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# 1 Geoarchaeological investigation of a prehistoric tell in a coastal environment: 2 the lowest levels at Kirrha (Plain of Delphi, Phocis, Greece)

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## 14 **Abstract**

15 The tell of Kirrha is the largest prehistoric site (Middle to Late Helladic I) in Phocis (Greece),  
16 covering an area of around 6 hectares. Located downstream of the deltaic plain of Delphi and  
17 close to the present-day coastline, its deepest, and therefore oldest, archaeological levels  
18 have never been reached. The following article discusses the results of the geoarchaeological  
19 investigation of the tell. Information about the internal structure of the tell was gathered for  
20 the first time through ARP and ERT geophysical surveys, two core drillings, some  
21 sedimentological analyses and radiocarbon dating. The date of its earliest occupation could  
22 also be obtained. The results indicate a thickness of occupation layers ranging from 9 to 11  
23 meters (until 2 m b.s.l.). While some archaeological indicators found in the cores (such as very  
24 isolated pottery fragments) suggest a probable Neolithic occupation, the radiocarbon dating  
25 results presented here indicate a first occupation at the very beginning of the Bronze Age  
26 (Early Helladic II). Palaeoenvironmental reconstruction reveals that the first inhabitants of  
27 Kirrha settled in a coastal-marsh-type environment that was being filled in by fine-grained  
28 alluvial deposits from the Pleistocene and Hylaithos rivers. Geophysical surveys also revealed that  
29 parts of the tell have been eroded by a palaeochannel or buried under alluvial sediments.  
30

31 **Keywords:** Prehistoric Greece, Phocis, tell, geoarchaeology, Bronze Age  
32

## 33 **1. Introduction**

34 The tell of Kirrha is a very important Bronze Age archaeological site found in Phocis, Greece.  
35 The area has been the theatre of excavation campaigns since the 1930s (Dor et al., 1960).  
36 Located downstream from the deltaic plain of Delphi, the excavations have uncovered a  
37 considerable number of Bronze Age structures and graves, spanning from the Middle Helladic  
38 period (around 2000 BCE) to the Late Helladic period (around 1100 BCE) (Dor et al., 1960;  
39 Orgeolet et al., 2017; Lagia et al., 2016; Montagné, 2019). Although Bronze Age remains are  
40 abundant in Phocis (Müller, 1992; Phialon, 2018), Kirrha is the only tell (also known locally as  
41 “Magoula” (Skorda, 2010; Dor et al., 1960)) in the region, standing at nearly 8 m a.s.l., and one

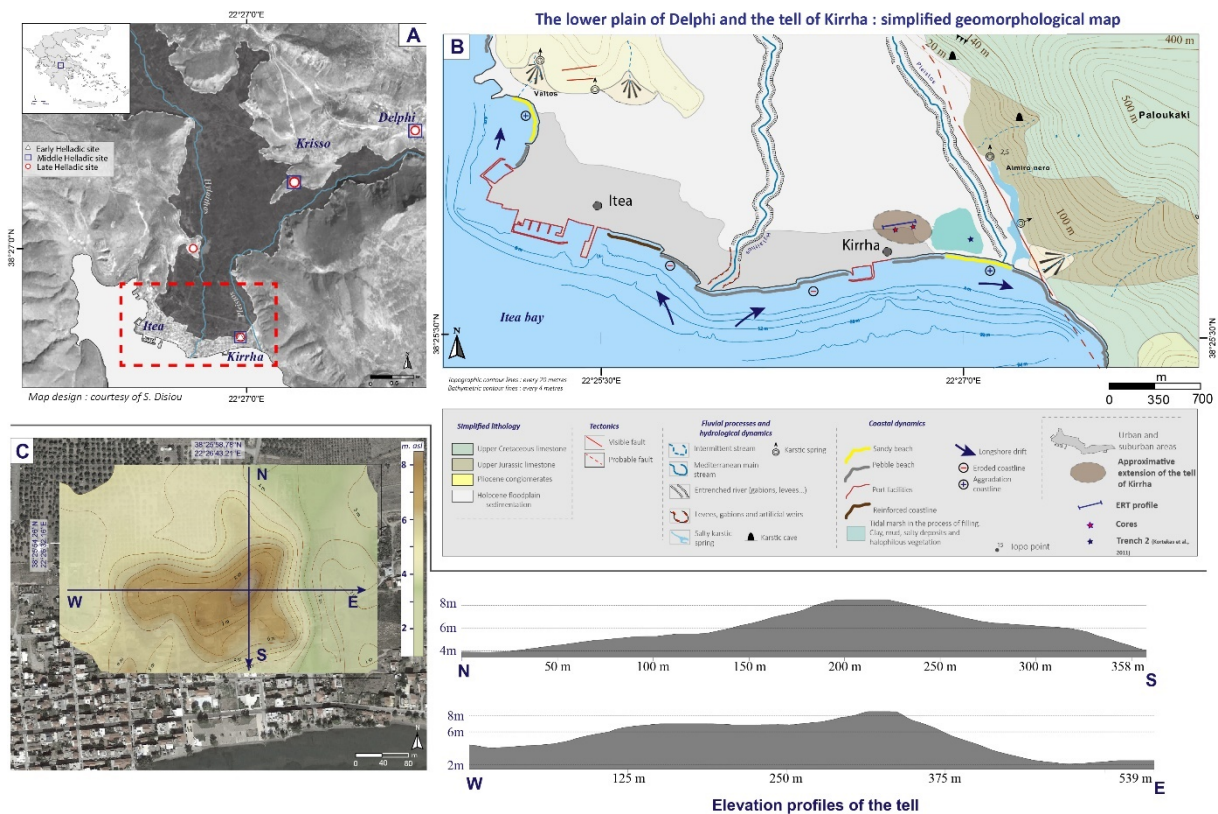
42 of the most densely populated prehistoric sites in the area (**Fig. 1-A**). Neolithic to Bronze Age  
43 tells (archaeological mounds) are very common in Greece and their formation processes are  
44 variable and complex. The significant accumulation of archaeological layers is linked to  
45 successive reconstruction phases in the same location over several centuries, sometimes  
46 millennia (Matthews, 2014; Andreou et al., 1996). Excavating and understanding the  
47 chronology of a tell is not an easy task since the most recent occupations are not necessarily  
48 located at the top (for a recent review of the type of problems encountered during excavations  
49 of tells, see Lespez et al., 2013, and Rosen, 1986). For several years, the geoarchaeological  
50 approach has proven to be highly valuable for studying Neolithic and Bronze Age tells in  
51 Greece, as it enables us to comprehend their internal structure and formation processes, as  
52 well as date them (Niebieszczanski et al., 2019; Lespez et al., 2013; Davidson et al., 2010). The  
53 excavation of the tell of Kirrha presents several challenges, including the fact that much of the  
54 remains lie beneath the modern village and that the deeper archaeological layers cannot be  
55 reached due to the presence of aquifers. The geoarchaeological study presented in this paper  
56 attempts to answer two questions that have remained unanswered since the first excavations  
57 in the 1930s: what are the lateral and vertical dimensions of the tell as well as the date of its  
58 earliest occupations? This study (which included geomorphological mapping, ARP and ERT  
59 surveys, core drillings, sedimentological analysis and radiocarbon datings) is the first attempt  
60 at partially overcoming the obstacles encountered in Kirrha, by providing new insights into the  
61 whole stratigraphy of the tell. As the morphology and landscapes of Mediterranean coastal  
62 deltaic plains have changed significantly since prehistoric times (Carozza, 2011), the retrieval  
63 of palaeoenvironmental information about the earliest occupations of the tell also presents a  
64 significant challenge for archaeological research in Phocis. From a methodological standpoint,  
65 this study opens up new possibilities for both field and laboratory methods used to  
66 understand prehistoric coastal tells in Greece.

## 67 **2. Physical setting**

68 The tell of Kirrha is located in the northern part of the Gulf of Corinth, downstream from the  
69 Delphi plain and within 200 meters of the current shoreline. The Gulf of Corinth is an active  
70 asymmetric rift with some of the highest extension rates in the world (13 and 15 mm/year)  
71 (Lykousis et al., 2007; Moretti et al., 2004). The rift is bordered by a series of East-West-  
72 oriented faults (including the Delphi/Arachova fault) which have been responsible for locally-  
73 destructive earthquakes (Valkaniotis et al., 2016; Valkaniotis et al., 2011) and sometimes  
74 tsunamis (Kortekaas et al., 2011). The Delphi plain is part of this regional setting: it is a graben  
75 surrounded by active boundary faults (see Chabrol et al., 2020 for a complete  
76 geomorphological map of the plain).

77 Although the exact size of the tell is uncertain, archaeological estimates based largely on  
78 rescue excavations (Skorda, 2010) suggest that it is at least 6 hectares in size. The site forms a  
79 small hill (**Fig. 1-C**), very prominent in the surrounding low-lying alluvial plain, 8 m above actual  
80 sea level at its summit. The tell is flanked by two temporary streams: the Pleistos to the east  
81 and the Hylaitos to the west, both of which have been channelised since the 19th century (**Fig.**  
82 **1-B**). The lower part of the plain is an asymmetrical delta formed by the alluvial deposits of  
83 the Hylaitos River and, to a lesser extent, those of the Pleistos River (Chabrol et al., 2020;  
84 Zurbach et al., 2012). The surrounding environment and the site's position relatively to the  
85 coastline have likely both undergone significant changes since the Bronze Age, as is the case

86 with many Greek deltaic plains (Ghilardi et al., 2012; Fouache, 2007). A portion of the site may  
 87 therefore have been eroded or partially covered by the alluvial deposits from these two rivers.  
 88 Geomorphological surveys have revealed the presence of a recently filled-in coastal marsh  
 89 east of the site (Kortekaas et al., 2011) and a saline karst spring at the junction between the  
 90 Paloukaki massif and the plain (Zurbach et al., 2012 ; Burdon et al., 1963) (**Fig. 1-B**). Shoreline  
 91 dynamics are currently primarily composed of a redistribution of fine-sized particles towards  
 92 the east of the bay, with a mostly sandy shoreline near the site (Chabrol et al., 2020) (**Fig. 1-**  
 93 **B**).



94  
 95 **Fig. 1.** Location and environmental context of the study area (A. General morphology and extent of the  
 96 plain of Delphi. B. Simplified geomorphological map of the plain of Delphi. C. Topography and elevation  
 97 profiles of the tell of Kirrha.

98  
 99 **3. Site history and archaeology**

100 Kirrha has been known for its remains from historical times since the 19th century and was  
 101 visited in the early 1920s by then young British archaeologist Oliver Davies, who first  
 102 recognised the site's importance to the prehistoric period. Davies even reported the presence  
 103 of Neolithic sherds on the surface of the tell, a detail that was to be forgotten for many  
 104 decades (Davies, 1929). In 1937 and 1938, classicists from the French School at Athens,  
 105 interested in historic Phocis, carried out a series of excavations which, most notably,  
 106 uncovered a large "prehistoric sector" to the north of the village's main church, in front of the  
 107 cemetery (**Fig. 2**). It revealed an important and long-lived settlement, especially for the Middle  
 108 Helladic period and the transition to the Late Bronze Age (Dor et al., 1960). Continuous rescue

109 excavations then took place from the 1960s onwards, confirming the site's importance as a  
110 settlement in the Middle Helladic period and particularly as a burial site during the MH III-LH I  
111 period. In 2008, a cooperative research project between the French School of Archaeology at  
112 Athens and the 9th Ephorate of Antiquities was conducted, aiming to apply a multidisciplinary  
113 approach to several important developments in Kirrean archaeology, including environmental  
114 reconstruction, habitat and burial practices (Orgeolet et al., 2017; Lagia et al., 2016;  
115 Montagné, 2019). The research presented here was conducted within this framework.

116

#### 117 4. Material and methods

118

119 Our dual methodological approach combines geophysical surveys and coring. Electrical  
120 resistivity surveying (both ERT and ARP methods) has proven its efficacy as a method for  
121 characterising subsurface structures and materials in diverse environmental and  
122 archaeological research domains (Piroddi et al., 2020; Niebieszczański et al., 2019; Siart et al.,  
123 2012; Gaffney, 2008), while coring is particularly useful for characterising successive  
124 environments within and around an archaeological site (Trebsche et al., 2022; Rick et al., 2022;  
125 Garcia-Garcia et al., 2017).

126



127

128

129 **Fig. 2.** Topography of the tell of Kirraha and location of the geophysical surveys (ARP and ERT), core  
130 samples and areas excavated since 1937. Isoline interval: 0.5 m.

131

132

133

#### 134 4.1 Geophysical survey

##### 135 4.1.1 Automated Resistivity Profiling (ARP) survey

136 The survey, carried out in 2008 using the multi-polar ARP03 device (ARP®, Automated  
137 Resistivity Profiling, Géocarta SA, Paris, France), aimed to assess the extent of the site and the  
138 nature of its various periods of occupation. The spacing of the dipoles, corresponding to the  
139 emitter-receiver distance, allows for three different depths of investigation (50 cm, 1 m, and  
140 1.7 m, respectively). The injected current is set at 10 mA and the system enables resistivity  
141 measurements at a 20cm interval regardless of the advancing speed. A surface area of 2.8 ha  
142 was surveyed, encompassing four zones (A, B, C, D) of the tell (**Fig. 2**). The surveyed zones  
143 themselves are constrained by the urban sprawl of the houses, private properties, and olive  
144 groves of Kirrha.

145

##### 146 4.1.2 Electrical Resistivity Tomography (ERT) section

147 A 366-meter-long ERT profile (ERT4) of the tell was measured using an ABEM Terrameter LS  
148 acquisition system, with an electrode spacing of 1.5 meters, and taking into account the  
149 topography using DGPS measurements at each electrode (**Fig. 1 & 2**) (Chabrol et al., 2014).  
150 The section was on an East/West axis across the tell (starting point coordinates: 38° 25'  
151 54.72088" N; 22° 26' 31.78923" E; end point coordinates: 38° 25' 54.60641" N; 22° 26'  
152 46.85820" E). The collected data was processed through an inversion program, resulting in a  
153 2D resistivity section representing the subsurface.

##### 154 4.2 Sediment core sampling and Seismic Cone Penetrometer testing (SCPT)

155 Two six-centimetre diameter cores were obtained from the tell. Their location corresponds to  
156 the two sectors excavated by the French School at Athens since 2009. Core Tell1 was located  
157 at the top of the eastern part of the tell (7.3 m a.s.l) (38°25'52.3"N; 22°26'45.99"E), while core  
158 Tell2 was placed in its western part at a lower elevation (5.7 m a.s.l) (38°25'52.66"N;  
159 22°26'37.19"E) (**Fig. 2**). The method used was percussion coring. Both cores reached a depth  
160 of 10 meters. SCPT (Seismic Cone Penetration Test) measurements were simultaneously  
161 conducted on Tell1. This method is valuable for assessing the hardness of archaeological and  
162 geological layers (Audibert et al., 2005). In the field, the cores were photographically  
163 documented into stratigraphic units based on texture and colour (using the Munsell code),  
164 and gaps created by compaction were recorded on the logs. The numerous ceramic fragments  
165 found inside the sediment were handed over to specialised archaeologists for identification.

##### 166 4.3 Sedimentological laboratory analyses

###### 167 4.3.1 Laser grain size analyses

168 While the sediment fraction >2 mm was simply sieved manually using several sizes of sieves,  
169 the fraction <2 mm was measured by a Malvern Mastersizer1000 laser granulometer. Grain  
170 size measurements were performed at various intervals: every 10 cm from the surface to a

171 depth of 8 meters below the surface, and every 5 cm for the last two meters in core Tell1 (8-  
172 10 mbs). In core Tell 2, only the final 2 meters (8-10 mbs) were sampled and analysed. Every  
173 sample was weighed and dried (24 h at 40 °C) and organic matter was removed (4 hours with  
174 H<sub>2</sub>O<sub>2</sub> treatment). Particles were then dispersed using 0.1 % of sodium hexametaphosphate  
175 and left in a deionised solution for 4 hours. Each sample was exposed to ultrasounds for 4 min  
176 before measurement.

#### 177 4.3.2 Magnetic susceptibility

178 Magnetic susceptibility is used to identify mineralogical differences between visually  
179 homogeneous stratigraphic units. Changes in sediment magnetism can indicate a mechanical  
180 or chemical alteration in the process of grain deposition or sedimentation (Ghilardi et al.,  
181 2008). In archaeology, and particularly in the case of a tell where a significant portion of the  
182 deep stratigraphy is unknown, this method is highly useful (Rosendahl et al., 2014). The  
183 magnetic characteristics of sediments depend on the soil's history (Dearing et al., 1996): for  
184 instance, a succession of fires can enhance the soil's magnetic properties. An anthropogenic  
185 or calcined layer may experience a modification of its magnetic field due to the increased  
186 temperature of its constituents (Djerrab A., 2002). The measurements were conducted using  
187 a Bartington MS2/MS2K dual frequency sensor (at low and high frequencies) every 2 cm,  
188 directly on both the cores and the core-catchers.

#### 189 4.3.3 CaCO<sub>3</sub> content

190 The CaCO<sub>3</sub> content of the sediment primarily identifies subtle changes in facies that may  
191 otherwise be invisible during core observation. In the context of a tell, such analyses can also  
192 help identify variations in composition within the layers of the tell. Carbonate content was  
193 measured using hydrochloric acid and a calcimeter (Fournier et al., 2012).

#### 194 4.3.4 Micropalaeontological analyses

195 Sediment samples were collected from the last two meters of core Tell1. Foraminifera were  
196 isolated through wet sieving (between 500 and 63 µm) and the trichloroethylene method  
197 (Murray, 2006). A dry splitter was used to divide the samples during counting (Emmanouilidis  
198 et al., 2020). It has to be noted that, due to the small number of samples, only a simple  
199 identification and count was performed.

#### 200 4.4 Radiocarbon datings (**Table 1**)

201 Three charcoal and one wood samples taken from core Tell1 were dated using the AMS  
202 method. A previous sample ("T2, marine shell") obtained from the former coastal marsh east  
203 of the tell, initially published in 2011 (Kortekaas et al., 2011), was reused in this study. All Tell1  
204 samples were calibrated using the IntCal20 atmospheric curve, while T2 was recalibrated using  
205 the Delta\_R 143±41 and the MarineCal20 curve (Reimer et al., 2020).

206

207

208

Core	Sample code	Sample name	Depth (cm bs)	Depth (cm bmsl)	Material	Conventional <sup>14</sup> C Age BP	2σ Max and Min Cal. Age	Study
Tell 1	Lyon - E822	Ech4	-822	101	charcoal	5670 ± 230	5056 BCE 4038 BCE	This study
Tell 1	Lyon - E837	Ech3	-837	116	charcoal	3780 ± 40	2344 BCE 2122 BCE	This study
Tell 1	Lyon - E876	Ech2	-873	155	wood	4205 ± 35	2816 BCE 2668 BCE	This study
Tell 1	Lyon - E1000	Ech1	-1000	279	charcoal	4510 ± 35	3359 BCE 3097 BCE	This study
4	Beta-172750	T2	122	0.05	Shell	4670 ± 40	2831 BCE 2388 BCE	Kortekaas et al., 2011

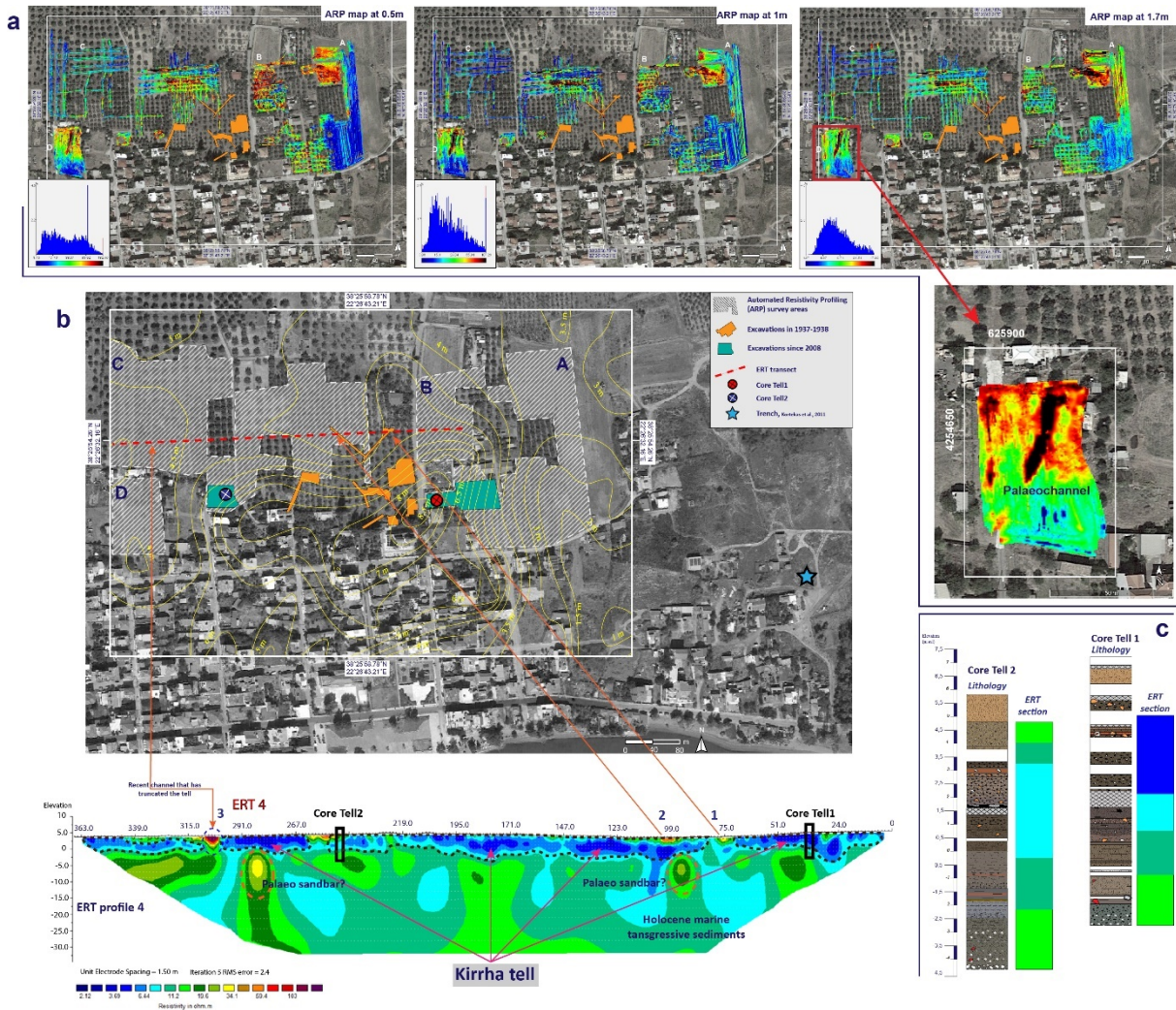
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211 **Table 1.** AMS <sup>14</sup>C radiocarbon dates calibrated using OxCal (v4.4.4) with the IntCal20 and MarineCal20  
 212 calibration curves

213

214 **5.Results**

215



216

217 **Fig. 3.** a/ results of the ARP surveys (in ohm.m) at three different depths: 0.5, 1 and 1.7 m. b/ results  
 218 and interpretation of the ERT transect. c/ correlation between cores Tell1 and Tell2 and the ERT values.



## 219 5.1 Geophysical survey

220 Four main zones (A, B, C, and D) (**Fig. 3-b**) were surveyed using ARP (Automated Resistivity  
221 Profiling). The apparent resistivity values show distinct patterns (**Fig. 3-a**): in the northern part  
222 of Zone A, the values at a depth of 0.5m range between 80 and 182 Ohm.m, indicating a high  
223 density of shallow-depth remains. However, the values are very low (between 8 and 17  
224 Ohm.m) in the eastern part of that same zone Ohm.m, corresponding to the edge of the former  
225 coastal marsh of Kirrha, which was primarily composed of fine-grained sediments (Chabrol et  
226 al., 2021, Kortekaas et al., 2011). It should also be noted that the apparent resistivity in this  
227 zone clearly increases from a depth of one meter and below, suggesting that at least part of  
228 the deepest levels of the tell may have been buried under fine alluvial sediments deposited  
229 by the Pleistos River.

230 Analysis of Zone B reveals a concentration of remains at very shallow depths. This is not  
231 surprising as the zone is located near the current excavations as well as those from 1937-1938.

232 Zone C is divided into two parts. The eastern part, with consistent resistivity values ranging  
233 between 80 and 182 Ohm.m and persisting at depth, also corresponds to the continuity of the  
234 remains discovered during the 1937-1938 excavations. The survey in the western part is less  
235 dense due to the presence of olive groves but shows some surface anomalies that tend to  
236 disappear with depth. It is likely that here, too, the remains have been covered by alluvial  
237 sediments.

238 Zone D, located in the southwest, strengthens this hypothesis: the very high surface values  
239 (>170 Ohm.m) delineate what appears to be a palaeochannel, which can be followed at least  
240 down to a depth of 1.70 m and extends for about sixty meters in length.

241 The ERT4 2D section (**Fig. 3b**) shows a series of low electrical resistivity values (2 to 5 ohm.m)  
242 in its upper section, extending from east to west and corresponding to the prehistoric tell.  
243 These low values are believed to result from the porosity of the archaeological layers  
244 composed mainly of silts and clays, potentially originating from the prehistoric mud  
245 structures. This unit is between 7- and 9-meters thick, which means that the lower levels of  
246 the tell are now below the current sea level, with the deepest archaeological layers estimated  
247 to be around 2 to 3 meters below sea level. Close to the surface, the section shows several  
248 areas of higher resistivity values, ranging from 35 to 105 ohm.m (no. 1 and 2, **Fig. 3b**), which  
249 could indicate the presence of massive ancient structures, lying just below the surface and  
250 already excavated during the 1937-38 excavations. To the west of the profile (no. 3, **Fig. 3b**),  
251 another area of high resistivity corresponds to a possible palaeochannel composed of pebbles  
252 and gravels. This palaeochannel can again be identified further south (Zone D) in the  
253 apparent resistivity maps obtained from the ARP surveys (**Fig. 3a**).

254 By contrast, the resistivity values below the tell (10 to 35 ohm.m) can be associated with sandy  
255 marine sediments. An attempt to correlate the cores with the ERT section clearly indicates  
256 that these values correspond to sandy sediments (**Fig. 3c**). The tell of Kirrha is located in a  
257 specific geomorphological setting, between Holocene marine transgression and more recent  
258 coastal progradation alluvial deposits.

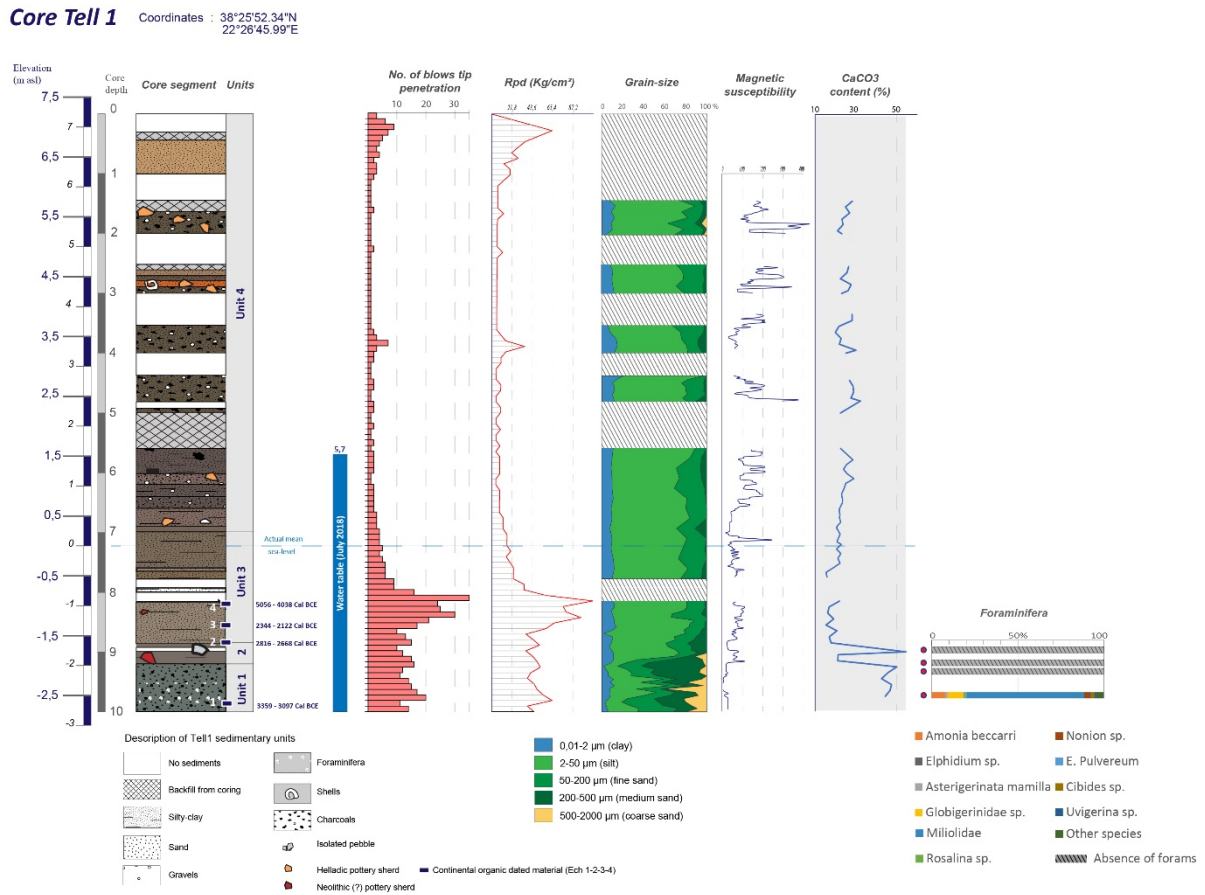
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260 5.2 General stratigraphy of the cores

261 Cores Tell1 and Tell2 reached depths of 2.7 m b.s.l. and 4.3 m b.s.l., respectively. Despite their  
 262 different elevations, the drill cores exhibit significant stratigraphic similarities: both  
 263 penetrated the archaeological layers and reached levels anterior to the earliest human  
 264 occupations.

265 Four main lithological units were recorded in both cores: SU1, SU2, SU3 & SU4.

266



267

268

269 **Fig. 4.** Stratigraphical and sedimentological chart of core Tell1

270

271 5.2.1 Stratigraphic Unit 1 (SU1) (**Fig. 4**)

272 SU1 (between 2.7 and 2.5 m b.s.l. in Tell1 and between 4.3 and 3.3 m b.s.l. in Tell2) mainly  
 273 consists of medium to coarse sands (74 %). Numerous marine shell fragments were found.  
 274 The high CaCO<sub>3</sub> content (reaching more than 50 % in some samples) of this unit may be  
 275 attributed to these shell fragments. The low magnetic susceptibility values could also be  
 276 associated with these carbonate contents, although the general magnetic susceptibility of the  
 277 alluvial deposits in the plain of Delphi is expected to be low due to the predominance of  
 278 sedimentary rocks in the watershed (Valkaniotis, 2009). Within this unit, benthic foraminifera

279 are primarily composed of infralittoral shallow marine and rich algal vegetation species,  
280 including *A. beccari*, *Elphidium* spp., rotaliids (*Rosalina* sp., *Nonions* sp.), and miliolids  
281 (*Quinqueloculina seminula*). A few planktonic specimens have also been identified  
282 (*Globigerinidae* sp.). While two Neolithic pottery sherds were found at the base of Tell2, SU1  
283 represents a pre-tell unit that can be dated back to 3359-3097 Cal BCE.

#### 284 5.2.2 Stratigraphic Unit 2 (SU2) (Fig. 4)

285 SU2 (between 1.9 and 1.6 m b.s.l. in Tell1 and between 2.5 and 1.45 m b.s.l. in Tell2) mainly  
286 consists of grey silty sediments with a minor proportion of fine-to-medium sand (25 %). No  
287 foraminifera were found within this unit. Plant remains were observed in Tell2. Some evidence  
288 of human influence is present, albeit diffuse: a fragment of Neolithic pottery in Tell1 and a few  
289 traces of burnt sediments in Tell2. The magnetic susceptibility values are slightly higher and  
290 more irregular than those in SU1. Contact between SU2 and SU3 occurred around 2816-2668  
291 Cal BCE.

292

#### 293 5.2.3 Stratigraphic Unit 3 (SU3) (Fig. 4)

294 SU3 (between 1.6 m b.s.l. and 0.25 m a.s.l. in Tell1 and between 1.45 m b.s.l. and 0.3 m a.s.l.  
295 in Tell2) mainly consists of light-brown silty sediments with a small fraction of fine sand (20 %).  
296 The proportion of sand decreases from the base to the top of the unit. In both Tell1 and Tell2,  
297 evidence of human influence is present: fragments of neolithic ceramics, burnt sediments, and  
298 a large quantity of macro-charcoal. The magnetic susceptibility values are slightly higher than  
299 in SU2 and remain irregular. By contrast, the sediment's CaCO<sub>3</sub> content is lower than in  
300 previous units (around 20 %). One of the two obtained dates (2344-2122 Cal BCE) is  
301 chronologically consistent with the date obtained at the top of SU2. However, the other dated  
302 sample, despite being higher in the stratigraphy, resulted in an older date (5056-4038 Cal BCE):  
303 further discussion regarding its validity is required (see Discussion 6.1).

304

#### 305 5.2.4 Stratigraphic Unit 4 (SU4) (Fig. 4)

306 SU4 (between 0.25 and 7.3 m a.s.l. in Tell1 and between 0.3 and 5.7 m a.s.l. in Tell2)  
307 corresponds to successive anthropic levels within the tell. The sediment grain size is highly  
308 consistent (10 % clay, 70 % silt, and 20 % fine sand), likely indicating collapsed structures that  
309 were originally constructed with sun-dried bricks. The gaps in the stratigraphy are due to the  
310 porosity of the sediments. The magnetic susceptibility values are higher than in previous units,  
311 but also very irregular, highlighting the significance of anthropogenic activity. SU4 contains  
312 numerous fragments of charcoal and Helladic ceramics, occasionally associated with gravel,  
313 isolated stones and burnt sediment.

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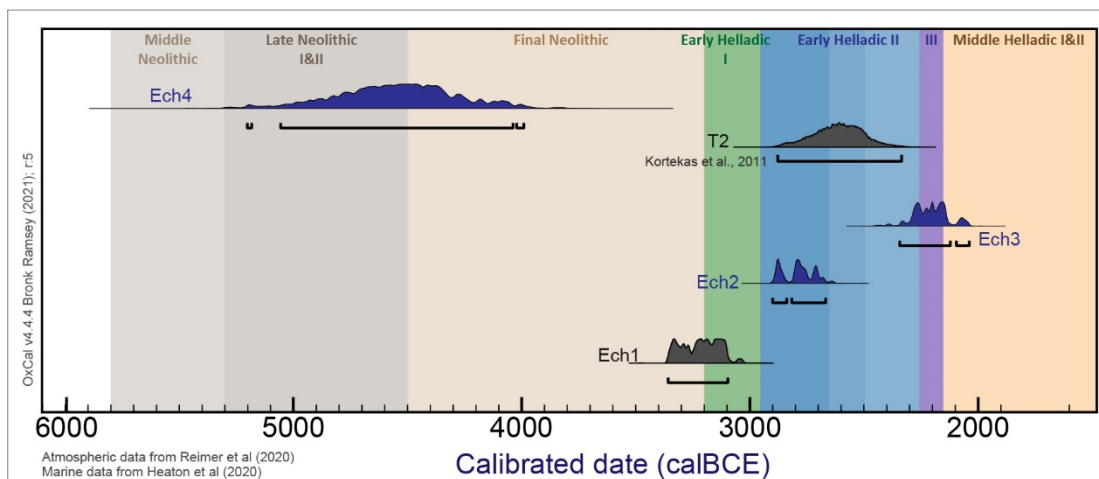
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## 318 6. Discussion

### 319 6.1 Radiocarbon results and archaeological chronology

320 The three samples *Ech1*, 2 & 3 provide highly accurate dates, with BP error margins of about  
321 thirty years. Their 2 $\sigma$ -calibration yields calendar ages with a range of 160 to 250 years  
322 (**Table 1**). Sample *Ech1* was collected in stratigraphic unit SU1, below the anthropogenic  
323 layers. Samples *Ech2*, *Ech3* and *Ech4* were all taken within the anthropogenic layers: they are  
324 framed by pottery sherds and the grain size is consistent with that of the upper levels (**Fig. 4**).  
325 According to the Early Helladic Mainland chronology of Cavanagh, Mee & Renards (based on  
326 the tell of Kouphovouno) (Cavanagh et al., 2016), and knowing that the dated samples are not  
327 strictly related to any archaeological artifacts due to the drilling method used, the deepest  
328 layers of the tell would thus correspond to a settlement of the Early Helladic 2 period (**Fig. 5**).  
329 This observation is consistent with the admittedly inaccurate description of the stratigraphy  
330 of the site by the French excavation team in the 1930s (Dor et al., 1960). In contrast, sample  
331 *Ech4* stands out from the others: its dating is much older (5056-4038 Cal BCE, Late Neolithic I  
332 & II to Final Neolithic). While some archaeological indicators (such as very isolated pottery  
333 fragments) found during the excavations suggest a probable Neolithic occupation (Orgeolet  
334 et al., 2017), sample *Ech4* does not allow us to formally address this question. Its stratigraphic  
335 position above the others does not exclude the possibility of reworked sediments. Likewise,  
336 the uncertainty of almost 1000 years in the calendrical age of this sample does not allow us to  
337 draw reliable archaeological outcomes.

338



339

340 **Fig. 5.** Chronocultural attribution of the radiocarbon dates published in this paper, according to  
341 Cavanagh et al., 2016 for the Early Helladic chronology. Blue-coloured samples (*Ech2*, *Ech3* and *Ech4*)  
342 were collected within anthropogenic layers of the tell. *Ech1* was collected in SU1 under the tell (**Fig. 4**)  
343 and *T2*, 350 meters west from the tell (**Fig. 1; 2**).

344

345

346

## 6.2 General palaeoenvironmental reconstitution of the tell of Kirrha

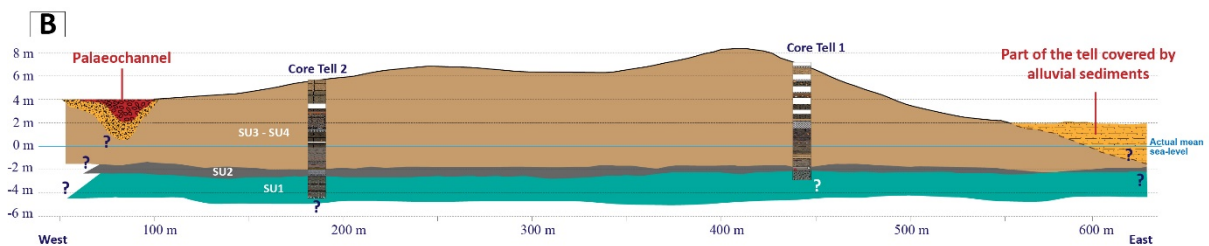
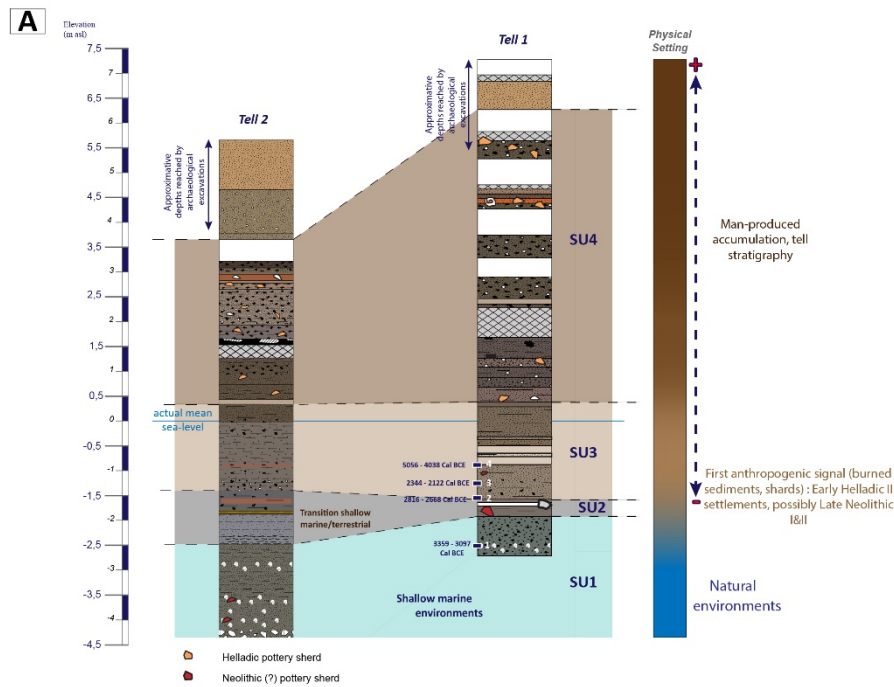
347 In order to attempt an initial description of the major stages of the formation of the Kirrha  
348 tell, it is necessary to consider its specific position, at the interface between a deltaic plain and  
349 the coastline.

350 ERT section and sedimentological evidence indicate that the deepest archaeological levels of  
351 the tell are found up to approximately 2 to 3 meters below sea level. Taking into account the  
352 current topography, this results in a maximum archaeological occupation thickness of 7 to 9  
353 meters. The pre-tell levels are mainly composed of sands with the presence of foraminifera  
354 (between 11.2 and 19.6 ohm.m in the ERT section): marine species associated with algal  
355 species (miliolids). Around 3359-3097 Cal BCE (Final Neolithic/Early Helladic 1 transition), the  
356 Kirrha area consisted of shallow marine environments with low hydrodynamics. This part of  
357 the gulf could have been protected from the waves by a barrier beach, creating vast areas of  
358 shallow marine water that would be progressively filled in by alluvial deposits and deltaic  
359 progradation. Lagoonal settlements were common during Neolithics and Bronze Age in  
360 Eastern Mediterranean (Fontana et al., 2017) and this type of environment is often found in  
361 the Greek deltaic plains during Bronze Age (Emmanouilidis et al., 2019; Pavlopoulos et al.,  
362 2006; Bruckner et al., 2005).

363 Between 3359-3097 Cal BCE and 2816-2668 Cal BCE (Early Helladic II), changes took place in  
364 the surroundings, presumably associated with coastal progradation. Marine sediments were  
365 replaced by terrigenous sediments (no longer containing foraminifera), and the grain size  
366 indicates less energetic depositional dynamics (between 10 and 11.2 ohm.m in the ERT  
367 section). In the context of deltaic progradation, the early inhabitants of the site (initial, diffuse  
368 traces of anthropisation were found) likely settled in a coastal marsh environment that  
369 gradually filled up with fine alluvial deposits from the Pleistos River. These wetlands, rich in  
370 biodiversity, were probably able to provide the natural resources needed for an initial  
371 permanent settlement. The essential supply in freshwater could have come from the outflow  
372 or underflow of the Pleistos, whose exact course during the Bronze Age is still unknown. It  
373 could also have come from the (now saline) spring at the foot of Mount Paloukaki, 300 metres  
374 to the east of the tell: of karstic origin (Burdon et al., 1963), the salt water is the result of a  
375 mixture of fresh and sea water that could be related to the Holocene sea-level rise (Arfib et  
376 al., 2004; 2006). In the Bronze Age, when the sea level was around 3 metres lower, water from  
377 this spring could potentially still have been drinkable.

378 From 2344-2122 Cal BCE (Early Helladic II and III) until the end of the prehistoric occupation  
379 (Late Helladic I), sedimentation became anthropogenic, and the tell of Kirrha expanded. The  
380 porosity of these anthropogenic layers is attested by the light SCPT values and low ERT values  
381 between 2 and 10 ohm.m). Due to the absence of radiocarbon dating and considering the  
382 inaccessibility of the deepest archaeological levels, it is not possible to specify the rates of the  
383 tell's evolution between the current sea level and the maximum depth reached by  
384 archaeological excavations (approximately 2 m) (**Fig.6**). However, archaeological  
385 excavations have shown that the site was abandoned during the Late Helladic I period  
386 (Orgeolet et al., 2017).

387



388

389 **Fig. 6. A/** Stratigraphic correlation attempt between Tell1 and Tell2. **B/** Transect along the axis of cores  
 390 Tell1 and Tell2 taking into account sedimentary and geophysical results (both ARP and ERT)

391

392

393 6.3 A coastal marsh around the site during the Bronze Age?

394 The question of the nature of the environment in which the first inhabitants of Kirrha settled  
 395 is still open. While stratigraphic unit SU1 appears to correspond to a shallow marine  
 396 environment, first evidence of occupation is found mainly from SU2 unit onwards (from 2 m  
 397 b.s.l.). This unit corresponds to a transitional shallow marine/terrestrial environment. A trench  
 398 excavated in the early 2000s to the east of the Kirrha site (**Fig. 1; 2**) allowed for the  
 399 characterisation and dating of a coastal marsh during the Early Helladic 1 (Kortekaas et al.,  
 400 2011). Although the sample dated by Kortekaas et al. (recalibrated in this study with the  
 401 MarineCal20 calibration curve) is slightly higher topographically, the date corresponds to that  
 402 of the beginning of the occupation of the tell in core Tell1 (**Table 1; Fig. 4; 5**). The remains of  
 403 this coastal marsh are still visible today to the east of the site (**Fig. 1**) (Chabrol et al., 2020).  
 404 Similar marshy sediments have also been discovered around the same depths during two  
 405 separate drilling missions to the north and west of the tell (Chabrol et al., 2014, 2016).

406

#### 407 6.4 Geomorphological assessment of the preservation of the tell of Kirrha

408

409 Tells, like all archaeological sites, are subject to the inevitable processes of erosion and  
410 sedimentation (Davidson, 1976). These processes can be natural or man-made (Tarolli et al.,  
411 2016), and can occur long after the site has been abandoned. They have a major influence on  
412 our understanding of these structures: a large part of the site may have been eroded forever  
413 or buried deep beneath the sediment (Forti et al., 2023). The tell of Kirrha is no exception. The  
414 ERT data associated with the cores indicate an average thickness of the archaeological layers  
415 of between 7 and 9 metres. To the west of the tell, the ARP data (zone D) revealed the  
416 existence of a palaeochannel around 20m wide (**Fig. 3a**). This palaeochannel can also be seen  
417 as a cross-section in the ERT section (values between 35 and 120 ohm.m), at a depth of around  
418 3.5 m (**Fig. 3b**). It has clearly eroded part of the archaeological layers and would therefore  
419 post-date the Bronze Age (**Fig. 6b**). It could be an ancient natural course of the Pleistos dating  
420 from before its channelisation in the second half of the 19th century (Zurbach et al., 2012).  
421 The 1840 cartographic documents of the traveller Ulrich clearly indicate that the downstream  
422 course of the Pleistos passed to the west of the modern village of Kirrha, and thus of the tell  
423 (Ulrich, 1840).

424 To the east of the tell, on the other hand, ARP data (Zone A) revealed very low surface  
425 resistivity values (between 8 and 20 ohm.m). These values increase with depth, suggesting  
426 that remains are buried under sediment (**Fig. 6b**). This eastern part of the plain, that of a  
427 former coastal marsh, is composed of fine-grained Pleistos sediments that were progressively  
428 deposited in a context of deltaic progradation. An unknown proportion of the eastern part of  
429 the Kirrha tell could therefore lie beneath these deltaic sediments. The upper topographic  
430 levels of the tell have been preserved from alluvial dynamics but have inevitably been heavily  
431 eroded by the construction and development of the modern village of Kirrha: roads, housing,  
432 drains, etc.

433

#### 434 6.5 Contribution of the method

435 Since the deepest layers of tells are difficult to access, drills are a very effective addition to  
436 archaeological excavations. In Greece, this approach has often been used successfully,  
437 whether in Macedonia (Niebieszczański et al., 2019; Lespez et al., 2013; Darcque et al., 2011),  
438 Thrace (Ammerman et al., 2008), Euboea (Davidson et al., 2010) or in the Peloponnese (Mee  
439 et al., 2014). The main difficulty in coring a Bronze Age tell is to be lucky enough to get through  
440 all the archaeological layers without encountering obstacles that would stop the drill. In our  
441 case, the high density of limestone blocks, pebbles and graves posed a major risk. Sediment  
442 compaction is the second problem with this method. Given the great variety of archaeological  
443 layers (clayey, sandy, burned levels, etc.), it is difficult to quantify this compaction accurately  
444 and thus reconstruct a continuous and clear archaeological stratigraphy.

445

446

447

## 448 **7. Conclusion**

449 The geoarchaeological investigation of the tell of Kirrha offers new insights into the history of  
450 the site and its environment. It demonstrates the advantages of combining geophysical  
451 surveys, penetrometer and percussion drilling to investigate the lowest layers of the site,  
452 which cannot be excavated. This study has addressed two main questions: the stratigraphy of  
453 the archaeological site, including the lower levels that cannot be reached during  
454 archaeological excavations, and the date of its earliest occupations. Indeed, the stratigraphy  
455 of the archaeological layers of the site was confirmed to be between 9 and 11 meters. The  
456 geophysical study also revealed that certain levels of the tell have been eroded by  
457 palaeochannels or buried under sediments from the Pleistos River.

458 The natural environment before the first occupation was a calm and shallow marine  
459 environment, at least until 3359-3097 Cal BCE. The radiocarbon dates of the deepest  
460 archaeological layers (SU2) suggest a first occupation at the beginning of Early Helladic II at  
461 this place (we must bear in mind that these results were obtained from only one drill core: we  
462 cannot exclude the possibility that other areas of the site deviate from the pattern observed  
463 here). The question of an earlier Neolithic occupation, perhaps elsewhere on the tell, remains  
464 open. It seems that the first inhabitants of the site settled in a marshy coastal environment:  
465 this raises questions about the nature of the settlement and opens up new regional  
466 discussions about the links between Early Helladic settlements and coastal environments.  
467 Altogether, the success and replicability of this approach may support similar initiatives for  
468 other prehistoric coastal tells.

469

470

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480

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