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# Holocene sedimentology and coastal geomorphology of Zakynthos Island, Ionian Sea: A history of a divided Mediterranean island

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ABSTRACT

The island of Zakynthos is one of the most seismically active areas in the Mediterranean region because it is located very close to the convergent boundary between the African and Eurasian plates. Its evolution during the Holocene has been influenced by tectonic activity, catastrophic events and relative sea level changes. The scope of the present paper is to examine the Holocene palaeoenvironmental changes of the coastal areas of Zakynthos Island using a multidisciplinary approach, combining sedimentological and palaeontological data with $^{14}C$ and OSL dating from four cores of a maximum depth of ~30 m. The integrated results reveal that sea level and tectonic activity have brought significant modifications in the coastal geomorphic settings of the island during the past ~10,000 yr B.P. The depositional environments and the palaeontological biofacies document four main geomorphological evolutionary stages of the island. We identified fully marine and lagoonal deposits with marine influence (before 4100 yr B.P.), as well as brackish and freshwater limnic depositional environments (around 4100 yr B.P. to present). The interpretation of our data indicates that Zakynthos island was separated into two main parts before the middle Neolithic period (around 7500 yr B.P.) with Vasilikos peninsula in the SE being isolated from the main island. The fact that Zakynthos Island was a divided Mediterranean island for a significant period of time in its prehistory is of great importance to understand better the archaeological landscapes of Zakynthos and the other Ionian Islands.

## 1. Introduction

Coastal areas and adjacent continental shelves constitute dynamic depositional environments, which are shaped by the interaction of tectonic activity, sea level change and diverse environmental factors related to human activities (Kraft et al., 1977; Anthony et al., 2014). This holds particularly true for the Mediterranean region for which morphotectonic evolution, climatic change and sea level rise have shaped out a highly diversified coastal geomorphology during the Holocene (Anthony et al., 2014). Coastal palaeoenvironmental changes in the Mediterranean region during the Holocene are, in turn, a fundamental parameter that influences present and past societies (Rapp and Kraft, 1994; Aberg and Lewis, 2000; Weiberg et al., 2016). Early Mediterranean civilizations made ample use of the coastal areas and islands of the central and eastern Mediterranean, as inferred from the wide distribution of the Phoenician, Greek and Roman settlements (Davis and Fitzgerald, 2004). The Balkan Peninsula, and particularly Greece, has hosted human societies for > 6000 years (Fouache et al., 2010). Several studies have documented coastal palaeoenvironmental changes in specific locations in Greece during the Holocene, demonstrating the role of factors such as relative sea-level changes, tectonic activity, catastrophic events (floods, tsunami, etc.), sediment budget and river deltas progradation (Vött, 2007; Marriner and Morhange, 2007; Evelpidou et al., 2010; Brückner et al., 2010; Ghilardi et al., 2012; Ghillardi et al., 2013; Pavlopoulos et al., 2013; Apostolopoulos et al., 2014; Papadopoulos et al., 2014; Avramidis et al., 2014; Anthony et al., 2014; Weiberg et al., 2016), In this study, we examine the role of such processes in the coastal geomorphological evolution of the island of Zakynthos, contributing to the better understanding of the coastal geomorphology and archaeological landscape of the island.

In the eastern Mediterranean region coastal areas and lagoons constitute important archives for the study of Holocene palaeoenvironmental changes. Several proxies have been employed to reconstruct shoreline dislocation, sea level and palaeoclimatic changes during the

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Holocene, including sedimentological, palaeontological, geochemical and archaeological methods (e.g., Fouache and Pavlopoulos, 2005; Vött, 2007; Brückner et al., 2010; Finné et al., 2011; Pavlopoulos et al., 2012; Haenssler et al., 2013; Weiberg et al., 2016). Sea-level rise is one of the principal processes that affected the geomorphology and coastal depositional environments of the Mediterranean region during the Holocene. As the result of the sea level rise, the consequent marine transgression inundated lowlands forming coastal lagoons, marshes and embayments. Moreover, the convergent boundary of Eurasian and African plates lies within the eastern Mediterranean and is one of the most seismically active regions worldwide. As a consequence of the high seismo-tectonic activity, coastal areas have been influenced by marine incursions due to tsunamis (Kontopoulos and Avramidis, 2003; Avramidis et al., 2013; Vött and Kelletat, 2015). For the Holocene there are several geoarchaeological findings that point to tsunami events all around the eastern Mediterranean Sea (Papadopoulos et al., 2014) and particularly in western and southern Greece (Vött et al., 2009, 2011; Kontopoulos and Avramidis, 2003; Scheffers et al., 2008; Bruins et al., 2008; Vött and Kelletat, 2015).

The goal of the present paper is to reconstruct the Holocene coastal palaeoenvironmental changes of Zakynthos Island, western Greece using multiproxy sedimentological, palaeontological and chronological data. For the purpose of the study, sedimentological, micro- and macropalaentological as well as geochemical methods were applied on two ~30-m-long cores, for which age models were constrained by $^{14}C$ and optically stimulated luminescence (OSL) dating. Our results were paired with available data from two previous studies on Zakynthos, i.e., Alykes lagoon (Avramidis et al., 2013) and Lake Keri (Papazisimou et al., 2000), to better understand the coastal evolution of the island during the Holocene.

## 2. Study area

Western Greece, including the Ionian Islands and Zakynthos Island, is one of the most seismically active regions in Mediterranean Sea (Papazachos and Papazachou, 1997) (Fig. 1A,B). The Ionian Islands occupy a key position in the central and eastern Mediterranean for their geotectonic framework, as they are part of a multiple junction region with different types of plate boundaries (Accordi et al., 2014) and underwent clockwise rotation, from the Palaeocene, for a total of 45–50° (Kissel et al., 1985; van Hinsbergen et al., 2005). Sedimentological and geomorphological studies conducted along the western Peloponnese and Ionian islands indicated the existence of several tsunamigenic events that took place during the Holocene (Avramidis et al., 2013; Vött and Kelletat, 2015). Zakynthos island is located very close to the convergent boundary between African and Eurasian plates (Fig. 1A) and is undergoing very rapid and intense ground deformations (around 50 mm/yr) (Lagios et al., 2007). The island has a complex palaeogeographic history as the result of the westward migration of external Hellenides, which played the key role for the syn- and post collisional phases (Underhill, 1989; Papanikolaou et al., 2011; Kokkalas et al., 2012; Karakitsios, 2013). The sedimentation in Zakynthos Island is characterized by the deposition of evaporites and calcareous rocks of Triassic to Miocene age and by the clastic deposits of Pliocene-Quaternary age (Fig. 2). Both compressional and extensional tectonism influenced the geomorphology and the sedimentation of the island (Zelilidis et al., 1998).

The study area covers the coastal areas of the northeastern and southern parts of the island, including Alykes lagoon, former Lake Makri now drained and located at today's airport area, and Keri Lake that has been known since ancient times as 'Herodotus springs' (Fig. 2). For the present study. Data from four cores have been evaluated including: (a) a 21-m-depth borehole from Alykes Lagoon (Avramidis et al., 2013); (b) two 30-m-depth boreholes from former lake Makri (this study); and (c) a 7-m-depth borehole (Papazisimou et al., 2000; Avramidis et al., 2017) from Keri Lake.

## 3. Material and methods

### 3.1. Sediment cores

For the present study data from two new cores (G-1: 37°45′27.22″ N, 20°53′20.23″ E and G-2: 37°44′37.44″ N, 20°52′40.32″ E), up to a maximum depth of 30 m, were drilled in the central and southern part of the island, near the Zakynthos airport, on the site of former Lake Makri. Geographical positions and elevations of the cores were determined with a differential GPS ProMark 3 Magellan. In addition, we have re-evaluated existing data from two cores that were drilled in the northern eastern part of the island in Alykes lagoon (Core GA-1; 37°50′32″ N, 20°45′51″ E; Avramidis et al., 2013) and in the southern part in Keri Lake (Core KZ; 37°41′07″ N, E 20°49′46″ E; Papazisimou et al., 2000; Avramidis et al., 2017) (Fig. 2). Cores GA-1, G-1 and G-2

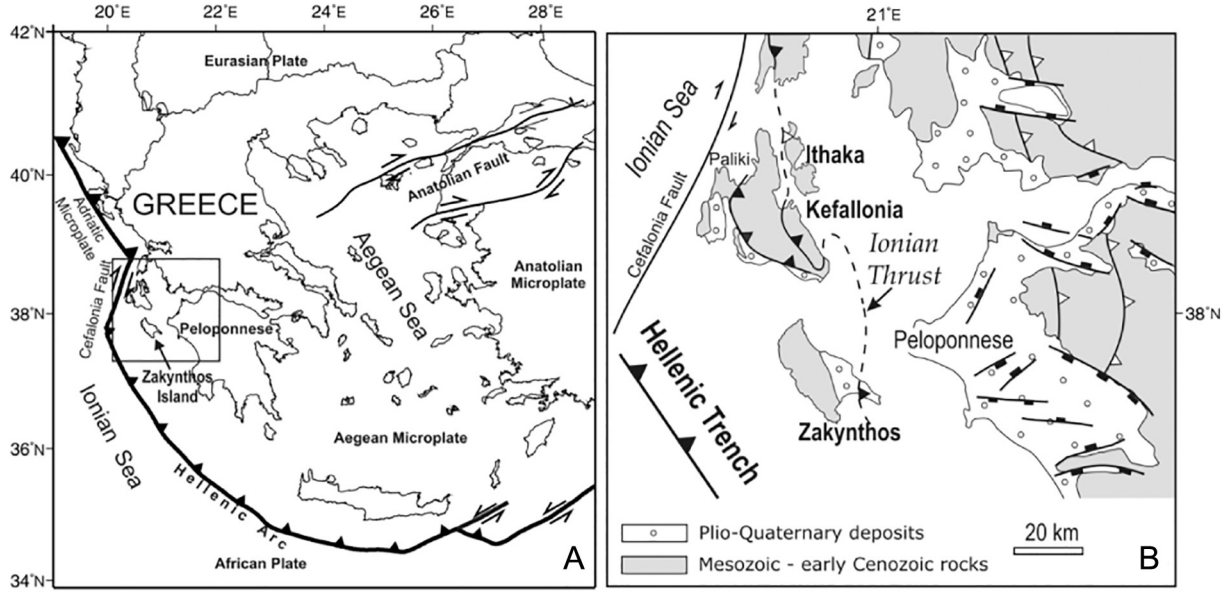


**Fig. 1.** (A) Simplified map of Greece showing the Hellenic trench, the major fault systems and the study area Zakynthos Island and (B) map of western Greece with the main fault systems and the Ionian Island Zakynthos, Kefalonia and Lefkada.

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