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Anthropogenic Erosion from Hellenistic to Recent Times in the Northern Gulf of Corinth, Greece

A Thesis submitted in partial satisfaction of the requirements
for the degree Master of Science

in

Earth Sciences

by

Katrina M. Cantu

Committee in Charge:

Professor Thomas Levy, Co-chair
Professor Richard Norris, Co-chair
Professor Isabel Rivera-Collazo

2020

The thesis of Katrina M. Cantu is approved, and it is acceptable in quality and form for publication on microfilm and electronically.

University of California San Diego

2020

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I would also like to thank our collaborators: Professor George Papatheodorou and Professor Maria Geraga of the University of Patras in Greece, who were instrumental in collecting the sediment cores and obtained and processed the remote sensing data utilized in this study.

ABSTRACT OF THE THESIS

Anthropogenic Erosion from Hellenistic to Recent Times
in the Northern Gulf of Corinth, Greece

by

Katrina M. Cantu

Master of Science in Earth Sciences

University of California San Diego, 2020

Professor Richard Norris, Co-chair
Professor Thomas Levy, Co-chair

Erosion of soils due to human activities such as deforestation, pastoralism, and agriculture is a problem that has been recognized since Antiquity. Greece, like much of the of the Mediterranean world, is particularly susceptible to soil loss due to the arid climate and steep, rocky terrain, and many previous studies have sought to date and attribute the aggradation of soil to human activity, climatic changes, or a combination of the two. This study uses near-shore sediment cores from Antikyra Bay in the Gulf of Corinth, Greece, to understand the sources and timing of erosional events in the study area of the Kastrouli–Antikyra Bay Land and Sea Project. Sedimentological analysis and radiocarbon dating of foraminifera and twigs show that there are two major periods of soil aggradation in this record: the first occurred in the Hellenistic and/or Roman period (ca. 1900 – 2100 BP), and the second starts in the Ottoman Period (ca. 350 BP) and persists until present day. In addition to documentation of soil aggradation, two paleo-shorelines were identified during the geophysical survey. A local relative sea level curve constructed for this study suggests the shallower of the two is between ~7.7 and 8.7 thousand years old, while the deeper feature formed around 8.9 to 9.7 thousand years ago.

Introduction

It has long been known that the soils of Greece and the wider Mediterranean were subject to periods of high erosion during the Holocene. The causes of these events have been variously attributed to changes in climate, land use changes, or some combination of the two (Vita-Vinzi, 1969; Fuchs, 2019; Pope et al, 2003). Intensification of agriculture, pastoralism, deforestation, and abandonment of agricultural land have all been identified as possible human activities responsible for increased erosion. The present study builds on previous research into erosion events in the Mediterranean by looking at near-shore marine sediment cores which represent over 2,000 years of sedimentation from a small but archaeologically significant area in central Greece, on the northwest side of Antikyra Bay.

Greece has been occupied by humans for at least 150,000 years, with Neolithic agriculture appearing around 6,000 years ago (Bintliff, 2012). The cyclical rise and fall of complex societies combined with the changing climate over the Holocene, thin soil cover, and steep terrain in much of Greece makes soil erosion a particularly interesting area of research for the region, with many publications addressing the topic (Bintliff, 2002). Results of previous studies do not show consistent ages for erosional events across the region, making identification of precipitating factors especially challenging.

In the Northeast Peloponnese region researchers found anomalously high sedimentation rates at the end of the Bronze Age, for the entirety of the Roman Period, and the Ottoman Period into the Modern Period (see Figure 1) (Fuchs, 2004; 2019). This is in contrast with findings from the Spartan Basin, which indicate highest deposition during the Helladic Period and the Classical through Early-Middle Roman Periods (see Figure 2) (Pope et al, 2003). The authors of the Peloponnese study attribute these erosion events almost entirely to human activity, specifically

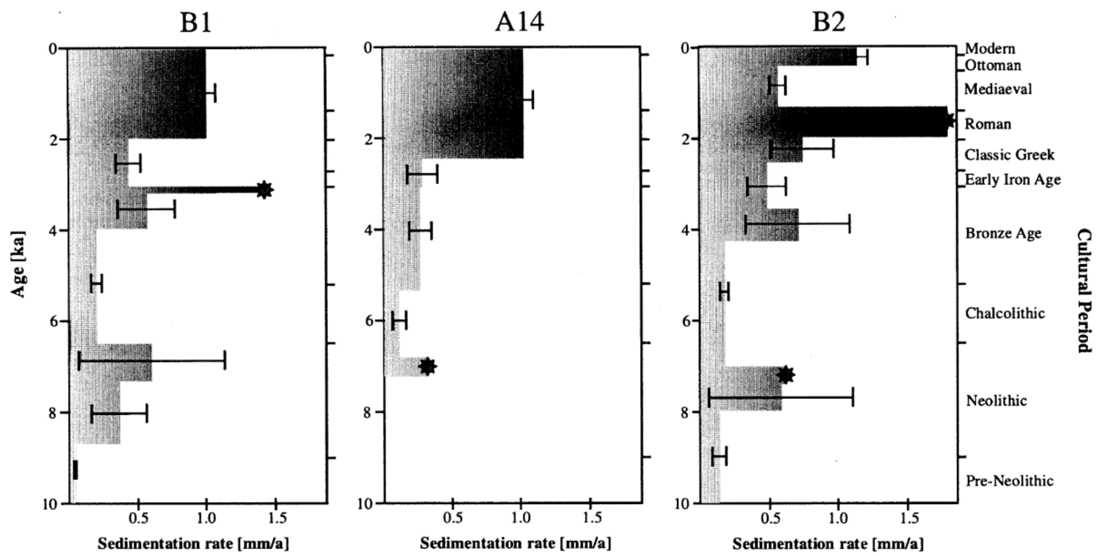

Figure 1: Holocene sedimentation rates from three sites in the Basin of Phlious, NE Peloponnese, Greece (Fuchs, 2004)

the Neolithic advent of intensive agriculture and, in later times, economic decline and abandonment of agricultural land. In contrast, Pope and colleagues believe aridification to be the primary driver of erosion, with human land use contributing only in combination with these natural trends.

In an earlier paper, Pope and van Andel (1984) find that in the Argolid region the sedimentation is highest from the Late Classical to Hellenistic Periods, picking up again around 1000 AD, the mid-Byzantine period. The lack of evidence for soil erosion during the Roman and Early Byzantine Period is attributed to good soil management practices such as terracing of slopes, and a later return to slope clearing is blamed for the increased deposition of the mid-Byzantine. The chronologies of these studies have long been considered suspect and have come under much scrutiny (Bintliff, 2002), making it difficult to ascertain whether these erosive events were local phenomena or part of broad cultural changes across the Mediterranean world. This is perhaps as open for debate as whether causes of erosion are rooted more in human behavior or natural forces. In the present study, we use shallow marine sediment cores to examine the issue of soil erosion in a more local context, specific to archaeological sites of interest to the researchers involved.

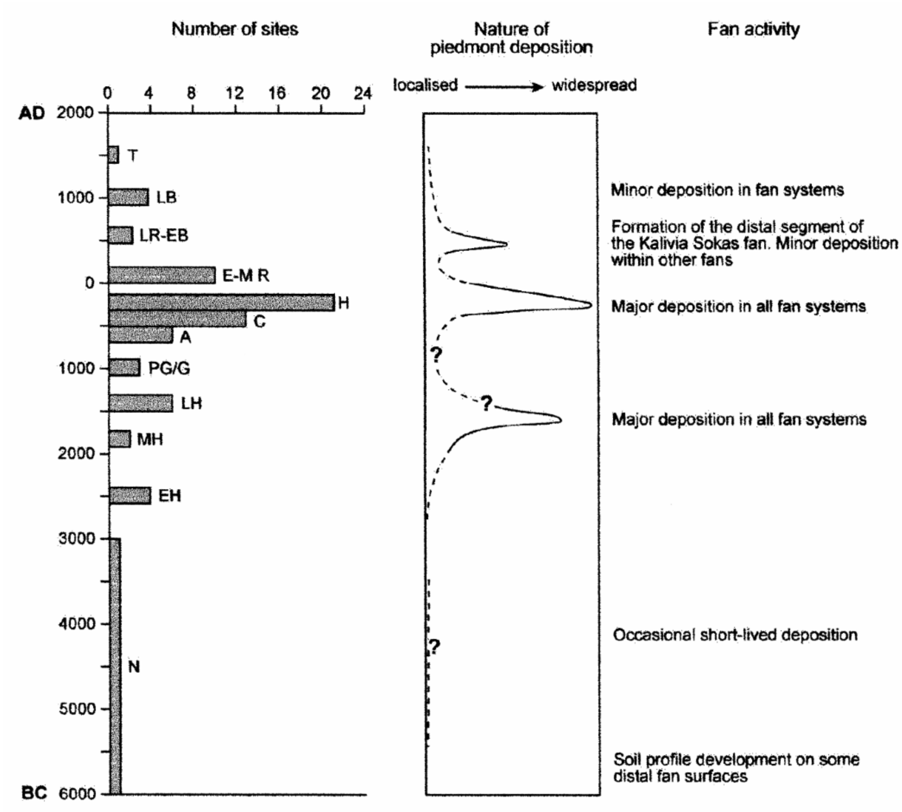

Figure 2: Archaeological sites and alluvial fan deposition in Spartan Basin, Greece (Pope et al, 2003)

Study Site

Antikyra Bay lies in the Northern Gulf of Corinth, in Central Greece (see Figure 3). Approximately 5 kilometers northwest of the coring sites and 500 meters above sea level lies Kastrouli, a fortified site with archaeological remains from the Mycenean through Classical times that in 2016 was excavated by a team of researchers from UC San Diego and University of

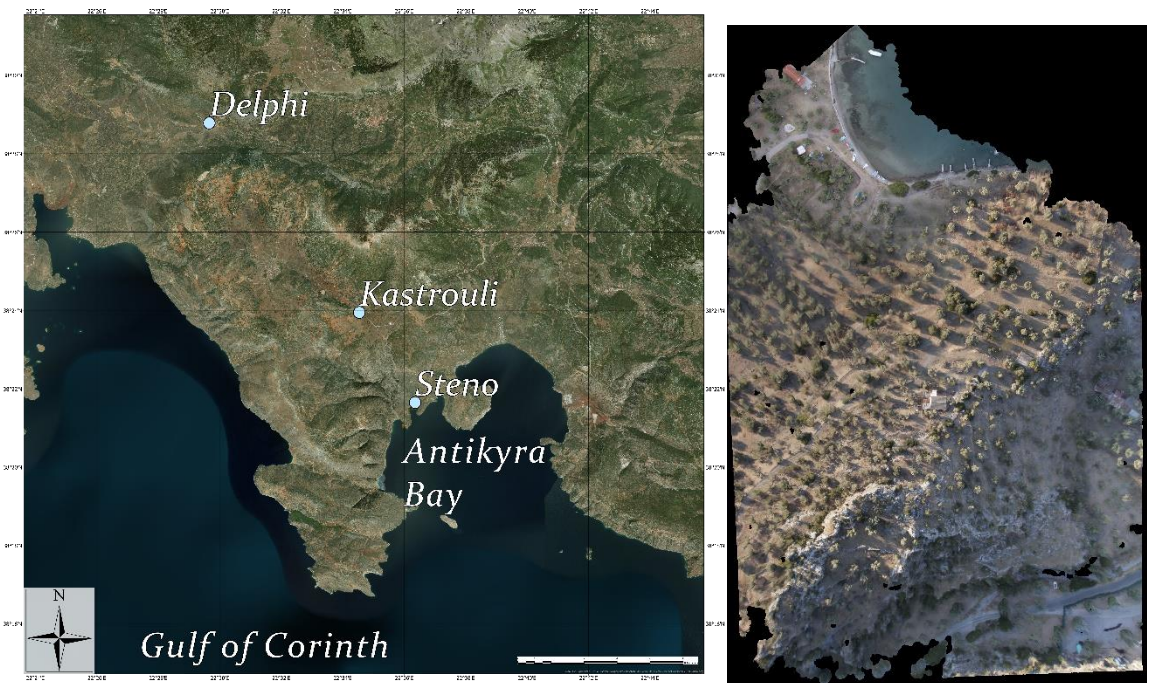

Figure 3: Map of Antikyra Bay region with nearby archaeological sites and orthophoto of Steno site (orthophoto credit: Matt Howland)

the Aegean, led by Professor Tom Levy of UC San Diego and Ioannis Liritzis of University of the Aegean. The area is characterized by often steep Mesozoic limestone slopes that are rocky with little soil cover, covered in scrubby vegetation consisting of grasses, small shrubs, and diminutive junipers and pines (Asch, 2003). Within the larger Antikyra bay are smaller bays or coves, particularly on the west side of the larger bay. Today these are host to small boats, and it is easy to imagine the bays as ports in antiquity. In addition to the maritime activity there are active olive orchards surrounding the bays.

The small bays in the study area are known as Valtos, Potami, Sotirios, and Isidoros (see Figure 4). A spring is found on Potami’s shore, a convenient source of freshwater for Steno and seafaring visitors. There are two freshwater streams feeding into the area, one located on the northwest side of Valtos, and another one the north side of Potami. On the small promontory separating Potami and Sotirios bays is a fortified site, Steno, one of a chain of Mycenean and other ancient sites around Antikyra Bay (Sideris, 2014).

These bays were chosen for coring sites due to their proximity and easy access to Kastrouli, and the likelihood of this location as a port compared to nearby bays. The collection of sediment cores along with 3D documentation of Potami Bay and Steno was undertaken to develop understanding of the coastal environment of the Mycenean civilization (Levy et al, 2018).

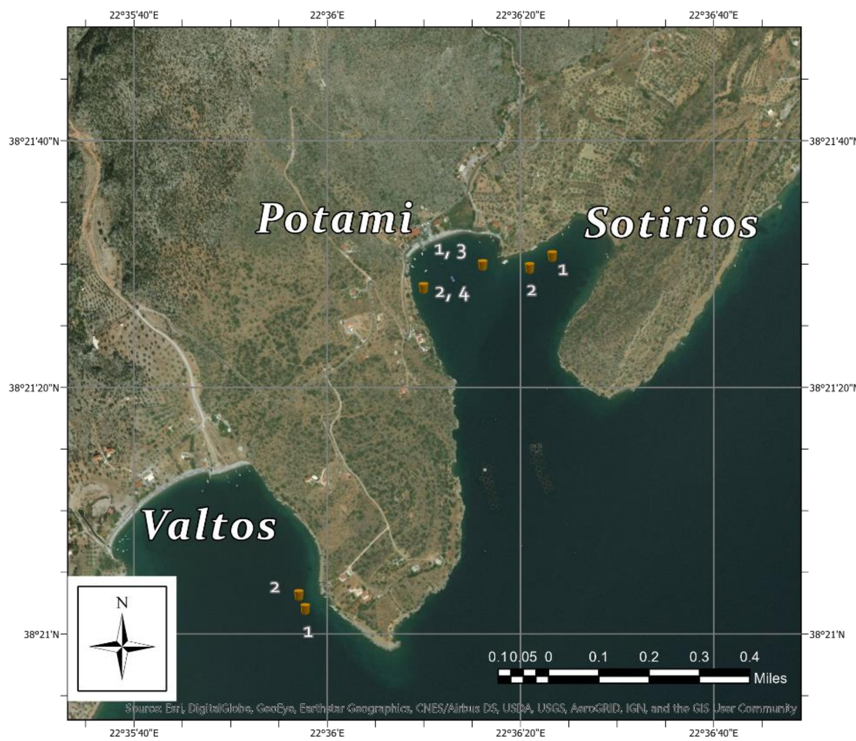

Figure 4: Coring locations

<u>Methods</u>

Marine Geophysical Survey

A team of researchers under the direction of George Papatheodorou and Maria Geraga from the University of Patras' Laboratory of Marine Geology and Physical Oceanography planned and conducted the survey in partnership with the UC San Diego group using a

Kongsberg GeoPulse Plus chirp sub-bottom profiler system and and EG and G side scan sonar. Navigation and positioning were achieved using a Hemisphere V100 GPS system with a 1.5 meter accuracy. A total area of approximately 2 square kilometers was surveyed with the side-scan sonar, from water depths of 3 to 30 meters, at 100 and 500 kHz frequency and survey lines overlapping by 50%. The sub-bottom profiling used frequencies between 1.5 and 11.5 kHz for the chirp signal and has a resolution of 10 centimeters. Over 40 profile lines were surveyed, totaling 40 km in length. In order to identify paleo-shorelines and reconstruct the paleogeography of the bays sub-bottom profile lines were aligned both parallel and perpendicular to the present shorelines of the bays (Levy et al, 2018).

Collection of Sediment Cores

Based on the results of the geophysical survey including side-scan sonar and sub-bottom profiling, 6 sites were chosen to collect sediment cores from. Due to the steep bathymetry of the bays and the method of collection, cores were taken very close to shore, about 30 to 60 meters from land, at a water depth of 6 meters. The cores were collected where loose sediment was thickest, based on the high-resolution chirp seismic profiles (see Table 1). Collection was done with a hammer core system consisting of a stainless steel, hand operated sliding hammer on a 6 meter-long agricultural supply pipe core barrel. The core barrel ends are fitted with stainless steel core cutters and catchers, designed by Professor Richard Norris and manufactured at Scripps Institution of Oceanography. This system was operated by four UC San Diego scientific divers, including Professors Levy and Norris, as well as a Greek professional diver (Levy et al, 2018). The core barrel was driven into the sediment until it could no longer penetrate despite repeated hammering. During collection this was interpreted as signaling the bottom of the loose sediments but given that the seismic data show around a meter more sediment thickness than the corresponding core length, it is possible that the cores terminate at the top of a layer of gravel or pebbles rather than bedrock.

Table 1: Core locations and sediment thickness: Antikyra Bay, Gulf of Corinth, Greece

Core Site	**Latitude**	**Longitude**	**Sediment Thickness (m)**	**Core Length (m)**
Valtos 1	38° 21′ 02.06”	22° 35′ 57.70”	2.5	1.7
Valtos 2	38° 21′ 03.18”	22° 35′ 57.08”	2.5	1.5
Potami 1 and 3	38° 21′ 29.91”	22° 36′ 16.10”	3.6	2.1, 2.2
Potami 2 and 4	38° 21′ 28.05”	22° 36′ 09.97”	2.9	2.3, 2.1
Agios Sotirios 1	38° 21′ 30.68”	22° 36′ 23.31”	3	1.9
Agios Sotirios 2	38° 21′ 29.68”	22° 36′ 20.96”	2.6	1.6
Agios Isidoros	38° 21′ 38.30”	22° 37′ 16.17”	2.3	1

Landscape Analysis

A relative sea level curve for the study area was constructed by combining Lambeck’s 2014 global eustatic sea level curve and published tectonic subsidence rates for the Antikyra Bay area (Elias, 2009; Lykousis, 2007). This was used to estimate the maximum possible ages of the base of the sediment, as well as submerged features documented in the geophysical survey (see Figure 5). Lambeck’s global sea level curve is constructed on models of ice volume and mantle rheology as well as sedimentological evidence from tectonically stable regions. This is not a Mediterranean sea level record, and the data used to construct it do not originate in or near the Mediterranean. Given the highly local variation in vertical land movement in the Mediterranean and particularly the Gulf of Corinth, it may actually be beneficial to use a global sea level curve rather than curves constructed from Mediterranean data sets. Combining a eustatic curve with local subsidence rates should account for regional isostatic and tectonic contributions over the time period we are concerned with for this study.

In order to understand where terrestrial material in our cores originated from, watersheds in the study area were identified using ArcGIS Pro 2.4.0 and Advanced Spaceborne Thermal

Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model 2 (GDEM 2) data. GDEM 2 is accurate to approximately 17 m at the 95% confidence level, with a spatial resolution on the order of 75 m (*ASTER GDEM 2 README*, 2011).

Sediment Core Analysis

Four cores were chosen for sedimentological analysis with the goal of understanding soil erosion in the Antikyra Bay area over time. After collection the cores were cut into roughly 1 meter lengths and shipped to Scripps Institution of Oceanography where they are kept refrigerated in the geological collections. They were then split using a circular saw, visually described, and photographed and scanned for relative elemental abundances using an Avaatech X-Ray Fluorescence (XRF) core scanner. The XRF scanning is done at 10 kV, 30 kV, and 50 kV to obtain the widest spectrum of elemental abundances possible.

Grain size is an important sedimentological characteristic that gives information about the depositional environment and source of sediments. Grain size analysis was performed using a Fritsch Analysette 22 Nanotech, which uses laser diffraction to determine particle size with a measuring range of 0.01 – 2100 μm. Samples were dried, disaggregated, and sieved to remove anything larger than 2 mm from the sediment before analysis. Each sample was analyzed 3 times, with samples having masses between approximately 50 and 150 mg.

Magnetic susceptibility of dried and disaggregated 10 mL sediment samples was measured with a Bartington MS2B sensor and MS3 meter. Magnetic susceptibility was used to demonstrate the presence of weakly magnetic iron bearing minerals such as goethite and hematite in the red layers, and their relative absence in the green/gray layers. Terra rossa soils are known to contain hematite and goethite, which give the soil its distinctive red color (Jordanova et al, 2013; Durn, et al, 1999).

In order to see if pollen has been well preserved and to get a sense of local agricultural activity over the entire period of time represented in the cores, 40 mg sediment samples were collected from the top, bottom, and middle regions of each core and sent to Dafna Langgut of Tel Aviv University for a preliminary pollen analysis.

Radiocarbon Dating and Age Model

Sediment samples were collected from the working halves of the cores and washed over successive 2 mm, 500 µm, 150 µm, and 63 µm sieves to obtain materials for radiocarbon dating. These samples were taken from the bottoms and tops of the cores, as well as the vicinities of major lithological changes.

Figure 5: Elphidium crispum specimen extracted from Potami 1

Due to a general paucity of terrestrial organic material in the sediment, all but two dated samples were foraminifera while the remaining two consisted of small, uncarbonized twigs (see Table 2). As there is a universal absence of planktonic foraminifera in the cores, which are considered preferable to benthic species for radiocarbon dating, the epifaunal species *Elphidium* *crispum* was selected for analysis (see Figure 5). Samples were sent to the University of Arizona Accelerator Mass Spectrometry Lab for analysis. Calibration of ages/ and dates were done using OxCal 4.3 / IntCal13 atmospheric calibration curve.

As they are calcifying marine organisms, foraminifera radiocarbon dates are subject to a reservoir effect, which results in radiocarbon dates that are older than they should be due to the residence time of carbon in the ocean being considerably longer than that of the atmosphere (Reimer & McCormac, 2002). This is a particular issue in the Gulf of Corinth, where a consistent reservoir correction has not been established by researchers (Broecker & Olson, 1961; Pirazzoli et al, 2004; Soter, 1998). Additionally, the presence of freshwater springs and streams in Potami Bay may further exacerbate attempts to correct carbonate dates across the core sites due to the freshwater (or hardwater) effect (Bente, 2013): surface and underground water in the area's limestone landscape would have dissolved the radiocarbon-dead rock, resulting in older dissolved carbon being added to the water. Two strategies were employed to best resolve this issue: 1) assume the top of Potami 4 is modern, set the age to zero and subtract the uppermost radiocarbon date from the rest of the dates; and 2) subtract the difference between foraminifera and wood dates from the same intervals within Potami 1 from the rest of the dates. Valtos and Sotirios core bottom dates were corrected using the first strategy (see Figure 6).

Ages for the bottom of the sediment that was measured in the chirp data but not retrieved via coring were estimated by extrapolation using the sedimentation rates for each core. Valtos 1 and Sotirios 1 cores were only dated at the bottom, so the sedimentation rate calculated from 0 cm to the base of the core was used in the extrapolation. Potami 1 and 4 had higher sedimentation rates in the top half of the cores, so the sedimentation rates from the lower portion of the cores was used.

Table 2: Radiocarbon Dates

Core	Depth Interval (cm)	Material	Uncalibrated 14C Age (±1σ)	Calibrated Age BP (95%)	Calibrated Calendar Age (95%)
Potami 4	210 – 212	Carbonate	3069 ± 25	3213 – 3358	1264 – 1409 BC
	161 – 163	Carbonate	2054 ± 24	1947 – 2113	4 AD – 164 BC
	71.5 – 73	Carbonate	1211 ± 24	1063 – 1231	888 – 720 AD
	23.5 – 25	Carbonate	719 ± 35	566 – 727	1385 – 1224 AD
	0 – 1.5	Carbonate	948 ± 22	796 – 925	1026 – 1155 AD
Potami 1	202 – 204	Carbonate	2787 ±24	2799 – 2955	850 – 1006 BC
	176 – 178	Carbonate	2881 ±21	2929 – 3075	980 – 1126 BC
	113 – 115	Carbonate	1807 ±35	1620 – 1825	330 – 126 AD
	113 – 115	Wood	345 ±19	316 – 482	1635 – 1468 AD
	97.5 – 99.5	Carbonate	1537 ±20	1370 – 1523	581 – 427 AD
	68 – 70	Carbonate	1195 ±20	1063 – 1179	887 – 772 AD
	68 – 70	Wood	246 ±19	153 – 309	1798 – 1641 AD
	29 – 31	Carbonate	871 ±20	730 – 899	1220 – 1051 AD
Sotirios 1	185 – 186.5	Carbonate	4786 ±23	5472 – 5590	3523 – 3641 BC
Valtos 1	172 – 175	Carbonate	3273 ±22	3453 – 3562	1504 – 1613 BC

Results and Discussion

The Isidoros core consisted almost entirely of cobbles and roots and was therefore not analyzed. Cores that were collected in the same location were extremely similar in their stratigraphy. Samples for dating were only collected from Valtos 1, Sotirios 1, and Potami 1 and 4, and results will only be discussed for these cores.

Western Antikyra Bay Relative Sea Level Over Time

In addition to providing information for the selection of core sites, the geophysical survey also revealed one, and possibly two, paleo-shorelines (Levy et al, 2018). The more obvious of the two is found at 26 meters depth, and a less distinct, possible paleo-shoreline is at 41.25 meters depth. The relative sea level curve constructed for this study suggests the shallower of the two is between ~7.7 and 8.7 thousand years old, while the deeper feature, if it is in fact a paleo-shoreline, would have formed around 8.9 to 9.7 thousand years ago. The shallower of the two may be a remnant of the 8.2 kiloyear climate event, which was a brief sea-level standstill in a period of otherwise rapidly rising waters following the end of the Pleistocene. In the summer of 2018, a UCSD team consisting of Dr. Levy, Dr. Norris, and Christian McDonald collected

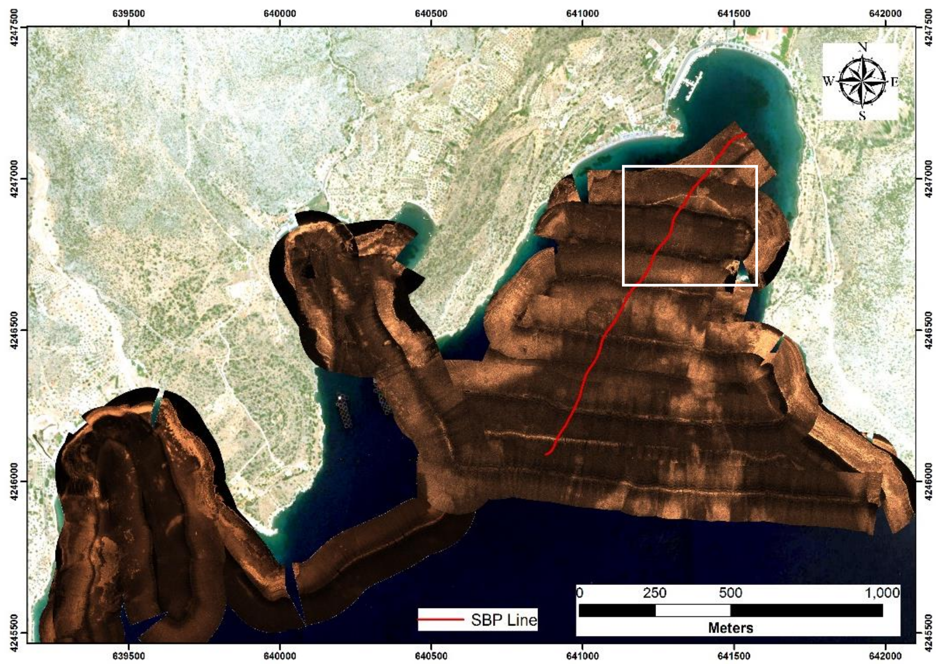

Figure 6: Side-scan sonar of study site. Paleo-shorelines in boxed area. Credit: George Papatheodorou and Maria Geraga

sediment samples from the paleoshorelines via SCUBA. These samples will be OSL dated in the future.

A comparison of the relative sea level curve with our radiocarbon-based age model (see Figure 8) shows broad agreement with the subsidence rates published by Elias et al. The one outlier is the age model for Sotirios 1, for which the bottom was dated (pre-correction for reservoir effect)

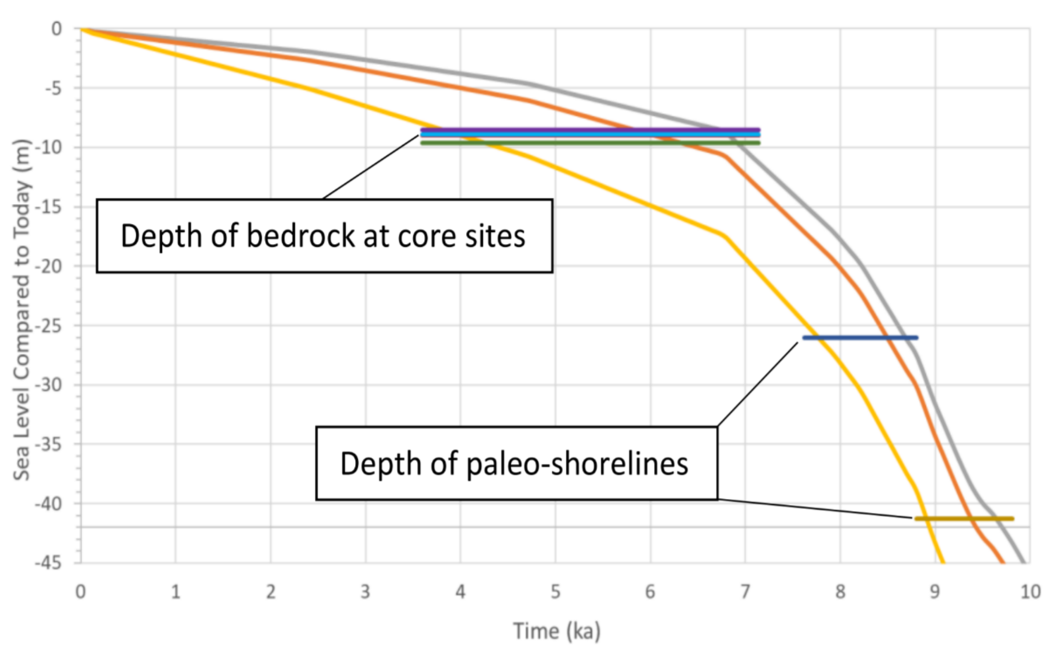

Figure 7: Relative Sea Level Curve for Western Antikyra Bay. Orange/Gray: High/low estimates of subsidence rates by Lykousis et al, 2007. Yellow: Estimated subsidence rate by Elias et al (2009).

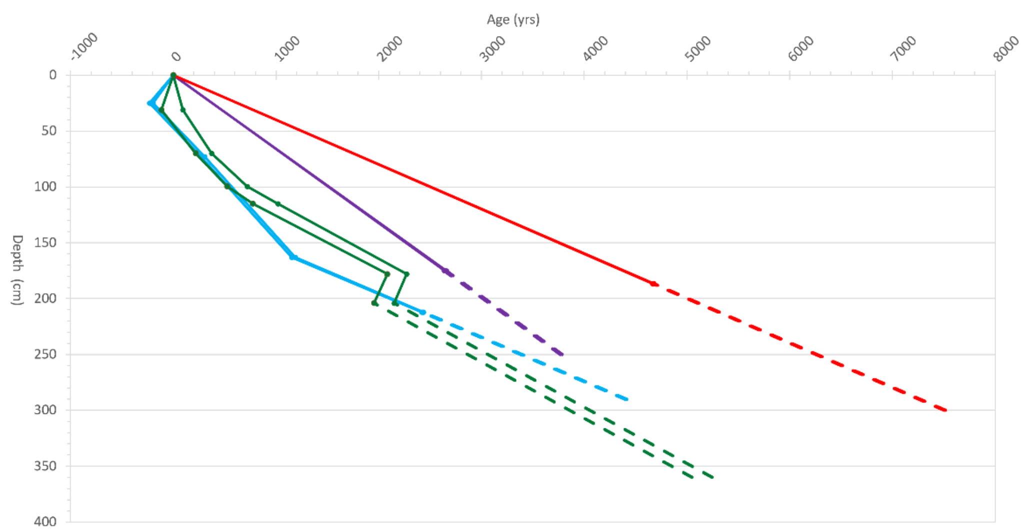

Figure 8: Age Model. Dashed lines represent extrapolated ages for bottom of sediment, as identified by seismic data. Blue: Potami 4. Green: Potami 1 (two lines representing range of calibrated ages for wood). Purple: Valtos 1. Red: Sotirios 1.

to around 5.5 calBP, roughly 2 thousand years older than the bottom ages of the rest of the cores. It is possible that this site was bypassed by most of the terrestrial runoff deposition, resulting in a much slower rate of sedimentation. If this is the case, the faster subsidence rate estimated by Lykousis et al would be a closer match. However, as we have only one date for this core and its stratigraphy is very similar to the apparently much younger Valtos core, it is also very likely that the bottom date is erroneous.

Sedimentary Record of Soil Erosion

The Valtos and Sotirios cores show fairly homogeneous sedimentation typical of shallow bays. With the exception of the top 10 to 30 centimeters or so, the sediment is a gray-green, shelly mix of sand and silt with occasional pebbles. Shell fragments are common throughout, and some layers exhibit a fe w to many intact shells over 2 centimeters in size. Articulated bivalves are present but somewhat rare, as are large gastropods over 3 centimeters in size. All faunal remains are typical of shallow marine environments of the Eastern Mediterranean. Posidonia seagrass roots and leaves are abundant in most units of Valtos 1, but absent in Sotirios 1. The top units show a gradual addition of red material.

The Potami cores are strikingly different, with alternating units of gray-green shelly material and finer grained, red material. These red units have much less shell material, with some units displaying an almost complete absence. The sediment is a mix of clay, silt, and occasionally some fine sand. It also includes a significant amount of charcoal in the range of 63 to 150 μm. The gray-green units are essentially identical to those in Valtos and Sotirios cores.

We interpret the red units to be terrestrial soil (Terra Rossa) deposited post-erosional event and washed to the Potami Bay via the watershed that empties into it on the north side (See Figure 11). In addition to visual observations that typical bay-type sediments are interrupted by

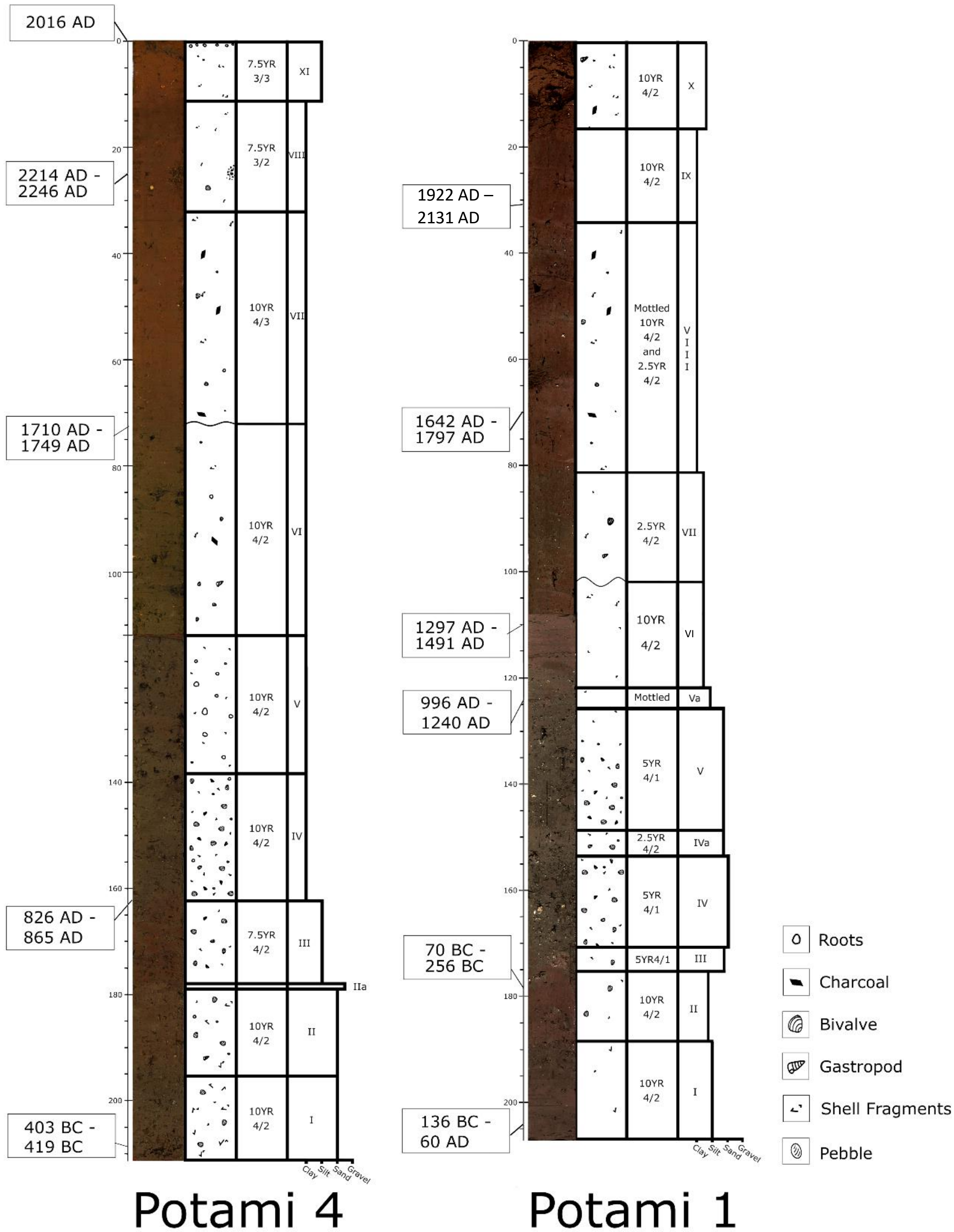

Figure 9: Core stratigraphy: Potami 4 and 1

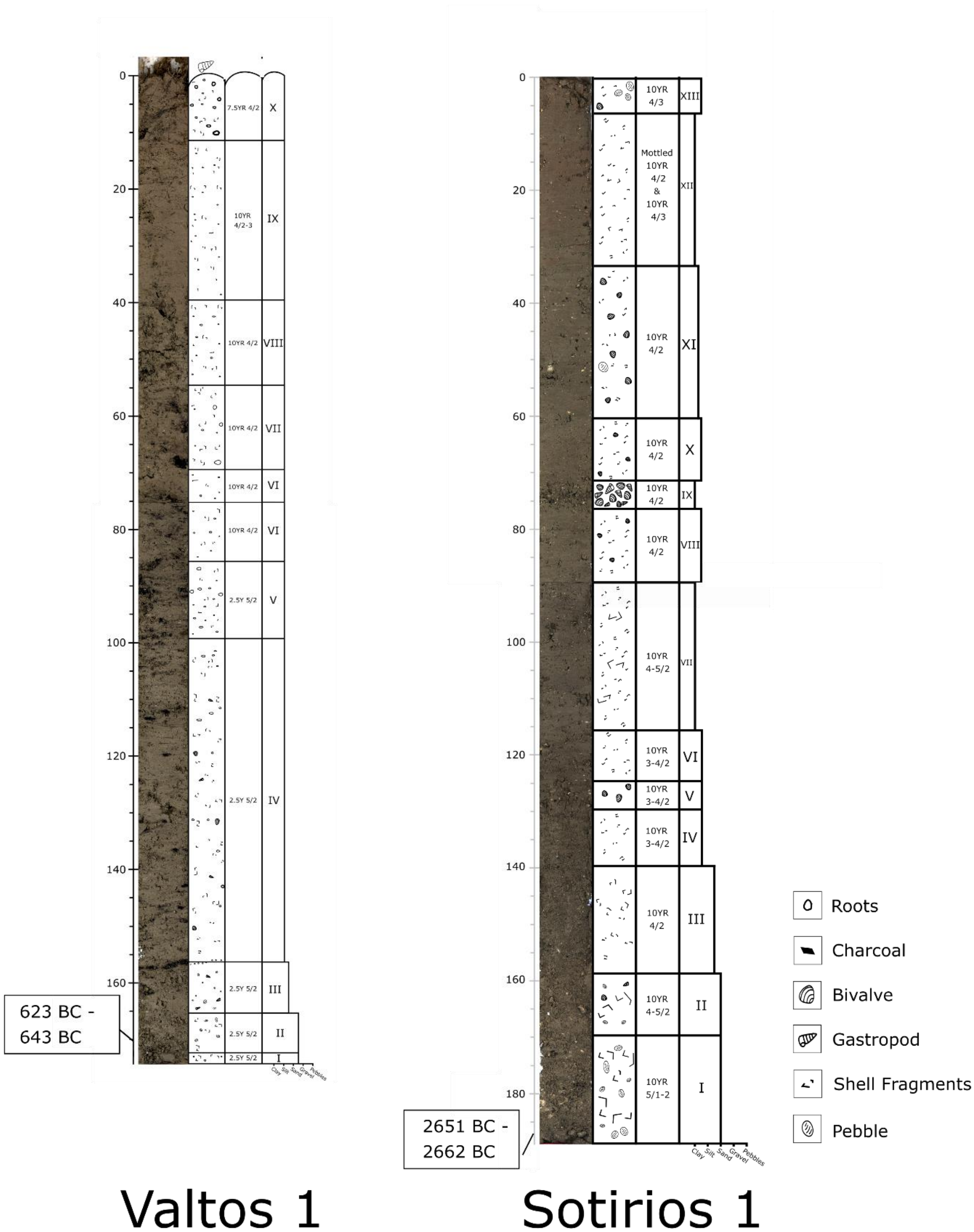

Figure 10: Core stratigraphy: Valtos 1 and Sotirios 1

units have finer median and mean grain size compared to gray-green units, higher magnetic susceptibility, and higher K/Zr and Fe/Ca. These characteristics agree well with our interpretation that these are terrigenous soil deposits.

The dominant soil type in the area, as in much of the Mediterranean, is often called "Terra Rossa". This is a somewhat ill-defined term, but for our purposes it will suffice. Classic Terra Rossa soil forms in Mediterranean climates—that is, hot dry summers and cool, wetter winters—that promote weathering of the parent rock types. In the case of Terra Rossa, the parent rock is dolomite or limestone (notably abundant in the Antikyra Bay region). While the exact source of other contributing materials has not been widely agreed upon, many have suggested the formation mechanism to be Saharan dust settling on carbonate rock and weathering along with it (Durn, 1999). It is characterized by 1) the presence of the iron-oxide minerals hematite and goethite which provide its distinctive red color, 2) a mix of silt and clay (including the potassium-rich clay mineral illite) which is considered ideal for agriculture due to good drainage properties (Durn, 1999), and 3) its propensity to erode easily from the rocky substrate it forms on (Yassoglou, 2017). The sedimentological and chemical analyses of the core material are therefore consistent with the defining characteristics of Terra Rossa soil.

The differences between the Potami cores and those from Valtos and Sotirios can be best explained by the proximity of the former to the larger watershed emptying into Potami bay, marked by the stream that flows into the sea from the beach. According to this analysis, the stream carries sediment from several kilometers into the hills and includes an area near the Kastrouli site that today is agricultural land. There is no such watershed emptying into Sotirios bay, and while Valtos bay has an even larger drainage, the core location is not close to it and the sediment most likely settled into the center of the bay rather than the outer edge where the core was taken.

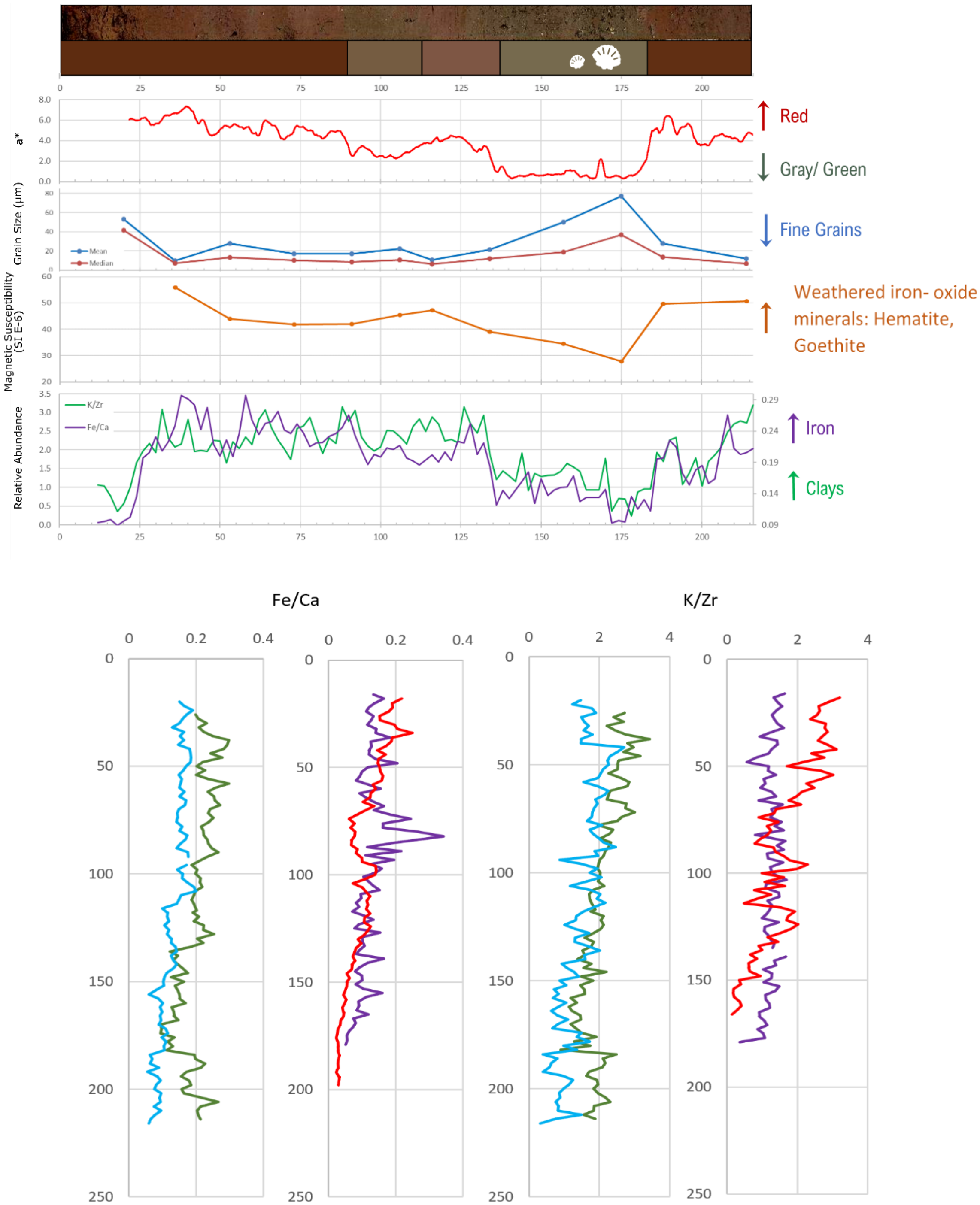

Figure 11: Sedimentological Data. Top: Potami 1 data. From top: 1) Spectral data 2) Grain size 3) Magnetic susceptibility 4) Relative elemental abundance Bottom: XRF data: Green: Potami 1, Blue: Potami 4, Red: Sotirios 1, Purple: Valtos 1

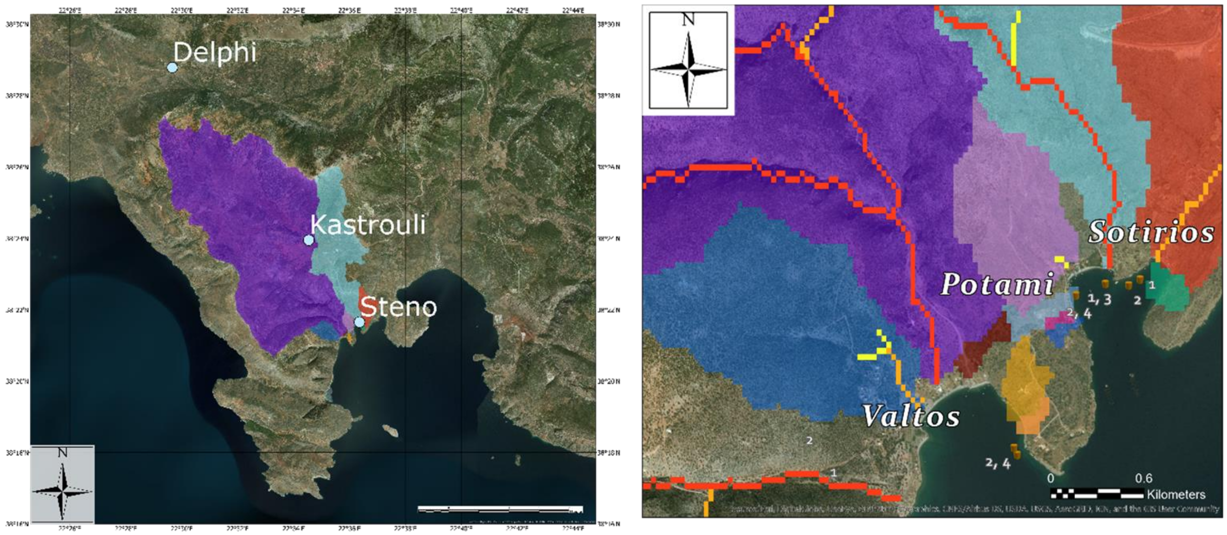

Figure 12: Watershed Analysis. Left: Overview of watersheds in study area. Right: Watersheds and streams adjacent to coring locations

Timing of Erosional Events

Both strategies employed to construct our age model resulted in a few negative ages in foraminifera dates, which, combined with the 2 age reversals between foraminifera dates, point to an inconsistent reservoir effect over time. This may be due to fluctuating amounts of freshwater delivery to the bays via springs or surface rivers (Philippsen, 2013). These issues are not insignificant on historical time scales. Indeed, the various historical periods in Ancient Greece are individually less than 500 hundred years long, making it difficult to identify whether soil mismanagement was greatest in the Roman period, for example, compared to the Classical period (a mere ~170 year difference). With that being said, the Potami cores show some clear temporal trends that are worth pointing out, reservoir effect notwithstanding.

The Modern period (1821 AD to the present) has contributed a disproportionately large amount of sediment, and to a lesser degree, so did the Ottoman period (1453 to 1821 AD). Both periods correspond to very red sediment. The Byzantine period (324 to 1453 AD) apparently corresponds to lower sedimentation that was mostly gray-green bay sediment. Further back in time the picture becomes less clear, but it is likely that either the Roman period or the end of the Roman period (324 AD) corresponds to an erosion event.

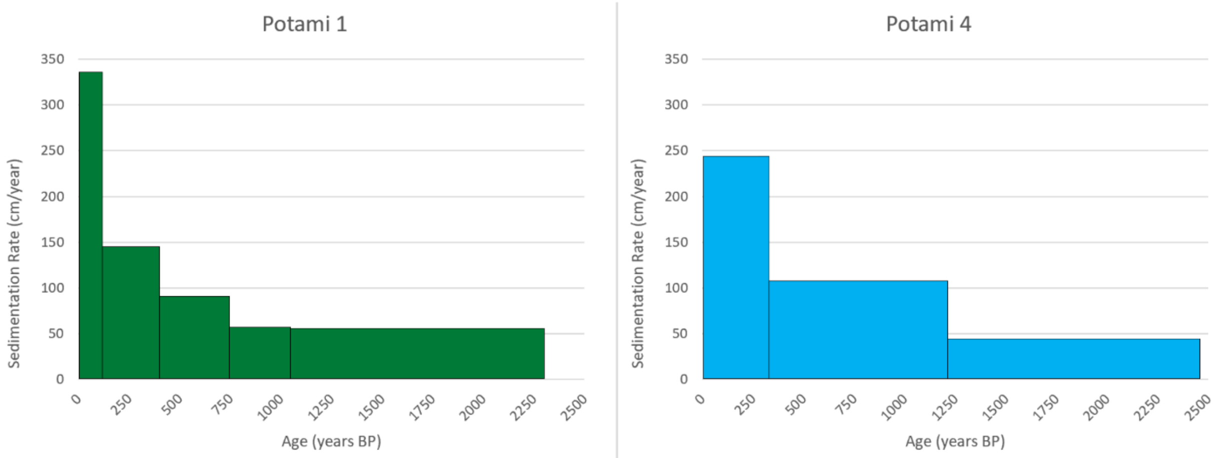

Figure 13: Sedimentation Rates: Potami 1 and 4 cores

Preliminary Pollen Analysis

In order to understand vegetation changes over time in the area, both Potami cores will be analyzed in their entirety for pollen, which will paint a better picture of land use practices over the last ~2,000 years. Preliminary work shows that olive cultivation was common in the area over the entire span of the record, which it still is today. The presence of grape likely points to coastal cultivation, as domesticated Vitis has very low pollen dispersal efficiency (Langgut, personal correspondence, 2018). The complete pollen analysis has the potential to indicate changes in agricultural intensity, types of crops grown, and deforestation in the area, all of which will contribute to the story unfolding within this study.

Mechanisms of Soil Erosion

The primary driver of large scale erosion is loss of vegetative cover (Yassoglou, 2017), which can be the result of a number of different natural and anthropogenic events. Deforestation for timber, to clear land for agriculture or habitation, or by human-caused fires are some of the commonly cited anthropogenic culprits (van Andel, Zangger, Demitrack, 1990). Overgrazing, particularly on rocky slopes, is another major cause (Yassoglou, 2017). While these practices are generally associated with intensive human occupation and economic activity, the abandonment or decreased maintenance of previously cultivated land is also a driver of soil erosion (van Andel, Zangger, Demitrack, 1990; Yassaglou, 2017, Pope and van Andel, 1984). This is particularly the case for terraces, which, while very effective at retaining soil, require regular maintenance (Yassaglou, 2017), otherwise they are just another unstable slope waiting for the next heavy rainfall to fail.

Short-term weather conditions as well as longer-term changes in climate can also result in increased erosion. Historians have linked the decline of the Ottoman Empire to the effects of the Little Ice Age on agriculture around the Eastern Mediterranean (Mikhail, 2015; White, 2013), and regional climate records do show increased precipitation variability during periods of the 16^{th} through early 20^{th} centuries around the Balkans (Touchan et al, 2005). Such conditions very well could have resulted in erosion due to loss of vegetation during dry periods, followed by disturbance of bare soil by heavy rains during wetter periods. However, identifying this as the primary cause of the erosion evidenced in the Antikyra cores is problematic because these climate conditions have the potential to negatively impact agriculture, which could in turn lead to the terrace abandonment discussed above.

Conclusion

The cause of Mediterranean aggradation events has long been disputed: Vita-Finzi (1969, p. 114-115) believed that human activity alone could not have caused widespread and concurrently timed erosion, instead blaming it largely on post-glacial climate changes. Pope and van Andel (1984) later claimed that Holocene erosion in the Argolid was largely due to land use practices beginning in the Neolithic, and Fuchs (2007) found that Late Holocene periods of erosion in the Peloponnese corresponded best with periods of more intense cultural activity rather than climate shifts.

Unlike much of the previous research done on the topic of erosion around the Mediterranean, this study is local in nature and was designed to understand the changing environment of specific, nearby archaeological sites included in the Kastrouli-Antikyra Bay Land and Sea Project. The geographic analysis shows the watershed feeding into Potami bay is only 19.4 square kilometers, ensuring that the results are relevant to our study area and not necessarily applicable to the region at large. This study will therefore not add much support to any of the various sweeping interpretations of Mediterranean erosion, but its utility to our project is likely much greater than large-scale basin studies.

The sedimentological analysis lays the groundwork for the palynological study in progress, which is expected to resolve the lingering question as to whether the primary driver for erosion was purely climatic or anthropogenic in nature, or a combination thereof. As with similar studies, the level of interpretation is limited by the challenges of obtaining a precise chronology. Future studies should look to improve age models by using multiple dating methods and include samples from within archaeological sites to better connect erosion processes to dateable cultural materials.

Works Cited

Van Andel, T. H., Zangger, E., & Demitrack, A. (1990). Land use and soil erosion in prehistoric and historical Greece. Journal of field archaeology, 17(4), 379-396.

Asch, K. (2003). The 1:5 Million International Geological Map of Europe and Adjacent Areas: Development and Implementation of a GIS-enabled Concept. Geologisches Jahrbuch, SA 3, Stuttgart: E. Schweizerbart´sche Verlagsbuchhandlung.

Bevan, A., & Conolly, J. (2011). Terraced fields and Mediterranean landscape structure: an analytical case study from Antikythera, Greece. Ecological Modelling, 222(7), 1303-1314.

Bintliff, J. (2012). The complete archaeology of Greece: from hunter-gatherers to the 20th century AD. John Wiley & Sons.

Bintliff, J. (2002). Time, process and catastrophism in the study of Mediterranean alluvial history: a review. World archaeology, 33(3), 417-435.

Broecker, W. S., & Olson, E. A. (1961). Lamont radiocarbon measurements VIII. Radiocarbon, 3, 176-204.

Durn, G., Ottner, F., & Slovenec, D. (1999). Mineralogical and geochemical indicators of the polygenetic nature of terra rossa in Istria, Croatia. Geoderma, 91(1-2), 125-150.Elias, Panagiotis, et al. “Permanent Scatterer InSAR Analysis and Validation in the Gulf of Corinth.” *Sensors*, vol. 9, no. 1, 2009, pp. 46–55., doi:10.3390/s90100046.

Emmanouilidis, A., Unkel, I., Triantaphyllou, M., & Avramidis, P. (2020). Late-Holocene coastal depositional environments and climate changes in the Gulf of Corinth, Greece. The Holocene, 30(1), 77-89.

Finné, M., Bar-Matthews, M., Holmgren, K., Sundqvist, H. S., Liakopoulos, I., & Zhang, Q. (2014). Speleothem evidence for late Holocene climate variability and floods in Southern Greece. Quaternary Research, 81(2), 213-227.

Fuchs, M. (2007). An assessment of human versus climatic impacts on Holocene soil erosion in NE Peloponnese, Greece. Quaternary Research, 67(3), 349-356.

Fuchs, M., Lang, A., & Wagner, G. A. (2004). The history of Holocene soil erosion in the Phlious Basin, NE Peloponnese, Greece, based on optical dating. The Holocene, 14(3), 334-345.

Jordanova, N., Jordanova, D., Liu, Q., Hu, P., Petrov, P., & Petrovský, E. (2013). Soil formation and mineralogy of a Rhodic Luvisol—insights from magnetic and geochemical studies. Global and planetary change, 110, 397-413.

Levy, T.E., Sideris, A., Howland, M., Liss, B., Tsokas, G., Stambolidis, A., Fikos, E., Vargemezis, G., Tsourlos, P., Georgopoulos, A., Papatheodorou, G., M. Garaga, R. Christodoulou, R.D. Norris, I. Rivera-Collazo, and I. Liritzis (2018). At-risk world heritage, cyber, and marine archaeology: The Kastrouli–Antikyra Bay land and sea project, Phokis, Greece. In Cyber-Archaeology and Grand Narratives (pp. 143-234). Springer, Cham.

Lykousis, V., Sakellariou, D., Moretti, I., & Kaberi, H. (2007). Late Quaternary basin evolution of the Gulf of Corinth: Sequence stratigraphy, sedimentation, fault–slip and subsidence rates. Tectonophysics, 440(1-4), 29-51.

Maas, G. S., & Macklin, M. G. (2002). The impact of recent climate change on flooding and sediment supply within a Mediterranean mountain catchment, southwestern Crete, Greece. Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group, 27(10), 1087-1105.

Mikhail, A. (2012). The Middle East in global environmental history. A Companion to Global Environmental History, 167-181.

Owens, M. J., Lockwood, M., Hawkins, E., Usoskin, I., Jones, G. S., Barnard, L., Schurer, A., & Fasullo, J. (2017). The Maunder minimum and the Little Ice Age: an update from recent reconstructions and climate simulations. Journal of Space Weather and Space Climate, 7, A33.

Philippsen, B. (2013). The freshwater reservoir effect in radiocarbon dating. Heritage Science, 1(1), 24.

Pirazzoli, P. A., Stiros, S. C., Fontugne, M., & Arnold, M. (2004). Holocene and Quaternary uplift in the central part of the southern coast of the Corinth Gulf (Greece). Marine Geology, 212(1-4), 35-44.

Pope, K. O., & van Andel, T. H. (1984). Late Quaternary alluviation and soil formation in the southern Argolid: its history, causes and archaeological implications. Journal of Archaeological Science, 11(4), 281-306.

Pope, R. J., Wilkinson, K. N., & Millington, A. C. (2003). Human and Climatic impact on Late Quaternary deposition in the Sparta basin piedmont: evidence from alluvial fan systems. Geoarchaeology: An International Journal, 18(7), 685-724.

Sideris, A. (2014). Antikyra history & archaeology. Athens: Municipality of Distomo.

Soter, S. (1999). Holocene uplift and subsidence of the Helike Delta, Gulf of Corinth, Greece. Geological Society, London, Special Publications, 146(1), 41-56.

Touchan, R., Xoplaki, E., Funkhouser, G., Luterbacher, J., Hughes, M.K., Erkan, N., Akkemik, Ü., & Stephan, J. (2005). Reconstructions of spring/summer precipitation for the Eastern Mediterranean from tree-ring widths and its connection to large-scale atmospheric circulation. Climate dynamics, 25(1), 75-98.

Vita-Finzi, C. (1969). Mediterranean valleys.

White, S. (2013). The Little Ice Age crisis of the Ottoman Empire: A conjuncture in Middle East environmental history. Water on sand: Environmental histories of the Middle East and North Africa, 71-90.