

# An absolute chronology for early Egypt using radiocarbon dating and Bayesian statistical modelling

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## Research



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The Egyptian state was formed prior to the existence of verifiable historical records. Conventional dates for its formation are based on the relative ordering of artefacts. This approach is no longer considered sufficient for cogent historical analysis. Here, we produce an absolute chronology for Early Egypt by combining radiocarbon and archaeological evidence within a Bayesian paradigm. Our data cover the full trajectory of Egyptian state formation and indicate that the process occurred more rapidly than previously thought. We provide a timeline for the First Dynasty of Egypt of generational-scale resolution that concurs with prevailing archaeological analysis and produce a chronometric date for the foundation of Egypt that distinguishes between historical estimates.

## 1. Introduction

The antiquity of Egyptian civilization has been a source of speculation for many centuries [1,2]. Flinders Petrie [3] published a relative chronology for Early Egypt based on the stylistic evolution of ceramics found in human burials. His system of Sequence Dates is regarded as the origin of the technique now known as seriation.

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However, it has become apparent that this relative scheme is no longer sufficient for detailed socio-political analysis. Problems include the subjectivity of object classification, variations in assemblages from site to site and the inherent challenges of interpreting broader social and economic change on the basis of funerary evidence alone [4–6].

The relative chronology of the era preceding state formation in Egypt is traditionally divided into the Badarian and Naqada (or Predynastic) periods, based on the archaeology of cemeteries in Upper Egypt (UE, the Nile Valley south of Cairo to Aswan). The Naqada period is further subdivided by means of the relative dating of pottery into IA–IC, IIA–IID and IIIA–IIID [7,8]. This system can only be fully applied to Lower Egypt (LE, the Nile Delta and Cairo region) after UE funerary practices are attested in that region, beginning in the latter part of Naqada II. The Egyptian state is normally defined to start with the First Dynasty, which was established during the Naqada IIIC cultural period. For this study, we take the foundation date to refer to the accession of king Aha of the First Dynasty, although his predecessor, Narmer, most probably held political control over the whole state [9]. Historical foundation dates vary widely and recent estimates range from 3400 to 2900 BCE [10–13].

An absolute chronology for the Predynastic would allow for new insights into this influential period in human history. Egypt was the first manifestation of the territorial state, in many respects the forerunner of all modern countries. The rate and direction of the changes that led to this political centralization can only be traced by absolute chronology. Furthermore, the formation of Egypt was accompanied by profound economic and cultural developments, epitomized by the spread of intensive agriculture and the invention of writing [14]. The latter is thought to have occurred independently in both Egypt and Mesopotamia, but more dating information is still required to establish exactly when and how this innovation took place. One of the most effective approaches to absolute chronology currently available uses Bayesian statistical modelling [15, 16]. The wealth of relative dating evidence available for Early Egypt makes it highly suitable for this sort of analysis. Here, we use such evidence to refine radiocarbon dates within Bayesian statistical models.

Radiocarbon dates are obtained by measuring the  $^{14}\text{C}/^{12}\text{C}$  ratios of biogenic materials. These data are converted into absolute (CE/BCE) years via a calibration curve composed over the Holocene of measurements on dendrochronologically dated wood [17]. Owing to fluctuations in the production and cycling of  $^{14}\text{C}$ , the resultant likelihood functions (or calibrated date distributions) are usually non-Gaussian and expressed as 68% or 95% highest posterior density (hpd) ranges. Taken in isolation, radiocarbon dates rarely allow for high-resolution chronological analysis, because of statistical scatter and the imprecision resulting from the calibration process. Typically, individual dates extend over 200–300 calendar years at 95% probability.

## 2. Experimental set-up

We dated organic materials from key sites of the Badarian and Naqada periods and the First Dynasty. In each case, the samples could be assigned to specific subphases of the relative chronology by means of ceramic typology and horizontal stratigraphy. Our dataset comprised 186 radiocarbon dates—74 from new measurements and 112 sourced from the published literature. Owing to restrictions on the exportation of archaeological material in Egypt, all new samples were obtained from museum collections in Europe and North America with the exception of a group of five freshly excavated seed samples from Tell es-Sakan in the Gaza Strip. We only selected items supported by the most secure curatorial and excavation records and prioritized short-lived remains such as seeds from granaries, reeds from basketry and fragments of linen [18]. The results sourced from previous analyses comprised all the dates available for our nominated sites with the exception of organics extracted from mud-based bricks and seals, which have previously been shown to be unreliable [18]. Of the 112 measurements, 48 were made on short-lived plant and animal remains, 47 on wood, 16 on charcoal and one on shell. Contextual and analytical details of all the samples are given in table S1 in the electronic supplementary material.

The new samples consisted of short-lived plant remains, hair and bone. All were prepared for radiocarbon dating using the Oxford Radiocarbon Accelerator Unit's standard acid–base–acid (ABA) pre-treatment procedures [19]. In cases where conservation treatment was suspected, an organic solvent rinse was applied [19]. For the most fragile hair samples, the base treatment was replaced by five exposures in an ultrasound bath in ultrapure water. The bone collagen obtained for dating was ultrafiltered wherever yields were sufficient. In a handful of cases, the collagen had been extracted by previous work ([20], see the electronic supplementary material, table S1). All samples were combusted in an elemental analyser and reduced to graphite in an excess of H<sub>2</sub> over an Fe catalyst [19]. The impact of possible diet-derived offsets in the radiocarbon measurements on bone and hair was avoided by monitoring  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values [21]. The radiocarbon data were measured by accelerator mass spectrometry [22].

Three of our samples showed evidence of contamination; a further three, as well as two published results, were plainly intrusive as they presented dates more than 1000 years after our period of study (see the electronic supplementary material, table S1). All eight of these samples (10 dates) were excluded from the Bayesian models. Multiple measurements were made on eight of our samples as part of routine reproducibility procedures, all but one of which passed the Ward & Wilson [23] test for statistical equivalence. Of the further seven previously published replicates, one group of four dates on the same sample of wood failed the test. In such cases, dates were included in the models as if they had come from separate samples (see electronic supplementary material, table S4).

### 3. Bayesian statistical models

#### (a) General specifications

We constructed Bayesian chronological models using the program OxCal [24,25] and the IntCal09 calibration curve [17]. Our 10 main models covered the period from the Badarian to the end of the First Dynasty. All the models consisted of sequences of archaeological phases, which enabled us to use the known ordering of such phases as a mathematical constraint—to refine the radiocarbon calibrations. Moreover, this approach allowed us to generate estimates for the transition points between phases, often the most important information for socio-political analysis. Each sample was allocated to a phase on the basis of its associated archaeological information. Where any ambiguity existed, such allocations were broadened to several phases. The radiocarbon dates obtained on each sample were then assigned outlier probabilities. For short-lived plants, human and animal remains, we used a prior outlier probability of 5%. Here, the model could move to either younger or older ages by selecting shifts from a Student's  $t$ -distribution ( $\nu = 5$ , see [25]), thus downweighting the influence of any individual result that conflicted with the sequence as a whole. However, wood, charcoal and shell (long-lived) samples were all treated as if they were likely to predate their contexts. This was necessary because radiocarbon dates reflect the biological age of the organic material in question—the date it ceases exchanging carbon with its environment. For inner tree rings (and any charcoal derived from them), this can be significantly earlier than the felling date of the tree. In addition, resources such as wood and shell can remain unused for many years before they are incorporated in a given context, widening such age offsets [18]. To account for these issues, dates on long-lived samples were modelled using an adapted Charcoal Model [25]. Here, the model was required to select shifts, and the direction of the shift was strongly biased towards younger ages (see the electronic supplementary material, table S6). Our analyses also took account of the minor variation in radiocarbon activity ( $19 \pm 5^{14}\text{C}$  years) recently proposed for Egypt [16,26].

All models ran successfully without limiting the range of possible calendrical solutions. However, for ease of repetition and more rapid convergence, the Naqada models were restricted to solutions between 5000 and 2000 BCE (more than a millennium on either side of archaeological estimates). Similarly, the Badarian models also all ran without restriction but were constrained to 6500–2500 BCE, more than 1500 years earlier and later than current expectation. No such

limitations were necessary for the First Dynasty model, because its higher density of data greatly facilitated model convergence. Along with the main models, various alternatives were run to test the sensitivity of the outputs to the starting assumptions. Such alterations included removing any provision for a localized offset in radiocarbon activity, eliminating all long-lived samples, as well as treating such samples as *termini post quos* and not applying any outlier analysis. The specifications and outputs of all the alternative models are given in the electronic supplementary material. Every model was run for at least five million iterations or until completion.

## (b) Details by period

The core of our First Dynasty model consisted of a sequence of eight abutting phases of uniform prior density [15], which represented the eight reigns attested in written sources for this period. In order to enhance modelling precision, we also added phases of radiocarbon dates at either end of this sequence. The first of these comprised 15 dates from the Naqada IIIA/IIIB cultural period, which immediately preceded the First Dynasty. The second included 11 dates from Second and early Third Dynasty contexts and acted as a *terminus ante quem*. The precise relationship between the rulers of the First Dynasty is by no means resolved. Here, we adopted the consensus view that the Dynasty consisted of a series of successive royal reigns, as opposed to joint or competing administrations. One ambiguous case is that of Queen Merneith, believed to be the mother of king Den, the fourth ruler of Egypt [27]. She either reigned unaccompanied or was co-regent while Den was a child. For this reason, we ran comparative models where her tenure was included within the reign of Den (see the electronic supplementary material). The eight phases of the First Dynasty were populated by 71 dates from two key sites of the early state: Abydos (UE, 31 dates) and North Saqqara (LE, 40 dates). The Abydos dates were predominantly new measurements on items from the subsidiary chambers of the Royal Tombs at Umm el-Qaab. Although the biological ages of these samples might be expected to cluster towards the end of the king's reign, any significant bias was nullified by two further considerations. Firstly, most of the samples would have contained some in-built age, especially the 11 bone specimens where the isotopic signal would represent an average over several decades [28]. Secondly, the measurements we included from the tombs of high-ranking officials of the First Dynasty at North Saqqara were temporally independent of the royal burials. These officials could all be connected with an individual ruler, or short series of rulers, but the date of their own burial was inestimable. For our models, the tombs of the officials were constrained to lie between the accession date of the king they served and the accession date of the king's third successor. The LE necropolis at Tarkhan was deliberately excluded from the modelling, although more than 20 radiocarbon dates were available for it. This decision was taken both because of longstanding difficulties with the historical allocation of its tombs and because the dataset was indiscriminately scattered (see electronic supplementary material, table S5 and figure S12).

We prepared four main site models for the Naqada period using 62 radiocarbon dates. We focused on the cemeteries of UE where the Naqada relative dating system was originally conceived. For the type-site of Naqada, we obtained 22 new measurements on short-lived materials. This group also included one sample from the adjacent and contemporaneous cemetery at Ballas. The remaining three sites were Cemetery U at Abydos, Naga ed-Der and Hierakonpolis. The Naqada relative dating system is based on shifts in material culture, so trapezoidal phases were employed that allowed consecutive phases to overlap [29]. Owing to the availability of samples, not every cultural transition could be modelled at each site. Thus, we concentrated our analysis on three junctures of particular archaeological significance: transition Naqada IB/IC, regarded by some scholars as the beginning of the Chalcolithic in Egypt [6]; transition Naqada IIB/IIC, as it signified the point at which UE funerary practices began to appear in LE [4,6] and transition IID/IIIA, because it is during phase IIIA that writing is first attested in Egypt [14].

Finally, we also constructed Bayesian models for four key sites of the Badarian period. The existing corpus of 12 dates for the period was extended to 20, including six new dates for the type-site of el-Badari. Each of the sites was modelled as a separate single phase of uniform probability

**Table 1.** Modelled dates for accession years of the First Dynasty and cultural transition dates for the Naqada and Badarian periods. Modelled durations for each period are also given. The duration of the Naqada period is taken to be the time from the end of the Badarian to the accession of Aha.

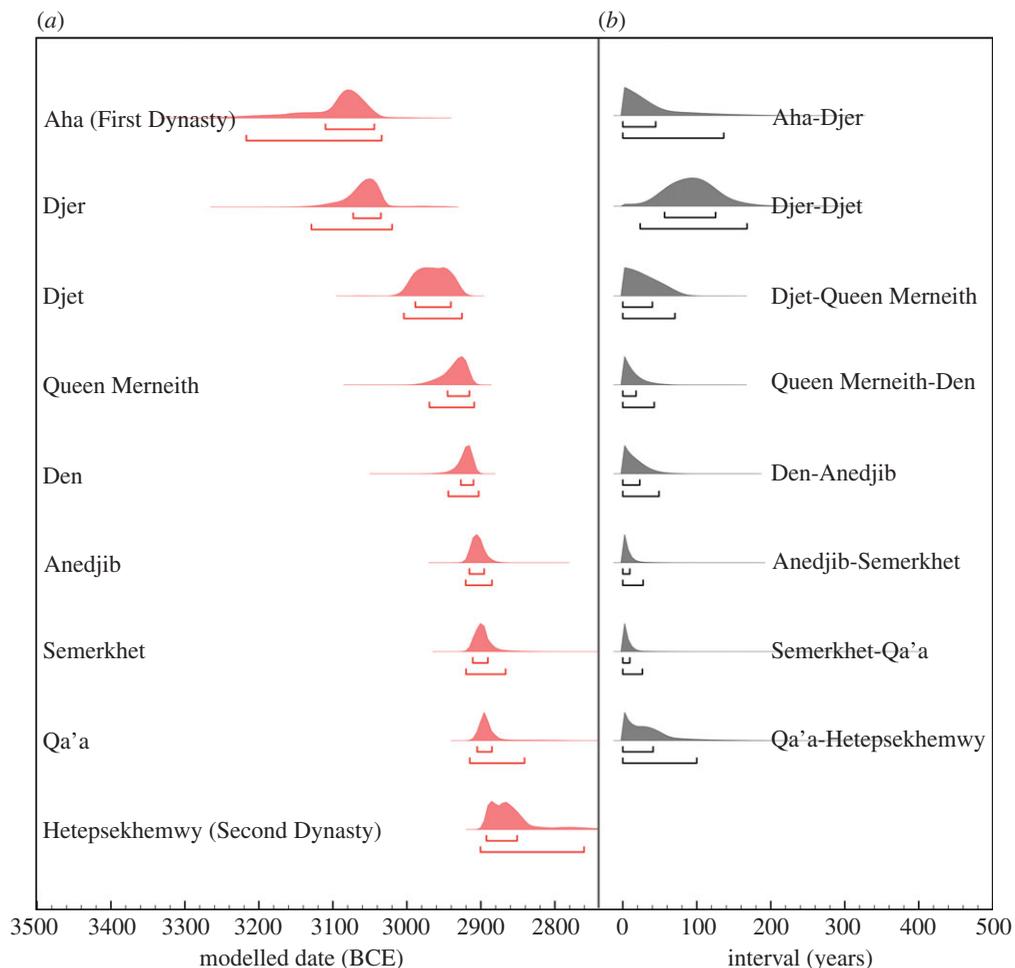
		modelled date			
		year BCE (68% hpd range)		year BCE (95% hpd range)	
		from	to	from	to
First Dynasty	Aha (foundation of state)	3111	3045	3218	3035
	Djer	3073	3036	3130	3021
	Djet	2989	2941	3005	2926
	Queen Merneith	2946	2916	2970	2910
	Den	2928	2911	2945	2904
	Anedjib	2916	2896	2921	2886
	Semerkhet	2912	2891	2921	2867
	Qa'a	2906	2886	2916	2842
	duration First Dynasty	170	270	153	375
Naqada	IB/IC	3690	3605	3731	3550
	IIB/IIC	3498	3413	3562	3367
	IID/IIIA	3352	3297	3377	3238
	duration Naqada	563	730	477	825
Badarian	start	4407	4308	4489	4266
	end	3800	3667	3896	3616
	duration Badarian	529	709	415	833

density. The conclusion of the Badarian is traditionally thought to predate or closely coincide with the onset of the Naqada period. In order to optimize our estimate for this juncture, we also prepared a single-phase model that included all 20 of the dates for the Badarian culture.

#### 4. Model outputs and discussion

Our Bayesian models provide an absolute chronology for the period in which we see the emergence of the Egyptian state. For the First Dynasty, where the density of samples was greatest, we produce hpd ranges of decadal-scale resolution that fix this sequence in absolute time. Our modelled estimates for the Badarian and Naqada periods provide a chronological basis for studying the rate of Egyptian state formation.

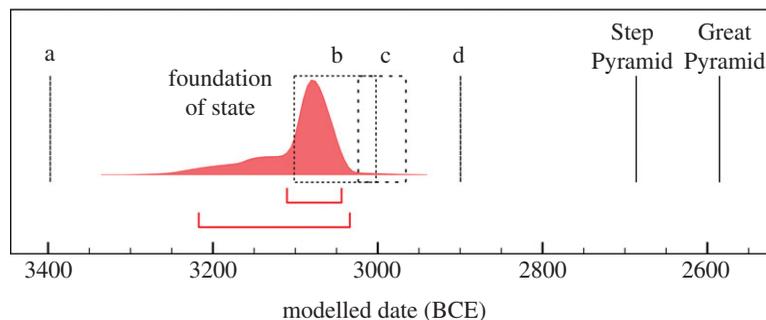
We propose that the absolute dates produced for transition points between reigns of the First Dynasty encompass the accession date of the incoming king (table 1 and figure 1*a*). Hence, our analysis generates a chronometric date for the foundation of Egypt (accession of king Aha) of 3111–3045 BCE (68% hpd range; median 3085 BCE) or 3218–3035 BCE (95% hpd range). The tail of this distribution to older ages is largely because of the shape of the radiocarbon calibration record in the late fourth millennium BCE, and the 68% hpd range is highly consistent across a number of alternative model configurations (see the electronic supplementary material, table S2). For example, we built a model based on the assumption that each king ruled for no longer than 100 years; it produced the narrower but congruent hpd ranges of 3096–3050 BCE (68%) and 3152–3032 BCE (95%).



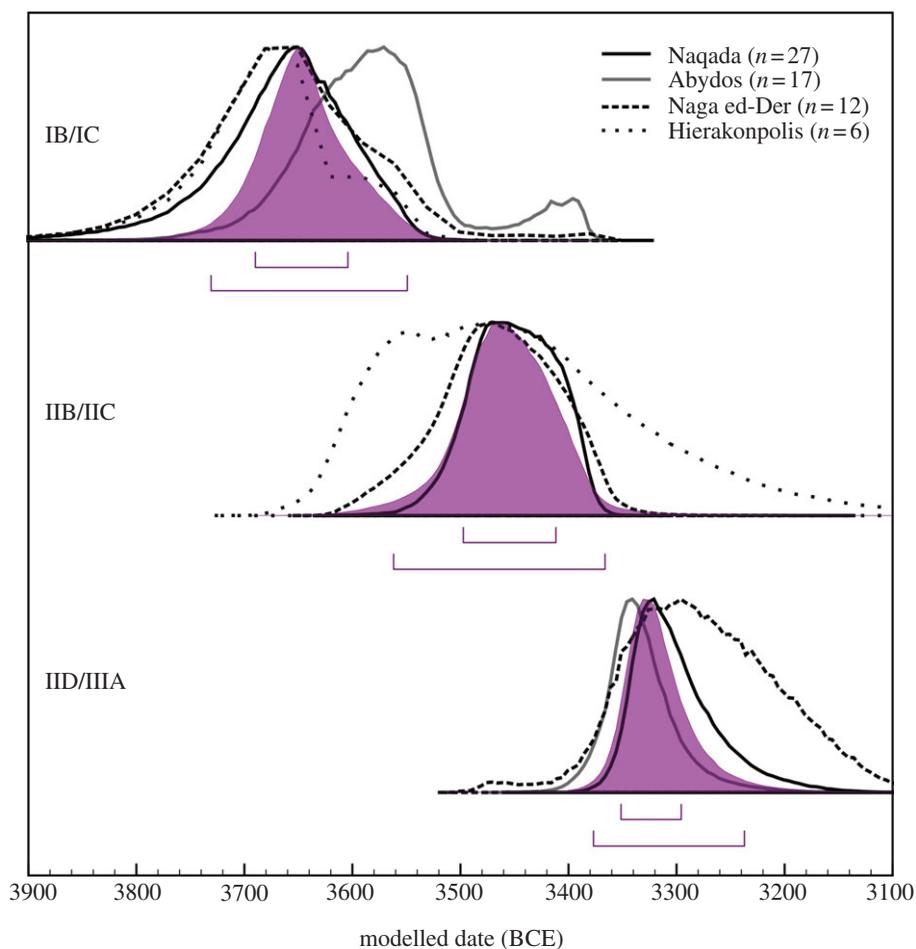
**Figure 1.** (a) Accession dates (first regnal year) obtained by this research for the first eight rulers of Egypt. (b) Intervals between the accession dates as indicated. In both cases (a,b), the marginal posterior density functions are shown with the corresponding 68% and 95% hpd ranges beneath. (Online version in colour.)

Significantly, our foundation date distinguishes between historical estimates (figure 2). Our First Dynasty model exhibits an average precision across all eight rulers of 32 calendar years (68% hpd range) or 79 years (95% hpd range). Such precision allows for more detailed interpretation than is ever possible from unmodelled radiocarbon data. Here, we suggest that the hpd ranges produced for the intervals between accession dates reflect the lengths of individual kings' reigns (figure 1b). This hypothesis concurs with the observation that the kings from Djer to Den have the largest tombs at Abydos, and Anedjib and Semerkhet much smaller scale monuments [27]. This profile of reign lengths persists across many variants of the First Dynasty model (see the electronic supplementary material, table S2). However, the strikingly long interval between kings Djer and Djet poses some difficulty (57–126 years (68%); 24–168 years (95%)). Djer's tomb is the largest at Umm el-Qaab, comprising some 318 subsidiary burials; hence the most parsimonious explanation may be that his reign lasted upwards of 50 years. However, the length of this interval could also be the result of a political hiatus or some other missing archaeological information.

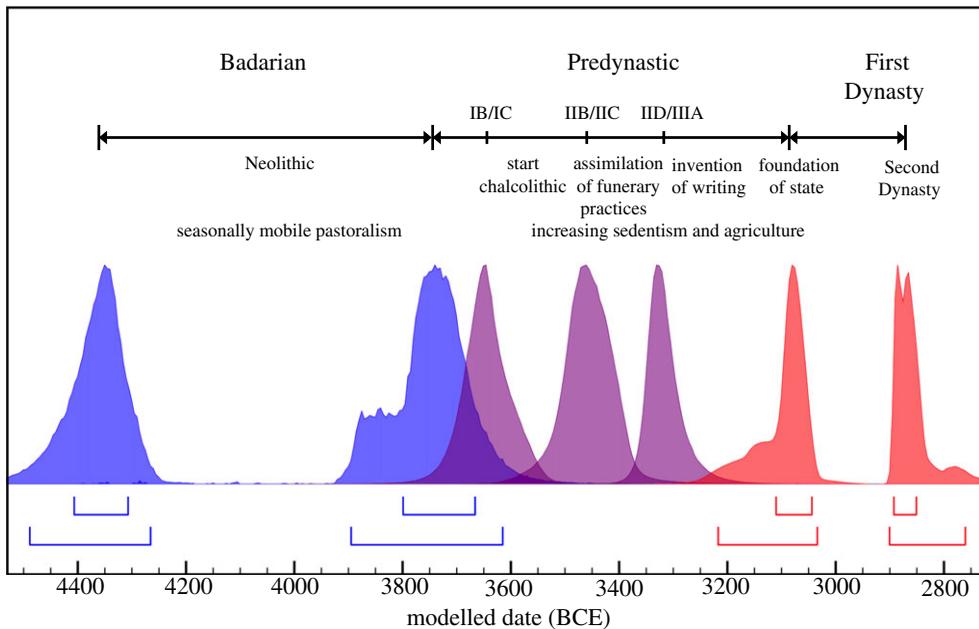
Our four site-based models for the Naqada period provide absolute dates for the key cultural transitions of the Egyptian Predynastic. The reduced levels of data mean the hpd ranges are significantly broader than those generated by the First Dynasty model (see the electronic supplementary material, table S3). Nonetheless, and in spite of the fact they were obtained from



**Figure 2.** The foundation date of Egypt (accession date of Aha, first king of the First Dynasty) obtained by this research. The date is given by the marginal posterior density function (shaded) with the corresponding 68% (3111–3045 BCE) and 95% (3218–3035 BCE) hpd ranges beneath. The median value is 3085 BCE. Alphabets a–d are historical estimates for the same event: (a) 3400 BCE [10]; (b) 3100–3000 BCE [12]; (c) 3032–2982 BCE [11] and (d) 2900 BCE [13]. The dates for the Step Pyramid and Great Pyramid are the accession dates taken from Kitchen [12] for the two kings to whom the monuments are attributed. (Online version in colour.)



**Figure 3.** The four Predynastic sites of UE modelled in this research returned coeval estimates for the pivotal transitions Naqada IB/IC, IIB/IIC and IID/IIIA. The modelled dates for each site are delineated as shown, and the averages are given by the shaded area with their 68% and 95% hpd ranges beneath. (Online version in colour.)



**Figure 4.** The sequence of events from the Badarian, through the Predynastic (Naqada period) to the establishment of the First Dynasty. The divisions are placed at the medians of each hpd range. (Online version in colour.)

independent site models, the modelled dates for the three transitions Naqada IB/IC, IIB/IIC and IID/IIIA all overlap at each site. Unfortunately, this outcome does not allow the geographical origin of each transition to be identified, so instead we chose to average the results (using the Sum function in OxCal) in order to summarize the situation across the region (see figure 3 and table 1). One of the salient features revealed is the shortness of the interval from IIB/IIC to IID/IIIA, which represents the period over which the assimilation of funerary practices took place between UE and LE. Our chronometric evidence suggests this period lasted only about five to six generations. The longer interval that follows, from Naqada IID/IIIA to the accession of Aha, denotes the period over which the country moved from cultural to political unification. It is during the early part of this period that writing is first attested in Egypt. Our dates for the beginning of Naqada IIIA centre on the late thirty-fourth century BCE (table 1) and coincide remarkably closely with the first evidence for cuneiform script in Mesopotamia [30].

The commencement of the Predynastic period in UE was characterized by a shift from seasonally mobile pastoralism to more sedentary life ways based on crop production [14]. Our date for the conclusion of the Badarian culture centres on the thirty-eighth century BCE, some 200–300 years later than previously thought [4,6,8]. This finding is corroborated by our date for the Naqada IB/IC transition—an independently obtained result that is also a matter of centuries later than many archaeological estimates [4,6]. Consequently, our data support a shortening of the Egyptian Predynastic, the period over which state formation occurred, to between 600 and 700 calendar years (table 1). This finding accentuates a contrast with neighbouring southwest Asia, where the transition from cereal production to state formation took somewhere between four and five millennia. It reinforces the suggestion that, despite their geographical proximity, prehistoric societies in Africa and Asia followed very different trajectories to political centralization.

A timeline summarizing the key absolute dates obtained by this research is given in figure 4. The findings amount to an extension of the absolute timescale for ancient Egypt back into the fourth millennium BCE. It is hoped that this new temporal patterning will lay the groundwork for archaeologists to reappraise this crucial period in socio-political history.

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