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Tracking Mid- to Late Holocene depositional environments by applying sedimentological, palaeontological and geochemical proxies, Amvrakikos coastal lagoon sediments, Western Greece, Mediterranean Sea

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ABSTRACT

This study presents sedimentological, palaeontological, geochemical, mineralogical, and organic petrography data from a 30 m deep core representing a Mid- to Late Holocene lagoonal depositional environment, of a coastal area of Amvrakikos Gulf, Western Greece. Three horizons were dated using ^{14}C. The sedimentological, palaeontological and geochemical interpretations of the lagoonal sediments reveal three major lithological units deposited between around 5200 and 1600 BP. The upper lithological unit extended to a depth of 11.20 m, the middle from 11.20 to 21.30 m, and the lower one from 21.30 to 30.00 m. A mean rate of sedimentation of 5.7 mm/y and a maximum rate of 12.6 mm/y were estimated. The mineralogical analysis and the magnetic susceptibility of the core points to a constant sediment – source supply. The Mid- to Late Holocene depositional environment mainly reflects inundation by the braid plain of the Arachthos and secondarily by the Louros River. The reconstruction of the depositional environments corresponds to a shallow marine and deltaic brackish lagoon and specifically to an environment proximal to river supply. The high rates of sedimentation, as well as the interpretation of depositional environments, indicate that the coastal sedimentological processes during the Mid- to Late Holocene were mainly controlled by the progradation of river deltas. Moreover, the geochemical proxies, the recovered molluscs and the microfauna, as well as the organic petrography analyses indicate periods of dysoxic and hypoxic conditions. These Holocene dysoxic and hypoxic events indicate that the recent dystrophic crises in the Amvrakikos Gulf are not only the result of human activities but also the contribution of natural processes.

1. Introduction

Coastal lagoons are areas of relatively shallow water, partly isolated from the sea by sand or shingle barriers (Kjerfve, 1994; Bird, 2008). Their evolution depends on the geological and geomorphological conditions in the adjacent area and the relative sea level changes. Lagoons are among the most threatened aquatic ecosystems, being under constant pressures such as sea level rise, storms, and river flooding. Subsequently, all these geological, geomorphological, and environmental changes are recorded in the lagoon sediments, constituting physical archives tracking Holocene environmental changes.

In the coastal areas of the Mediterranean region, the Holocene marine transgression caused the inundation of coastal lowlands, forming inlets, embayments and lagoons. Sediments are transported into a lagoon by rivers, tidal currents entering from the sea, and by winds blowing sand from bordering coastal dunes. In areas with a microtidal regime such as the Mediterranean Sea coast, lagoon depositional environments are mainly influenced by fluvial–deltaic processes. For this reason, in Greece the development of almost all coastal lagoons is associated with a fluvio-deltaic system (Greek Coastal Zone Management Report, 2006). Sea level and palaeoclimatic changes during the Holocene in the Eastern Mediterranean region, based on sedimentological, archaeological,

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palaeontological, and geochemical data, have been described and reviewed by Fouache and Pavlopoulos (2005), Vött (2007), and Brückner et al. (2010). Recent studies concerning sedimentological characteristics and depositional environments of coastal lagoonal areas in western Greece have been made by Avramidis et al. (2013), Haenssler et al. (2013), Papatheodorou et al. (2012), Panagiotaras et al. (2012), Kontopoulos and Koutsios (2010), Avramidis et al. (2008), Kraft et al. (2005), and Kontopoulos and Avramidis (2003). The interplay with local tectonic activity is significant, as western Greece is an area with high seismicity, sea level rise, and sediment supply. These factors influence depositional environments, as well as allowing comparison between ancient and recent environmental conditions and sediment assemblages of the Amvrakikos Gulf.

Lagoons in which large primary production occurs, with organisms adjusted to seasonal fluctuations of salinity, may suffer dystrophic crises due to the accumulation of excessive concentrations of organic matter and subsequent increase in bacterial heterotrophic activities, leading to consumption of the dissolved oxygen. The oxygen depletion (sometimes even anoxia) leads to sulfate reduction, resulting in hydrogen sulfide accumulation, which provokes a large increase in mortality of the macro and microfauna. Hence, only a very small number of macro (e.g. Lucinid bivalves) and microorganisms (e.g. *Quinqueloculina*) are able to overcome the respective induced stress and survive under such hypoxic conditions, taking advantage of their special and unique adaptations. Consequently, these organisms are bioindicators of oxygen depleted environments (Gupta, 2003; Roeselers and Newton, 2012).

The understanding of palaeoenvironmental changes through sedimentological, palaeontological, geochemical, and mineralogical studies provides information regarding depositional environments, elemental fluxes, palaeoclimate reconstruction, sea level fluctuation, tsunamogenic phenomena, and tectonic activity (Roser and Korsch, 1988; Rollinson, 1993; Fralick and Kronberg, 1997; Kontopoulos and Avramidis, 2003; Vött, 2007; Vött et al., 2009, 2011; Avramidis et al., 2013). 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, and (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, and chemical and physical weathering (Huntsman-Mapila et al., 2006; Parker et al., 2006; Haberzettl et al., 2007; Haenssler et al., 2013). Clay minerals released to the sedimentary system are not only a function of weathering and soil formation, but also reflect the mineralogical composition of the source materials (Hillier, 1995). Holocene clay assemblages of sediments record the changes in the conditions of supply, among which climate is one factor among others (e.g. hydrological process, tectonics) (Meunier, 2005).

The scope of the present paper is to examine the Mid- to Late Holocene palaeoenvironmental changes of a coastal lagoon area in Amvrakikos Gulf, one of the largest semi-enclosed embayments of the Mediterranean Sea. For this reason and in order to outline the coastal depositional environments and processes, a multidisciplinary approach was applied, combining sedimentological, palaeontological, geochemical, mineralogical, ^{14}C dating, and organic-petrography data from a 30 m core, which was retrieved from Logarou Lagoon. Moreover, based on palaeontological bioindicators and identification of petrographic components (macerals), an attempt was made to define hypoxic and anoxic conditions and the origin (terrestrial higher plants/marine) of the organic matter, and in addition to estimate the maturity (rank) of the organic matter in the studied profile.

2. Regional setting

The Amvrakikos Gulf is located in the northwestern part of Greece (Fig. 1a), situated in the Ionian geotectonic zone and part of the Pindos foreland basin (Avramidis et al., 2000). It is a semi-enclosed embayment, about 35 km long and 15 km wide, and one of the largest semi-enclosed gulfs in the Mediterranean Sea. In the northern part of the Amvrakikos Gulf, one of the largest wetland systems of Greece is developed, made up of lagoons such as Rodia, Tsoukalio, and Logarou (Fig. 1b) as well as reed-beds and marshes.

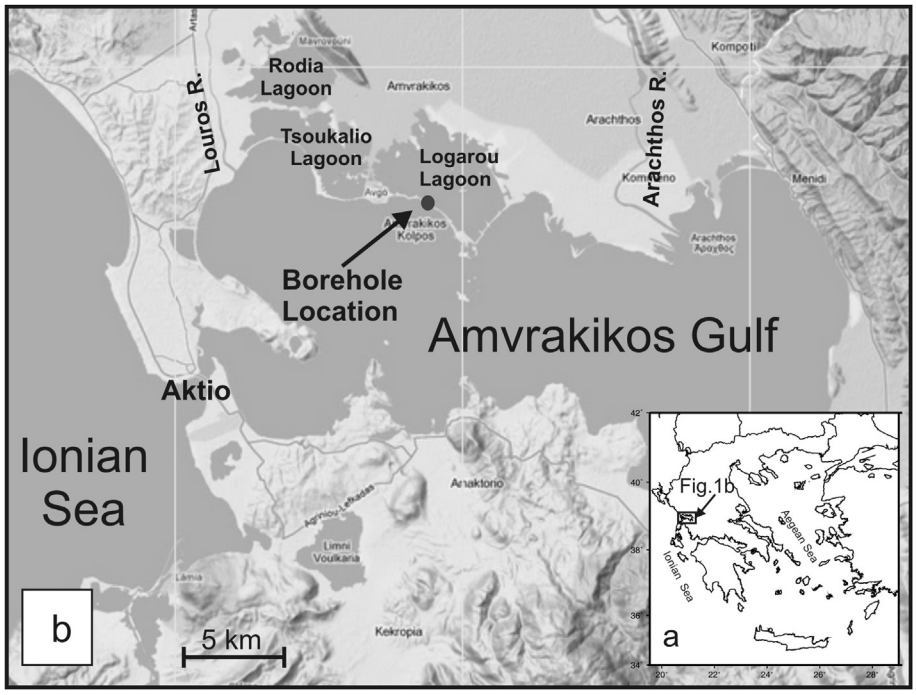

Fig. 1. (a) Map of Greece and in the inserted box is shown the Amvrakikos Gulf and (b) map of the Amvrakikos Gulf with the lagoon wetlands, the main two rivers and the location of the borehole.