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Case study

Radiocarbon dating of Kastrouli settlement: A critical assessment

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ABSTRACT

The Kastrouli Late Mycenaean/Helladic settlement in Phokis near Delphi has produced extremely significant data since its inception in 2016, that has enriched our knowledge of the peripheral Mycenaean world. New radiocarbon dating data are presented and critically assessed with earlier reports concerning the span of the habitation and its later reuse. Five new dates are presented and modelled by Bayesian statistical analysis and critically discussed along with other radiocarbon (^{14}C) and both optically stimulated luminescence (OSL) and thermoluminescence (TL) dates (a total of 22) from the site. When considering the 95% probability range, there are two charcoal dates from Building 1 with ranges from 1411 to 1128 (calibrated) BC. For Building 2 the dates span between 1447 and 1281 BC, also if the limits of range are considered. The two dates on the burnt wood base of Building 2 suggest an earlier date ca.1440-1300 BC (Phase A), and a charcoal sample in the floor of building 1 suggests a later range of ca.1290 to 1130 BC (Phase B) same with a human femur bone from tomb A 1382-1221 BC. Phase A (part of the new ages) falls well within the Late Helladic era LH III B/C. Phase B includes also five radiocarbon ages of the bones from Tomb A which were about the same span of 1360-1112 BC (LH III B/C), concordant with archaeological typology. These ^{14}C set of dates are expected as they derive from a comingled burial. The lower 95% probability boundary of ^{14}C ages corresponds to middle LH III C interval. Long calibrated age ranges are largely a product of wiggles in the calibration period for the period concerned, suggesting that any desired accuracy less than at least a century is unattainable. The results of OSL/TL and radiocarbon have wide enough uncertainties to allow that Kastrouli may have been occupied throughout the LH III B-C eras, and it is confirmed that the tomb was reused sometime during the Sub-Mycenaean, Geometric and later eras.

1. Introduction

In the Phokis region of central Greece, not far from Delphi, is the small, fortified site called Kastrouli (N 38º 23′ 56.7″, E 22º 34′ 30″, 550 m asl). It is close to the modern town of Desfina. The site's boundaries are defined by a former fortress wall that surrounds a space of about 17,000 m^2, with abundant pottery sherds and other archaeological artifacts. In Greece, the Late Bronze Age (c. 1300–1100 BC), often referred to as the "Mycenaean" or Late Helladic III B–C, is noted for epic sagas like the Trojan War. It appears that Kastrouli was a significant fortified centre at that time. It was situated in a prime spot with views of the Corinthian Bay. A comprehensive and detailed interdisciplinary analysis has resulted in the publication of numerous archaeological and archaeometrical data from the site [1,2].

Previously overseen by the University of the Aegean (2016-2020), the Kastrouli Archaeological Project is currently being carried out under the direction of the Euphoria of Antiquities of Phokis. The research has already uncovered surprising discoveries, including cyclopean walls, Mycenaean clay figures, stirrup jars, ceramics, metal artifacts, and colossal, defensive walls and large buildings that may be part of a small Mycenaean administrative building or palace [3–6].

According to surface discoveries at Kastrouli, the settlement system may indicate that a transition from central citadels into community clusters has occurred. Kastrouli is a relatively independent town on the outskirts of important Mycenaean palatial centres due to the evidence of using local clay for pottery production

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Table 1a
Sampling details and radiocarbon dating results of the new samples that were measured in the framework of present study. (#Collagen yield is presented only for the case of bone samples. For the charcoal samples the percentage of the combusted carbon is presented only for the case of the samples measured at DEM).

Laboratory code	Sampling description	Age ^{14}C (BP)	δ^{13}C (‰)	Sample type	C combusted/ Collagen yield (%)#	Calibrated Age (BC)	Probabilities
DEM – 2733	Building 2, 20/7/2018, C3, UNIT 10, PB#141, G10	3103 ± 30	-26.2	Burnt wood charcoal base of burnt roof beam	78.1	1436 – 1281	(95.4%)
DEM – 2803	Building 1, (Fig. 15 Sideris & Liritzis 2018) this was found north of the south/southwest exterior wall of the building in 2017.	3058 ± 30	-23.4	Burnt wood charcoal	79.3	1411 – 1256 1248 – 1226	(90.3%) (5.2%)
UCIAMS - 253532	KAS-B2-2018 Building 2, 20/7/2018, C3, UNIT 10, PB#141, G10	3135 ± 15	-	Burnt wood charcoal base of burnt roof beam	-	1447 – 1386 1339 – 1319	(86.1%) (9.3%)
UCIAMS - 253533	KAS-B1-2017 Building 1, 30/7/2017, Interior, 3.2 m from west, 3.70 m from south, 20 cm from the surface ground (at the east)	2995 ± 15	-	Burnt wood charcoal	-	1368 – 1359 1285 – 1191 1181 – 1158 1145 – 1128	(1.2%) (83.3%) (5.6%) (5.4%)
UCIAMS - 253541	KAS2-TA-2016 From Tomb A comingled burial, human bone, has 7% collagen from earlier data on bone diagenesis (Kontopoulos et al., 2019)	3030 ± 15	-	Femur Bone, Human	4.6	1382 – 1343 1308 – 1221	(25.7%) (69.8%)

[7], the presence of marine food diet [3], engineering hydraulic works [1,8], the development of husbandry and livestock, as well as a healthy oral dental status [9,10]. Understanding the function and intensity of their relationship depends on how Kastrouli interacted with the surrounding palaces at Boeotia and farther out in the Corinthian Gulf. Given the optimal geographical circumstances for supra-regional interactions, mobility, and trade, the Phokis region should be seen as a hub of cultural interaction and a melting pot of

Despite having very high archaeological potential, additional research concerning the chronology of the hillock's usage and subsequent reuse in the Kastrouli town is still necessary. Until recently limited attempts at dating were undertaken for this important Mycenean settlement, driven and triggered by an initial evaluation of scattered finds [11] and as a prerequisite part of ancient DNA investigation [8,12]. The present case study presents new data and revisits the widely discussed final stage of Late Bronze Mycenaean period in Kastrouli near Delphi, Central Greece in the periphery of Mycenae.

2. Research aim

In an effort to better understand the chronology of the site, the present study presents, for the first time, an assessment of the chronological context of Kastrouli's occupation, based on new radiocarbon dates on charcoal and bones discussed in relation to the archaeological typological work of the excavated artifacts. As in dating studies comparison with previously calculated results is essential, available dates by both radiocarbon [12,13] and stimulated luminescence dating of pottery and rock artifacts [13,14] will be also considered, included and compared. In total, twelve (12) ^{14}C dates along with five (5) ages of ceramics and five (5) surface OSL dating of stone, are critically discussed. All dating samples, including both new and previously dated samples, were collected from two Late Helladic Tombs (A and B) and two Buildings at Kastrouli. The methodological approach aims towards high precision dating and absolute chronological baselines for both the chronology and the human activity of the Kastrouli settlement while contending with the problematic plateaus in the radiocarbon calibration curve for the period concerned (15th century BC).

3. Samples and techniques

Six (6) new, fresh samples were collected from the three excavation periods for ^{14}C dating measurements. These are two human bones from comingled burial of Tomb A (see [3–5]) and four charcoal samples (see [3,4,6]). From these five were accepted because one bone did not produce adequate collagen quantity. The four charcoals derive from the locations inside of building 1 and 2; two from burnt base roof beams that represent a final destruction phase and in Building 1 another one from a burnt layer near the southern wall (Map 1 and Table 1a).

Two charcoal samples, each one of approximate mass 6 grams, were collected and processed at the radiocarbon Unit of the Laboratory of Archaeometry, NCSR "Demokritos" (code DEM-), which uses the Gas Proportional Counting technique (GPC). This technique involves turning the sample into carbon dioxide (CO_2) gas and detecting the radioactivity through the beta particles that are released when the ^{14}C atoms decay in cylindrical gas proportional counters [15]. The pretreatment that was applied includes the following steps [16]: 1) mechanical cleaning to remove all readily visible non-charcoal particles from the sample; 2) light grinding of the charcoal to smaller particles; 3) immersion of the samples in an HCl acid solution at 4% concentration at 80°C while stirring for at least 30 minutes and as long as required to dissolve any carbonates from the soil present; 4) subsequent immersion of the samples to 4% NaOH solution, followed by prolonged stirring, for at list 14 hours at room temperature; 5) a new immersion of the samples into a 4% solution of HCl acid at 80°C and stirring for more than an hour. Finally, the samples were then neutralized with deionized water and dried in an oven at 90°C. Steps 3 to 5 consist of an acid-base-acid (ABA hereafter) procedure. After drying, all samples were burned in a de Vries-style continuous combustion system to produce gas CO_2 [16]. By reacting with $KMnO_4$, all other oxides were eliminated, and the CO_2 was then precipitated as calcium carbonate in a $CaCl_2/NH_4$ solution. As a result, the samples

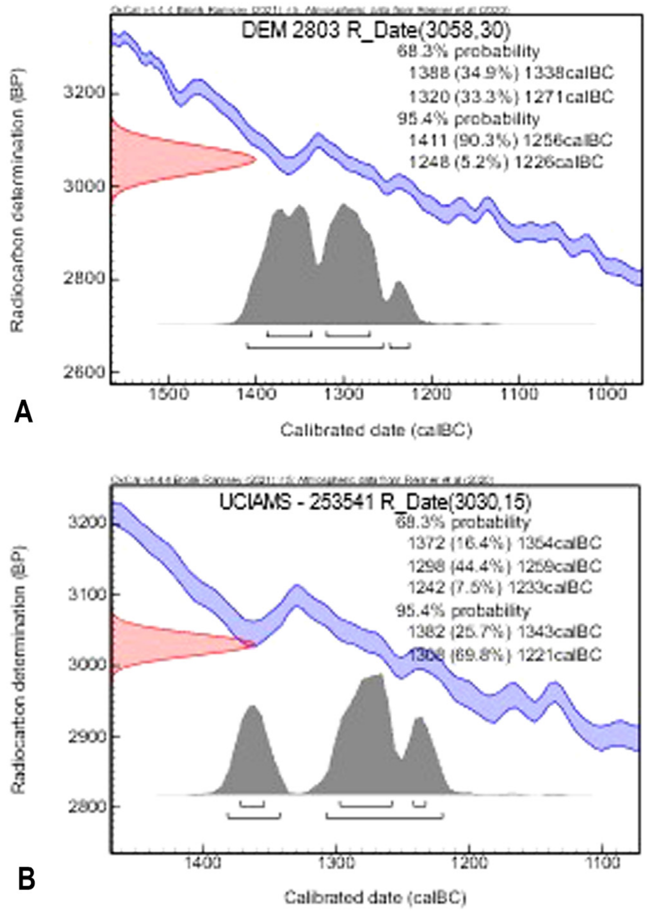


Fig. 1. Radiocarbon age Calibration examples for a selected sample that was measured in two different laboratories.

were once more converted to CO_2 by HCl acid treatment. The sample was run through an activated charcoal column held at 0°C in the final purification phase to eliminate the gas' contaminants [17]. Finally, each sample's mass was set to a preset value before being measured in the counters [16]. Both samples were successfully dated.

The four (4) remaining samples include two human bone samples from Tomb A along with two additional charcoal samples. Due to their corresponding low mass, these were processed at the KECK Carbon Cycle AMS Facility, Earth System Science Department, in UC Irvine, USA (code UCIAMS), which uses the Accelerator Mass Spectrometry (AMS) technique. For the case of the charcoal samples, a modified ABA procedure (steps 3 to 5) was applied, using 1N NaOH and 1N HCl at 75°C prior to combustion and graphitization. The time and intensity of the treatment varied depending on how fragile the material was. There was an ultra-pure water rinse after each acid or base wash. Following the final cleaning, the samples were dried in an oven at 100°C before combustion to CO_2 and subsequent graphitization. The bone samples were cut into roughly equal 1 cm long pieces. The spongy material and any encrustations were scraped away with a lancet. The samples were then washed with deionised water and put in an ultrasonic bath to remove soil or dirt precipitations. Bone samples were further decalcified in 1N HCl, gelatinized at 60°C and pH 2, and subjected to ultrafiltration to select a high molecular wt fraction (>30 kDa). The extracted material in all cases was then transformed into graphite targets using an automated graphitization equipment. After the first treatment and combustion it was realised that one of the two bone samples was not suitable for dating, as it did not produce enough collagen; in fact, the collagen yield, namely the ratio of the collagen weight over the weight of the total bone's mass was less than 1%. The other bone sample along with the two charcoal samples, namely three samples in total, were fine and were successfully dated.

All ^{14}C ages were calibrated to calendar ages with the IntCal20 calibration curve [18]. Only DEM results have been corrected for isotopic fractionation according to the conventions of Stuiver and Polach [19], with $\delta^{13}C$ values. For the cases of AMS measurements, the $\delta^{13}C$ values measured on the prepared graphite are not accurate; therefore, these are not reported in the corresponding Tables. Nevertheless, besides the five (5) new ^{14}C dates, a number of additional absolute ages were also used. These include a) six different radiocarbon ages that were very recently reported by Lazaridis et al. [12], in a comparative study on the ancient DNA data from 727 individuals of the Southern Arc area, namely Anatolia and its neighbours in South-eastern Europe and West Asia over the past 11,000 years; b) one radiocarbon age in conjunction to three optically stimulated luminescence (OSL) ages, from three pottery fragments that were reported by Liritzis et al. [11]; and c) seven stimulated luminescence (either thermoluminescence, TL or OSL) ages of ceramic and stone samples that were collected from the settlement at Kastrouli and have been previously reported by Liritzis et al. [14]. Among these, five stone fragments were dated using the surface optical luminescence dating [13,20,21]. A total of twenty-two dates will be discussed in the present study. For an extended explanation of the optical stimulated luminescence methodologies that were applied, the readers could refer Liritzis et al. [14]. For reasons of clarity, the radiocarbon ages that are the subject of the present study are divided into two distinctive groups. The first one, hereafter Group A, consists of 5 ages that are reported for the first time in the literature. The rest 7 ^{14}C bone ages together with 10 luminescence ages of ceramic and stone that were previously reported but were not discussed in a summary chronological framework belong to Group B (presented in Table 1b and the luminescence dates in Table S1 of the **Supplementary**).

4. Experimental results

Tables 1a, b and Table S1 (supplementary) present all new and earlier data that is related to archaeometric ages; for charcoal and bones by ^{14}C as well as ceramics and stone by stimulated luminescence (OSL/TL). As Table 1a also reveals, two different charcoal samples of same spot in Building 2 were measured in two different radiocarbon laboratories. The results provide a validity check on the radiocarbon ages from the two charcoal samples. The two samples come from same location but due to severe ploughing in the past in this in general shallow infill plateau of the settlement, it is not certain if the samples define the same firing event. Thus, we prefer to plot them as two independent ages in Figs. 2 and 4. Fig. 1 presents such an example of radiocarbon age comparison, following calibration according to the most recent dataset of 2020 [18], using the OxCal calibration software v.4.4.4 [22] for the charcoal sample that was collected from Building 1 (C3/Unit 10/G-10). All calibrated ages, given within 2σ confidence levels, are presented in Tables 1a, b for Groups A and B respectively. The same tables, besides the given ages, do present details on the archaeological context of the excavated site. In cases where the calibrated dates (at 95.4%) are multi-modal, namely indicate multiple separate distribution peaks, Tables 1a, b present all individual ranges instead of the entire span. Table S1 (supplementary) presents the mandatory information required for the stimulated luminescence ages of five pottery and five stone samples that were all collected from the same settlement.

Table 1b
Additional radiocarbon dating results for samples collected from the same site that already exist in the related literature. Carbon and nitrogen isotopic data are measured by Elemental analyzer isotope ratio mass spectrometry (EA-IRMS). None of the $\delta^{13}C$ values are significantly depleted and the nitrogen values are consistent with isotopic values from Greece for C3 plants. The $\delta^{13}C$ values could indicate even a small marine contribution, and the somehow elevated $\delta^{15}N$ values could also be caused by the consumption of high trophic-level food, or manured plant food, or other environmental/physiological parameters such as drought.

Laboratory code	Sampling description	Age ^{14}C (BP)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	Collagen yield (%)	Sample type	Calibrated Age (BC)	Probabilities	Reference
PSUAMS – 6186 (KS-T2B)	Late Helladic Tomb A	3045 ± 25	10.31	-18.94	3.2	Femur Bone, Human	1397 - 1222	(95.4%)	Lazaridis et al. [12]
PSUAMS – 6187 (KS-T2C)	Late Helladic Tomb A	3015 ± 20	8.92	-18.90	3.3	Femur Bone, Human	1382 – 1342 1308 – 1198	(14.8%) (79.8%)	Lazaridis et al. [12]
PSUAMS – 6809 (KAS-4)	Late Helladic Tomb A	2975 ± 25	9.08	-19.45	3.6	Femur Bone, Human	1367 – 1360 1285 – 1112	(0.4%) (95.0%)	Lazaridis et al. [12]
PSUAMS – 6823 (KAS-10)	Late Helladic Tomb A	2990 ± 25	8.93	-18.90	3.2	Femur Bone, Human	1371 – 1356 1295 – 1123	(2.7%) (92.7%)	Lazaridis et al. [12]
PSUAMS – 7560 (KS-T1-4)	Late Helladic Tomb A	3030 ± 20	8.73	-19.10	3.2	Femur Bone, Human	1386 – 1339 1316 – 1217	(27.1%) (68.4%)	Lazaridis et al. [12]
PSUAMS – 7825	Tomb B	2500 ± 20	10.1	-19.00	3.4	Femur Bone, Human	773 – 725 703 – 662 651 – 544	(18.7%) (18.5%) (58.3%)	Lazaridis et al. [12]
DHS – 6605	Tomb A/B?	2584 ± 26	–	-22.10	-	Femur Bone (right), Human	810 – 757 680 – 671 606 – 597	(92.8%) (1.3%) (1.3%)	Liritzis et al. [11]

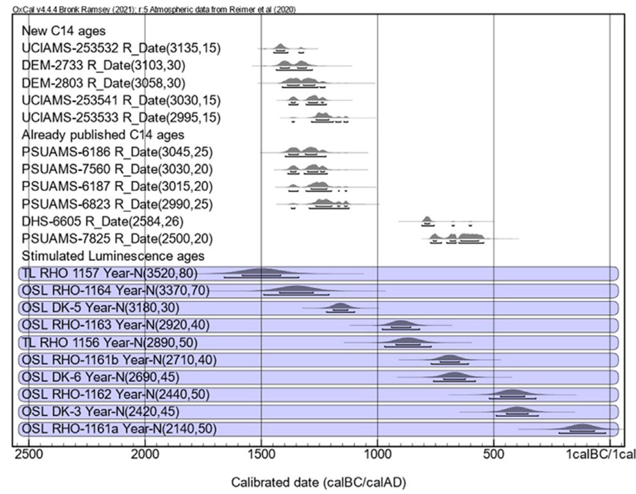


Fig. 2. Unmodelled radiocarbon ages for all charcoal and bone samples; stimulated luminescence ages of pottery, stone and wall samples are also presented for the sake of comparison.

5. Discussion

Fig. 2 presents all unmodeled ages within the framework of the present study, namely 12 radiocarbon and 10 stimulated luminescence ages. All 5 new calculated radiocarbon ages of Group A (Fig. 2) range well between 1411 and 1128 (calibrated) BC, falling well within the Late Helladic era, and specifically a later part within the LH III B2 / LH III C (early) (1290 to 1130 BC) and the earlier part within early LH III A1/early LH III B (1447-1281 BC) (See [8] and p.6 from [23]). Moreover, one of the samples (UCIAMS – 253533, Building 1) also extends to as late as 1128 cal. BC, right within the LH III C. The relatively large errors that are associated with these ages imply that Kastrouli could have been active during the LH II B through LH III A2 to middle LH III C periods as well [24,25]. Similar ages were also revealed for 5 radiocarbon ages from Group B as well as some among the stimulated luminescence ages from [11,12,14]. The charcoal samples of the two burnt probably roof wooden beams from the two buildings indicate same firing event with a range ~1300-1440 BC considering the 95% probability span falling within the earlier part. The age of bones from Tomb A falls within the later span.

The relatively large errors of the radiocarbon are directly attributed to the shape of the calibration curve. According to Fig. 1, this curve indicates a wiggle within the calibrated age range between 1400 and 1300 (calibrated) BC. For ^{14}C conventional dates within the range 3200-3000 BP due to the wiggle at 3190 & 3040 BP and in the later age span 2940 to ~2900 BP, attributed once again to wiggle, the induced probability confidence limits for the calibrated ages span at least over one century. Hence in Fig. 1 (right) even at the 95.4% confidence level, only the 69.8% (~70%) has a probable span of 1368-1221=147 years or ±75 years. Another wiggle within the calibration curve is also noticeable later within the range between 6th to 8th century BC, as Fig. 3 reveals. Overall, from the wiggle variation including the often-disregarded reservoir corrections from freshwater, marine or dietary issues, the alleged accuracy of a few decades of conventional ^{14}C dates in this time interval ranging between 3300-3000 BP is not attainable at all. The often-quoted radiocarbon dates with a high accuracy are misleading.

Last, the two ^{14}C age calibration of bones of later reuse period measured in two different laboratories outlines the apparent radiocarbon variation character in the 8th to 6th c. BC. Wiener [26] has discussed these kinds of problems when applying radiocarbon dating specifically to the late Holocene period in the Aegean region.

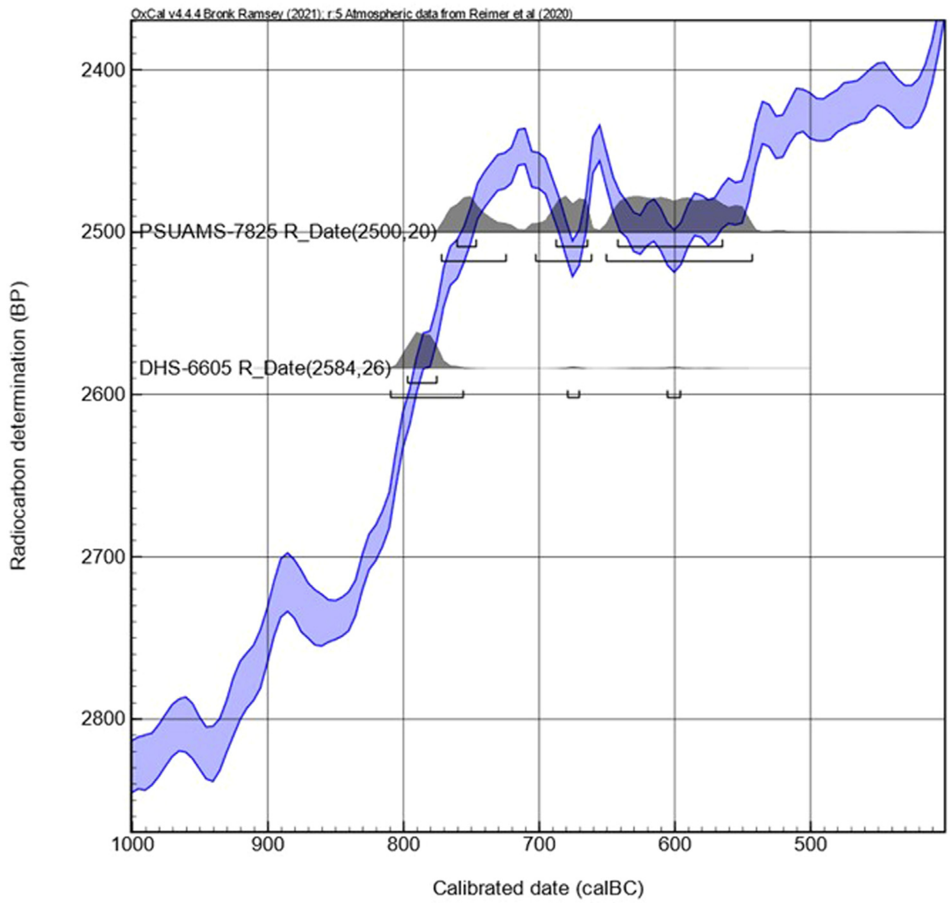


Fig. 3. Two Radiocarbon age Calibrations of bones of later reuse period measured in two different laboratories. Noticeable is the wiggly character in the 8th to 6th c. BC.

Out of the total 22 dates by ^{14}C and OSL/TL that are discussed here, nine (PSUAMS-7825, DHS-6605, DK-3, DK-6, RHO-1156, RHO-1163, RHO-1161a, b and RHO-1162) do not belong to the Mycenaean era. The LH III B-C reflects the end of the Mycenaean civilization which fell in the same period with other neighbouring cultures, called the Late Bronze Age collapse and onset of Dark ages (Iron age) [27,28].

These dates span between the Greek Middle Geometric Period and Geometric/Dark Age down to later Classical/ Hellenistic period, indicating further settlement activity evidenced during these later periods/ages. Nevertheless, the restricted number of samples with dates younger than 800 BC (calibrated) does not allow us to conclude that the Kastrouli settlement was continuously active from the Greek Middle Geometric Period until the Classical times. It is quite interesting to note that among the dates that do not belong to the Mycenaean era, seven were calculated using stimulated luminescence techniques and two by ^{14}C. The spread of ages is due to the fact that no organic material for ^{14}C is always available at a site, and that frequently more abundant inorganic material (stone and ceramics) could be recovered, which is appropriate for luminescence dating. Hence both dating techniques are corroborated for the determination of settlements occupational development. The span in the OSL dates appear because the available material of scattered ceramics and masonry stones reflects a wider reuse and repairing of the site. The ^{14}C dates were focused on the bones of Late Mycenaean tomb and associated tomb stone and two burnt buildings.

Specific centuries within the Aegean and Balkan chronology witness a decrease in the number of dates, indicating a peculiar hiatus or gap. One is the established 4th millennium BC gap, for which there has been a lot of archaeological discussion i.e. whether an occupation gap exist in the transition from Early to Middle Bronze Age, perhaps due to the 4.2 kyr climate event and/or other factors [29–31]. It is of great interest to notice the lack of dates in our study within the 900-1050 BC time interval of the Kastrouli occupation, that is connected to the onset of dark ages. The early archaic period by sample DHS (810-760 cal BC, 99.7%) and PSUAMS are initially contemporary with PSUAMS expanding to later Classical period. However, the number of total ages in the present study is insufficient to support the existence of this specific hiatus.

A total of 10 radiocarbon ages (Tables 1a, b), along with two OSL ages from pottery (DK-5, RHO-1157) and one from stone (RHO-1164) in Table S1, provide the archaeological evidence for at least one occupational and cultural phase at the settlement of Kastrouli with continuous activity. Nevertheless, dealing with the large errors in these ages still poses a challenge. To deliver high-quality chronological output information extracted from this specific group of radiocarbon dates and narrowing the confidence limits, a Bayesian model analysis was applied [32,33]. The definition of the Bayesian method for analysing radiocarbon dates and its use in archaeology has previously been published and is the subject of extensive discussion [34,35]. Such a modelling is feasible and trustworthy only when the samples that were dated come strictly from the same stratigraphy, belonging to the same archaeological/cultural phase. In fact, in the present study this is the case for the charcoal and the bone samples, as Tomb A is characterised by the archaeologists as Late Helladic (refer to Table 1b).

Fig. 4A shows the modelled radiocarbon and stimulated luminescence ages belonging to the Helladic phase, along with the calculated beginning and end boundaries of the modelled phase

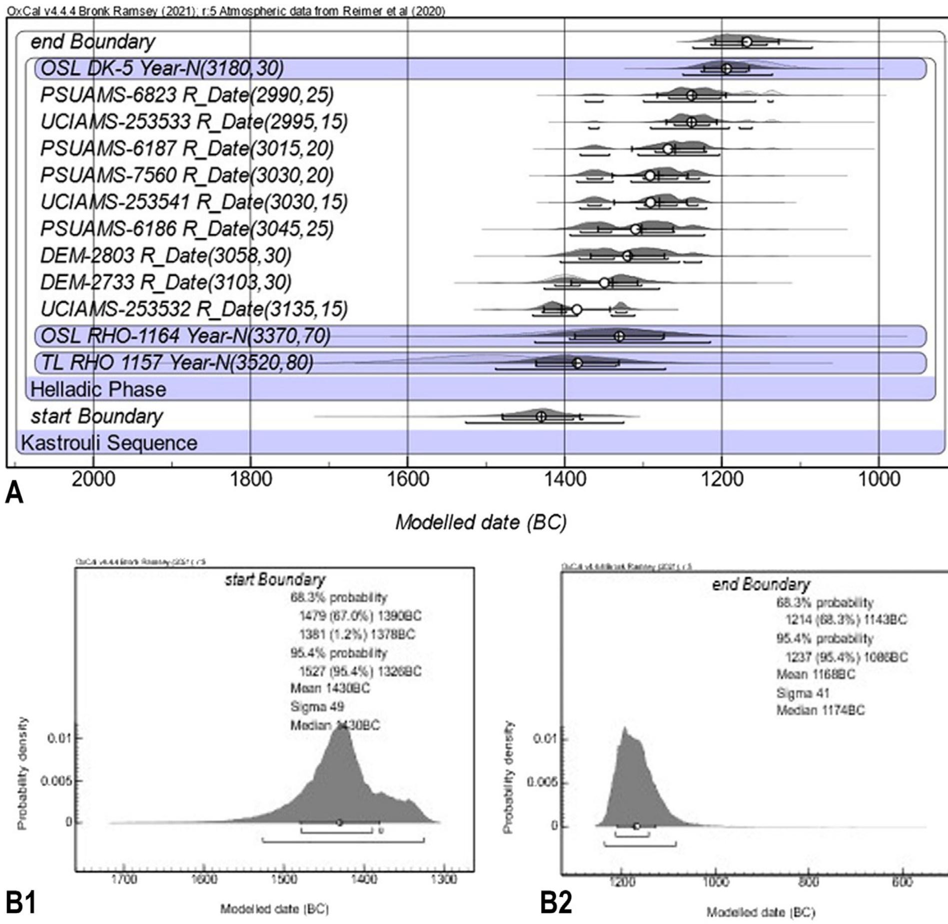
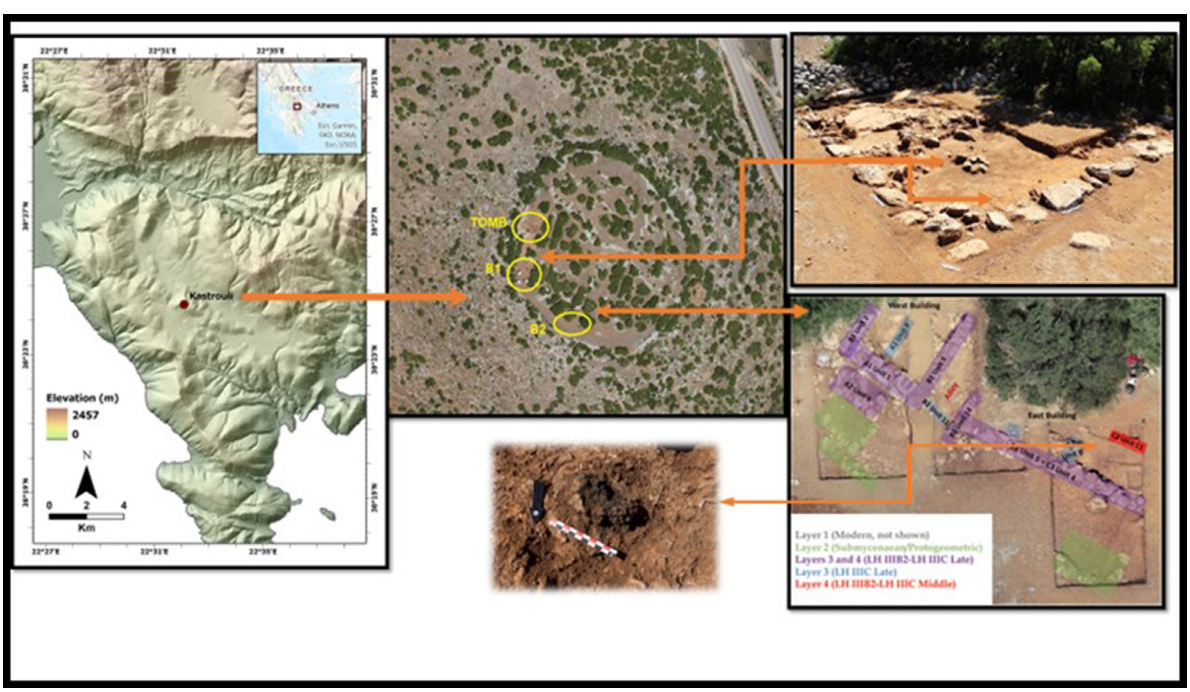


Fig. 4. A) Modelled radiocarbon and stimulated luminescence ages belonging to the Helladic phase. B1) Start and B2) end boundaries of the modelled phase.



Map 1. Images of the site highlighting the areas of interest of the present study. Left: Kastrouli location in southern Phokis, Centre: the settlement in a circular shape and the three excavated areas, Tomb A, Building 1 (B1) and Building 2 (B2); Right Up: The Building 1 at the end of the 2017 season (Fig. 18, in [4]), where two samples come from, one from the foundation of the transversal wall on the entire length of its southern side a thin layer of charcoal and ashes, and another from the base of a burnt rather roof beam base in the middle of the building; Right down: The B2 east - southern terrace with preliminary architectural phases C2 Unit 11 where two samples from the burnt roof beam come from with a close up photo [6].

presented in Fig. 4B. According to these modelled ages and at the confidence level of 95.4%, the start boundary of the Helladic phase lies within 1527 and 1326 cal. BC (median 1394 cal. BC), while the corresponding end boundary within 1237 and 1086 cal. BC (median 1174 cal. BC), lasting 220±54 years. According to Figs. 2 and 4A, the calibrated probability distribution for UCIAMS-253533 has a significant distribution (83.3%) in the interval 1285-1191 cal. BC and as such agrees less well with the distribution of other samples from the same period. Thus, the statistical weight of this specific measurement seems different, as this age might not belong to the corresponding phase. Nevertheless, from archaeological evidence the date is not an outlier in the inclusion of the Bayesian model but represents a follow up event in the same building 1. It should be noticed that the infill (embankment) is shallow in the Kastrouli hillock. Under present conditions and wiggly time span concerned the probabilities are indicative and the dates should be taken in their broader range span. The OSL ages incorporated into the above discussion reinforce the complex chronology of the concerned archaeological periods. Ceramic fabric (pots and figurines) dating from Tomb A range from LH III A2 to LH III C Early or Developed based on typological and aesthetic criteria [3]. There is no doubt that Tomb A was utilized for a considerable amount of time, which was further supported by a sizable, comingled burial that had at least 19 bodies who were identified by a biological anthropological investigation of the skeletal remains [9].

Although the bone dating indicated a LH III C period of last destruction of the site the dates obtained some centuries later of another bone as well as the dates from ceramics and stone masonry imply reuse of the settlement. However, the oldest span of some ^{14}C dates indicate a LH III A2/B phase. The meticulous excavation has revealed building phases within the LM III. Nevertheless, materials within this LM III span deposited in the same context cannot be excluded. In addition, wood dated was itself centuries old when used. Compulsory maintenance in the houses involves new interventions, changes and additions that usually take place every two generations (ca 60 years). Hence, such uncertainty is reasonable but does not change much our time range and interpretation [36].

Despite the fact that the precise chronology for the Late Helladic era is still debated [25,37,38], it seems reasonable to date the pottery and figurines from Tomb A to various ages between about 1370 and 1090 BC (the widest time-range feasible) or between 1320 and 1170 BC (shortest possible time span). Previous work at the site had suggested an occupational horizon of LH IIIA2 - IIIC Early in both the tomb and residential areas [3]: 1370 and 1090 BC (the longest possible time-range) or between 1320 and 1170 BC (the shortest possible time-range). One hundred and fifty years was thus, the shortest possible period during which the Tomb A has been in use ([4]: 222)

The shortest period lasted 150 years during which Tomb A was in continuous use. In fact, the lower boundary of this time span is congruous with the 1170 BC lower boundary from ^{14}C (see Fig. 4b). The TL ages of the two pottery samples are 890±240 BC and 1530±290 BC. The higher date, which coincides with the typological dates for 80 years minimum or 130 years maximum, is not a concern [14].

The younger typological/stylistic date of 1170 BC as the latest date is concordant with the lower ceramic TL date which implies that we should consider Tomb A being used at least until 1130 BC (890+240) and certainly since 1240 BC (1530-290), for this comingled burial. The lowest TL date for Tomb A's use and the biggest overlap between typological pottery dates are separated by around 40 years. The stylistic and TL pottery dates also suggest that the tomb was used continuously for at least two centuries, from 1320 BC to 1130 BC, or for a shorter time from 1320 BC to 1170 BC, followed by reuse in the Geometric to Early Archaic and later eras.

The new ^{14}C dates in conjunction to earlier data confirm the reuse of Kastrouli and seems plausible immediately after the destruction (s), but rather not for long either sparsely or by very few habitants. The OSL surface luminescence dates of stone taken from the Tomb A's lowest level of slabs, right above the bedrock, may support this conclusion, which provides further evidence for its construction yet with the expected large errors attached to luminescence dates for the anticipated accuracy sought on archaeological and typological grounds. The longer span with higher boundary (1660-1040 BC, RHO-1164) conforms to the dates of the pottery and figurines as well as habitations of the site. The other OSL of Tomb A stone age (1044-764 BC) has no overlap with the higher one.

Moreover, the fortified wall placed stones at lower dates (844-544 BC, RHO-1161b; 564-284 BC, RHO-1162; and 274 BC-26AD, RHO-1161a) indicate a successive occupational phase, but one has a marginal overlap with the lowest end of the OSL of Tomb A, in accordance with the pottery finds. The other two are successive, and if they are correctly correlated, they may indicate some major repairs on the wall during the second quarter of the 6th century BC and around the 2nd century BC.

It is confirmed that the tomb was reused sometime during the Sub-Mycenaean, Geometric and later eras. The Hellenistic/Roman presence is attested by several finds including rock-cut tombs in the area and modern town of Desfina. Several factors might have prompted such a transitional move from the end of Mycenaean to the Sub-Mycenaean and Dark Ages-Geometric period; most evidently being a new comingled burial. To this theory, the right femur found in the top strata of the tomb before the excavation began, gave a calibrated ^{14}C date of 810-760 BC [11,14]. Although heroic worship would have been more in keeping with what is known from other Mycenaean graves [39,40], looting cannot be completely ruled out at this early stage.

In light of the luminescence dating gross accuracy in this period, the dates for the pottery, fortified stone wall, and tomb confirm the settlement's Late Bronze period and subsequent reuse. When compared to the type of tools from the Tombs A and B as well as the two buildings A and B, discussed along the calibrated ^{14}C dates of the settlement the Kastrouli chronology provided a complete history of its use.

6. Conclusions

New ^{14}C dates on charcoal and bone remains from the Mycenaean peripheral settlement of Kastrouli were discussed within the frame of earlier bone ^{14}C dates and OSL dating of pottery and stone from the fortified wall and the Tomb A confirm the Late Helladic III date occupation of Kastrouli down to later Hellenistic /Roman times. An observed small gap for about 150 years coincides with the Dark Ages. It is worth emphasizing that while there is a gap in the radiocarbon dating chronology, there are only 8 dates from different contexts.

The 1000-1500 calibration curve indicates a wiggle within the calibrated age range between 1400 and 1300 cal. B.C. responsible for the large errors of the calibrated ages. Indeed, the wiggle at 3190 and 3040 BP and in the later age span wiggly variation ∼2900 – 2940 BP induced probability confidence limits for the calibrated ages span nearly or more than a century. The luminescence of pottery and the surface stone luminescence dates corroborate and reinforce ^{14}C dates for the whole occupational history of Kastrouli settlement.

Author contributions

"Conceptualization, I.L; methodology, I.L., G.S.P.; software, G.S.P.; validation, G.S.P., I.L., and T.E.L.; formal analysis, G.S.P., I.L.;

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.culher.2023.02.008.

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