

Dating Knossos and the arrival of the earliest Neolithic in the southern Aegean

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Knossos, on Crete, has long been famous both for its Minoan period remains and for the presence, at the base of the stratigraphy, of an early Neolithic settlement. The chronology and development of the Neolithic settlement, however, have hitherto been unclear. New light is now thrown on this formative period by combining new and older radiocarbon dates with contextual information in a Bayesian modelling framework. The results from Crete and western Anatolia suggest that an earlier, small-scale Aceramic colonisation preceded the later Neolithic reoccupation of Knossos.

Keywords: Aegean, Knossos, Neolithic, early farmers, sea-faring, radiocarbon dating

New AMS ¹⁴C dates—discussion

In the framework of the current dating project, 14 new AMS determinations were produced (see Table 1 in the main text). Of these, 12 come from material collected during the 1997 excavations. Charcoal or charred seeds were selected after flotation and were subjected to Oxford's routine wet chemistry protocol (Acid-Base-Acid) prior to AMS ¹⁴C dating at ORAU. The new radiocarbon dates range from 7.8–6.1 ka ¹⁴C BP, or 7.0–5.0 ka BC.

The two remaining determinations were produced on charred *Triticum aestivum/durum* grains, which were found in Knossos Aceramic Stratum X (1959–1960 season) and studied by Hans Helbæk. There was no indication as to the exact provenance of the two dated seed samples other than the labels 'Knossos I' and 'Knossos II' on the sample bags. We know that Helbæk examined a large cache of grains (>3000 grains) from the Aceramic Neolithic Stratum X in trench AC of the Central Court. Some of these seeds were used in the 1960s to produce BM-436: 7740±140 BP. They were described as carbonised grains associated with a wooden stake from area AC, Pit F, layer 27 (Barker *et al.* 1969; Table S1). The two new AMS determinations (Beta-325102, Beta-325103) are identical to BM-436, but more precise, and support the idea that the dated wheat grains from Helbæk's collection belonged to the same grain cache he studied from Stratum X.

All determinations were calibrated using the IntCal13 calibration curve (Reimer *et al.* 2013). In order to evaluate how comparable are the old and new radiocarbon data, we constructed two separate Bayesian statistical models using the OxCal platform. The stratigraphic information available for each sample formed the prior information employed in the models. Different outlier models (General, SSimple, Charcoal) were used to assess how the dates conform to the overall archaeological stratigraphy.

In the first calibration and Bayesian modelling exercise (Figure 3 in the main text, Table S2) all dates from the 1997 excavations (new dates from recent sampling are printed in blue) were used to compile the Bayesian framework. Of the 29 determinations only 3 are deemed to be outliers in the model (OxA-28667, OxA-9219, DEM-660). OxA-28667 from level 37 relates to material recovered from a pit cutting through lower level 39, its age being identical to samples from level 39. OxA-9219, an oak charcoal sample, is *c.* 100 years older than the rest of the determinations from level 35, possibly affected by inbuilt age ('old wood' effect). DEM-660, a conventional determination is also too old for its context.

In the second model, 21 determinations from Evans' 1957–1960 and 1969–1970 excavations were used to build two separate sequences, the Central Court and the West Court series (Figure 4a & b in the main text, Table S3). These include 19 conventional dates and the 2 newly obtained AMS dates (printed in blue). Again the model is quite robust, identifying only one outlier

(BM-126). The two determinations (BM-278, BM-124) from the same wooden stake found at the bottom of trench AC in Stratum X (Pit F, Level 27) were statistically combined using the *R-Combine* function of OxCal, giving an uncalibrated weighed mean of 7964±111 BP. It has been suggested that these 2 determinations were affected by inbuilt age rendering them older by *c.* 100–200 years when compared to the short-lived seed material from the same context (e.g. Winder 1991; Reingruber & Thissen 2009). Therefore, BM-278 and BM-124 were modelled using the Charcoal outlier model (Dee & Bronk Ramsey 2014).

This function assumes that offsets due to inbuilt age, within a given phase, are distributed in an approximately exponential fashion. The correction, therefore, draws from a suitably scaled exponential function, and produces new estimates for the older samples that are more in line with their short-lived counterparts. The latter are relatively unchanged and act as anchors in the modelling process. Hence the start of the Aceramic phase is affixed in Evans' sequence by BM-436, as well as by the two indistinguishable new AMS dates from the cereal grains in Helbæk's collection (Beta-325102, Beta-325103). The latter are also statistically similar to the single determination (BM-272) from overlying Stratum IX.

Establishing the start of the subsequent EN I phase in the 1957–1960 excavations is problematic in the sense that the only available charcoal determination from Stratum IX (BM-272) is statistically identical to the grain-derived determination from Stratum X (BM-436). This parallels the situation with OxA-28667 from EN I level 37 which was identical to the ages derived from material from the lowermost Aceramic level 39. There are three possible explanations for this: i) older, intrusive material from the lowermost occupation (Stratum X and level 39) became mixed with material from the overlying phase (Stratum IX and levels 38 and 37) as a result of occupational or depositional disturbances, pit digging, burrows etc.; ii) Strata X and IX, level 39 and lower surface of level 38, are contemporary and belong to same occupational phase of the site; iii) the charcoal used to produce BM-272 from Stratum IX may be affected by a degree of inbuilt age (old wood effect). Evans (1994: 5) re-assigned the grain date BM-436 to Stratum IX, instead of X, as was originally described in the initial publication (Barker *et al.* 1969), but his reasons for doing so are unknown. This might have been an attempt to keep aside the earliest dates (BM-278 and BM-124) for the initial 'camp site' phase of Knossos and the somewhat younger grain date for overlying Stratum IX.

Table S1. Summary of previously available radiocarbon determinations from Neolithic Knossos. Material comes from trenches both in the West and Central Courts of the Minoan Palace. The calibration of the conventional radiocarbon dates was performed with the international calibration curve IntCal13 (Reimer *et al.* 2013) in OxCal v.4.2.4. Samples dated at the British Museum (lab code BM) and at the NCSR “Demokritos” Laboratory of Archaeometry (lab code: DEM) were measured using the conventional CO₂ techniques (gas proportion and liquid scintillation). Samples measured in the Oxford Radiocarbon Accelerator Unit (ORAU; lab code: OxA) were measured using Accelerator Mass Spectrometry. Original publications are specified next to the lab code: ^a Burleigh and Matthews (1982), ^b Burleigh *et al.* (1977), ^c Barker *et al.* (1969), ^d Barker & Mackey (1963), ^e Facorellis & Maniatis (2013). Table adopted and modified from Facorellis and Maniatis (2013).

LAB CODE	LOCATION	TYPE	COLL. YEAR	¹⁴ C AGE (yr BP)	±	δ ¹³ C (‰)	CALIBRATED AGE (yr BC)	
							68.2%	95.4%
WEST COURT								
BM-716 ^a	West Court, Sounding FF, Level 38, Sample 3 Final Neolithic	charcoal	1970	5003	213	-25.0	4045–3530	4330–3360
BM-579 ^b	West Court, Stratum II Late Neolithic	charcoal	1969	5534	76	n/a	4460–4330	4535–4240
BM-575 ^b	West Court, Stratum III/II Late/Middle Neolithic transition	charcoal	1969	5636	94	n/a	4555–4355	4705–4330
BM-580 ^b	West Court, Stratum III Late Middle Neolithic	charcoal	1969	5522	88	n/a	4460–4265	4555–4075
BM-717 ^a	West Court, Sounding EE Level 18, Sample 19; Late Neolithic	charcoal	1970	5806	124	-25.8	4795–4500	4950–4365
BM-718 ^a	West Court, Sounding EE Level 27, Sample 23; Level 34, Samples 27-29; Middle Neolithic	charcoal	1970	5892	91	-24.5	4905–4615	4995–4540
BM-719 ^a	West Court, Sounding AA/BB Level 164, Sample AR (IA); Level 174, Sample AY (IA); Level 181, Sample BA (IA); Level 183, Sample BI (IA); Early Neolithic II	charcoal	1970	5967	41	-24.4	4910–4790	4950–4725

SUPPLEMENTARY MATERIAL

LAB CODE	LOCATION	TYPE	COLL. YEAR	¹⁴ C AGE (yr BP)	±	δ ¹³ C (‰)	CALIBRATED AGE (yr BC)	
							68.2%	95.4%
BM-1371 ^a	West Court, Sounding AA/BB Level 272, Sample CW (II); Level 277, Sample CY (II); Early Neolithic I	charcoal	1970	6201	252	-24.7	5465–4845	5625–4580
BM-1372 ^a	West Court, Sounding AA/BB Level 279, Samples CM, DF, DG (II); Level 286, Sample CL (II) Early Neolithic I	charcoal	1970	6482	161	-24.3	5615–5305	5720–5065
CENTRAL COURT								
BM-581 ^b	Central Court, Stratum II Late Neolithic	charcoal	1969	5588	145	n/a	4615–4265	4770–4055
BM-279 ^c	Central Court, Sample 6, Stratum IV Charcoal sample from Upper Neolithic level	charcoal	1960	5680	150	n/a	4690–4365	4905–4235
BM-577 ^b	Central Court, Stratum IV Late Early Neolithic Neolithic II	charcoal	1969	5884	188	n/a	4990–4535	5220–4360
BM-274 ^c	Central Court, Sample 4, Area A, Level 15, Stratum V Charcoal from habitation level	charcoal	1960	6140	150	n/a	5295–4855	5465–4720
BM-126 ^d	Central Court, Sample 5, Pit F, Area A, Level 16A, Stratum V Near the top of the Early Neolithic levels	charcoal	1960	7000	180	n/a	6045–5715	6235–5560
BM-273 ^c	Central Court, Sample 3, Area AC, Level 17, Stratum VI Charcoal from habitation deposit.	charcoal	1960	6210	150	n/a	5325–4960	5475–4800
BM-272 ^c	Central Court, Sample 2, Area AC, Level 24, Stratum IX From occupation layer associated with 1st brick houses and immediately overlying earliest camp occupation above bedrock Early Neolithic I	charcoal	1960	7570	150	n/a	6590–6250	6755–6070

SUPPLEMENTARY MATERIAL

LAB CODE	LOCATION	TYPE	COLL. YEAR	¹⁴ C AGE (yr BP)	±	δ ¹³ C (‰)	CALIBRATED AGE (yr BC)	
							68.2%	95.4%
BM-436 ^c	Central Court, Sample 1, Pit F, Area AC, Level 27, Stratum X Found in association with wooden stake (BM-278 & BM-124) Aceramic Neolithic	charred grains (cf. <i>T. aestivum</i>)	1960	7740	140	n/a	6770–6435	7045–6370
BM-278 ^c	Central Court, Sample 1, Pit F, Area AC, Level 27, Stratum X Remains of carbonized wooden stake Aceramic Neolithic	charcoal	1960	7910	140	n/a	7030–6645	7175–6470
BM-124 ^d	Central Court, Sample 1, Pit F, Area AC, Level 27, Stratum X Remains of carbonized wooden stake lowest level above bedrock Aceramic Neolithic	charcoal	1960	8050	180	n/a	7250–6690	7490–6570
DEM-638 ^e	Central Court, Knossos-6, trench II, layer 9 Depth 2.00 m	charcoal	1997	6223	120	–25.0	5320–5025	5470–4855
DEM-640 ^e	Central Court, Knossos-10, trench II, layer 12 Depth 2.20 m	charcoal	1997	5980	43	–25.0	4935–4800	4990–4745
DEM-641 ^e	Central Court, Knossos-12, trench II, layer 13 Depth 2.40 m	charcoal	1997	6134	116	–25.0	5225–4910	5330–4780
DEM-642 ^e	Central Court, Knossos-13, trench II, layer 14 Depth 2.50 m	charcoal	1997	5977	36	–25.0	4930–4800	4975–4770
DEM-658 ^e	Central Court, Knossos-20, trench II, layer 24 Depth 3.95 m	charcoal	1997	6106	40	–25.0	5200–4955	5210–4935
DEM-659 ^e	Central Court, Knossos-22, trench II, layer 28 Depth 4.15 m	charcoal	1997	5991	55	–25.0	4945–4800	5010–4725
OxA-9221 ^e	Central Court, Knossos-7, trench II, layer 28/2 Depth 4.15 m	charcoal (<i>Quercus</i> evergreen type)	1997	6042	34	–25.0	4995–4855	5035–4840

SUPPLEMENTARY MATERIAL

LAB CODE	LOCATION	TYPE	COLL. YEAR	¹⁴ C AGE (yr BP)	±	δ ¹³ C (‰)	CALIBRATED AGE (yr BC)	
							68.2%	95.4%
DEM-660 ^e	Central Court, Knossos-23, trench II, layer 29 Depth 4.25 m	charcoal	1997	7339	57	-25.0	6250–6095	6365–6070
OxA-9218 ^e	Central Court, Knossos-4, trench II, layer 29/4 Depth 4.25 m	charcoal (<i>Quercus</i> evergreen type)	1997	5990	50	-23.3	4945–4800	5005–4725
DEM-670 ^e	Central Court, Knossos-24, trench II, layer 30 Depth 4.50 m	charcoal	1997	5801	151	-25.0	4835–4485	5025–4345
DEM-661 ^e	Central Court, Knossos-25, trench II, layer 31 Depth 4.90 m	charcoal	1997	6213	65	-25.0	5295–5060	5315–5000
DEM-663 ^e	Central Court, Knossos-26, trench II, layer 32 Depth 5.80 m	charcoal	1997	6154	30	-25.0	5210–5045	5215–5015
OxA-9220 ^e	Central Court, Knossos-6, trench II, layer 32/2 Depth 5.80 m	charcoal (<i>Quercus</i> evergreen type)	1997	6160	50	-22.5	5210–5050	5290–4955
OxA-9217 ^e	Central Court, Knossos-3, Trench II, layer 33/7 Depth 6.50 m	charcoal (<i>Quercus</i> evergreen type)	1997	6145	50	-24.0	5210–5025	5220–4945
OxA-9219 ^e	Central Court, Knossos-5, trench II, layer 35/2 Depth 7.10 m	charcoal (<i>Quercus</i> evergreen type)	1997	6361	37	-22.7	5460–5300	5470–5230
OxA-9216 ^e	Central Court, Knossos-2, trench II, layer 37/16 Depth 7.40 m	charcoal (<i>Quercus</i> evergreen type)	1997	6185	50	-23.2	5215–5055	5295–5000
OxA-9215 ^e	Central Court, Knossos-1, trench II, layer 39/1 Depth 7.80 m	charcoal (<i>Quercus</i> deciduous type)	1997	7965	60	-24.3	7035–6775	7050–6685

Table S2. Calibrated and modelled ages for the radiocarbon determinations obtained on material from the 1997 excavations at the Central Court of Knossos and included in the Bayesian framework presented in Figure 3 in the main text.

Dates/Phases	Calibrated and modelled age ranges (yr BC)	
	68.2%	95.4.2%
Central Court 1997		
<i>End boundary Level 9</i>	4920–4830	4960–4760
DEM-638 (6223±120)	4930–4840	4950–4790
DEM-640 (5980±43)	4930–4850	4950–4810
DEM-641 (6134±116)	4940–4860	4960–4830
DEM-642 (5977±36)	4950–4880	4960–4840
DEM-658 (6106±40)	4960–4890	4970–4850
Levels 24-9 (sequence) Early Neolithic II & Middle Neolithic		
<i>Transition boundary Level 28 to 24</i>	5000–4900	4990–4850
OxA-9221 (6042±34)	4980–4910	5000–4870
DEM-659 (5991±55)	4980–4910	5000–4870
Level 28 Early Neolithic II		
<i>Transition boundary Level 29 to 28</i>	5000–4920	5030–4880
OxA-9218 (5990±50)	5010–4940	5050–4910
DEM-660 (7339±57) (<i>outlier</i>)	5030–4950	5060–4910
Level 29 Early Neolithic II		
<i>Transition boundary Level 30 to 29</i>	5060–4980	5100–4930
DEM-670 (5801±151)	5060–4990	5100–4950
DEM-661 (6213±65)	5070–5010	5110–4980
DEM-663 (6154±30)	5080–5020	5120–5000
OxA-9220 (6160±50)	5080–5020	5130–5000
OxA-28414 (6103±33)	5090–5030	5140–5010
OxA-9217 (6145±50)	5100–5040	5150–5020
Levels 33-30 Early Neolithic I		
<i>Transition boundary Level 35 to 33</i>	5110–5040	5220–5020
OxA-28382 (6207±34)	5150–5070	5240–5050
OxA-21420 (6210±38)	5150–5070	5240–5050
OxA-28415 (6276±34)	5150–5070	5260–5060
OxA-9219 (6361±37) (<i>outlier</i>)	5150–5070	5340–5040
Level 35 - Early Neolithic I		
<i>Transition boundary Level 37 to 35</i>	5180–5100	5200–5070
OxA-21419 (6075±45)	5210–5150	5220–5080
OxA-9216 (6185±50)	5210–5130	5290–5080
OxA-28381 (6157±32)	5210–5140	5220–5090
OxA-28667 (7704±37) (<i>outlier</i>)	5220–5130	5350–5080
Level 37 – Early Neolithic I		
<i>Transition boundary Level 38 to 37</i>	5260–5150	5500–5080
<i>End boundary Level 39</i>	6620–6470	6640–6280

Dates/Phases	Calibrated and modelled age ranges (yr BC)	
	68.2%	95.4.2%
OxA-21418 (7735±40)	6640–6550	6650–6490
OxA-28380 (7729±37)	6640–6550	6650–6490
OxA-28416 (7786±36)	6650–6590	6690–6560
OxA-28417 (7821±37)	6670–6600	6700–6580
OxA-31963 (7823±37)	6670–6600	6710–6580
OxA-9215 (7965±60)	6740–6600	6890–6560
Level 39 – Aceramic		
<i>Start boundary Level 39</i>	6790–6620	6970–6590

Table S3. Calibrated and modelled ages for the radiocarbon determinations obtained on material from the earlier excavations by Evans (1957–1960 and 1969–1970) in the Central and West Courts of Knossos, respectively. The determinations were included in the Bayesian framework presented in Figure 4.

Dates/ Phases	Calibrated and modelled age ranges (yr BC)	
	68.2%	95.4%
Knossos West Court 1969-70		
<i>End boundary FN</i>	4340–3800	4430–3230
BM-716 (5003±213)	4360–3910	4420–3660
Final Neolithic		
<i>Transition boundary LN to FN</i>	4430–4250	4500–4000
BM-579 (5534±76)	4440–4340	4500–4260
BM-717 (5806±124)	4470–4340	4540–4270
Late Neolithic		
<i>End boundary MN or LN</i>	4490–4370	4570–4330
BM-580 (5522±88)	4530–4410	4620–4360
BM-575 (5636±94)	4550–4410	4650–4360
Middle Neolithic or Late Neolithic		
<i>Transition boundary MN to MN-LN</i>	4640–4440	4770–4400
BM-718 (5892±91)	4800–4610	4860–4530
Middle Neolithic		
<i>Transition boundary EN II to MN</i>	4890–4710	4940–4590
BM-719 (5967±41)	4920–4800	4990–4760
Early Neolithic II		
<i>Transition boundary EN I to EN II</i>	5130–4830	5380–4790
BM-1371 (6201±252)	5350–4980	5510–4860
BM-1372 (6482±161)	5460–5040	5580–4900
Early Neolithic I		
<i>Start boundary EN I</i>	5570–5080	5890–4860

Dates/ Phases	Calibrated and modelled age ranges (yr BC)	
	68.2%	95.4%
Knossos Central Court 1957-1960		
<i>End boundary Stratum II</i>	4590–4190	4750–3750
BM-581 (5588±145)	4600–4330	4740–4160
Stratum II- Late Neolithic		
<i>Transition boundary Stratum IV to II</i>	4700–4420	4840–4290
BM-279 (5680±150)	4790–4530	4930–4420
BM-577 (5884±188)	4840–4560	5000–4450
Stratum IV – Early Neolithic II		
<i>Transition boundary Stratum V to IV</i>	5020–4670	5210–4530
BM-274 (6140±150)	5180–4850	5320–4740
BM-126 (7000±180)	5220–4820	5780–4660
Stratum V - Late Early Neolithic I		
<i>Transition boundary Stratum VI to V</i>	5330–4950	5890–4770
BM-273 (6210±150)	5470–5100	6000–4900
Stratum VI – Early Neolithic I		
<i>Start boundary VI</i>	5770–5140	6240–5030
<i>End boundary Stratum IX</i>	6490–6010	6550–5520
BM-272 (7570±150)	6510–6280	6570–6120
Stratum IX – Earliest Early Neolithic I (?)		
<i>Transition boundary Stratum X to IX</i>	6560–6440	6600–6340
Beta-325103 (7690±40)	6590–6500	6610–6460
Beta-325102 (7740±40)	6600–6500	6630–6480
BM-436 (7740±140)	6600–6490	6690–6430
BM-124 (8050±180)	n/a	n/a
BM-278 (7910±140)	n/a	n/a
Carbonized wood (Mean: 7964±111)	6610–6490	6750–6400
Stratum X - Aceramic		
<i>Start boundary Stratum X</i>	6660–6520	6910–6480

Table S4. Calibrated and modelled age ranges for the start of the earliest Neolithic layers at three Anatolian (Çukuriçi, Barcin, Ulucak) and three Greek sites (Knossos, Franchthi and Mavropigi) mentioned in the main text. The age ranges result from the Bayesian modelling of all published determinations from the respective sites. The probability distributions associated with these age ranges are shown in Figure 6.

<i>Start boundaries for the earliest Neolithic phase</i>	<i>Calibrated and modelled age ranges (yr BC)</i>	
	68.20%	95.40%
Çukuriçi - Start XIII	6560–6470	6660–6460
Barcin - Start VIe	6620–6510	6690–6480
Ulucak - Start VI	6770–6680	6840–6660
Mavropigi –Start Phase I	6650–6490	6820–6460
Franchthi - Start IN	6690–6610	6740–6560
Knossos 1957-1960 C. Court - Start X	6660–6520	6910–6480
Knossos 1997 - Start 39	6790–6620	6970–6590
Knossos Start X & 39 Combined	6710–6610	6810–6590

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