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# $^{14}$C dating of the Early to Late Bronze Age stratigraphic sequence of Aegina Kolonna, Greece

E.M. Wild [a,*], W. Gauß [b], G. Forstenpointner [c], M. Lindblom [d], R. Smetana [e], P. Steier [a], U. Thanheiser [f], F. Weninger [a]

[a] VERA Laboratory, Faculty of Physics – Isotope Research, University of Vienna, Währinger Strasse 17, A-1090 Wien, Austria
[b] Austrian Archaeological Institute at Athens, Leof. Alexandras 26, Gr10683 Athens, Greece
[c] University of Veterinary Medicine Vienna, Dept. of Pathobiology, Institute of Anatomy, Unit on Archaeozoology and Comparative Morphology, Veterinärplatz 1, A-1210 Vienna, Austria
[d] Dept. of Archaeology and Ancient History Uppsala, University Box 626, SE-751 26 Uppsala, Sweden
[e] Altertumswissenschaften, University of Salzburg, Residenzplatz 1/I, A-5020 Salzburg, Austria
[f] Vienna Institute for Archaeological Science (VIAS), Althanstraße 14, A-1090 Vienna, Austria

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A B S T R A C T

Aegina Kolonna, located in the center of the Saronic Gulf in the Aegean Mediterranean (Greece), is one of the major archaeological sites of the Aegean Bronze Age with a continuous stratigraphic settlement sequence from the Late Neolithic to the Late Bronze Age. Due to its position next to the maritime cross roads between central mainland Greece, the northeast Peloponnese, the Cyclades and Crete, the island played an important role in the trade between these regions. In the course of new excavations, which focused on the exploration of the Early, Middle and Late Bronze Age at Kolonna, several short lived samples from different settlement phases have been $^{14}$C-dated with the AMS method at the VERA laboratory. Bayesian sequencing of the $^{14}$C data according to the stratigraphic position of the samples in the profile was performed to enable estimates of the transition time between the cultural phases. The Aegina Kolonna $^{14}$C sequence is one of the longest existing so far for the Aegean Bronze Age, and therefore of major importance for the absolute Bronze Age chronology in this region. Preliminary results indicate that the Middle Helladic period seems to have started earlier and lasted longer than traditionally assumed. Further, at the present stage of our investigation we can give also a very tentative time frame for the Santorini volcanic eruption which seems to be in agreement with the science derived VDL date.



## 1. Introduction

The archaeological site at Aegina Kolonna is located on the island of Aegina in the center of the Saronic Gulf (Fig. 1) in the Aegean Mediterranean (Greece). Archaeological excavation work at Kolonna has been performed since the late 19th century by Greek, German and Austrian excavators. Aegina Kolonna is one of the major centres of the Aegean Bronze Age and one of the few archaeological sites in Greece with a continuous stratigraphic settlement sequence from the Late Neolithic to the Late Bronze Age. The importance of the Kolonna site and the entire island may be explained in part because of its location in the centre of the Saronic Gulf, on what seems to have been, at that time, the crossroads between central mainland Greece, the northeast Peloponnese, the Cyclades, and Crete. Impressive fortifications, the earliest known shaft grave in the Aegean, the famous "treasure of Aegina," and a number of additional "prestige" items mainly of Cretan and Cycladic origin mirror the wealth and the key role of ancient Kolonna.

The importance of Kolonna is also shown by the abundant ceramic finds originating from distant cultural regions and by the fact that Kolonna produced high quality pottery, which was exported to the entire Aegean Mediterranean. Thus, Aegina Kolonna is truly significant for the synchronization of cultural phases of the Aegean Bronze Age [1–3].

## 2. New excavation

Recent excavations since 2002 focused on the exploration of the Early, Middle and Late Bronze Age at Kolonna. Regarding our stratigraphic research a 3.5 m high earth profile (see e.g. Fig. 2) forms the backbone of our stratigraphic work. The oldest layers excavated so far date to the beginning of Early Bronze III, the youngest ones reach Late Bronze II. The excavations unearthed major parts

* Corresponding author. Tel.: +43 664 60277 51704; fax: +43 1 4277 9517.
*E-mail address:* Eva.Maria.Wild@univie.ac.at (E.M. Wild).

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Fig. 1. Map of the Saronic Gulf and the Island of Aegina in its centre [18].

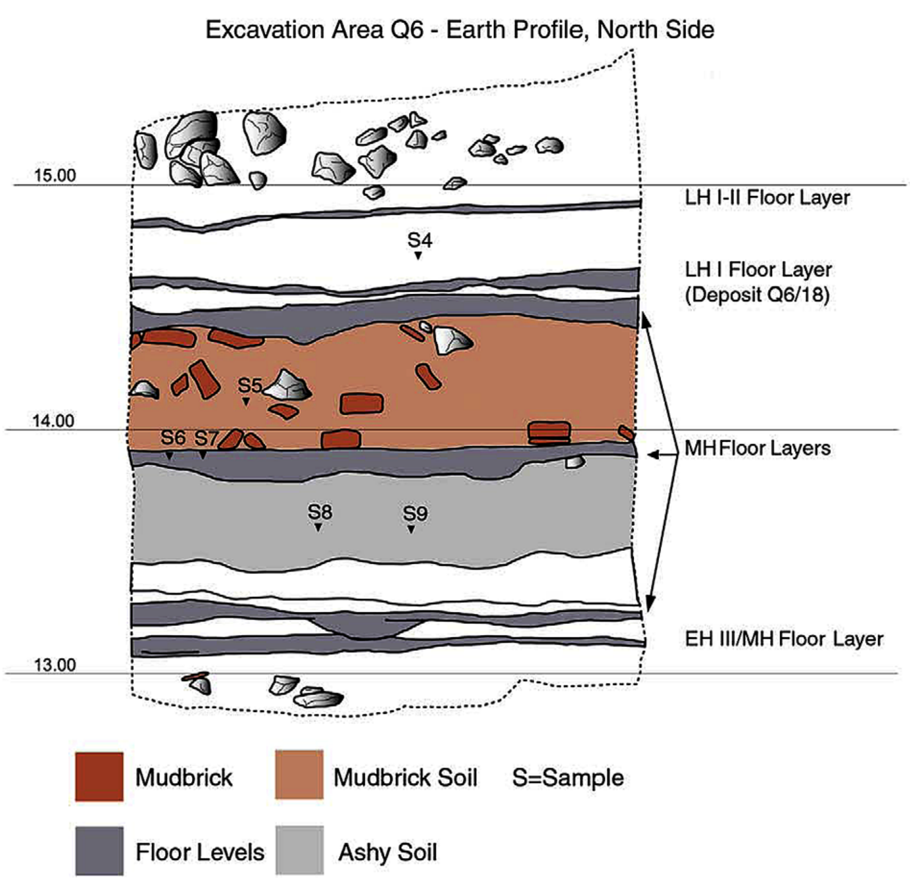


Fig. 2. Vertical stratigraphic sequence at the new excavation area.

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**Table 1**
$^{14}C$ data of all samples from the Aegina Kolonna site determined at the VERA-laboratory.

| Laboratory number | Stratigraphic position* | Sample material | Ceramic phase | $\delta^{13}C$ [a,b] [‰] | $^{14}C$ age[b] [BP] | Calibrated age[c] | $\delta^{15}N$ [d] [‰] | %C [d] | C/N [d,e] |
|---|---|---|---|---|---|---|---|---|---|
| VERA-3861HS | Metallofen 2 | charcoal (humic acids) | D | -23.6 ± 0.8 | 4096 ± 27 | 2860BC (21.0%) 2809BC<br>2753BC (7.4%) 2721BC<br>2702BC (65.8%) 2572BC<br>2513BC (1.2%) 2504BC | | | |
| VERA-3863HS | Metallofen 1 | charcoal (humic acids) | D | -23.6 ± 0.5 | 4049 ± 27 | 2834BC (3.8%) 2818BC<br>2661BC (1.8%) 2649BC<br>2635BC (89.7%) 2481BC | | | |
| VERA-3864HS | Metallofen 1 | charcoal (humic acids) | D | -25.1 ± 0.6 | 4128 ± 27 | 2871BC (26.6%) 2802BC<br>2780BC (63.9%) 2617BC<br>2611BC (4.9%) 2581BC | | | |
| VERA-2678 | FG XVIIId | Hordeum vulgare | E | -22.7 ± 1.0 | 3724 ± 35 | 2274BC (1.9%) 2257BC<br>2208BC (93.5%) 2024BC | | | |
| VERA-2680 | FG XVIIId | Hordeum vulgare | E | -23.5 ± 0.8 | 3722 ± 35 | 2272BC (1.4%) 2258BC<br>2206BC (93.7%) 2024BC<br>1988BC (0.2%) 1986BC | | | |
| VERA-2681 | FG XVIIId | Hordeum vulgare | E | -20.1 ± 1.5 | 3739 ± 35 | 2279BC (5.4%) 2251BC<br>2230BC (1.3%) 2221BC<br>2211BC (88.7%) 2032BC | | | |
| VERA-2679 | FG XVIIIh | Hordeum vulgare | E | -21.0 ± 0.9 | 3761 ± 35 | 2289BC (80.8%) 2121BC<br>2095BC (14.6%) 2041BC | | | |
| VERA-2682 | FG XVIIIc | Hordeum vulgare | E | -21.7 ± 1.0 | 3712 ± 35 | 2204BC (93.6%) 2018BC<br>1995BC (1.8%) 1981BC | | | |
| VERA-2683 | FG XVIIIc | Hordeum vulgare | E | -22.9 ± 0.8 | 3721 ± 35 | 2272BC (1.3%) 2259BC<br>2206BC (93.6%) 2023BC<br>1991BC (0.6%) 1985BC | | | |
| VERA-4641 | 19/36 | bone, Ovis/Capra, metacarpus | E | -15.9 ± 0.8; -19.1[d] | 3759 ± 35 | 2288BC (79.5%) 2121BC<br>2095BC (15.9%) 2041BC | 6.5 | 35 | 3.1 |
| VERA-2688 | 11b2/20 | bone, Ovis/Capra, femur | E | -16.6 ± 0.9; -18.0[d] | 3698 ± 33 | 2199BC (9.4%) 2163BC<br>2152BC (82.4%) 2014BC<br>1998BC (3.7%) 1979BC | 4.5 | 43 | 3.2 |
| VERA-2692 | 19/28 | bone (goat)† | F | -18.1 ± 1.1; -18.3[d] | 3704 ± 36 | 2201BC (92.2%) 2015BC<br>1997BC (3.2%) 1979BC | 4.7 | 40 | 3.1 |
| VERA-4640 | 19/27 | bone, Bos, tibia | G | -16.6 ± 1.2; -19.2[d] | 3800 ± 44 | 2457BC (3.4%) 2418BC<br>2407BC (3.7%) 2376BC<br>2367BC (0.7%) 2356BC<br>2351BC (85.0%) 2132BC<br>2085BC (2.6%) 2057BC | 6.1 | 38 | 3.2 |
| VERA-4639 | 19/23 | bone, Bos, ulna† | G | -23.0 ± 1.9; -20.7[d] | 3809 ± 32 | 2402BC (2.0%) 2382BC<br>2348BC (93.4%) 2139BC | 4.9 | 24 | 3.3 |
| VERA-4638 | Q6/056 | bone, Ovis/Capra, tibia | G | -20.5 ± 1.1; -19.9[d] | 3646 ± 32 | 2135BC (21.7%) 2078BC<br>2064BC (73.7%) 1926BC | 3.1 | 41 | 3.2 |
| VERA-4281 | Q3/148 | Hordeum vulgare | G | -23.4 ± 0.4 | 3740 ± 36 | 2280BC (6.2%) 2249BC<br>2231BC (1.7%) 2219BC<br>2213BC (87.5%) 2032BC | | | |
| VERA-4282 | Q3/149 | Hordeum vulgare | G | -24.3 ± 0.5 | 3711 ± 34 | 2203BC (93.9%) 2021BC<br>1994BC (1.5%) 1982BC | | | |
| VERA-4283 | Q3/150 | Hordeum vulgare | G | -23.4 ± 0.4 | 3780 ± 37 | 2339BC (1.9%) 2315BC<br>2310BC (87.0%) 2125BC<br>2091BC (6.5%) 2043BC | | | |
| VERA-4636 | Q6/054 | bone, Ovis/Capra, coxa | H | -17.6 ± 1.2; -19.9[d] | 3628 ± 30 | 2125BC (7.9%) 2091BC<br>2044BC (87.5%) 1900BC | 4.1 | 42 | 3.2 |
| VERA-4637 | Q6/055 | bone, Bos, long bone | H | -17.5 ± 1.2; -19.5[d] | 3643 ± 30 | 2134BC (18.4%) 2081BC<br>2061BC (77.0%) 1922BC | 6.7 | 46 | 3.2 |

(*continued on next page*)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| VERA-4280 | Q3/151 | Hordeum vulgare | H | -24.4 ± 0.6 | 3724 ± 39 | 2278BC (3.2%) 2251BC<br>2229BC (0.6%) 2222BC<br>2211BC (90.4%) 2020BC<br>1994BC (1.2%) 1982BC | | | |
| VERA-4279 | Q3/136 | Hordeum vulgare | H | -21.7 ± 0.5 | 3718 ± 38 | 2274BC (1.7%) 2257BC<br>2208BC (91.9%) 2016BC<br>1996BC (1.8%) 1980BC | | | |
| VERA-2687 | 11b1/04 | bone, Bos, mandibula | H | -16.8 ± 1.0; -16.0[d] | 3694 ± 35 | 2199BC (8.8%) 2161BC<br>2153BC (80.8%) 2008BC<br>2003BC (5.7%) 1977BC | 4.7 | 44 | 3.1 |
| VERA-4634 | Q6/045 | bone, Sus, tibia | I | -19.3 ± 1.6; -19.8[d] | 3544 ± 37 | 2009BC (1.0%) 2002BC<br>1976BC (94.4%) 1756BC | 7.8 | 38 | 3.2 |
| VERA-4278 | Q3/127 | indet. cereal | I | -21.9 ± 0.6 | 3522 ± 38 | 1947BC (95.4%) 1746BC | | | |
| VERA-4277 | Q3/126 | Hordeum vulgare | I | -25.4 ± 0.6 | 3368 ± 36 | 1745BC (85.6%) 1604BC<br>1587BC (9.8%) 1535BC | | | |
| VERA-4038 | Q6/41 | indet. cereal | I | -24.7 ± 0.9 | 3506 ± 34 | 1923BC (95.4%) 1743BC | | | |
| VERA-4037 | Q6/37 | indet. cereal | I | -22.6 ± 0.7 | 3708 ± 34 | 2202BC (93.6%) 2020BC<br>1994BC (1.8%) 1982BC | | | |
| VERA-4039HS | Q6/42 | indet. cereal (humic acids) | I | -21.9 ± 0.8 | 3691 ± 37 | 2198BC (7.9%) 2165BC<br>2151BC (87.5%) 1965BC | | | |
| VERA-4575 | Q6/139 | bone, Sus, mandibula | I | -19.0 ± 0.5; -18.7[d] | 3537 ± 36 | 1961BC (95.4%) 1751BC | 6.5 | 35 | 3.1 |
| VERA-4576 | Q6/138 | bone, Bos, radius | I | -19.9 ± 0.6; -19.1 [d] | 3482 ± 37 | 1899BC (90.3%) 1731BC<br>1719BC (5.1%) 1692BC | 6.2 | 47 | 3.2 |
| VERA-4578 | Q6/141 | bone, Ovis/Capra, mandibula | I | -22.2 ± 0.7; -19.9[d] | 3501 ± 39 | 1931BC (93.9%) 1738BC<br>1709BC (1.5%) 1697BC | 5.7 | 39 | 3.1 |
| VERA-4579 | Q6/142 | bone, Ovis/Capra, tibia | I | -17.8 ± 0.7; -16.8[d] | 3526 ± 38 | 1952BC (95.4%) 1747BC | 3.5 | 43 | 3.1 |
| VERA-4580 | Q6/142 | bone, Bos, metatarsus | I | -19.3 ± 0.4; -18.2[d] | 3506 ± 33 | 1919BC (95.4%) 1745BC | 6.8 | 32 | 3.1 |
| VERA-4276 | Q3/100 | indet. cereal | I | -22.7 ± 0.6 | 3506 ± 37 | 1932BC (95.4%) 1741BC | | | |
| VERA-4275 | Q3/86 | indet. cereal | I | -24.1 ± 0.6 | 3544 ± 38 | 2009BC (1.1%) 2002BC<br>1976BC (94.3%) 1756BC | | | |
| VERA-4581 | Q3/105 | bone, lion, tibia | I | -18.1 ± 1.0; -18.3[d] | 3639 ± 36 | 2135BC (18.2%) 2078BC<br>2064BC (77.2%) 1907BC | 8.3 | 44 | 3.2 |
| VERA-4577 | Q6/138 | bone, Ovis/Capra, metatarsus[†] | I | -22.8 ± 0.7 | 3458 ± 39 | 1887BC (95.4%) 1686BC | nd[**] | nd | nd |
| VERA-4571 | Q6/80 | bone, Ovis/Capra, tibia | J | -18.5 ± 0.7; -18.9[d] | 3469 ± 38 | 1887BC (95.4%) 1691BC | 5.5 | 35 | 3.2 |
| VERA-4574 | Q6/90 | bone, Sus, radius | J | -21.5 ± 1.1; -19.4[d] | 3430 ± 39 | 1879BC (13.4%) 1839BC<br>1830BC (82.0%) 1634BC | 7.5 | 34 | 3.1 |
| VERA-4573 | Q6/92 | bone, Ovis/Capra, humerus | J | -21.2 ± 0.6; -19.1[d] | 3485 ± 36 | 1901BC (91.5%) 1733BC<br>1716BC (3.9%) 1693BC | 4.4 | 39 | 3.2 |
| VERA-4572 | Q5/31 | bone, Ovis/Capra, femur | J | -21.0 ± 0.5; -19.4[d] | 3407 ± 38 | 1876BC (5.5%) 1842BC<br>1821BC (2.4%) 1797BC<br>1781BC (87.5%) 1612BC | 4.6 | 39 | 3.2 |
| VERA-4570 | Q6/89 | bone, Sus, radius | J | -20.9 ± 0.7; -19.2[d] | 3428 ± 36 | 1877BC (11.9%) 1841BC<br>1826BC (6.7%) 1795BC<br>1783BC (76.9%) 1635BC | 8.5 | 33 | 3.0 |
| VERA-4633 | Q6/017 | bone, Ovis/Capra, metatarsus | K | -16.9 ± 1.5; -18.8[d] | 3333 ± 29 | 1689BC (95.4%) 1527BC | 4.3 | 43 | 3.2 |
| VERA-4033 | Q6/016 | indet. cereal | K | -27.8 ± 0.8 | 3197 ± 45 | 1607BC (4.3%) 1573BC<br>1559BC (0.9%) 1549BC<br>1539BC (90.2%) 1393BC | | | |
| VERA-4632 | Q6/016 | bone, Ovis/Capra, tibia | K | -14.4 ± 1.3 | 3356 ± 36 | 1740BC (77.9%) 1600BC<br>1594BC (17.5%) 1531BC | nd | nd | nd |
| VERA-4631 | Q6/015 | bone, Ovis/Capra, radius[†] | K | -15.7 ± 0.7 | 3349 ± 36 | 1737BC (7.5%) 1710BC<br>1695BC (87.9%) 1529BC | nd | nd | nd |
| VERA-4630 | Q6/013 | bone, Ovis/Capra, tibia[†] | L | -16.1 ± 0.7; -19.5[d] | 3313 ± 48 | 1736BC (2.9%) 1712BC<br>1695BC (92.5%) 1494BC | 5.1 | 37 | 3.2 |
| VERA-4284 | Q3/115 | Hordeum vulgare | M | -24.5 ± 0.5 | 3044 ± 35 | 1411BC (95.4%) 1212BC | | | |

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| | | | | | | |
|---|---|---|---|---|---|---|
| VERA-4582 | Q3/156 | charred wood (twig) | M | -26.3 ± 0.6 | 2986 ± 33 | 1375BC (4.7%) 1340BC<br>1320BC (90.7%) 1118BC |
| VERA-4285 | Q3/159 | legumes | M | -20.9 ± 0.6 | 3040 ± 37 | 1411BC (94.3%) 1208BC<br>1202BC (0.6%) 1196BC<br>1139BC (0.5%) 1135BC |

* Stratigraphic position: general excavation area / actual layer.

** Not determined

[a] Determined with the AMS system, the $\delta^{13}C$ value reflects mass dependent isotope fractionation in nature and in the laboratory. For most bone samples $\delta^{13}C$ values of the extracted gelatin determined with an EA-IRMS system are also given

[b] 1 sigma uncertainty

[c] 95.4% probability, determined with OxCal 4.0 and the IntCal04 calibration curve

[d] Determined for subsamples of the dated gelatin with an EA-IRMS system (elemental analyzer-isotope ratio mass spectrometer), for VERA- 2692 gelatin was extracted from a subsample of the bone for this measurements; long time precision of a repeatedly measured standard material: 0.1‰ for $\delta^{15}N$ and $\delta^{13}C$.

[e] Atom-% ratio

† Indicates samples with a collagen yield between 1% and 0.5% (see text)

of a very large-scaled, presumably at least two storied building, erected of massive undressed stone blocks in its lowest lines. The building technique, its dimensions and the rich finds unearthed inside the building indicate that it was the mansion of the Middle Bronze and Late Bronze Age settlement at Kolonna. Judging from present archaeological evidence, the building was constructed at the beginning of the Middle Bronze Age, perhaps at the same time as the first palaces in Minoan Crete. Within its existence the building was remodelled several times and until now three major architectural phases are distinguishable. At the beginning of the Late Bronze Age the building went out of use. It was partly destroyed first by a Late Bronze Age (LH IIIA) potters' kiln and later by the constructions of the later Greek sanctuary of the first millenium, when remains of the earlier habitations at Kolonna were levelled and cleared away in order to build the sanctuary.

The most interesting finds recovered inside the large building are high-quality Cretan drinking vessels, as well as locally produced imitations of Cretan pottery. The latter is a clear indication of the strong Cretan influence at Aegina Kolonna. Other imported and locally produced pottery of high quality furthermore indicate the importance and high social status of the people living inside the building [2,3].

The long stratigraphic sequence at Kolonna with rich finds of its material culture is perfectly suitable for an intensive diachronic $^{14}C$ analysis, which is at present one of the major exigencies in the Aegean Bronze Age absolute chronology, in particular for the Early and Middle Bronze Age [1,4]. The absolute terms for these periods in the Aegean presently relate to a few and often old $^{14}C$ data from various sites but so far no continuous stratigraphic sequence of a length comparable to the Kolonna site has been $^{14}C$ dated systematically. In spite of intensive $^{14}C$ analysis throughout the Aegean, the problem of the discrepancy between the absolute chronology and the historical chronology particularly for the end of the Middle Bronze Age and the beginning of the Late Bronze Age is still unsolved [4].

## 3. Radiocarbon dating

### 3.1. Materials and methods

In the course of the new excavations several samples from the different settlement phases corresponding also to different cultural periods were collected for radiocarbon dating. In the sample selection main attention was put on a – as far as possible – secure context between the sample and the archaeological layers which were assigned to the respective cultural phases according to characteristic pottery assemblages. A further criterion in the selection was that the samples comprise short-lived terrestrial material as e.g. charred seeds and animal bones. Also one charcoal sample from a twig with preserved bark was acquired for dating. The plant remains were identified by an archaeobotanist and the animal bones by an archaeozoologist. In order to exclude a marine diet component, bones from herbivores (Capra/Ovis and Bos) were used but also four bones from *Sus scrofa domesticus* (omnivore). The $^{14}C$ samples were mainly taken from compact long bones.

Apart from the shortlived samples, three charcoals were also among the selected $^{14}C$ samples. The latter were inspected by a dendrochronologist and pieces which according to the bending of the tree rings may originate from the outer part of a trunk or from a twig were used for dating. In total approx. fifty samples were $^{14}C$-dated with the AMS method at the VERA laboratory.

The standard ABA method (1 M HCl – 0.1 M NaOH – 1 M HCl at 60 °C) of the VERA lab was applied for the pre-treatment of the carbonized samples (see e.g. Wild et al. [5]). The three charcoals and one charred seed sample completely dissolved during the alkaline

**Table 2**
$^{14}C$ ages of samples from Aegina Kolonna determined earlier with the radiometric method.

| Laboratory number | Stratighraphic position* | Sample material | Ceramic phase | $^{14}C$ age[a] (BP) | Calibrated age[b] |
|---|---|---|---|---|---|
| HV 5843 | FG IX (floor of corridor house) | indet. plant remains | C | 3755 ± 105 | 2470BC (95.4%) 1905BC |
| HV 5842 | Metallofen 1 | charcoal | D | 4130 ± 45 | 2873BC (95.4%) 2580BC |
| HV 5841 | FG XVIII | charcoal | E | 3625 ± 65 | 2198BC (2.6%) 2166BC<br>2150BC (87.7%) 1871BC<br>1846BC (2.9%) 1812BC<br>1804BC (2.2%) 1776BC |
| HV 5840 | FG XVIII | charcoal | E | 3820 ± 65 | 2468BC (91.9%) 2131BC<br>2086BC (3.5%) 2050BC |
| VRI 0395 | FG XVIII | charcoal | E | 3670 ± 90 | 2337BC (0.5%) 2323BC<br>2308BC (90.8%) 1865BC<br>1850BC (4.1%) 1773BC |

* stratigraphic position: general excavation area/actual layer.
[a] 1 sigma uncertainty.
[b] 95.4% probability, determined with OxCal 4.0 and the IntCal04 calibration curve.

step. From these samples only humic acids precipitated from the alkaline solution could be used for $^{14}C$ dating.

Collagen from the animal bones was extracted and purified with a "modified Longin" method, i.e. the Longin procedure [6] was extended by a NaOH and a subsequent HCl treatment before gelatinisation, and the extraction yield determined. In several $^{14}C$ laboratories a collagen yield > 1% of the initial sample amount is used as an indication for bones yielding reliable $^{14}C$ dates. In addition some other parameters, e.g. the $\delta^{13}C$- and $\delta^{15}N$-values, the C-content in the gelatin (%C) and the C/N ratio may be used to characterize the extracted collagen [7]. These parameters are usually determined with an elemental analyser coupled to an isotope ratio mass spectrometer (EA-IRMS) operated in the continuous flow mode. At VERA the EA-IRMS measurement was performed with a *CE Instruments* NC 2500 elemental analyser – *Micromass Optima* mass spectrometer system for subsamples of the $^{14}C$ dated gelatine samples.

After the chemical pre-treatment the samples were further processed as described in Wild et al. [8,5] and the $^{14}C$ measurements were performed following the VERA protocol for routine measurements [9].

The VERA $^{14}C$ data (Table 1) plus three $^{14}C$ dates (ceramic phase E) determined earlier with the conventional $^{14}C$ method in Hannover and Vienna (Table 2) were combined with the stratigraphic information by Bayesian sequencing using the OxCal 4.0 program [10,11] to improve the uncertainty of the calibrated sample ages and the resulting time spans of the individual ceramic phases.

### *3.2. Results and discussion*

The $^{14}C$ data of all samples measured at VERA are given in Table 1 together with the $\delta^{13}C$ values determined with the AMS system and the information about the sample location in the excavation area. Five bones with collagen yields between 1% and 0.5% are indicated in the table. For all other bones collagen yields above the 1% limit were determined. The quality parameters determined by EA-IRMS measurement are listed in Table 1 as well. All values lie in the range of bones assessed to yield reliable $^{14}C$ dating results [7]. Only one low-collagen sample (VERA-4639) showed a lower C-content which may be caused by the presence of some inorganic material, the other parameters of this sample are in the accepted range.

Among the dated bones were four samples from omnivores (*Sus scrofa domesticus*), where a marine component (fish residues) in the diet could be possible. A marine portion in the feed would lead to a shift of the $^{14}C$ data to older ages (reservoir effect). By comparison of the omnivore dates with data of coeval not-affected samples no age offsets and thus no indication for a marine influence could be detected, e.g. the weighted mean value (3510 ± 14 years BP) of the unaffected dates and the single *Sus scrofa domesticus* age of 3537 ± 36 years BP (VERA 4575) from the so called "Minoan layer" in ceramic phase I agree within 1 $\sigma$ uncertainty. This conclusion is also corroborated by the measured $\delta^{13}C$ and $\delta^{15}N$ values, which do not indicate the consumption of a considerable amount of marine food. Marine diet should increase both the $\delta^{13}C$ and $\delta^{15}N$ values (see e.g. Schwarcz and Schoeninger [12]). The $\delta^{13}C$ values of the pigs are in the range of the values determined for the majority of the herbivores and the slightly higher $\delta^{15}N$ values may reflect the omnivore diet. Unexpected $\delta^{13}C$ values of $-16‰$ and $-16.8‰$ were determined for the herbivore samples VERA-2687 and VERA-4579. Whether these values indicate a C4 component in the feeding remains unclear but seems to be supported by the concordance of the sample ages with the $^{14}C$ data of the other samples (animal and plant remains) from the same ceramic phases. For clarification a more detailed stable isotope study would be required.

The $^{14}C$ data determined earlier with the radiometric method in Hanover and Vienna are given in Table 2 together with the information on the stratigraphic position of the dated samples and the sample material.

Fig. 3 shows an OxCal 4.0 plot with the results of the Bayesian sequencing of the $^{14}C$ data. From the entire $^{14}C$ data set presently available for the Aegina Kolonna Bronze Age period some few dates were not incorporated into the sequence due to either sample quality reasons, e.g. only humic acids could be dated or due to a poor agreement index (<20%).

Three obviously too old $^{14}C$ ages of humic acids from the charcoals (VERA-3861HS, VERA-3863HS and VERA-3864HS) from the earliest stages of the EBA III (ceramic phase D), which completely dissolved during the ABA treatment, were not incorporated into the sequence, as these ages may be affected by a re-use or an "old wood" effect or a contamination with "old" humic acids. These dates are in agreement with a $^{14}C$ date of a sample (HV-5842) from the same layer determined earlier with the conventional method in Hanover but are inconsistent with the $^{14}C$ date of a sample (HV-5843) from the underlying horizon (ceramic phase C, end of the EBA II period) determined by the same lab. Therefore we do not consider this part of the stratigraphy in the Aegina Kolonna sequence at the moment.

The $^{14}C$ date of a lion's bone (VERA-4581) which was probably affected by a contamination with a cast material, and a $^{14}C$ date determined for humic acids from a seeds sample (VERA-4039HS) which completely dissolved in the alkaline step of the pre-treatment were also not included into the sequence. Further, three $^{14}C$ dates (VERA-4277, VERA-4037 and VERA-4033) which yielded

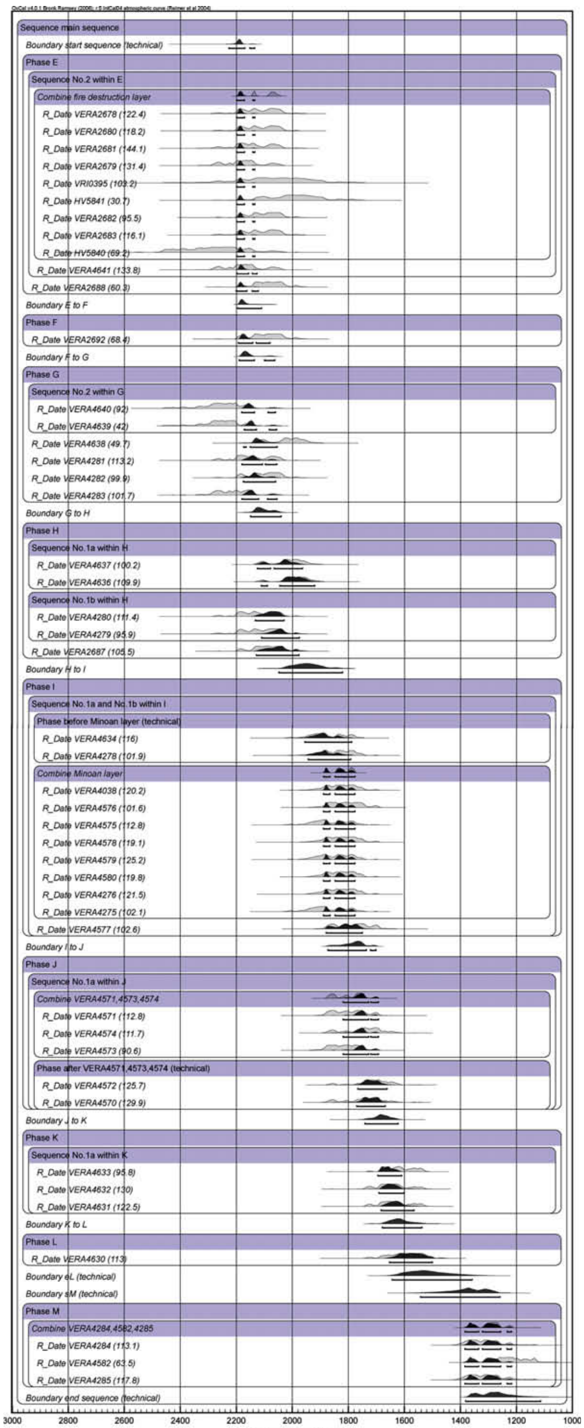


**Fig. 3.** OxCal plot of the Bayesian sequence of the $^{14}C$ data from Aegina showing the ceramic phases (E to M) and the transitions (boundaries) between them. Note that there is a hiatus between phase L and M. The probability distribution for the individual calendar ages resulting from the Bayesian model are displayed in dark grey, the results of single sample calibrations are indicated in light grey. Concerning the stratigraphy three types of information are used in the model: (a) grouping into ceramic phases, (b) local continuous sample sequences (1a, 1b and 2) and (c) well defined layers or contexts representing a short time span, e.g. 'fire destruction layer', 'Minoan layer'. In the latter case the analysed samples were treated as coeval (technical remark: we used the 'Combine' command of OxCal in order to show the consistency of all single sample calibrations in the plot. This result differs only marginally from the values calculated with the alternative 'R_Combine' command, because by using 'Combine' the individual sample calibrations are treated as independent, ignoring the shared use of the calibration data and their uncertainties. R_combine would allow to show only a single distribution for combined samples).

a very poor agreement index (<20%) in a first run were excluded from the present sequence as well. Interestingly these three outliers were small single seeds, which may have been mobile in the sediment.

The $^{14}C$ data of the five low-collagen bones were not excluded from the sequence. $^{14}C$ data of bone samples with such a relatively low preservation state should be treated with caution (see e.g. van Klinken [7]), but the agreement indices of all but one of these bone data were above 60% and show the compatibility of these dates with the entire data set. A lower agreement index of 42% was only determined for sample VERA-4639 which is assigned to the ceramic phase G at the beginning of the Middle Bronze Age. Removing this sample and samples VERA-2687 and VERA-4579 from the sequence would not change the presented picture of the chronology of cultural periods from the EH/MH transition to the LH period. The only significant effect would be a $\sim$50 yr extension to younger ages of the time range for the ceramic phase E/F transition within the EH III period caused by the removal of sample VERA-4639.

Presently the sequence comprises 46 $^{14}C$ dates, which are distributed over almost the entire time span covered by the excavation. An overall agreement index of 100.2% was calculated for the sequence. This value indicates the consistency of the model with the input data (for details of the agreement indices see e.g. Rhodes et al. [13]).

Compared to the un-modelled data our $^{14}C$ sequence of Aegina Kolonna, which should presently be treated as preliminary (some refinements are planned) allows a more precise estimate for the transition dates between the individual phases. A time frame within which the transition occurred with a certain probability (boundary time range) can be derived from the Bayesian model. The thus determined time ranges for the individual cultural transitions detected in the Aeginetan profiles throughout the Bronze Age period are given in Table 3 together with archaeological information as cultural (Bronze Age) period, settlement and ceramic phases and first appearances of ceramic styles. These transitions exhibit a framework for the absolute chronology of the Early to the Late Bronze Age of Mainland Greece and the Islands.

A relative sharp time interval for the important transition from EH to MH period can be deduced from the Kolonna sequence. Date ranges for the EH/MH transition of 2191 BC to 2064 BC ($2\sigma$) and the MH/LH transition of 1742 BC to 1623BC ($2\sigma$) indicate that the MH period may have lasted a bit longer, respectively began a bit earlier than suggested initially [1]. Our results seem to be in agreement with the historical chronology, which suggests a start of the Middle Minoan IA period (equivalent to MH I on the Greek Mainland and the Islands) in Crete in the First Intermediate period in Egypt within 2160 BC – 2025 BC [4]. A calibrated $^{14}C$ age of 2280 BC to 2130 BC ($2\sigma$) determined by Manning [14] for a short lived sample from the coeval early Middle Cycladic period also supports our finding.

A further result derived from the sequence is a – at the moment very tentative – time frame for the Santorini volcanic eruption, which occurred during the time period of ceramic phase K. Time spans of 1742 BC to 1623 BC ($2\sigma$) within which the transition from ceramic phase J to phase K (transition from MH III to LH I, see above) occurred and 1679 BC to 1538 BC ($2\sigma$) for the transition from ceramic phase K to L (LH I to LH II) were determined. However, it must be noted that the latter boundary is weakly defined due to the fact that only one $^{14}C$ date from an herbivore bone with poor collagen preservation is available from phase L at the moment. Clearly more $^{14}C$ data from samples near the K/L boundary are needed to verify this value. But although very preliminary at the present stage of our investigation, these results seem to be in agreement with the science based date of the Thera VDL (Volcanic Destruction Layer) [15,16]. Regarding the latter the ongoing dis-

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**Table 3**
Chronological chart of Aegina Kolonna.

| *Cultural period, conventional (high) (a) and historical chronology (b)* | *Settlement Phase* | *Ceramic Phase* | *Research Areas* 1 2 3 4 | Imports First Appearance | *Boundary between Ceramic Phases* | modeled calibrated date 68.2% probability (d) | modeled calibrated date 95.4% probability (d) |
|---|---|---|---|---|---|---|---|
| Neol to EH I | I | Phase A (c) | | | | | |
| | II | Phase B | | | | | |
| EH II a: EBA II Late: 2450/2350 to 2200/2150 BC | III | Phase C | | | | | |
| | III (Rebuild.) | Phase C | | | | | |
| | IV | Phase D | | Peloponnese | | | |
| | | | | | beginning of E | earlier than 2181 BC (e) | earlier than 2136 BC (e) |
| EH III a: EBA III: 2200/2150 to 2050/2000 BC | V (Destr.) | Phase E | | | | | |
| | V (Reconstr.) | Phase E | | Central Greece | | | |
| | | | | | boundary E / F | 2191 to 2169 BC | 2196 to 2111 BC |
| | VI | Phase F | | Cycladic (schist fabric) | | | |
| b: EBA III/MBA transition: 2160 to 2025 BC | | | | Local Cycladic Imitations | | | |
| | VI | Phase G | | | boundary F / G | 2183 to 2154 BC | 2191 to 2064 BC |
| | VII | Phase G | | Lustrous Decorated | | | |
| MH I a: MBA I: 2050/2000 to 1950/1900 BC b: MBA I: 2160/2025 to before 1800 BC | | | | | boundary G / H | 2139 to 2061 BC | 2150 to 2041 BC |
| | VIII | Phase H | | Minoan, Cycladic (Melos/Thera) | | | |
| | VIIIA | Phase H | | | | | |
| MH II a: MBA II: 1950/1900 to 1750/1720 BC b: MBA II: before 1800 to 1700 BC | IX | Phase I | | Local Minoan Imitations | boundary H / I | 2007 to 1904 BC | 2049 to 1822 BC |
| MH III a: MBA III: 1750/1720 to 1680 BC b: MBA III: 1700 to 1600/1580 BC | X | Phase J | | | boundary I / J | 1811 to 1745 BC | 1873 to 1702 BC |
| LH I a: LBA I: 1680 to 1600/1580 BC b: LBA I: 1600/1580 to 1510/1485 BC | X | Phase K | | SE-Aegean | boundary J / K | 1707 to 1648 BC | 1742 to 1623 BC |
| LH II a: LBA II:1600/1580 to 1445/1415 BC b: LBA II:1510/1485 to 1400/1390 BC | | Phase L | | | boundary K / L | 1661 to 1591 BC | 1679 to 1538 BC |
| | | | | | end of L | later than 1610 BC (e) | later than 1644 BC (e) |
| | Hiatus | | | | | | |
| | | | | | beginning of M | earlier than 1285 BC (e) | earlier than 1259 BC (e) |
| LH IIIA a: LBA IIIA: 1445/1415 to 1340/1330 BC b: LBA IIIA: 1400/1390 to 1340/1330 BC | | Phase M | | Cypriote | | | |
| | | | | | end of M | later than 1367 BC (e) | later than 1382 BC (e) |

Research Areas
1) Fortification Wall
2) "Inner Settlement" (Innenstadt)
3) South Slope, Q-trenches (Südhügel)
4) Well Deposit

—— vertical stratigraphic sequence
····· existing deposits, but not in vertical stratigraphic sequence

Notes:

(a) long absolute chronology for the the Aegean Bronze Age based on the few presently published $^{14}$C dates [1,2,19];
(b) historical chronology based on the Egyptian Chronology and its relations to the Aegean (according to Refs. [4,20–22]);
(c) with subphases (A1, A2, etc.);
(d) time range for the respective confidence level (1$\sigma$ and 2$\sigma$);
(e) no time range is given for boundaries at the beginning or the end of the sequence or hiatus.

cussion about the discrepancy between the date derived from the synchronisation with the Egyptian historical chronology and the science based date is worth to note [17].

## 4. Conclusion

The $^{14}$C sequence from Aegina is one of the longest sequences existing so far for the Aegean Bronze Age, and therefore of major importance for the absolute Bronze Age chronology in this region. We report here preliminary results of this sequence which allow us – at the present state of our investigation – a fairly precise estimate for the EH/MH and MH/LH transitions. Less precise and secure appears the end of the sequence, i.e. the LH I–LH II part. In these time periods definitely more data are needed to verify the present appearance of a time frame for the Thera eruption.

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