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Holocene record of palaeoclimatic impact in Epanomi coastal lagoon basin, Thermaikos Gulf, North Greece

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Abstract. Sediment cores of 4m were sampled in Epanoni coastal lagoon basin in Eastern Thermaikos Gulf. Within this study, we present results of Magnetic Susceptibility (MS) measurements and sedimentological analysis (XRD and grain-size distribution) for the first meter EP1-1 aiming to contribute to the reconstruction of the paleoclimatic regime in Thermaikos Gulf during the Holocene. Based on MS and XRD, we concluded that probably a wet episode is reflected at 3760±25 BP resulting in greater material transfer with higher values of magnetic susceptibility. The increased ratio of the coarser sediments in depths 40-50cm suggests an increased run-off. Subsequently that, the presence of gypsum in the upper layers of 14-39cm depth indicates a dry period with intense evaporation.

Keywords: Paleoclimate, Epanomi coastal lagoon, Holocene, Thermaikos Gulf

1. Introduction

Paleoclimatic records are essential for understanding the current warming and drying scenario in the Mediterranean basin from a long-term perspective of natural climate variability (Ljungqvist et al., 2016). The Holocene climate includes several climate events, as the so-called 8.2 ka event, 4.2 ka event, and 3.2 ka event (Alley et al., 1997; Mayewski et al., 2004). These events correspond to cooler and more arid climate setting on a worldwide scale, including the eastern Mediterranean. Although many records in the Mediterranean region and the Levant point to a climatically dry period occurring around 4200BP, some questions need to be addressed regarding climate variability in the mid-Holocene (Bini et al., 2019). This study focuses on Thermaikos Gulf North Greece, a small gulf in the Northern Aegean, in the Eastern Mediterranean. We aim to reach conclusions about paleoclimatic records based on the sediment core material. In this respect, Magnetic Susceptibility (MS) measurements, radiocarbon, grain size, and XRD analysis were carried out.

2. Study area and methods

2.1. Physical environment and fieldwork studies

The study area is located at the east coastline of the Thermaikos Gulf (Figure 1). Epanomi coastal lagoon is bordered on the east by a low hilly terrain consisted of fluvio-lacustrine Pliocene (Gonia Formation) and terrestrial - red beds Pleistocene (Moudania Formation) deposits forming a coastal hilly relief (Syrides 1990) while on the west a sand barrier isolates the lagoon from the sea. A 4m sediment core was recovered in the Holocene layers of the Epanomi coastal lagoon according to the international quality standards (ISO 22475). The level of the top of the core was measured at -3.8cm±0.2 a.s.l. using RTK GNSS instrumentation. In this study, we present analysis results for the first meter (1m) core sample EP 1-1. The core consisted of fluvial sediment deposited on the lagoon bottom due to the diminishing rate of the sea level rise prior to 4000 yr BP for the Thermaikos Gulf (Vouvalidis et al, 2005).

Figure 1. Hydrographic network and EP1-1 core site

2.2. Laboratory studies

Core samples were first subjected to Magnetic Susceptibility (MS) measurements. The whole core was passed through a Bartington MS2C at 2 mm intervals. In addition, the cores were split lengthwise and subsampled for radiocarbon, mineralogical and grain-size analysis. Radiocarbon AMS analysis was perfomed in Laboratory for Low-level Radioactivities», Ruđer Bošković Institute (Table 1). The sedimentological analysis was applied at 5cm intervals. The mechanical sieve method was specifically used for particles > 2.00 phi (250 μm). Particle sizes < 2.00 phi (250 μm) measured with laser diffraction using the equipment of Hellenic Navy Hydrographic Service (HNHS). The analysis of the mineralogical phases was performed with X-ray diffraction analysis (XRD).

Table 1. AMS ^{14}C dating results in EP 1-1

Lab code	Type	Depth (cm)	^{14}C age (BP)
Z-7503 A2275	Charcoal	63.6	3760 ± 25

^{14}C dating was calibrated using OxCal v.4.2.2. In addition, a sea-based calibration of values was performed using 14CHRONO Marine20 Reservoir Database (http://calib.org/marine/).

3. Results and discussion

Grain size analysis was carried out to construct and interpret the grain-size frequency distribution (Figure 2). The fine-grained component has a modal about 0.31μm-56.23 μm, and coarse-grained component a modal about 56.23μm-4500μm particle sizes diameter. Generally, distributions of most hydraulic and aeolian sediments are polymodal highlighting different transport or depositional processes (Tanner 1964, Bagnold and Barndorff-Nielsen 1980).

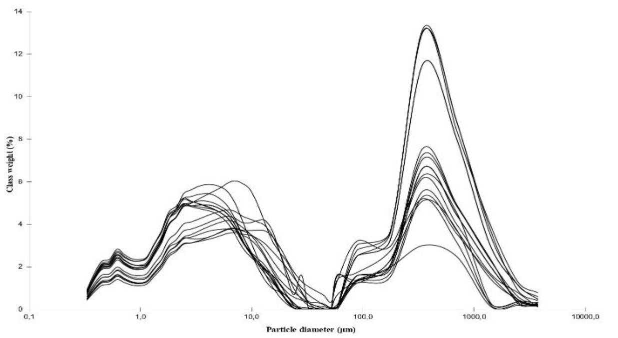

Figure 2. Grain-size distribution of samples from EP 1-1.

To understand the depositional mechanisms, the following equations were used for the two components, as proposed by Sahu 1964 (where Y is the discriminant index, Mz the graphic mean size, s the standard deviation, Sk the inclusive graphic skewness and KG the graphic kurtosis):

- Y2 equation was used to distinguish between beach (back-shore) and shallow agitated marine environments (subtidal environment):

$$Y2 = 16.6534Mz + 65.7091s^2 + 18.1071Sk + 18.5043KG$$

If the value of Y2 < 65.3650 beach deposition is suggested whereas if > 65.3650 a shallow agitated marine environment is likely.

- For the discrimination between shallow marine and fluvial environments, Y3 equation was used:

$$Y3 = 0.2852Mz - 8.7604s^2 - 4.8932Sk + 0.0482KG$$

If Y3 < -7.419 the sample is identified as a fluvial (deltaic) deposit, and if > -7.419 the sample is identified as a shallow marine deposit.

Figure 3 shows the scatter graph of Y2 against Y3. The process and environment of deposition were decoded, indicate that all samples are characterized as being all fluvial deposits in a shallow marine environment. This observation is consistent with the study area considering the hydrographic network (Figure 1). Today the NW stream that outflows the study area has been diverted and does not affect it. It is worth noting that future work would be the in-depth statistical analysis of overlapping coarse, fine, and very fine components. Weibull and Normal function are suitable for mathematically describing grain-size distribution of fluvial and lacustrine sediment (Sun et al., 2002).

Regarding the lithology, it is evident in Figure 5 that the sand component is rising sharply between 40cm and 50cm depth. In contrast, mud has a significant presence in 50-100cm layers with a small sand peak in about 56.5cm depth. Generally, the predominance of fine-grained sediments and the absence of coarser component suggests low-energy deposition conditions (Boggs 2009). Therefore, it could be reasonably assumed that up to 50cm moderately low energy conditions of deposition are present followed by an increased run-off in 40-50cm depth as it is suggested by the increased ratio of the coarser sediments.

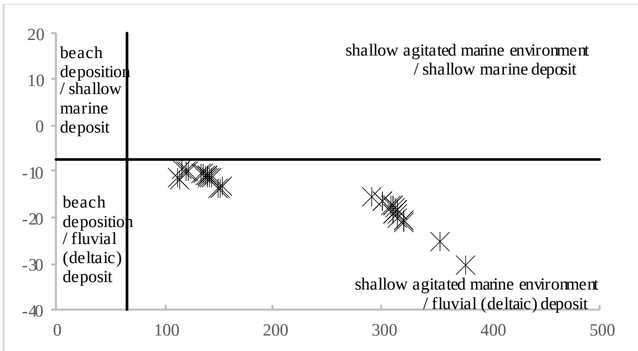

Figure 3. Correlation of statistical values Y2 and Y3 of all samples in EP1-1 core.

According to the MS results, core EP1-1 presents a peak at 60cm depth (Figure 5). Looking in detail, from the old to the recent sediment samples (bottom to up), we observed relatively stable values about $70*10^{-5}$ (SI) up to 78cm. Then MS measurement increase presenting a peak at 60cm depth with values about $91*10^{-5}$ (SI). Thereafter MS values decreased to $80*10^{-5}$ (SI). Normally, MS high values indicate the high concentration of magnetic minerals, mainly ferromagnetic, such as magnetite and hematite, but also paramagnetic and to a lesser extent diamagnetic mineral, which contribute to a small ratio of the total magnetisation of the materials. However, in fluvial deposits increased MS measurements are probably related to the presence of warmer and wetter climatic conditions resulting in high transfer rates. In contrast, lower values are likely to highlight colder and drier climates and therefore lower material transfer rates.

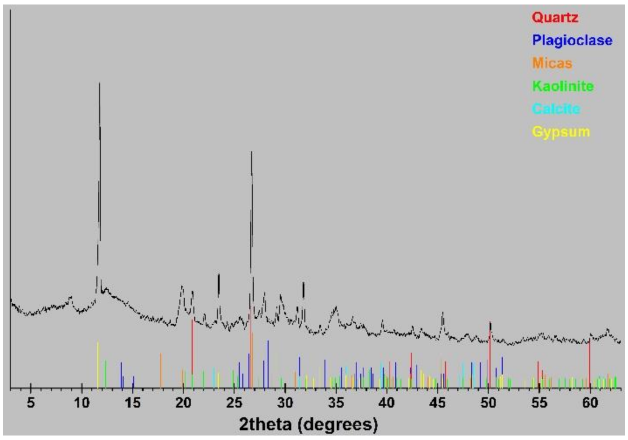

Figure 4. The mineralogical phase of quartz, gypsum, and calcite for sediment layer 34-39cm

According to XRD results, quartz is the main mineralogical phase in EP 1-1, except the layer 34-39cm where gypsum prevails (Figure 4). İn total the gypsum phase detected at the 14-39cm depth. We also noticed that in the layers that the gypsum appears the MS measurements decrease. The calcite mineralogical phase occurs only in 29-59cm depth.

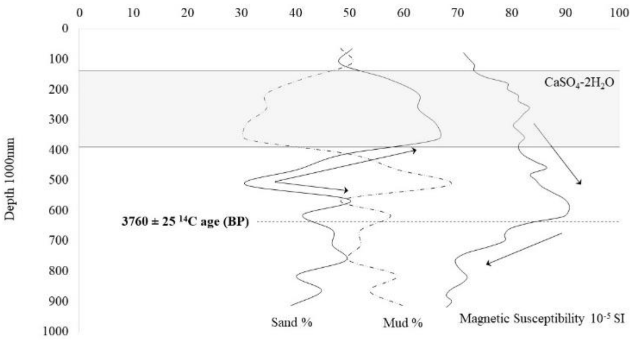

Figure 5. Lithology (sand% and mud%) and Magnetic Susceptibility (MS) measurements (10^{-5} SI) data. It has been also marked the gypsum mineralogical phase presence and ^{14}C date.

Based on the above remarks from MS and XRD, we conclude that probably a wet episode is reflected at 50-60cm layer resulting in greater material transfer with higher values of magnetic susceptibility. That also explains the increase of sand component in this layer. Radiocarbon analysis for this layer resulted in 3760 ± 25 BP (4125 cal BP). The presence of gypsum in the upper layers of 14-39cm depth indicates a dry period with intense evaporation. This is consistent with sedimentological evidence at Lake Malik (Albania), highlighted high lake levels between ca. 4200 and 4100 cal a BP (Fouache et al., 2010). Moreover, Znchetta et al., 2012 have demonstrated three prominent peaks in sediments from Lake Shkodra (Albania) indicating drier conditions between ca. 4100 and 2500 cal, ca. 4100–4000 cal BP, ca. 3500 cal BP and at ca. 3300 cal BP. It should be noted that these observations for mid/late Holocene have also been reported for Ohrida (Lacey et al., 2015) and Prespes (Leng et al., 2013) lake in the wider area of western Macedonia.

The so-called 4.2 ka cooling event has been described in many records from the Mediterranean area (Bar-Matthew et al., 1999; Weiss and Bradley, 2001; Magny et al., 2009; Wagner et al., 2009; Vogel et al., 2010). A weak African monsoon led to low lake levels in North Africa and the Near East (Kotthoff et al., 2008; Magny et al., 2009). At the same time, the decreased moisture availability of Atlantic origin and the cold dry air from the Siberian high formed cold and dry conditions in the Mediterranean supported by a positive NAO (North Atlantic Oscillation) index.

After 4.2 ka cooling event, many researchers have reported more humid conditions. Francke et al, 2013 detected a higher mean grain size along with increased K and Fe concentrations in a sediment core from Lake Dojran suggesting a stronger inflow and a more marked erosion under a more humid regime after 4.2 ka. Magny et al., 2009 have also reported more humid conditions for central and western Mediterranean between 3950 and 380=0 cal yr BP. Finally, Chantzi and Almpanakis 2020 underlined two major trends in sediments from the Kastoria Lake basin: the transition to wetter conditions until 4.7 kyr BP following by drier conditions from 4.7 kyr BP to present. However, this shift to a drier regime in the mid/late Holocene was disturbed by wetter fluctuations (2.4 kyr BP and 3.5 kyr BP) with an increased run-off on the land surface under a more humid period.

4. Conclusions

Sediment cores of 4m were sampled in Epanoni coastal lagoon basin. Within this study, we present the results from the first meter (1m) EP 1-1. Our goal was to come up with paleoclimatic data in Thermaikos Gulf during the Holocene. Grain size analysis was carried out to construct and interpret the grain-size frequency distribution. The fine-grained component presented a modal about 0.31μm-56.23 μm and coarse-grained component a modal about 56.23μm-4500μm particle sizes diameter. Statistical parameters of graphic mean size (Mz), standard deviation (s), inclusive graphic skewness (Sk), and graphic kurtosis (KG) were calculated for the two major components. Equations, as proposed by Sahu 1964, were used indicating that all samples are characterized as being all fluvial deposits in a shallow marine environment. However, further work has to be carried out to better understand the overlapping coarse, fine, and very fine components. Based on the MS and XRD results, we conclude that probably a wet episode is reflected at 50-60cm layer resulting in greater material transfer with higher values of magnetic susceptibility. According to the radiocarbon analysis, this layer is estimated at 3760 ± 25 BP (4125 cal BP). The sand component is rising sharply between 40cm and 50cm depth implying an extended run-off. Finally, the presence of gypsum in the upper layers of 14-39cm depth indicates a dry period with intense evaporation. Our findings are in a good agreement with previous studies reporting more humid conditions subsequently to the 4.2 ka cooling event and specifically the more humid conditions for central and western Mediterranean between 3950 and 3800 cal yr BP.

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