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Middle to late Holocene palaeoenvironmental study of Gialova Lagoon, SW Peloponnese, Greece

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A B S T R A C T

The coastal areas of Eastern Mediterranean have long been the subject of research, due to their rapid geomorphological changes, but also because of their archaeological interest. Our study is focused on a shallow coastal lagoon of Peloponnese, Gialova Lagoon, which for several years has attracted the scientific interest of archaeologists, geomorphologists as well as sedimentologists. Gialova lagoon is located near the ancient city of Pylos, the kingdom of king Nestor during the Mycenaean period (1600–1100 BC). The objectives of this study are: (a) to reconstruct the middle to late Holocene depositional environments of the lagoon and (b) to correlate our data to already existing publications, in order to shed new light on the Holocene evolution of the lagoon and the associated coastal palaeoenvironmental changes. An 8 m deep vibracore was drilled and a multi proxy analysis was carried out on the sediment sequence, including sedimentological (grain size analysis and moment measures, total organic carbon – TOC, total nitrogen – TN and total phosphorus – TP), high resolution geochemical (XRF-scanning) and palaeontological (micro- and macro faunal) analysis. The chronological framework is based on five ^{14}C datings forming the basis for an age depth model, calculated using the OxCal software. The radiocarbon dates from previous studies (6 cores, ~20 dates) were also taken into account. The data synthesis and interpretation provided robust and coherent indications regarding the palaeoenvironment, shoreline changes and the rate of geomorphological changes of the coastal area of Gialova Lagoon, as well as useful information about the palaeonvironmental and palaeoclimatic conditions that prevailed during the Mycenaean period. The interpretation, reveal a transition from a shallow marine environment (6500-5800 yr B.P.) to a brackish/lagoonal (5800-3300 yr B.P.), followed by a shift towards a freshwater/marsh environment (3300 yr B.P. to present).

1. Introduction

Coastal lagoons are considered environmentaly sensitive areas formed behind the sand and gravel barrier shorelines, at the terminal area of the coastal alluvial plains or at river mouths (Kraft et al., 1980; Fontana et al., 2017; Giaime et al., 2017). They are shallow and highly dynamic ecosystems at the interface between coastal and marine environments, which can be permanently open or intermittently closed off (Esteves et al., 2008). At the face of recent climate changes they can be considered the most threatened ecosystems, due to sea level rise, storm and river flooding, as well as human activities (Avramidis et al., 2015a).

Human activities in the coastal areas of western Greece have been recorded since the Palaeolithic period, however, studies concerning the pattern of prehistoric and historic settlement in the context of coastal environmental changes, for Greece are limited (Weiberg et al., 2016; Avramidis et al., 2017). The evolution of coastal landscapes is considered an important factor that affected the development of ancient human societies as well as the environmental dynamics of the past (Rapp and Kraft, 1994; Aberg and Lewis, 2000). In Peloponnese, one of the main areas where the ancient Greek civilization developed, the coastal palaeoenvironmental changes were influenced mainly by relative sea

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level changes (Vött, 2007), tectonic activity, catastrophic events (floods, tsunami etc) (Kontopoulos and Avramidis, 2003; Papadopoulos et al., 2014; Vött and Kelletat, 2015) sediment budget and river deltas progradation (Vött et al., 2007; Brückner et al., 2010).

Coastal areas, such as lagoons, are important providers of useful information about Holocene climatic changes, sea level fluctuations, tectonism (Bird, 1985) and high energy events such as meteorological tsunamis/storms and seismic tsunamis (Shanmugam, 2012). Shoreline shifting, sea level and palaeoclimatic changes during the Holocene in the eastern Mediterranean region, based on sedimentological (Vött, 2007; Fouache and Pavlopoulos, 2005), archaeological/palaeontological (Pavlopoulos et al., 2012; Brückner et al., 2010) and geochemical data Finné et al. (2011; 2017) have been described and reviewed.

Sedimentological, palaeontological, geochemical and mineralogical studies provide information regarding depositional environments, elemental fluxes, palaeoclimate, sea level fluctuation, tsunamigenic phenomena and tectonic activity (Vacchi et al., 2016; Avramidis et al., 2013; Vött et al., 2009, 2011, Vött, 2007; Kontopoulos and Avramidis, 2003; Roser and Korsch, 1988; Rollinson, 1993; Fralick and Kronberg, 1997). For lagoonal geochemical profiles, relative changes and altering trends of elemental concentration provide information about palaeoenvironmental changes (Kylander et al., 2011). Many researchers used elemental ratios such as Rb/Sr, V/Cr, Fe/Mn, Ca/Ti, Sr/Ti, Na/K, Mg/Ca, Zr/Rb, Zr/Ti, K/Rb (Zr + Rb)/Sr, as geochemical proxies to delineate existing physical, sedimentological and geochemical processes such as evaporation, precipitation, dissolution of solid phases, Eh and pH changes, chemical and physical weathering (Haenssler et al., 2014; Haberzettl et al., 2007; Parker et al., 2006; Huntsman-Mapila et al., 2006).

The main purpose of this paper is to study the palaeoenvironmental evolution and the coastal geomorphology of Gialova lagoon, southwestern Greece, and correlate the new data with the previous studies conducted in the area (Wright, 1972; Kraft et al., 1975; Zangger et al., 1997; Koutsoubas et al., 2000; Yazvenko, 2008; Avramidis et al., 2015a; Willershäuser et al., 2015) (Fig. 3). The implementation of our data will offer information concerning the rate of sedimentation in these sensitive environments and also provide a record of the local environmental changes that occurred during the middle to late Holocene. The depiction of the palaeoenvironment will contribute significantly in the comprehension of future environmental changes as well as in the clarification of problems related to sea level changes, climatic changes and geomorphic alterations in the ecosystems, as well as to changes caused from natural hazards (such as tsunamis) and human activity.

2. Geographical and geological setting

Gialova lagoon is a typical shallow Mediterranean lagoon located in SW Peloponnese, Greece (Figs. 1a and 2). The maximum depth is 1 m found at the center of the lagoon. North of Gialova lagoon flows Xyrolagkados river which used to flow into the northern part of the lagoon (Fig. 1b) until 1950, when drainage works conducted in the area, changing the river flow towards Voidokoilia bay (Fig. 1b).

The study area belongs to the Gavrovo geotectonic zone (Aubuin, 1959) and mainly consists of (a) Holocene alluvial deposits and sand dunes, (b) Pliocene and Pleistocene deposits of conglomerates, marls and fine grained sandstones, (c) Eocene to Oligocecne flysch deposits and (d) upper Cretaceous to Eocene limestones (Fig. 1b). Gialova lagoon is located in the Tyflomytis alluvial plain which is built up by Pliocene marls and conglomerates (e.g IGME, 1980; Kraft et al., 1980; Zangger et al., 1997) (Fig. 1b). The lagoon is separated from the Ionian Sea to the west by Voidokoilia barrier system which is characterized by a semicircular shape formed by the wave refraction processes (Kraft et al., 1980; Zangger et al., 1997; Zangger, 2008) (Fig. 1b). South of Gialova lagoon, a 200–300 m wide sand barrier, is separating the lagoon from Navarino bay (Figs. 1b and 2). Navarino bay has been used since antiquity as a natural harbor well protected against storms (Loy, 1967; Zangger et al., 1997; Davis, 2008; Papatheodorou et al., 2005). The present day geomorphology of the study area has evolved due to significant Neogene uplift and subsidence processes, combined with local fault tectonics (Zangger et al., 1997). The area has been repeatedly affected by large magnitude earthquakes and tsunamis since it is directly exposed to the subduction zone of the Hellenic Trench and normal faults that form the boundaries between the mountains and the coastal plains along the SW part of Peloponnese (Fountoulis and Mavroulis, 2013; Papadopoulos et al., 2014; Willershäuser et al., 2015).

The area surrounding Gialova Lagoon is important in an archaeological context; several archaeological sites have been discovered and some of them are still excavated (Fig. 2). Numerous archaeological studies have thus been conducted in the region, providing useful information about the human occupancy in the area over the last 6000 years (Fig. 2) (Blegen and Rawson, 1967, Balcer, 1974, Korres, 1977, McDonald and Hope Simpson, 1961, 1964, 1969, 1972, Yialouris, 1966, 1968). Nestor's Palace, which is located almost 4 km north of Gialova lagoon, has been the benchmark of ancient Pylos in the Mycenaean period. In addition, Early to Late Helladic, archaeological sites have been excavated on the northern and eastern flanks of Gialova lagoon, whereas Hellenistic and Roman age sites have been excavated at the sand barrier that separates Gialova lagoon from Navarino bay (Fig. 1).

3. Materials and methods

3.1. Sediment coring

For the present study, multi proxy data from an 8 m long sediment section was retrieved. The sediment core G-A was bored in the eastern part of Gialova lagoon near Tyflomiti springs (Figs. 1 and 2), using an Eijkelkamp vibrating corer with open window barrel tubes. After the extraction, barrel tubes were sealed with cling film and transported for further analysis in the laboratory of Sedimentology, University of Patras. Sediment types and structures, color, as well as contact depths and bed characteristics, were recorded. The geographical position of the core was recorded using a DGPS ProMark 3 Magellan accuracy subcentemeter.

3.2. Sedimentology

Standard sedimentological analyses were carried out on 35 samples including grain size analysis, calculation of moment measures, such as mean, sorting, kurtosis and skewness, total organic carbon (TOC), total carbon (TC), total nitrogen (TN), calcium carbonate content ($CaCO_3$) and total phosphorus (TP).

Sediment classification was based on grain size analysis and based on Folk (1974) nomenclature. Material coarser than 4 Φ was dry sieved while fine grained material >4 Φ was analyzed with a Malvern Mastersizer 2000, and finally grain size distributions were calculated. Grain size statistical parameters such as mean, sorting, skewness and kurtosis were calculated using GRADISTAT V.4 software (Blott and Pye, 2001). The Munsell color classification was determined using a Minolta CM-202 handheld spectrophotometer and the RGB with the use of Image J software. For the samples that the sand fraction was above 30%, the functions proposed by Sahu