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LOCATING ARCHAEOLOGICAL HORIZONS WITH ^{14}C SEDIMENT DATING: THE CASE OF THE LOST CITY OF HELIKE

YANNIS MANIATIS,[1] YORGOS FACORELLIS,[1] STEVEN SOTER,[2] DORA KATSONOPOULOU[3] and BERND KROMER[4]

ABSTRACT. In 373 BC a catastrophic earthquake and seismic sea wave destroyed Helike, a Greek city near Aigion on the southern shore of the Gulf of Corinth. The ruins were buried by sediments of unknown depth, leaving no trace of the city. We here discuss the radiocarbon dating of organic sediment samples recovered from seven boreholes drilled on the coastal plain in the area where ancient sources located Helike. Most of the samples apparently acquired a substantial addition of older carbon from natural sources, and hence their apparent ages are older than the true ages of sedimentation. However, if we assume that the addition is systematic, we can use the apparent ages to show that the sedimentation rate was initially rapid (about 1 cm yr^{-1}) for the strata between 40 and 10 m below the surface, and then decreased by an order of magnitude about 6500 yr ago. A related change in the sediment deposition at about the same time has been found in many other marine deltas throughout the world, probably due to the deceleration of the global sea-level rise. We conclude that in the boreholes sampled by the present data, the horizon corresponding to ancient Helike is less than 8 m deep.

INTRODUCTION

Helike was founded in the Bronze Age on the southern shore of the Gulf of Corinth, about 7 km southeast of Aigion in the northern Peloponnesos. It was the principal city in the Achaian area. In 373 BC a powerful earthquake and seismic sea wave destroyed Helike and submerged the land where it was built. Reportedly no one survived. (For a review of historical sources and the archaeological background, see Marinatos (1960)). Soter and Katsonopoulou (ms.) carried out an extensive sonar survey of the area. They showed that the site is no longer under water and concluded that the ruins were buried by prograding alluvial sediments. Accordingly, they shifted the search to the broad coastal plain. In 1991–1995 they drilled 45 boreholes on land, most in the area between the Selinous and Kerynites Rivers, and recovered ceramic fragments and carbonaceous sediment for dating. This paper reports the first results of ^{14}C dating on samples from seven of the cores analyzed mainly at the National Center for Scientific Research "Demokritos".

Radiocarbon dating of sediments has been the subject of much discussion and controversy (Gilet-Blein, Marien and Even 1980; Fowler, Gillespie and Hedges 1986; Hedges 1992; Scharpenseel and Becker-Heidmann 1992; Orlova and Panychev 1993). Sediments contain different organic fractions which may or may not be related directly to the sedimentation event of interest (Kigoshi, Suzuki and Shiraki 1980; Balesdent 1987; Chichagova and Cherkinsky 1993). The common organic fractions in soils and sediments are the total undissolved carbon content, humic and fulvic acids, lipids, amino acids and microfossil cellulose. Depending on the chemical treatment applied to the samples one or more of these fractions may be isolated and dated. Despite the painstaking efforts of many researchers, there is no general conclusion as to which fraction or combination of fractions best reflects the sedimentation date. Each case and even each sample presents a different problem because the amounts of the various organic substances in a sediment may vary considerably among different layers or locations. The systematic use of the same particular organic component from all samples is therefore not always feasible, as the extraction of an adequate quantity of that component may not be possible. On the other hand, if a mixture of several organic fractions are dated together, their variable relative proportions can shift the date by a different amount each time.

[1]Laboratory of Archaeometry, Institute of Materials Science, NCSR "Demokritos", 153 10 Aghia Paraskevi, Attiki, Greece
[2]National Air and Space Museum, Smithsonian Institution, Washington, DC 20560 USA
[3]American School of Classical Studies, Souidias 54, 106 76 Athens, Greece
[4]Institute of Environmental Physics, University of Heidelberg, Neuenheimer Feld 366, D-6912 Heidelberg, Germany

In some cases, several independently datable types of materials or microfossils, such as wood fragments, plant remains, shells or snails, are contained in the same sample. These can be used as controlled samples and dated separately; they can provide a more reliable date of the sedimentation event (Donner and Junger 1980; Andree *et al.* 1986; Srdoc *et al.* 1986).

Method

We drilled several boreholes in selected locations (*ca.* 38°13′ N, 22°08′ E), to depths of as much as 40 m to find evidence of the city. The numbers and locations of the boreholes from which samples were selected and dated in this study are shown on the map of the area under investigation (Fig. 1). Twenty of the samples containing organic matter were dated, using the CO_2 technique in proportional counters of *ca.* 4-liter volume. To avoid contamination from the drilling machinery, we used silicon-based rather than carbon-based grease. After drilling, the samples were transported to the laboratory, and stored until further treatment in a freezer at low temperature (–27°C), to avoid contamination from growing soil microorganisms (Mook and Waterbolk 1985). To remove any carbon-containing contaminants from the bulk samples, we used the following procedure: Removal of the first 5 mm around the core, oven drying at 105°C, mild grinding and removal by hand of all rootlets and stones, where necessary, and heavy grinding to reduce the soil granulometry and make the chemical treatment more effective.

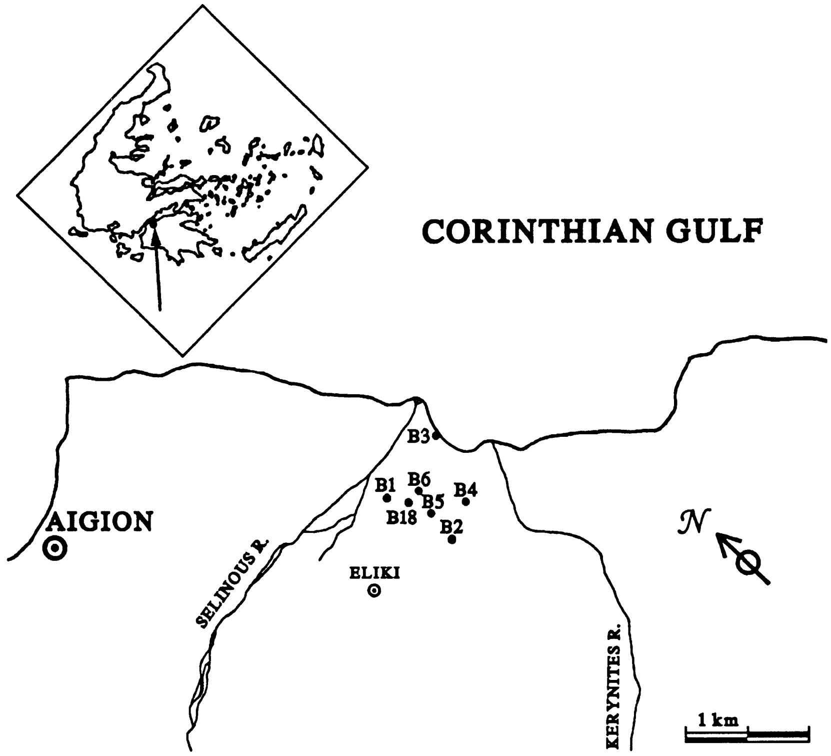

Fig. 1. Map of the area of ancient Helike according to historical sources, showing boreholes from which samples were dated in this study. The area is near latitude 38°13′ N, 22°08′ E.

To select the best chemical treatment for the samples, we considered the following: 1) according to the literature, no particular organic fraction has been determined to yield the correct age of sedimen-

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tation; 2) the ancient city horizon would have been either a vegetation horizon (freely growing or cultivated) outside the city or a clearly distinguishable compact soil horizon inside the city; 3) both horizons would have been exposed and settled, perhaps with minor modifications, for *ca.* 1 ka, from the foundation of the city until its destruction. During this long period, many generations of plants would have produced a layer of dead and rotting plant remains; 4) it would be more important to produce a consistent sequence of relative dates with depth for each borehole than to attempt to obtain the true age for every sample by separating all the different organic fractions and dating them individually.

Taking the above factors into consideration, we decided to use the routine chemical treatment generally applied for peat and charcoal. This would remove most of the mobile organic components and leave the carbonized plant material (undissolved carbon). However, some samples were given different treatments for comparison, and also the macroscopic plant remains found in some sediments were dated separately. The detailed chemical treatments follow.

Routine Sample Treatment (RST)

This consisted of soaking in 4% HCl solution in a water bath at 80°C for 3–5 days to remove soil carbonates and soluble organic components, followed by extraction of the humic acids with 4% NaOH solution. The sample was then re-acidified with 4% HCl in a water bath at 80°C for 30 min, washed with deionized water to pH 6, dried in an oven at 105°C and finally ground to a fine powder.

Selected Sample Treatment (SST)

For three samples from borehole B6, a more prolonged and extensive treatment in both HCl and NaOH was performed. Both the HCl- and NaOH-soluble fractions were also dated. The yellowish hydrolyzate over the precipitated sediment in the HCl solution, apparently containing salt crystals, was siphoned into a separate container, neutralized with NaOH and evaporated in a water bath, while new HCl solution was added to the sediment. The sample was stirred every hour. The extraction ended when the hydrolyzate above the sediment became colorless (*ca.* 22 days). Then the salt crystals with the hydrolyzed organic substances were oven-dried at 105°C. The same was done for the sediment in the NaOH solution. The brown alkaline solution over the precipitated sediment, consisting mainly of humic acids, was siphoned and neutralized with HCl, while new NaOH solution was added to the sediment. The extraction ended when the brown solution above the sediment became very light in color (10–17 days). The chemical treatment of the remaining sediment continued as for the routine samples. In addition, three samples were split into two parts. One part was sent to and dated at the Heidelberg laboratory using the conventional sediment preparation method, which involves the treatment of samples only in 2N HCl at 80°C for 24 h (this procedure removes the carbonates and leaves most of the other fractions intact). The other part was dated in Demokritos using the procedure for routine samples described above.

Microfossil Treatment (MT)

The microfossils located in some sediments were small pieces of wood and seaweed leaves. These were pretreated by the standard method (Mook and Streurman 1978), dated separately and used as control samples. Some shells and snails were also found in some samples but in quantities too small to be dated with the conventional technique. After the chemical pretreatment, the samples were combusted and their organic material was converted to CO_2 using the de Vries-type continuous combustion method (de Vries and Barendsen 1953; Münnich 1957). Due to the very low carbon content of the sediments (Table 1), in most cases, we performed many multiple combustions, between 7 and 14 for each sample, to obtain sufficient CO_2 gas for reliable results. This CO_2 gas was purified using a purification procedure described elsewhere (Kromer and Münnich 1992).

Results

Figure 2 shows a diagram of the lengths of the boreholes studied in relation to present mean sea level. The area under investigation is a coastal plain with relatively low relief. The surface elevations of five of the boreholes used in this study are between 5 and 9 m above sea level (MSL); one borehole (B3) was drilled very near sea level and one (B2) was near the foothills at 16 m above MSL.

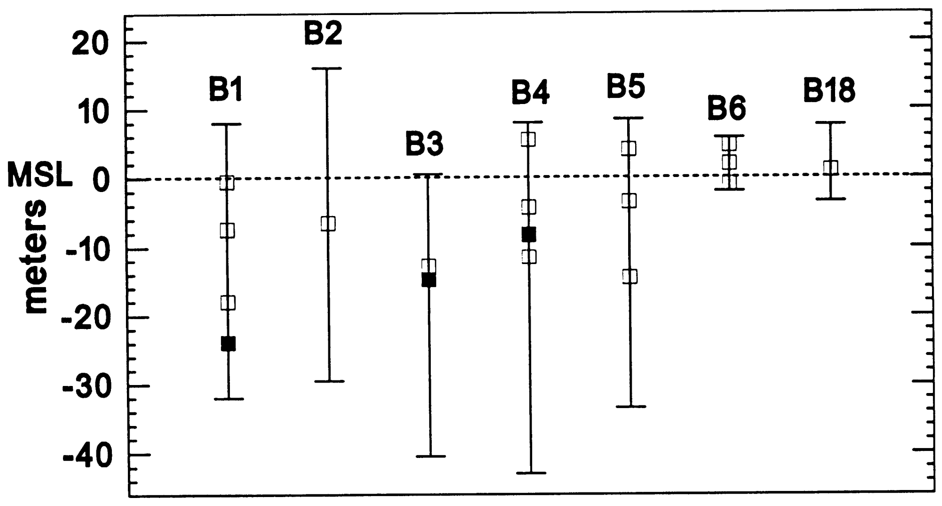

Fig. 2. Relative depth with respect to the mean sea level of cores from the Eliki area from which samples have been dated. □ = the organic sediment, ■ = wood and seaweed.

Table 1 lists all the data for this study. ^{14}C dates were converted to calendar dates using the CALIB 3.0 Program (Stuiver and Reimer 1993). $\delta^{13}C$ correction was applied selectively to three sediment samples and shows that the deviations are not significant for the accuracy required in this case. The large deviation of sample HD-16126 is probably due to seaweed remains in this sediment.

The ages of the samples (with the exception of the HCl and NaOH extracts) reflect, as discussed earlier, mostly the age of the remaining insoluble organic fraction. This is the most resistant and it is presumed to give the oldest age (Kigoshi, Suzuki and Shiraki 1980; Gilet-Blein, Marien and Evin 1980). Samples DEM-193 and -333 are from the same depth of borehole B5 but the second was given a more prolonged and intensive treatment with HCl. This treatment increases the apparent age by 1800 yr. The same effect is observed with DEM-308 and -318 from borehole B18. However, in this case, the increase is only 200 yr. This must be because the HCl solution dissolves some of the younger organic components, and when the treatment is long and intense, the ages become older by amounts that depend on the relative proportions of the soluble components in each sample. In both cases, the absolute ages of the samples, irrespective of actual treatment, are considered too old to be accepted as the true ages of sedimentation.

We also dated selected samples from three different depths of borehole B6, at 1.13, 3.83 and 6.73 m from the surface. From each depth, three samples were dated: the organic residue; the HCl extract; and the NaOH extract. The chemical treatment is described above (SST). Table 1 shows that at a depth of 1.13 m, the residue (DEM-332) yields an age of 3940–3707 BC, the HCl extract (DEM-334) an age of AD 1409–1954 and the NaOH extract (DEM-335) an age of 1252–402 BC. Similar compli-

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TABLE 1. Summary of ^{14}C Dating of Sediments in the Helike Area*

Lab no.	Bore-hole	Depth from Surface (m)	Type of Sample	Age BP (± 1σ)	$\delta^{13}C$ (‰)	Cal age AD/BC (± 1σ)	Cal age BP (± 1σ)	% of Carbon in sample
DEM-190	B1	8.49 ± 0.05	Sand, gray clay, silt	7239 ± 97	−25.00	6171 – 5971 BC	8121 – 7921	0.623
DEM-191	B1	15.37 ± 0.05	Sandy silt	7696 ± 41	−25.00	6536 – 6456 BC	8485 – 8405	1.564
DEM-165	B1	25.96 ± 0.04	Brown clay	8857 ± 54	−25.00	7971 – 7742 BC	9924 – 9696	2.068
DEM-185	B1	31.90 ± 0.10	Wood	8781 ± 148	−25.00	8001 – 7581 BC	9934 – 9530	38.026
DEM-166	B2	22.49 ± 0.07	Sandy silt, clay	8047 ± 50	−25.00	7039 – 6788 BC	8989 – 8738	0.974
HD-16202	B2	22.49 ± 0.07	Sandy silt, clay	7647 ± 97	−27.94	6538 – 6384 BC	8488 – 8334	0.193
DEM-195	B3	13.25 ± 0.05	Sandy silt	3339 ± 67	−25.00	1720 – 1511 BC	3639 – 3459	0.934
DEM-188	B3	14.75 ± 0.75	Seaweed	5398 ± 101	−25.00	4100 – 3794 BC	6050 – 5744	30.190
DEM-196	B4	2.50	Sandy silt	4747 ± 121	−25.00	3652 – 3367 BC	5599 – 5314	0.393
DEM-197	B4	12.30	Sandy silt, clay	8559 ± 328	−25.00	7935 – 7093 BC	9905 – 9210	0.625
HD-16126	B4	16.20	Black silt	6313 ± 47	−17.33	5279 – 5227 BC	7228 – 7176	1.857
DEM-187	B4	16.20	Wood	6458 ± 153	−25.00	5566 – 5266 BC	7516 – 7216	47.616
DEM-283	B4	16.20	Seaweed	6249 ± 87	−25.00	5277 – 5062 BC	7155 – 6770	54.350
DEM-192	B4	19.45 ± 0.05	Black silt	9221 ± 131	−25.00	8347 – 8042 BC	10,354 – 10,032	0.389
DEM-186	B4	38.55 ± 0.05	Brown black clay, silty clay	10,406 ± 583	−25.00	10,940 – 9041 BC	12,908 – 10,994	2.098
DEM-193	B5	4.45 ± 0.05	Silty sand	6787 ± 111	−25.00	5734 – 5580 BC	7678 – 7474	0.264
DEM-333	B5	4.45 ± 0.05	Silty sand (prolonged HCl treat.)	8534 ± 114	−25.00	7586 – 7448 BC	9536 – 9398	0.183
DEM-167	B5	12.00	Black clay	5823 ± 27	−25.00	4760– 4619 BC	6709 – 6568	2.847
HD-16353	B5	12.00	Black clay	5348 ± 36	−27.14	4240 – 4092 BC	6189 – 6041	2.541
DEM-198	B5	23.00	Silty sand	9414 ± 72	−25.00	8828 – 8356 BC	10,537 – 10,303	1.420
DEM-332	B6	1.13 ± 0.08	Brown clay	5016 ± 70	−25.00	3940 – 3707 BC	5890 – 5657	0.227
DEM-334	B6	1.13 ± 0.08	HCl extract	335 ± 208	−25.00	1409 – 1954 AD	541 – 0	0.024
DEM-335	B6	1.13 ± 0.08	NaOH extract	2680 ± 307	−25.00	1252 – 402 BC	3202 – 2352	0.036
DEM-375	B6	3.83 ± 0.04	Brown, green, black clay	2405 ± 50	−25.00	522 – 398 BC	2471 – 2347	0.907
DEM-377	B6	3.83 ± 0.04	HCl extract	854 ± 43	−25.00	1165 – 1248 AD	785 – 702	0.905
DEM-380	B6	3.83 ± 0.04	NaOH extract	1508 ± 60	−25.00	534 – 631 AD	1416 – 1319	0.738
DEM-376	B6	6.73 ± 0.08	Brown clay	7389 ± 184	−25.00	6410 – 6004 BC	8360 – 7954	0.351
DEM-378	B6	6.73 ± 0.08	HCl extract	1737 ± 109	−25.00	147 – 424 AD	1803 – 1526	0.586
DEM-381	B6	6.73 ± 0.08	NaOH extract	1324 ± 87	−25.00	650 – 784 AD	1300 – 1166	0.526
DEM-318	B18	6.58 ± 0.10	Brown clay (prolonged HCl treat.)	5743 ± 167	−25.00	4787 – 4368 BC	6737 – 6398	0.424
DEM-308	B18	6.58 ± 0.10	Brown clay	5539 ± 42	−25.00	4450 – 4337 BC	6399 – 6286	0.684

*The shaded areas represent different chemical pretreatment (see text)

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cations occur with the samples of the other two depths. The results of all these differently treated samples are plotted in Figure 3 according to depth. The lines fitted to each group of samples are indicative only of the trends. Only the HCl extract gives a meaningful correlation with depth, starting from *ca.* AD 1650 (300 cal BP) at 1.13 m below surface and reaching *ca.* AD 250 (1700 cal BP) at 6.73 m. The absolute ages for these samples, although young, cannot be ruled out entirely as the true ages of the sediments. The NaOH extracts show an inverse correlation with depth. However, at the two lower depths, they approach the HCl extract ages. The behavior of these extracts may indicate the infiltration of old humic acids, carried by water, from the surface downward. Greater amounts are obviously concentrated nearer the surface, producing older ages. This signifies the danger of leaving this component in a sediment sample for dating. Finally, the residual carbon left after the intensive treatments with HCl and NaOH demonstrates the most peculiar but nevertheless most informative behavior. The shallower and deeper samples yielded ages that are too old. The middle sample, at a depth of 3.83 m, produces the youngest age, which approaches the ages of the two extracts at this depth, but older by *ca.* 1600 and 1000 yr than the ages of the HCl and NaOH extracts, respectively. Under the optical microscope, this sediment indicates a thick vegetation horizon. Since this sample consists of the undissolved organic fraction, its age is likely to reflect the remaining plant material in this sediment and is therefore the best candidate to show the true age of this layer (Mook and Waterbolk 1985). Its actual age is 522–398 BC, which could mean that this vegetation horizon was created just before the catastrophic event of 373 BC that destroyed ancient Helike, and may well be associated with the city horizon. This might be attributed to trapping of vegetation, which would have an age at burial, by past seismic events (Srdoc *et al.* 1986). Further research in the area may confirm this hypothesis.

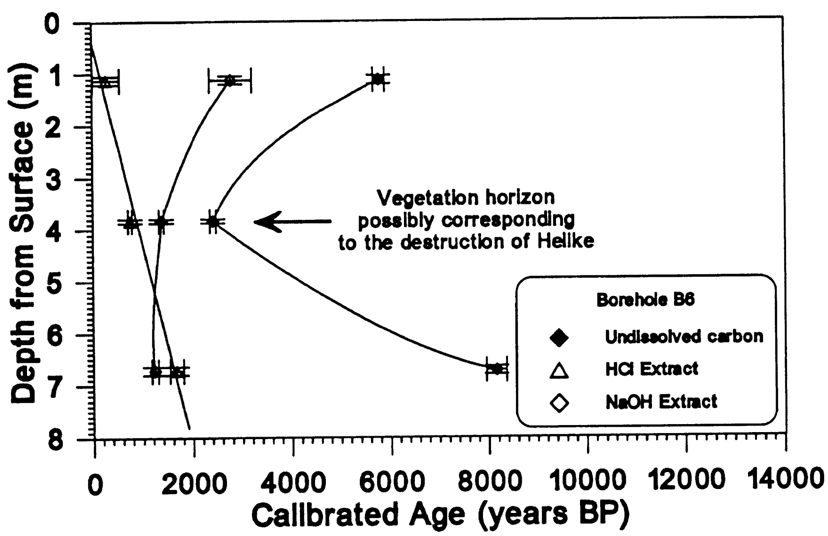

Fig. 3. The calibrated ages of different organic fractions separated with different chemical treatments from borehole B6 are plotted *vs.* depth

The conventional sediment pretreatment (HCl only), applied in Heidelberg for two samples divided in half, gave only slightly different results, with the equivalent samples dated at Demokritos using the routine sample treatment described above. Specifically, the samples HD-16202 from borehole B2 at 22.49 m and HD-16353 from borehole B5 at 12.00 m dated in Heidelberg, both give ages younger by *ca.* 400 yr from samples DEM-166 and -167, respectively (Table 1).

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This effect probably reflects the evidence presented above with the results of the extracts from borehole B6 (Fig. 3). We showed that, as the depth increases, the age of the NaOH extract approaches the age of the HCl extract, becoming younger by *ca.* 400 yr, at *ca.* 7 m below surface. Therefore, if the samples are treated with HCl only, as was the case in Heidelberg, the younger NaOH soluble component is not removed and the ages become younger. Hence, the systematic difference of 400 yr may not be coincidental.

The sediment from borehole B4 at 16.20 m contained clearly visible pieces of wood and seaweed, obviously constituting a vegetation horizon near the sea. For this experiment, the wood and seaweed particles were separated mechanically and dated in Demokritos using the MT method. The rest of the sediment was dated in Heidelberg, again applying the conventional sediment pretreatment. The results shown in Table 1 give, within one standard deviation, the same ages for all three samples (HD-16126, DEM-187, DEM-283). This is consistent with the observation that the sample was a thick vegetation horizon, and would have had macroscopic and microscopic plant remains of the same age. The use of the NaOH treatment, which dissolves only a small component, makes no difference for this sample.

Clearly visible seaweed particles found in a sandy horizon of borehole B3, at 14.75 m depth, were removed and dated to 4100–3794 BC (DEM-188). No other organic content existed in this sample for dating. However, a sample of sediment obtained from 1.5 m higher in the same borehole (DEM-195) gave an age *ca.* 2 ka younger, using the routine sample treatment (Table 1). Since the sedimentation rate is unknown, it is difficult to judge if this difference is more than one would expect for 1.5 m difference in depth.

Discussion

To understand the local sedimentation process, we plotted all the ages obtained from similarly pretreated RST sediment samples in Figure 4. Most of these ages are almost certainly older than the actual ages. The two shallowest data points in Figure 4 (at 1.1 and 2.5 m) have apparent ages of about 6000 cal BP, but they are from the same depths at which we have found Roman ruins in this area. In

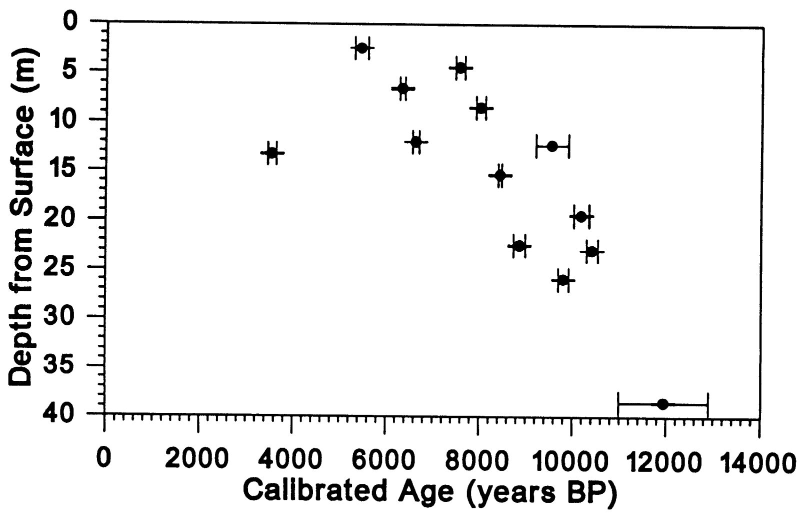

Fig. 4. Calibrated ages in years BP *vs.* depth below the surface for all RST borehole samples dated in this study

addition, the age-depth trend for the RST samples is a few thousand years older than the trend obtained by luminescence dating of ceramic fragments in boreholes in the same area (Liritzis *et al.* ms.). Hence, the samples dated by RST must have acquired an unknown amount of older carbon.

Despite the fact that the RST samples in Figure 4 came from different boreholes and contain a natural enhancement of ^{12}C from unknown sources, a general trend is apparent in the data. The sedimentation rate was evidently faster below 12 m and slower above, with a change of slope in between. Although the ages obtained by the RST method are older than the true ones, we may still use them to estimate the true age of the change of slope.

To do this, we first plot the RST results from borehole B4 in Figure 5. Between 39 and 12 m depth, the apparent sedimentation rate is very fast, about 26 m in 2400 yr, or 1.1 cm yr^{-1}. Above 12 m, the rate is much slower, on the order of 2.5 m in 5400 yr, or 0.5 mm yr^{-1}. These results alone suggest that if ancient Helike lies in this part of the plain, it is shallower than 12 m, since it would have been difficult to sustain a city for many centuries where the sedimentation was as rapid as 1 m per century.

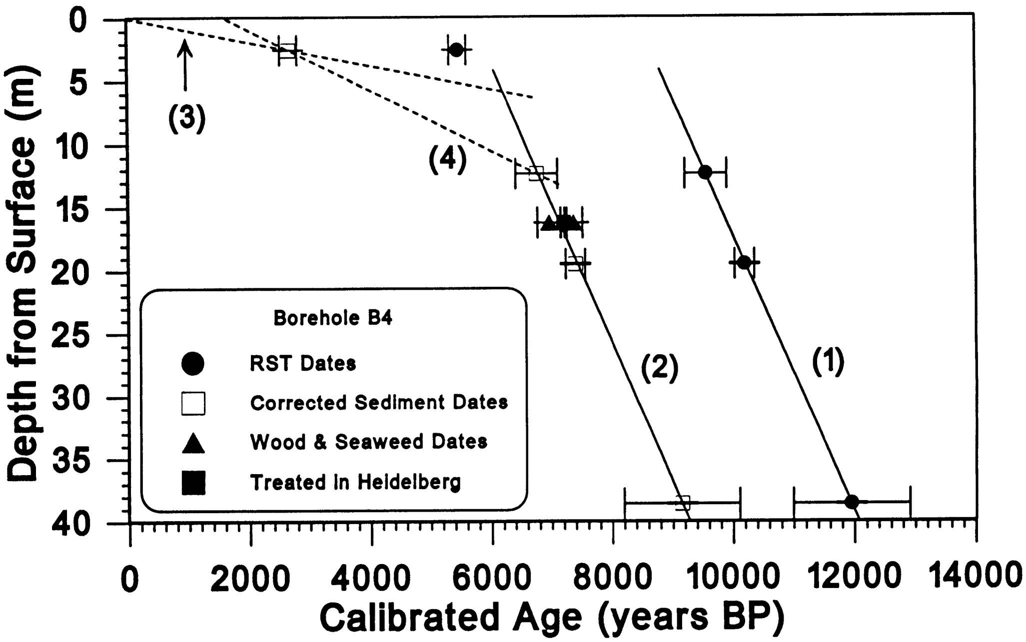

Fig. 5. Calibrated ages in years BP for samples treated with (RST) and one sample treated in Heidelberg from borehole B4 *vs.* depth. The ages of microfossils (wood and seaweed) are also shown. Line (1) is the linear fit to the RST ages of the three deepest samples, where the rate of sedimentation is high. Line (2) is the same line shifted 2800 yr to younger ages, to intersect the ^{14}C age of the wood and seaweed at 16 m depth. Line (3) intersects the shifted point for the shallow sample and the origin, and represents a lower bound on the shallow sedimentation rate. Line (4) represents the upper bound on the shallow sedimentation rate, assuming that the change of slope occurs at 12 m depth and that there was a hiatus in sedimentation near the surface.

The RST data show that the three deepest points (12–39 m) fall exactly on the straight line 1. This suggests that if the addition of unknown older carbon is either constant or changes linearly with depth, then the true sedimentation rate in this interval is also linear. The RST point at 2.5 m is much younger than indicated by the linear trend at greater depths. In any case, the surface layers should be younger than 2000 yr. We thus expect a large change of slope between 2.5 and 12 m depth.

Borehole B4 contained a horizon very rich in organic materials—pieces of wood and seaweed—at a depth of 16.2 m. We dated the sediment sample at Heidelberg and the wood and seaweed samples in Demokritos as mentioned above. Table 1 shows the comparable ages obtained at both laboratories. The true age of this particular layer is therefore fixed by this triple dating at *ca.* 7200 cal BP. Figure 5 shows that this age is about 2800 yr younger than the linear trend (line 1) of the RST ages at the same depth.

There are other examples of organic sediments with apparent ^{14}C ages older than the true sedimentation ages. For example, Warne and Stanley (1993) found that ^{14}C ages of sediments from Nile Delta boreholes ranged systematically from 500 to as much as 3500 yr older than ceramic fragments in the same borehole dated by archaeology. An increment of 2800 yr in apparent age, as in the B4 data, corresponds to the addition of about 28% older carbon, which is close to the value reported for lake sediments in the former Yugoslavia (Srdoc *et al.* 1986).

If we assume the same fractional addition of older carbon for all samples in B4, we can "correct" all the RST dates by the same amount. The resulting dates fit the straight line 2, shifted to younger ages by 2800 yr. This suggests that the actual time of the rapid sedimentation rate was from before 9000 BP up to about 6500 BP or a few hundred years later.

We can find bounds for the time when the sedimentation rate changed (assuming an abrupt change between two linear rates), by first drawing the straight line 3 through the origin and the "corrected" point at 2.5 m and extending it to line 2. The intersection of lines 2 and 3 suggests that the change of slope occurred at 6200 cal BP and is now 6 m deep. However, the line representing the more recent sedimentation may not intersect the origin. The presence of Byzantine and Roman remains within 2 m of the surface in some parts of the survey area suggests there may have been a hiatus in deposition during the last 1000–1800 yr. The limiting case would then be represented by the straight line 4, drawn through the "corrected" data points at 2.5 and 12 m. This corresponds to the lower limit for the change of slope at about 6800 cal BP near a depth of 12 m.

Although the estimated depth of the change of sedimentation rate ranges from 6 to 12 m, the corresponding age falls within a relatively narrow range of 6500 ± 300 cal BP. An abrupt change of the rate of delta sedimentation at about this date is actually expected. Stanley and Warne (1994) analyzed ^{14}C dates from boreholes in marine deltas throughout the world and found that all of them began rapid progradation between 9500 and 7400 cal yr BP (8500 and 6500 yr BP). They ascribe this to the deceleration of global sea level rise at that time. When global sea level was rising rapidly, the aggradation of terrestrial deposits maintained the same pace, while the horizontal extension of the delta front (progradation) was minimal or negative. But a deceleration in the rate of sea level rise caused a rapid progradation of the shore, with subhorizontal terrestrial deposits overriding the steeply dipping marine deposits. Probably the marine delta of the Helike plain also experienced this phenomenon. This suggests that the deeper samples in our boreholes are from the more steeply dipping marine strata, with a higher apparent rate of vertical sedimentation (Hardy, Dart and Waltham 1994). The environmental indicators for our borehole samples deeper than 5 m below the present sea level are in fact predominantly of marine origin.

We applied a similar analysis to the data from borehole B1, plotted in Figure 6. Again the RST dates suggest a linear rate of sedimentation with a high value of about 1 cm yr^{-1}. In this case the rapid sedimentation extends to within 8.5 m of the surface. We had no suitable samples for dating in this borehole within the upper region where the rate must be lower. We assume that the change of slope occurred *ca.* 6500 cal BP. Since the surface must be relatively young, the high sedimentation rate up to 8.5 m suggests that the horizon of ancient Helike is above that depth in the area of B1. A piece of

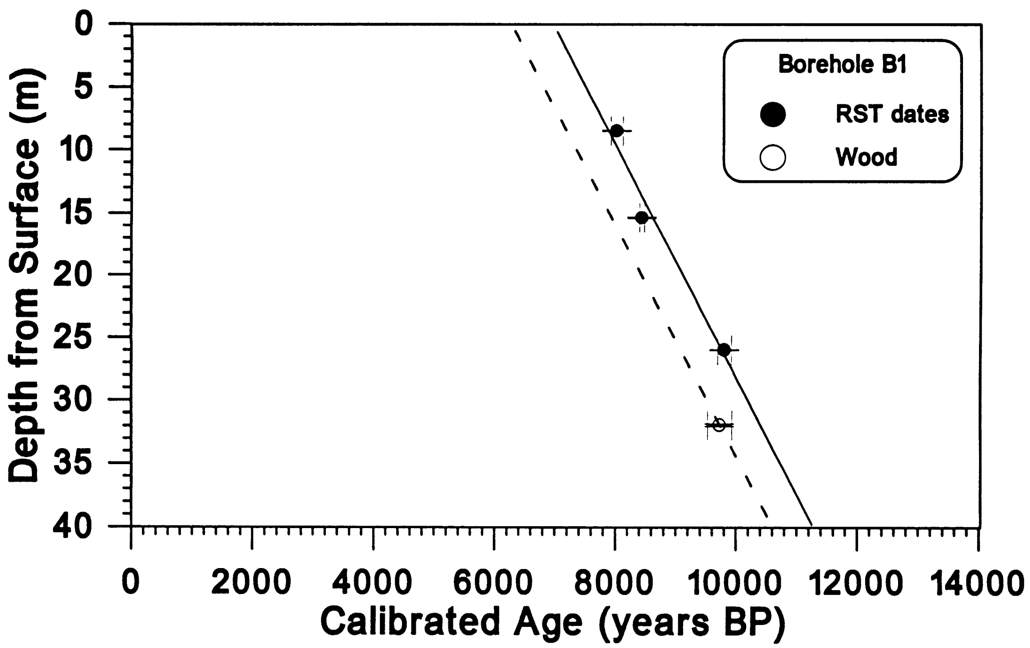

Fig. 6. Calibrated ages in years BP for RST samples from borehole B1 and one wood sample found in the core *vs.* depth. - - - - = an attempted correction of the dates.

wood at 31.9 m gave a date about 600 yr younger than the linear RST trend, equivalent to about 7% addition of older carbon. This differs significantly from the results in B4, suggesting that the corrections based on microfossils in one layer and applied to all samples may not be reliable.

The data suggest that the horizon of ancient Helike is within 12 m and probably within 8 m of the surface. This agrees with the results of dating by optical stimulated luminescence of non-diagnostic ceramic fragments in boreholes in the same area (Liritzis *et al.* ms.).

Conclusion

There is a correlation between the data from different boreholes in an area of a few square kilometers in the Helike plain, with some obvious anomalies. This is found despite the high seismicity of the area (Mouyaris, Papastamatiou and Vita-Finzi 1992) and the fact that it is located between two rivers with changing beds and high-energy episodes of alluvial deposition and erosion.

We have shown that systematic sediment dating based on the total undissolved carbon content can provide useful information for understanding the sedimentation history of a marine delta, even though the ages obtained may be older than the true ones. In this case, we have used the data to suggest that the horizon of ancient Helike is shallower than 8 m in parts of the plain.

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