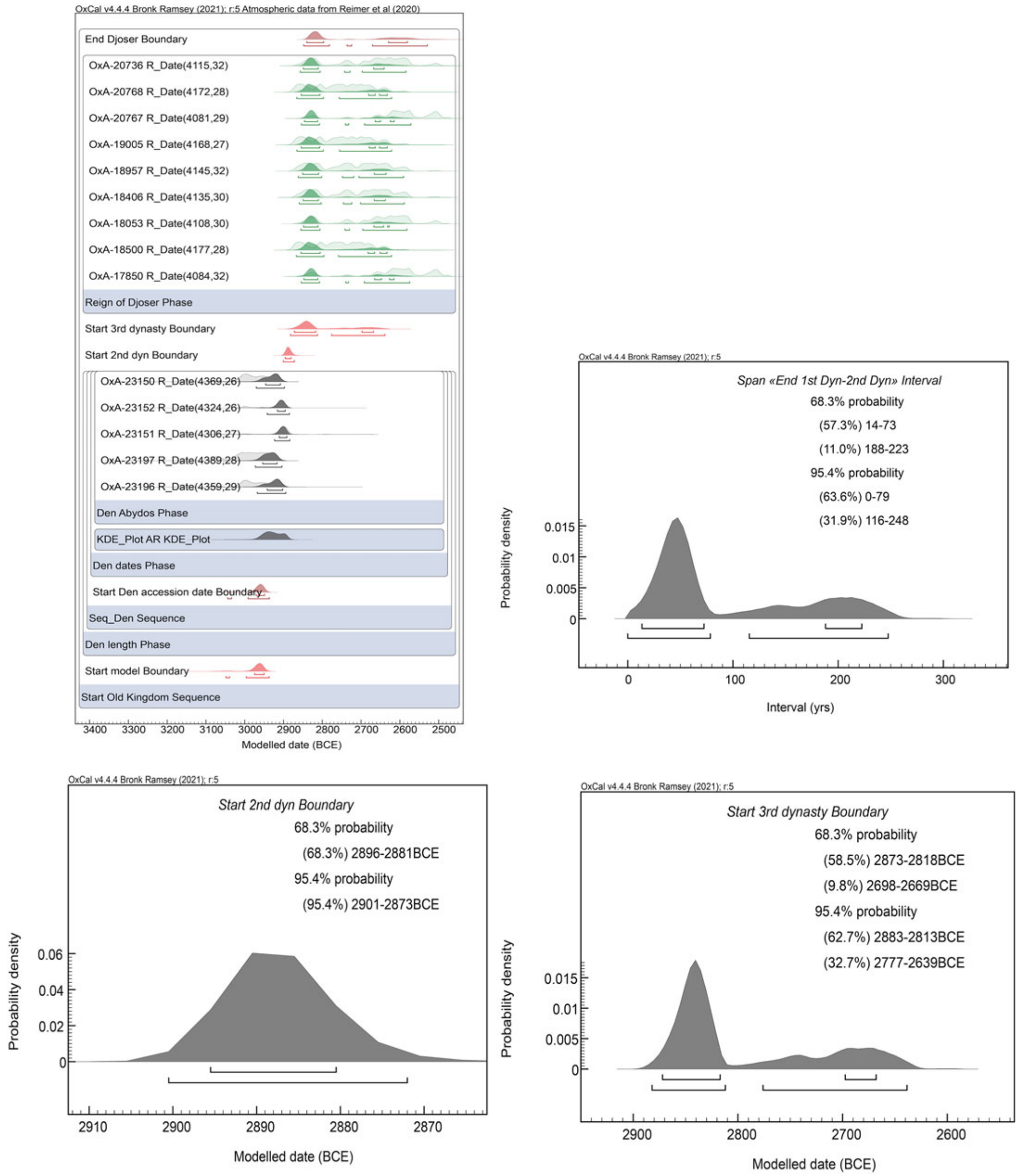

Figure 8 Modeling of the span of the 2nd Dynasty by integrating Abu Rawash as well as Abydos Umm el-Qaab (Den) and Saqqarah (Djoser) data.

Delta_R("Offset Egypt", 16,4);

Sequence("Start Old Kingdom")

{

Boundary("Start Model");

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```
Phase("Den length")
{
Sequence("Seq Den")
{
Boundary("Start Den accession date");
Phase("Den Dates")
{
KDE_Plot("AR occupation", N(0,1), U(0,1)){ ...};
Phase("Abydos data"){....};
};
};
Span("Span Den", 65+5*T(5));
};
Boundary("Start End 1st-2nd Dyn");
Interval("Span End 1st-2nd Dyn");
Boundary("Start 3rd Dyn");
Phase("Reign of Djoser"){...};
Boundary("End Djoser");
};
```

The start of the 3rd Dynasty is modeled from 2883 to 2813 (62.7%) or 2777–2639 (32.7%), and the span between the end of Den's reign and the start of the 3rd Dynasty is of 0–79 yr (63.6%) or 116–248 yr (31.9%) (Figure 8). We must emphasize the double methodological challenge of modeling the chronology of this historical period. The dates for the two studied kings are concentrated in two distinct plateau-ages, separated by only a few decades. Moreover, as the number of ^{14}C dates associated with the reign of King Djoser is lower than that associated with King Den, and as there are no other constraints built into the model, the model is slightly unbalanced and may favor the probabilities closest to the dates associated with King Den. For all these reasons, it is not possible to conclude between these two intervals without adding more constraints to the model (Figure 8).

Old Kingdom Modeling

Refining a precise chronology for the Egyptian Old Kingdom is an ongoing issue which is crucial not only for gaining a better understanding of Ancient Egyptian history, but also

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because the related chronologies of neighboring societies from the 3rd millennium are strongly correlated with that of Egypt. To investigate chronometric clues hidden within archaeomaterials as well as archaeological evidence is trickier than for more recent periods because of the scarcity of available material. In addition, this period is not as well-known as others could be from textual sources. The 3rd Dynasty in particular presents many challenges, followers of King Djoser are not well-documented and associated contextualized material is not easily available. This is also particularly apparent for the 2nd Dynasty, for which almost nothing is known. In this respect, this new set of data from King Den offers an amazing opportunity to refine more precisely the start of this major historical period. For the first time we have a precise contextualized set of data being sourced from continuing archaeological excavations and which clearly links with the structuration of the Egyptian state. Pending the availability of another well-contextualized dataset closer to the beginning of the 3rd Dynasty, this one should be used as the basis of our model to set the absolute chronology of the Old Kingdom. It will then be built step by step by integrating new series of well contextualized dates carried out on archaeomaterials from current excavations in Egypt and associated with as many different kings as possible. Each new series bringing independent constraints into the general model. This is the goal of the current research program Meryt[1] which aims to model an accurate, complex and multi-technical absolute chronology for the Egyptian Old Kingdom (~3000–2200 BCE), through an integrated approach bringing together all the analytical criteria of Egyptology, archaeology, and archaeometry.

CONCLUSION

The challenge of determining precise absolute chronological points for Egyptian rulers relies on the possibility to carry out ^{14}C dates on samples clearly associated with the activity of a single king. The majority of objects dated to the reign of Den currently housed within museum collections were acquired over a century ago and thus documentation detailing the archaeological context of their discovery is lacking. Despite the possibility to conduct AMS analyses on these objects, this remains the principal limitation with museum collections.

Basing analysis on samples collected through the ongoing excavation of archaeological sites enables the possible identification of the relationship between the sample and the relevant king for individual sites. Considering this, excavations conducted at Abu Rawash from 2008 until 2014 presented an incredible opportunity to refine the absolute time range for one of the first kings of Egyptian history, King Den. In addition to this, investigations were necessary to gather available historical and archaeological data for the proposition of an updated estimate to the length of Den's reign. The modeled temporal density so far obtained both relies on new contextualized ^{14}C dates and an updated reading of his reign. It remains a dynamic result, which will continue to be refined as more data is obtained and continues to be integrated within the model. This will provide crucial information to our understanding of the chronology of the Old Kingdom, specifically the date at which it began and the structuration of the Egyptian state.

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