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In Search of Ancient Helike, Gulf of Corinth, Greece

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ABSTRACT

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In 373 BC an earthquake destroyed and submerged Helike, a Greek city on the southern shore of the Gulf of Corinth. A large archaeological/archaeometrical enterprise has been initiated since 1991. Dozens of Boreholes scanned the coastal area of Aegialia, geophysical prospection has been carried out, sonar surveys have been made offshore, trial excavation has been executed, while C-14 dating on sediment (wood, plants) and luminescence dating on tiny ceramic sherds extracted from the bore holes has been performed.

In particular, quartz and feldspar inclusions were removed from fine pieces of ceramic sherds, extracted from boreholes, and the "single aliquot method" of green (GLSL) and infrared (IRSL) light stimulation luminescence was applied for the determination of equivalent radiation dose (ED) aiming at the accurate dating of these ceramics, and at locating the ancient lost city of Helike.

The dates obtained spanned between the Byzantine period, c.9th century A.D. back through the Roman and Hellenistic/Classical times to the Mycenean period and the 2nd to 3rd millennia B.C., all following a stratigraphic sequence with depth varying from 0.40 m to 12 m. All dating results are critically assessed and focus on the question regarding the location of ancient Classical stratum (3–5 m below ground) which belongs to the lost (submerged) Helike.

ADDITIONAL INDEX WORDS: *Helike, Holocene, luminescence, boreholes, classical, ceramic, optical stimulated luminescence, chronostratigraphy, radiation dose, sediment.*

HISTORICAL BACKGROUND-PREVIOUS WORK

Helike was the most important coastal city of ancient Achaia, in northwestern Peloponnese, Greece. It was founded in Mycenean times, and Homer refers both to the city and the area. Since its foundation. Helike became the capital, first of the lonian *Dodekapolis* (League of Twelve Cities) and consequenty of the Achean Dodekapolis. When, in historical times, the Achean cities were organized under a *Koinon* (social community), Helike became the religious and political center of Achaia. This position was held until the time of its destruction in 373 B.C., a winter night, when a catastrophic earthquake destroyed the city. The land on which the city was built sank into the Gulf of Corinth and its inhabitants were completely annihilated by this disaster. As literary sources suggest, remains of the submerged city were visible under seawater at least until the Byzantine period (for historical and archaeological background information, see MARINATOS, 1960). They were subsequently buried under river-borne sediments. The approximate location of Helike has long been known but its exact site is yet to be found. Most previous efforts to locate Helike (1950–1974) concentrated on the seabed (EDGERTON and THROCKMORTON, 1970; SCHWARTZ and TZIAVOS, 1979). The results of subsequent sonar research in the area led to the return and focus of the research on the land (SOTER and KATSONOPOULOU, 1998; LIRITZIS, 1981; KATSONOPOULOU, 1994).

Since 1991 several boreholes (max. depth 40–45 m) were drilled at selected sites in the plain between the delta of the two rivers (known from ancient times) Selinous and Kerynites (Figure 1). This was the area where Pausanias, in the second century A.D., placed a village called Helike, at a distance of 40 *stadia* from Aegion (1 stadium about 220 m), and described it as the site of the famous lost Classical city.

In fact, Soter and Katsonopoulou (1998) conducted an extensive sonar sutvey in the area in 1988 and established that the site is no longer under water. They concluded that it is now situated under the coastal delta, which has prograded since antiquity with the deposition of river-borne sediments. Accordingly, during 1991–97 60 bore holes (average depth 20 m) were drilled on the delta plain within an area of about 8 km^2. Strata containing ceramic fragments were found in about half of the holes, mostly within an area of 1.5 km^2 between the Selinous and Kerynites Rivers (Figure 1). All the

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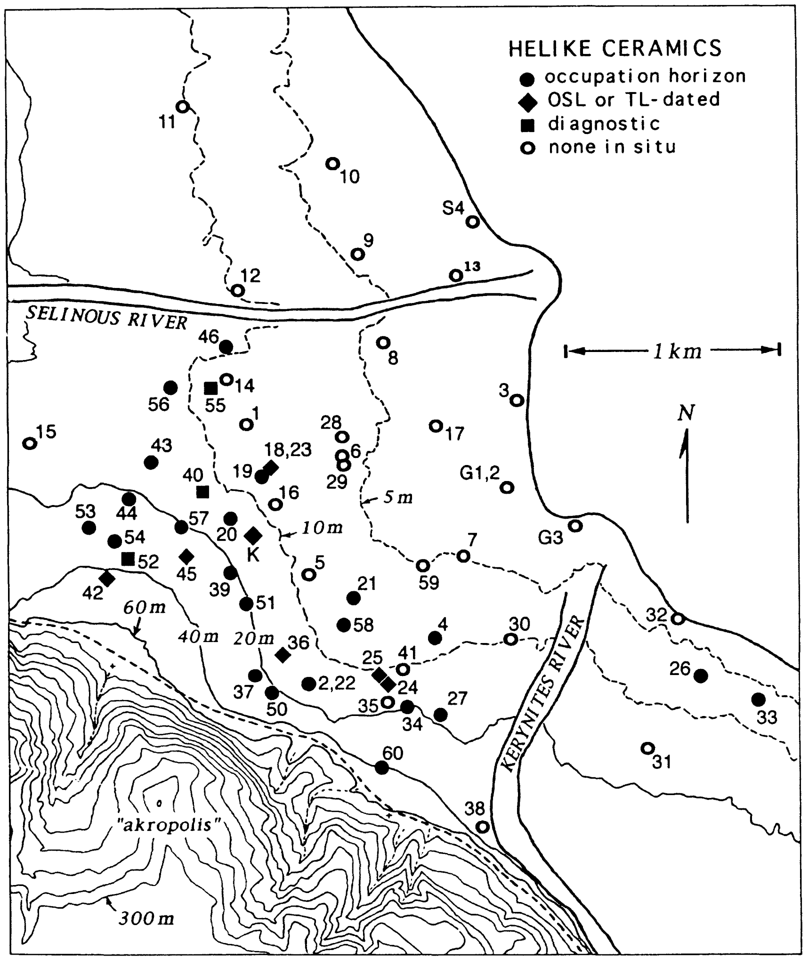

Figure 1. The Aigialeia area in the delta of Kerynites and Selinous rivers, where the submerged city of Helike is situated according to the research and historical accounts. The numbers refer to bore holes and the symbols to information regarding the presence of ceramics.

ceramic fragments came from within 13 m of the surface and were above present sea level. Since Helike was submerged in the earthquake of 373 BC, the area may subsequently have been uplifted, as suggested by geological evidence (STEWART and VITA-FINZI 1996; SOTER, 1998).

Guided by geophysical prospection and borehole inspection, in 1995 we began excavation of what is now called the Klonis site, at K in Figure 1 (KATSONOPOULOU and SOTER, 1997). The excavation, which reached a depth of 3.9 m, brought to light a large rectangular building dated to the Roman period. This may belong either to a settlement or group of structures built over the site of Classical Helike, reported by ancient Greek traveller Pausanias in the 2nd century AD. An extensive destruction layer of stone, brick, roof tile and plaster, both in and outside the building, suggests that it was destroyed by a violent earthquake.

The deeper excavation layers yielded fine black-glazed ceramic fragments of the 5th century BC, the handle of a Protogeometric kantharos, and two sherds from Mycenean vases. These older fragments probably originated in deeper strata and were brought up into the Roman horizon with the digging of a well during Roman times. It thus appears that the Classical and Bronze Age horizons are present below the Roman one in this part of the plain, and that the ceramic fragments found in many bore holes within a few meters of the surface may belong to an extensive Roman occupation horizon.

An important goal of the drilling was to find the depths corresponding to the Classical period through dating and identification of ancient environment. By dating enough core samples we hoped to establish an age-depth relationship here. However, most of the core samples recovered for carbon dating consisted of dispersed black organic sediment, which is problematic for dating purposes, and relatively few of the samples were of identifiable wood or plant origin (MANIATIS *et al.,* 1996). In addition, relatively few of the ceramic fragments from the bore holes were archaeologically diagnostic. Therefore, in order to fill in the chronostratigraphic picture, we dated some of the more numerous (usually small) non-diagnostic sherds by OSL.

Preliminary analysis of microfauna showed that the sandy sediments between the upper and lower ceramic horizons were deposited in a brackish (lagoonal) environment. The visual inspection of the boreholes suggested that the possible Helike stratum lies between 3 to 5 meters below the coastal plain (KATSONOPOULOU, 1994). The research continued with further analyses on the sedimentary environments in the core samples, in an effort to locate evidence of marine deposition in the lower ceramic-bearing horizon.

This paper presents a brief critical review of the work and refers especially on the Optical Stimulated Luminescence (OSL) dating method in obtaining the age of fine ceramics and discusses the results. The detailed presentation of the OSL methodology and dates is described elsewhere (LIRITZIS *et al.,* 1997).

THE LUMINESCENCE DATING METHOD

The conventional nuclear dating method of thermoluminescence (TL) is well known and has been successfully applied to archaeological ceramics and burnt clay fabric (AITKEN, 1985), as well as to geological materials (MCDOUGAL, 1968; WINTLE and HUNTLEY, 1979). The firing of any clay artifact clears all the trapped electrons from the lattice defects of the material. The ionizing radioactivity of the clay and its environment (including surrounding sediment after burial) then re-supplies free electrons which accumulate in traps. The age of a ceramic sample is found from the relationship.

AGE = equivalent dose (ED)/annual dose-rate,

where the "equivalent dose" (ED) measures the total exposure to radioactivity accumulated by the sample, and the "dose rate" is the (assumed constant) annual rate of exposure. The ED increases with time in proportion to the number of trapped electrons. In the laboratory, the trapped electrons can be evicted by heating the sample. On recombining with atoms, the electrons produce a measured luminescence, from which one calculates the ED. The dose rate is determined by measuring the radioactivity of the sample and its environment, employing appropriate conversion factors (Table 1).

In TL, the determination of the ED is based on measurement of the growth curve of the high temperature component or the deep thermally sensitive electron traps of minerals such as quartz and feldspars, following the "additive dose growth curve" procedure (AITKEN, 1985; LIRITZIS and GALLOWAY, 1982; LIRITZIS *et al.,* 1994). However, in the OSL method, the ED is found using optical rather thermal stimulation (HUNTLEY *et al.,* 1985; WINTLE, 1993; BOTTER-JENSEN and DULLER, 1992; GALLOWAY, 1992). OSL uses monochromatic light (usually green with quartz or infrared with feldspars) to evict electrons from light-sensitive traps. These electrons recombine with luminescence centres to emit light of a characteristic wavelength, the intensity of which is measured.

The OSL method has been improved with the introduction of the "single aliquot technique" and similar approaches and relevant correction procedures, which uses one disc prepared from the sample to carry out all the measurements to determine the ED (DULLER, 1991, 1994; GALLOWAY 1993, 1994; LIRITZIS *et al.,* 1994; LIRITZIS *et al.,* 1997; MURRAY *et al.,* 1997).

Table 1. *Alpha-particle, beta-particle and gamma-ray dose-rates for isotopic equilibrium, in mGy/yr*[1]*, per 1 ppm by weight of Oxide parent isotope (UO_3, ThO_2 and Rb_2O) and per 1% of K_2O. For conversion from Element Oxide to ppm Concentration values, divide UO_3 with 0.8322, ThO_2 with 0.8788, Rb_2O (%) with 0.9158 and K_2O (to K) with 0.8301 (Liritzis and Kokkoris, 1992).*[2]

Oxide of Parent Isotope	Alphas	Betas	Gammas
ThO_2	0.6423	0.0241	0.0444
UO_3	2.3564	0.1222	0.0922
K_2O	0	0.6824	0.2042
Rb_2O	0	0.000464	0

[1] The annual dose is calculated with the equation: D [mGy/y] = 1.602×10^{-10} [mGy/MeV] $\times$ λ[1/y] $\times$ N $\times$ E[MeV]., λ[1/y] = $\log_e 2/\tau$ = 0.693147/τ, where λ = decay constant, τ = half life, N = number of atoms of the nuclei. For the U-series: D[mGy/y] = D(^{238}U for 1 ppm) * 238/237.9782 * 99.274% + D(^{235}U for 0.00711 ppm) * 0.83212.

[2] Corrigenda: In the original publication (Liritzis and Kokkoris, 1992) the gamma dose-rates of 11.09 for UO_3 in their table 2 was overlooked, it was for U concentration values instead of UO_3; thus it should be 9.22 instead of 11.09. As a result, in their table 4 the value of ($\alpha + \beta + \gamma$) for UO_3 is 257.1 instead of 258.9. The Liritzis and Kokkoris (1992) dose-rates conversion tables, considering the above correction, are today valid. In comparison with other tables there are differences 1–2% due to slightly different values of isotopic data used by the authors. In conclusion there is a satisfactory agreement.

The single aliquot OSL method has some advantages over the multiple aliquot OSL and the conventional TL dating methods: (a) it requires a smaller minimum sample (1–2 cm^2 sherd, compared to more than 9 cm^2); (b) it uses a single disc for all measurements of ED, avoiding normalization problems; and (c) it reduces laboratory time (to tens of minutes following sample preparation, compared to some hours for TL). In the present application, most of the ceramic sherds available from the bore holes were so small that dating was only possible by application of the single aliquot technique.

The annual dose rate comprises the beta and gamma radiation components from the radioactive isotopes of uranium, thorium and potassium present in the ceramic sample and its immediate environment, and a small component from cosmic rays. Beta radiation was measured with a plastic scintillator (GALLOWAY and LIRITZIS, 1991); the gamma component was measured by high resolution Ge detector spectrometry (GALLOWAY, 1991a; GALLOWAY and LIRITZIS, 1992) of sediment in the core sample surrounding the ceramic fragment.

The ceramic sherds were cleaned by removing any adhering sediment (to avoid beta radiation from the material) and gently crushed and ground with a mortar. Sample preparation followed standard procedures (gentle grinding, initial selection of grain size, 10–15 min Calgon wash, 30–60 min of 40% HF acid etch, 50–70 min conc.HCl acid wash and etch, final selection of inclusion grain sizes). In this way quartz grains were recovered and feldspars were removed. The latter was also checked from the absence of infrared stimulated luminescence (IRSL). In cases where the sherds were very small (1–2 cm^2), the recovered quantity of quartz and feldspars grains was not sufficient, and if feldspars were the major mineral component, in order to avoid loss of such grains from etching, the HF acid attack was limited to 15–40 min.

Table 2. *Ceramic fragments and luminescence dating results.*

Sample Number	Depth (m)	Initial Grain Size Range (μm)	Response Function	N	Total Dose ED (Gy)	Dose Rate (mGy/yr) Dβ	Dγ	Dcor (mGy/yr)	Date
B36:1	0.75	60–100	linear	1	3.5 ± 0.7	2.60	0.64	3.2 ± 0.2	900 ± 230 AD
K1	1.40	60–106	linear	2	4.2 ± 0.8	2.36	0.64	2.9 ± 0.1	550 ± 300 AD
K2	1.45	106–250	supralinear	2	5.4 ± 0.7	2.39	0.71	3.0 ± 0.1	200 ± 250 AD
B25:2	4.35	90–120	linear	2	4.5 ± 1.5	1.68	0.55	2.2 ± 0.1	50 ± 750 BC
B42:1	5.70	70–150	saturating	1	7.9 ± 0.3	1.79	0.74	2.7 ± 0.1	930 ± 180 BC
B18:1	6.50	70–150	saturating	1	8.2 ± 0.3	1.68	0.65	2.5 ± 0.1	1280 ± 160 BC
B18:2	6.50	70–150	saturating	1	11.0 ± 0.4	1.97	0.65	2.8 ± 0.1	1930 ± 230 BC
B25:3	7.55	70–106	linear	2	10.3 ± 0.7	1.95	0.43	2.4 ± 0.1	2300 ± 350 BC
B45:1	9.20	70–150	saturating	4	8.0 ± 1.0	1.67	0.49	2.1 ± 0.1	1800 ± 500 BC
B24:1	11.80	70–150	supralinear	1	10.5 ± 1.5	2.10	0.68	2.3 ± 0.1	2600 ± 700 BC

[1] Sample designations are as follows. B36:1 is the 1st dated ceramic sample from the 36th bore hole, B25:2 is the 2nd such sample from the 25th bore hole, etc. Samples K1 and K2 are brick fragments from walls at the Klonis site.
[2] N is the number of independent measurements of ED that were made and averaged.

Thereafter, IRSL cleaning of feldspar signal was followed by GLSL on the remaining mixture of minerals. All aliquots were preheated prior to any OSL reading at 200 °C/1 min for quartz and 220 °C/10 min for feldspars.

The "additive-dose growth curve" method, similar to the TL dating of pottery (LIRITZIS and GALLOWAY, 1982; AITKEN, 1985), and ocassionally the "regeneration" method (WINTLE and HUNTLEY, 1979), were applied, the data points being fitted by saturating exponentials, while background (Bg) was subtracted from all OSL readings (LIRITZIS *et al.*, 1997).

The various applied tests and the dating results obtained for ten ceramic sherds, following the "single aliquot method", are summarised in Table 2.

DISCUSSION OF THE RESULTS

Table 2 gives the measured radiation data and the derived ages for ceramic samples listed in order of depth, as well as the grain size range, the response function of the additive dose growth curve, the total dose ED, the beta and gamma dose-rates. Dcor refers to the annual dose rate corrected for water content using the formulae of ZIMMERMAN (1971). It is known that the water alters the radiation recorded by the material during the time, thus a correction is applied assuming certain water uptake values (percentage of saturation). Even a wide deviation from the simple assumption of constant exposure to water would not greatly alter the calculated ages. If, for example, we make the (improbable) assumption that the sherds and sediments found above the water table had always been completely dry, then their calculated ages would be 8% less than those given in the table, while an assumption of twice the present water content would increase the ages by 8%. For samples below the present water table, changing the water content by ±33% of the assumed value would change the ages by ±8%. These extreme changes in age associated with assumed water content are comparable with or smaller than the uncertainties quoted in the table.

Samples K1 and K2, recovered from the Klonis site prior to its excavation, yielded OSL ages in good agreement with the archaeological evidence for late Roman occupation (3rd to 5th centuries AD), which helps to calibrate the accuracy of the OSL method in this environment. Sample K2 was dated also by TL, which yielded a date of 150±320 BC (Dr C. MICHAEL, *personal communication,* 1995), consistent with the OSL result. Samples B18:1 and B18:2 were from the same core interval in bore hole B18, but gave OSL ages that differ by about 650 years, exceeding the sum of the error bars. However, the two samples could well differ in age by that amount if the core interval sampled a destruction horizon.

Figure 2 plots ten ceramic luminescence dates, five diagnostic ceramic dates, and five radiocarbon dates, as a function of depth below the surface. These samples came from locations with a wide range of surface elevations, located as much as 1.7 km apart on the coastal flood plain of two seasonal rivers. The plain is a coalesced Gilbert-type fan delta in a region of active tectonism (DART *et al.*, 1994). Under these geologically rather chaotic conditions, the drilling logs as expected showed little stratigraphic continuity even between nearby cores. Nevertheless, the sample dates generally fall within a broad linear band of increasing age with depth, a normal chronostratigraphic sequence.

The near-surface sample B36:1, dated only by TL, yielded a date of about 900 AD. The linear age-depth trend suggests that the top thousand years of deposition are missing. This apparent hiatus might be due to a sharp decline in the sediment deposition rate or to net erosion in recent times.

The five diagnostic ceramic fragments included in Figure 2 were dated by archaeological criteria. Sample B37 is a Hellenistic fragment found at 3 m depth, and B55 is a Hellenistic/Roman fragment (5th century BC) from 4.6 m. Both conform to the age-depth trend defined by most of the other samples. In B52 we found Classical fragment at 1.3 and 2.0 m, which places them above the main age-depth trend. Sample B40 is a fine black-glazed Classical fragment recovered from 10.3 m. It occupies a distinctly anomalous position in the plot, suggesting that the depth of the Classical stratum may be far from uniform in some parts of the plain. However, we cannot exclude the possibility that this fragment fell in from an undated ceramic-bearing layer encountered at 4 m depth during the drilling of this bore hole.

The radiocarbon dates extent the linear trend of the OSL

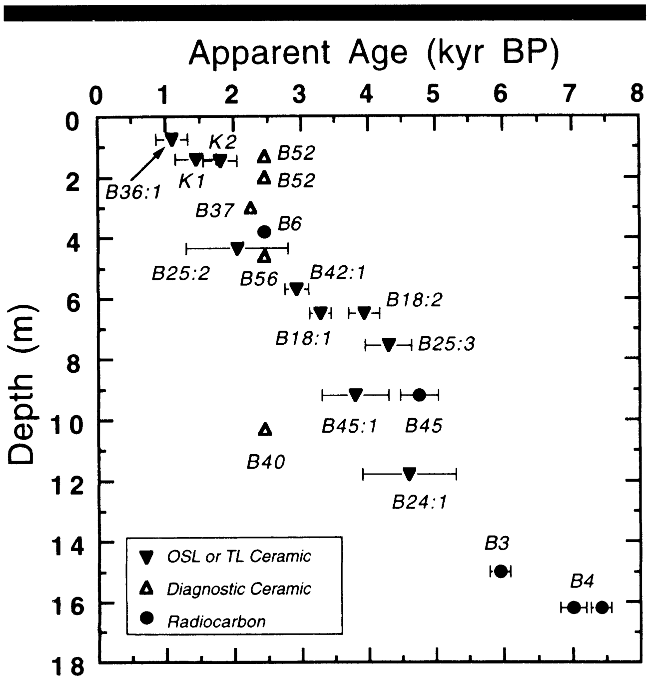

Figure 2. Depth versus age before present of ceramics and organics recovered from respective bore holes in numbers. Dates are given with their error bars.

results to greater depths. In Figure 2, we include Carbon-14 dates for samples of clearly identifiable plant material: peat from 3.8 m in B6, dated at 2450±60 cal BP (with respect to 2000 AD); seaweed from 14.75 m in B3, at 5950±150 cal BP; and wood and seaweed both from 16.2 m in B4, at 7420±150 cal BP and 7010±190 cal BP, respectively. We also include an AMS C-14 date for a small charcoal sample found together with the OSL-dated ceramic fragment B45:1 in an occupation layer at 9.2 m; it yielded an age of 4755±285 cal BP (University of Arizona, AA18115).

In addition, we dated a sample (B23:1) of finely laminated sand from 13 m depth by the single aliquot quartz method. Its beta dose rate was 0.65±0.07 mGy/yr. Assuming total solar bleaching during the deposition of the sand, the calculated OSL date of 4 of the 11 consequtive layers was 9500±750 BP. We regard this as the maximum age. The linear trend of data in Figure 2 predicts an age of about 6000 BP at the depth of the sand lamina. This result implies partial bleaching of the laminae during deposition; after sun exposure the samples had already a geological dose equivalent to about 3000 years.

The sample ages suggest that the delta was repeatedly occupied from the Bronze Age through Byzantine times. This is not surprising, given its natural advantages.

The almost linear trend of age versus depth in Figure 2, excluding the much reworked upper surface layers of the last 1000 years, suggests a sediment depositional rate of about 26 cm-per-century. This approximate rate indicates a depth of 4 m (3 to 5 m) for the Classical sedimentary horizon.

However, the 5th century BC diagnostic sherd from B40 suggests that the Classical horizon could be much deeper in parts of the plain. Taking all the data into consideration, it appears that the Classical and Bronze Age horizons lie within 12 meters of the surface, depending on location in the plain. If Classical Helike is actually within our survey area, the ruins of the city should be within the range of practical excavation.

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