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Holocene evolution and sedimentation rate of Alikes Lagoon, Zakynthos island, Western Greece: preliminary results

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Abstract. In the present study we present preliminary results from Alikes lagoon in Zakynthos island, an area that is one of the most seismically active regions of Greece. In order to estimate – interpret the Holocene evolution of the area and to reconstruct the palaeoenvironmental changes, we based on data derived from a 21 m sediment core. Sediment types, structure, colour, as well as contact depths and bed characteristics were recorded in the field. Standarised sedimentological analysis was carried out, on 46 samples including grain size analysis, calculation of moment measures, and micro- and molluscan fossils of 17 selected samples. Moreover, radiocarbon age determinations have been made on individual *Cardium* shells from two horizons and whole – core Magnetic Susceptibility (MS) measurements were taken. The interpretation of depositional environments suggests a coastal environment (restricted-shallow) with reduced salinity such as a lagoon margin and in a tidal flat and/or marsh particularly. The maximum age of the studied sediments is about 8500 BP. The rate of sedimentation between 8280 BP while 5590 BP was 5.3 mm/yr and between 5590 BP and modern times is on the order of 1.03 mm/yr. These sedimentation rates results are similar to other coastal areas of western Greece.

1 Introduction

Studies related to coastal sedimentological environments, allow the recognition of coastline changes and give information about the rate of sedimentation, eustatic sea level changes and tectonic movements. Such environments that can record these environmental changes and associate them with tectonic activity, variations in water and sediment yield, are the lagoon – lagoonal areas (Bird, 1985). Different approaches have been taken in order to reconstruct the Holocene coastal – lagoon environmental changes basen on geological, geochronological and sedimentological methods. Similar studies in western Greece, that investigated and reviewed the Holocene environmental changes in coastal lagoonal areas, have been carried out by Kontopoulos and Avramidis (2003), Kraft et al. (2005), Vött (2007), Avramidis et al. (2008) and Kontopoulos and Koutsios (2009).

In this study we present preliminary results of Zakynthos Alikes wetland – lagoon, concerning the Holocene palaeonvironmental evolution – changes of the area, based on a 21.2 m sediment core, GA-1.

2 Geological and tectonic setting

The study area is the Alikes wetland (an old salt pan), which is located on the nothern part of Zakynthos island, one of the Ionian islands, and expand in an area of 400 000 m^2 (Figs. 1, 2 and 3). The Ionian islands of western Greece form part of the para-autochthonous Apulian foreland of the Hellenides orogen and include rocks of the Pre-Apulian (or Paxos) and Ionian isopic zones (Aubouin and Dercourt, 1962; Underhill, 1989). Zakynthos island is characterised by two geotectonic zones the Pre-Apulian and the Ionian zone. It is located near the north-western terminus of the Hellenic Trench (Fig. 1), very close to the convergent boundary between the African and European plates and the diapirism area of the evaporates, that belong to the Alpine basement.

The area is one of the most seismically active regions in Europe and neotectonic faulting comprise mainly NNW-SSE trending faults (Lekkas, 1993), while the sedimentological evolution of the island was influenced by both compresional and extensional tectonics (Zelilidis et al., 1998). Sedimentation in Zakynthos island can be distinguished in Cretaceous to Miocene carbonates and Plio – Quaternary clastic (Fig. 2).

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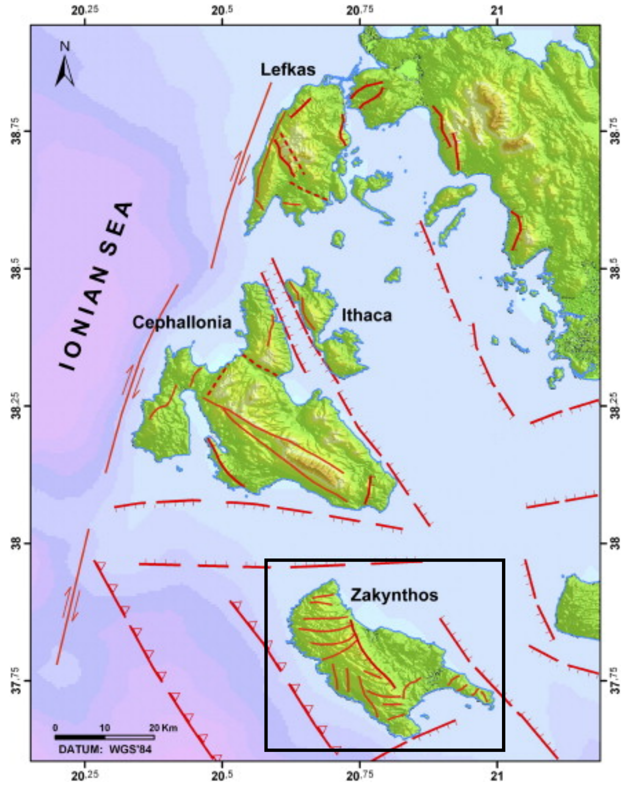

Fig. 1. Regional map of the Ionian islands. Inserted box shows Zakynthos island.

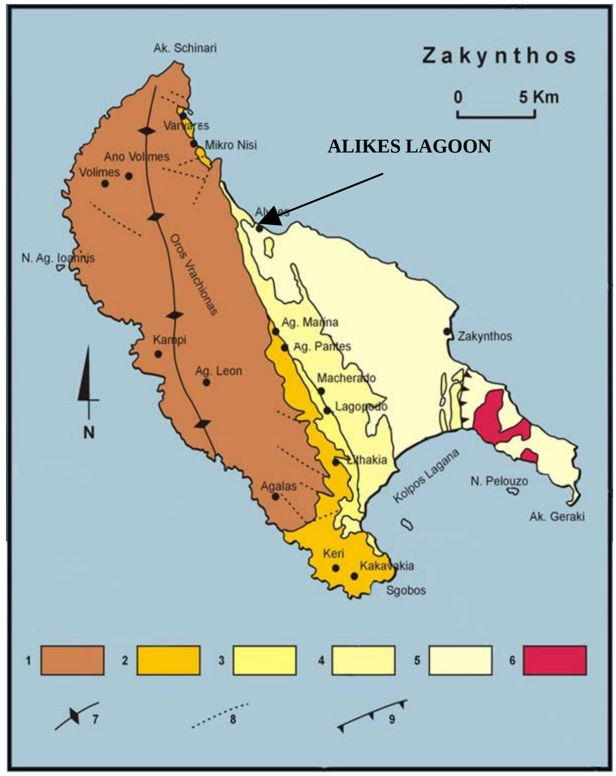

Fig. 2. Simplified geological map of Zakynthos Island. Legend: 1. Cretaceous carbonates, 2. Eocene carbonates, 3. Oligocene marly carbonates, 4. Miocene clastics and carbonates, 5. Pliocene-Quaternary alluvial deposits, 6. Ionian evaporites and breccias, 7. Anticline, 8. Fault, 9. Main thrust.

In the study area, during the last decades human activity such as agriculture, irrigation works and building development influenced the water surface of the lagoon. On the northwest side, the Alikes lagoon is separated from the Ionian Sea by a low relief sand barier while its communication with the open sea is limited by a sort and narrow inlet (Fig. 4). The maximum water depth of the lagoon is up to 45cm and the average depth is only up to 15 cm (Fig. 5).

3 Method

The exploratory core GA-1 was bored by the Technological Educational Institute of Mesolonghi and the University of Patras, on February 2008, at the geographical posistion 37°50′32″ N, 20°45′51″ E (Fig. 3). The drilling equipment used was a rotation Longyear 38, with single tube core barrel with tungsten carbide bit and 101 mm diameter.

All the segments of the core were sealed with cling film. Sediment types, structure, colour, as well as contact depths and bed characteristics, were recorded. Colour were identified using a Minolta CM-2002 hand held spectrophotometer.

Standarised sedimentological analysis was carried out, on 46 samples including particle size analysis, calculation of moment measures, such as mean, sorting, kurtosis

Fig. 3. General view of Alikes lagoon and the location of borehole GA-1.

Fig. 4. The narrow inlet in the northern part of the lagoon.

Fig. 5. General view of the lagoon with maximum depth up to 45 cm.

and skewness. Particle size distribution was made using a Malvern Mastersizer 2000, while moment measures were calculated using GRADISTAT V.4 and based on Folk (1974) nomenclature. Moreover micro- and molluscan fossils of 17 selected samples were examined.

Whole – core Magnetic Susceptibility (MS) measurements were taken using a Bartington MS2 magnetic susceptibility meter with MS2-F probe type. Radiocarbon age determinations have been made on individual Cardium shells from two horizons, and results such as Conventional Radiocarbon Age and Two – Sigma calendar calibration were taken. Radiocarbon analysis was carried out in Beta Analytics Labs.

3.1 Results

3.2 Core description

Most of the observed sedimentary units, are composed of fine material, fine to coarse silt and a few coarser intercalations of fine to medium sand (Fig. 6).

We recognised three main sedimentary units the upper UI (3.00–7.50 m), middle UII (7.50–16.80 m) and lower UIII (16.80–21.20 m) (Fig. 6).

Unit I: refers to the upper part of the core segment between depth 3.00 m to 7.50 m (Fig. 6). We didn't take into account material between depths 0.00–3.00 m, as it is classified as filling material (pave) for road construction. The unit consists of poorly to very poorly sorted, grayish olive, laminated fine to medium silt, rich in organic matter with bioturbation structures and shell fragments. Silt is intercalated by three main horizons of poorly sorted, olive brown to dark olive, fine to medium sand (5.00–5.22 m, 6.00–7.00 m and 7.25–7.50 m). Contacts between silt and sand are characterised as slightly erosional. The sand fraction consists of foraminifera, ostracodes and mollusks in proportion less than 2% to the clastic grains. Also, there are carbonate – cementing aggregates in abundance in the sand fraction.

Unit II: refers to the middle core segment between depth 7.50–16.80 m (Fig. 6), which consists of poorly sorted, very dark greenish gray fine silt, with shell fragments, thin layers rich in organic matter with plant remains and abundant shell fragments and *Cardium* shells. The sand fraction contains mostly micro- and macrofossils and abundance of plant remains. Caliche-like evaporate, largely of a calcium carbonate type, is found cementing some of the grains together into aggregates. Internally to this unit we distinguished three layers (8.60–9.00 m, 12.40–12.60 m and 14.65–15.10 m) consisting of poorly sorted grayish olive fine silt which is characterised by ripple lamination.

Unit III: refers to the lower core segment between depth 16.80–21.20 m (Fig. 6), which consists of poorly sorted, greenish gray fine to coarse silt. This unit is characterized by the presence of *Cardium, Cerithiumc Hydrobia* and *Ammonia* shells and abundant organic matter. Also, there are carbonate-cementing aggregates in abundance in the sand fraction.

In the lower part of the unit we observed an increase in sand participation and we distinguished a layer of poorly sorted, light olive gray to grayish olive, coarse silt.

3.3 Particle size distribution – moment measurements

The distribution of particles throughout the core indicate a relative uniform distribution of grain size. Sediment types are fine to coarse silt (Fig. 7) with three intercalations of medium sand in the upper unit UI. The presence of sand is low, ranging between 0 to 5%, clay percent ranges between 2 to 20% and silt between 69 to 85% (Fig. 7). In the upper

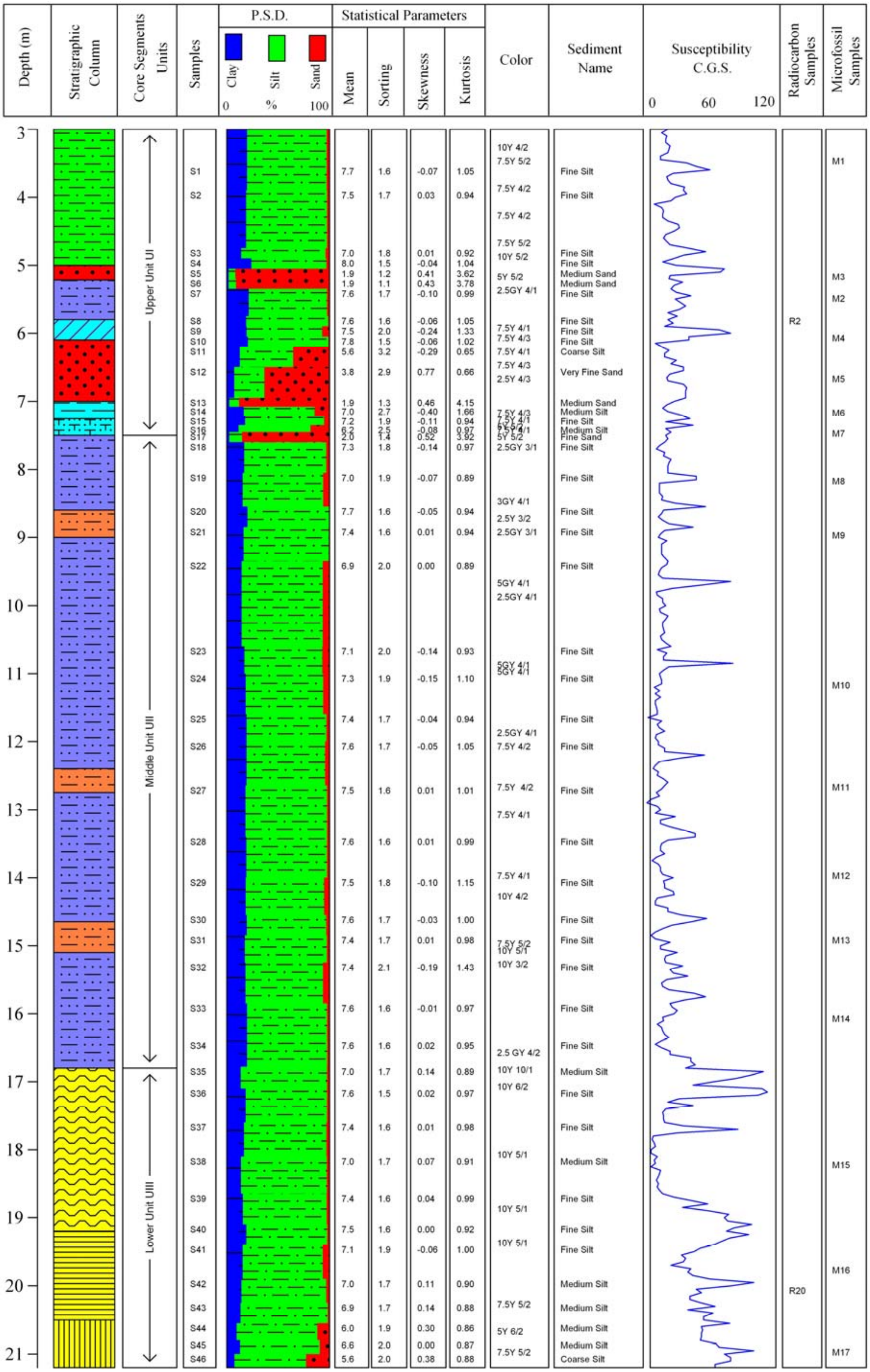

Fig. 6. Borehole GA-1 profile, showing the sedimentary units, the grain size distribution, statistical parameters, color, the samples location and the results of magnetic susceptibility.

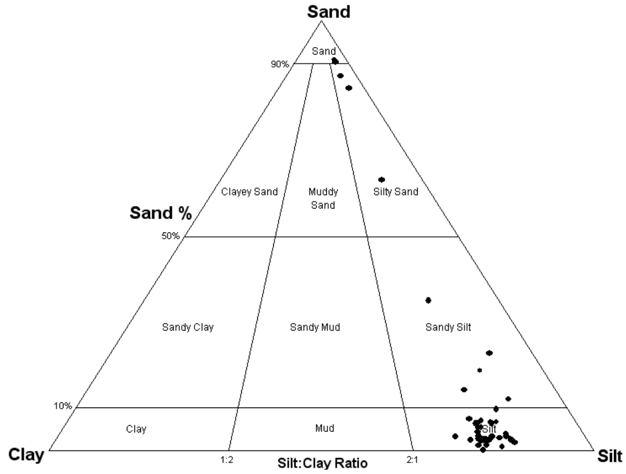

Fig. 7. Ternary diagram of sand – silt – clay.

core segment UI, the silt material is characterised as poorly to very poorly sorted, with values of $\sigma 1$ range between 1.46 to 2.73 Φ (Fig. 6). Skewness indicate basically a symmetrical distribution and values of kurtosis propose a mesokurtic distribution. Mean values ranges between 6.98 to 7.96 Φ (Fig. 6). The sand layers of the upper unit UI appear to be poorly to very poorly sorted ($\sigma 1$ 1.13 to 2.86) with mean values ranging between 1.86 to 3.83 Φ (Fig. 6). Skewness in all sand samples indicate very fine skewed distribution while kurtosis propose mainly an extremely leptokurtic distribution. The very fine skewed value is caused by the presence of a fine tail in the sand- dominate size frequency curve. This fine tail in combination with the poorly to very poorly sorting and extremely leptokurtic kurtosis may be suggesting an event analogous with a fluvial flood. This event may occur in a coastal environment such as a sandy tidal flood. If this is the case then the silt beds of this unit which have a very low sand content, poorly to very poorly sorting and normal distribution, have deposited in a sheltered muddy tidal flat or marshy area.

The grain size analysis in the middle unit UII indicates, a uniform distribution of poorly sorted ($\sigma 1$ 1.55 to 1.98) fine silt, with mean values vary from 6.85 to 7.58 Φ. Skewness and kurtosis indicate mainly a symmetrical and mesokurtic distribution, while the participation of sand is very low $<5\%$ (Fig. 6). These grain size statistical parameters are the same as those of the silt beds of the unit I. This event and the very low sand content suggest also a sheltered muddy tidal flat or marshy area.

The lower unit UIII of the core is characterized by poorly sorted fine to medium silt and an increase of the sand participation in the lower part of UIII, (depth 20.55–21.20 m), where we have the presence of coarse silt. Participation of sand is low $<7\%$ with exception at the lower part of UIII, where it increases up to 23%. Skewness present a symmetrical to fine skewed distribution, while kurtosis a mesokurtic one. The samples from the coarse silt from the lower part of the unit UIII, indicate a platykurtic distribution of grain size (Fig. 6). According to the grain size statistical parameters, the main part of the unit III has deposited also in a sheltered muddy tidal flat or marshy area. In the lower part of the unit III, where the sand content increases, the skewness is near symmetrical to fine skewed and the kurtosis is slight platykurtic, may indicate that this part has been deposited in a mixed flat environment.

3.4 Magnetic susceptibility

Magnetic susceptibility values indicate a non uniform distribution between the three core units. Highest readings were observed in the lower core segment UIII reaching 112 C.G.S. units and an average value 45 C.G.S. units (Fig. 6). The middle core section UII indicate a decrease in magnetic susceptibility with maximum values at 79 C.G.S. units and an average of 16 C.G.S. The upper core section UI reach a relative higher average value than UII, with highest reading at 77 and an average value of 25. From the above measurements a clear differentiation in magnetic susceptibility values can be observed in the lower core segment UIII. The above variations can be related to different sediment sources and local tectonic activity.

3.5 Radiocarbon dating

The results of radiocarbon analysis for the samples R2 and R20 (Fig. 6) are presented in Table 1. Radiocarbon Dates are reported as RCYBP (radiocarbon years before present present = AD 1950). By international convention, the modern reference standard was 95% the ^{14}C activity of the National Institute of Standards and Technology (NIST) Oxalic Acid (SRM 4990C) and calculated using the Libby ^{14}C half life (5568 years). The Conventional Radiocarbon Age represents the Measured Radiocarbon Age corrected for isotopic fractionation, calculated using the delta ^{13}C ($^{13}C/^{12}C$ ratio) The calendar calibrated results are calculated from the conventional radiocarbon age and are listed as the Two Sigma Calibrated Results. The radiocarbon dating indicates a maximum age of the examined sediment samples R-20 at 8280 BP sample (depth 20 m), and an age of 5590 BP for sample R-2 (depth 5.75 m).

3.6 Fauna composition

The faunal composition was examined on 17 samples (M1–M17, Fig. 6) and is represented by poor assemblages of foraminifera, ostracodes and molluscs (*Ammonia beccarii*, *Elphidium crispum*, *Quinqueloculina seminula*, *Cyprideis torosa*, *Cardium edulis Hydrobia* (H.) cf. *ventrosa*) (Fig. 8). This fauna suggests a coastal environment (restricted-shallow) with reduced salinity, such as a lagoon margin and particular in a tidal flat and low marsh.

Table 1. Radiocarbon dates of shell samples from the studied core.

Sample	Depth (m)	Material	Analysis	Measured Radiocarbon Age	Conventional Radiocarbon Age	2 Sigma Calibration	Radiocarbon Age with Calibration curve
R-2	5.75	Cardium Shell	AMS	4850+/−50 BP	5250+/−50 BP	5710 to 5540 BP	5590 BP
R-20	20.00	Cardium Shell	AMS	7330+/−50 BP	7790+/−50 BP	8360 to 8160 BP	8280 BP

Fig. 8. Representative fauna from the examined samples. **(a)** *Elphidium crispum* sa. M2, **(b)** *Hydrobia ventrosa* sa. M7, **(c)** *Ammonia beccarii* sa. 10, **(d)** *Cyprideis torosa* sa. M3 and **(e)** *Quinqueloculina seminula* sa. M7.

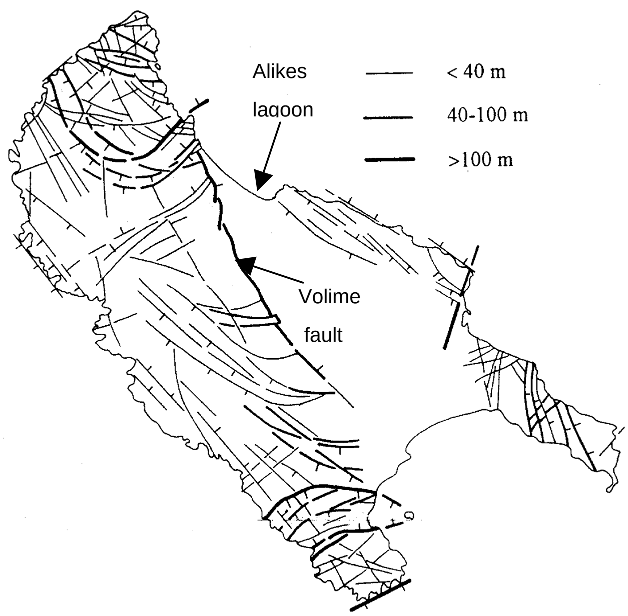

Fig. 9. Neotectonic map of Zakynthos island showing the vertical displacement for each fault and the location of Alikes lagoon and Volime fault (Lekkas, 1993).

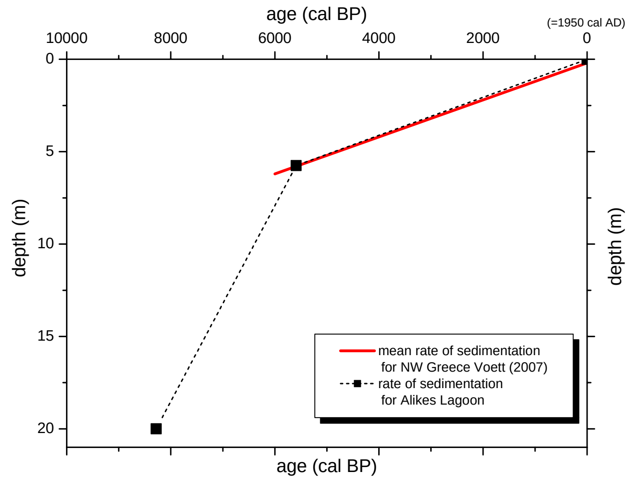

Fig. 10. Mean rate of sedimentation curve for northwest Greece according to Vött (2007) and rate of sedimentation for Alikes lagoon.

4 Discussion and conclusion

Recent studies regarding the rate of sedimentation and relative sea level changes in coastal lagoon sediments in western Greece, have been carried out by Kontopoulos and Avramidis (2002), Kraft et al. (2005), Kelletat (2005), Vött (2007) and Kontopoulos and Koutsios (2009). The above studies correlate the radiocarbon data with the tectonic regime, the sea level changes and with some archaeological records. In the present study we reveal two different stages of sedimentation rate: the first one between 8280 BP and 5590 BP (5.3 mm/yr) and the second one between 5590 BP and modern times (1.03 mm/yr). The above sedimentation rates are similar to previous studies in coastal environments of western Greece and distinguish a difference in relative sea level curve during mid Holocene (5000–6000 cal BP) Vött (2008).

The Alikes lagoon is located near the tectonic structure of Volime fault (Fig. 9), which shows a vertical displacement over 100 m (Lekkas, 1993) (Fig. 9). The activity of Volime fault controlled the Holocene evolution and depositional environments of Alikes lagoon and influenced the rate of sedimentation. The recorded change of sedimentation rate after mid-Holocene (5000 BP) can be related both to seismotectonic activity of Volime fault and to sea level change. Although local tectonism influences the depositional environment and the reconstruction of relative sea level curves, the results of the present study are comparable with the mean relative sea level evolution of northwestern Greece Vött (2008) (Fig. 10).

Along the Mediterranean region and particularly in Greece, examples of tidal flats Foraminifera, with extremely compressed tidal range (mean range of 45 cm and a extreme range of 75 cm) have been described by Scott et al. (1979) and Piper and Panagos (1981). The fauna of the study sediment suggests a coastal environment (restricted- shallow) with reduced salinity such as a lagoon margin and particularly in a tidal flat and/or marsh. The grain size statistics advocate the mentioned environmental determination. The maximum age of the studied sediments is about 8500 BP, while differences in magnetic susceptibility are related to sediment source area and to the local seismo-tectonic activity.

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