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Late Holocene tectonic implications deduced from tidal notches in Leukas and Meganisi islands (Ionian Sea)

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ABSTRACT

In this paper the tectonic behavior of Leukas and Meganisi islands (Ionian Sea) is examined through underwater research carried out in both islands. A possible Late Holocene correlation between coseismic subsidences is attempted and evidenced by submerged tidal notches in both islands. These subsidence events probably occurred after the uplift that affected the northernmost part of Leukas around 4 to 5ka BP. In conclusion, although the whole area was affected by a similar tectonic strain, certain coseismic events were only recorded in one of the two islands and in some cases they affected only part of the study area.

KEYWORDS **Submerged shorelines. Late Holocene. Tidal notch. Leukas and Meganisi Islands. Ionian Sea.**

INTRODUCTION

The western (Ionian Sea) margin of Greece is one of the most seismically active parts of the Mediterranean, with intense shallow depth seismicity and magnitudes reaching up to 7.4 (*e.g.* Papazachos, 1990; Louvari *et al.*, 1999). The area is a zone of post-Pliocene contraction (Sorel, 1989), reflected in numerous inverse faults/thrusts, folds and evaporite doming and intrusions (British Petroleum Co., 1971; Underhill, 1988).

Crustal deformation of Ionian Sea has been studied through GPS measurements (*e.g.* Kahle *et al.*, 1995; Peter *et al.*, 1998; Cocard *et al.*, 1999; Hollenstein *et al.*, 2006; Serpelloni *et al.*, 2007, 2013; Anzidei *et al.*, 2014). According to Hollenstein *et al.* (2006), the north part of the Ionian Sea is characterized by vertical velocities of subsidence of the order of -2 to -2.5mm/yr, while the south part by -3.5 to -4.5mm/yr. Furthermore, the authors report an interseismic subsidence of -4mm/yr for the Ionian Islands.

In particular, the Cephalonia Transform Fault (CTF), separating the Apulia or Adriatic (Africa) and Aegean (Eurasia) lithospheric plates, which is clearly visible from the bathymetric maps of the area, developed close to the western side of Leukas and Cephalonia islands (Fig. 1) (Valkaniotis *et al.*, 2014). Its slip rate varies between 7 and 30mm/yr based on GPS measurements (Anzidei *et al.*, 1996; Hollenstein *et al.*, 2006).

A prolongation of the CTF is found parallel to the western coast of Leukas Island and constitutes a very active seismic fault segment (Leukas segment; Louvari *et al.*, 1999). According to Louvari *et al.* (1999) the Leukas segment is characterized by a dextral strike-slip motion combined with a small thrust component. Leukas Island is characterized by intense seismicity. The instrumental

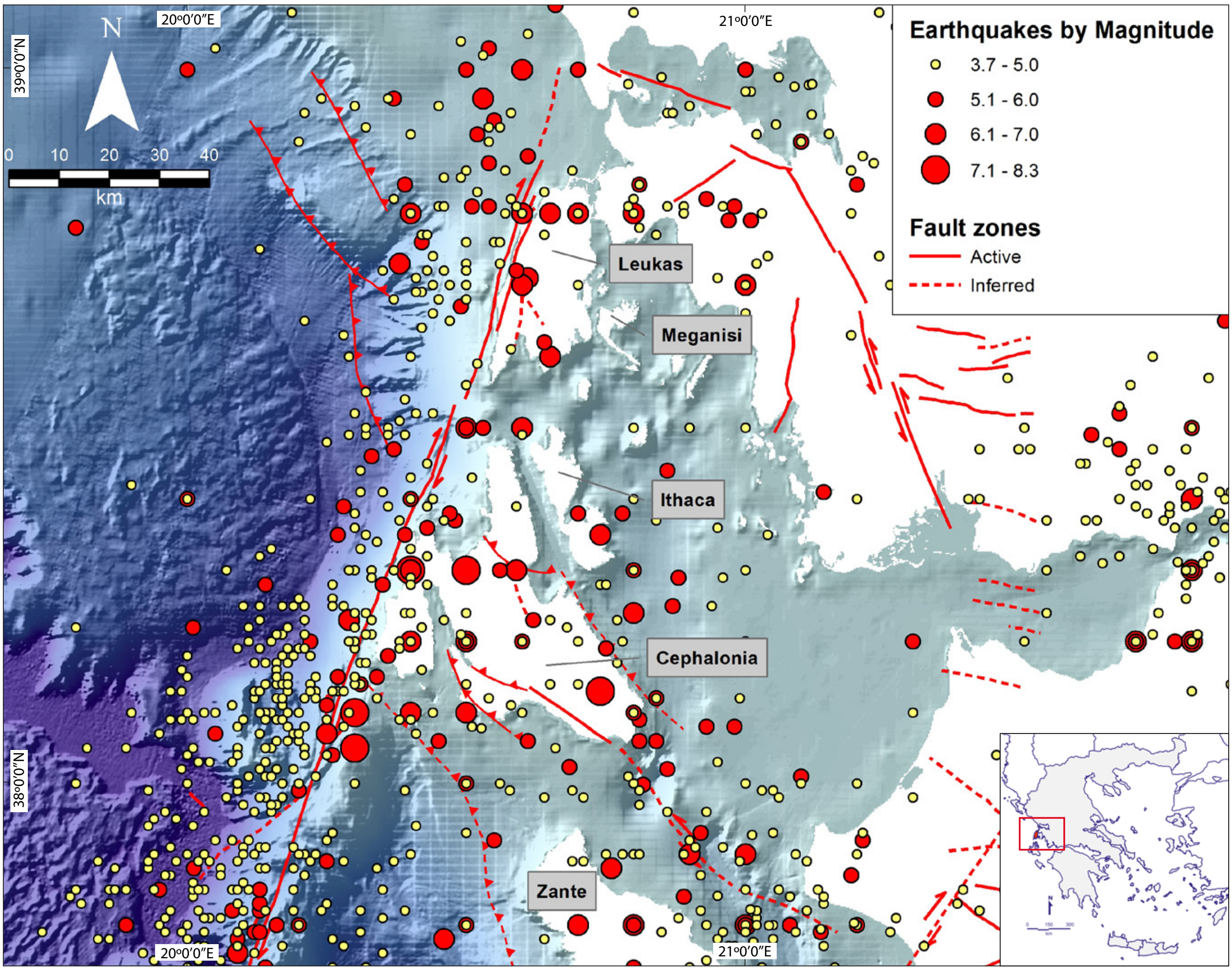

FIGURE 1. Tectonic setting of the study area (after Valkaniotis *et al*., 2014) and seismicity since 550B.C.

records show that strong earthquakes with surface-wave magnitude (Ms) up to 6.5 have taken place frequently in the area, associated with the strike-slip fault segment to the west of the island striking NNE-SSW and the thrust structure offshore NW Leukas (Fokaefs and Papadopoulos, 2004). Since 1612, at least 20 earthquake events have been reported for Leukas along with descriptions of the damages triggered by the earthquakes (Papathanassiou *et al*., 2005). According to these authors the list of historical events suggests that earthquakes appear in couples (twin or cluster events) and the re-occurrence period ranges between 2 months and 5 years.

In this paper, we focused on the investigation of tidal notches in Leukas and Meganisi Islands. We discuss four submerged shorelines at Meganisi (Ionian Islands, Greece) and provide some chronological estimations that allowed us to identify a sequence of coseismic subsidences that occurred during the last few millennia. We have also estimated the average coseismic subsidence displacement and the average return time of these vertical displacements. Furthermore, we examine the tectonic behavior of the Island of Leukas, after the uplift that affected the northernmost part of the island around 4 to 5ka BP, and correlate the coseismic subsidences observed in Meganisi during the latest Holocene with a corresponding sequence of coseismic movements as suggested by submerged tidal notches in Leukas Island.

MATERIALS AND METHODS

Field observations, mapping and measurement in both Meganisi and Leukas islands took place in 2012. All coasts were systematically surveyed in detail, using a boat in order to access all sites and establish the continuity of observations. Figure 2 depicts the sites where we located evidence of relative sea level changes, which are discussed below.

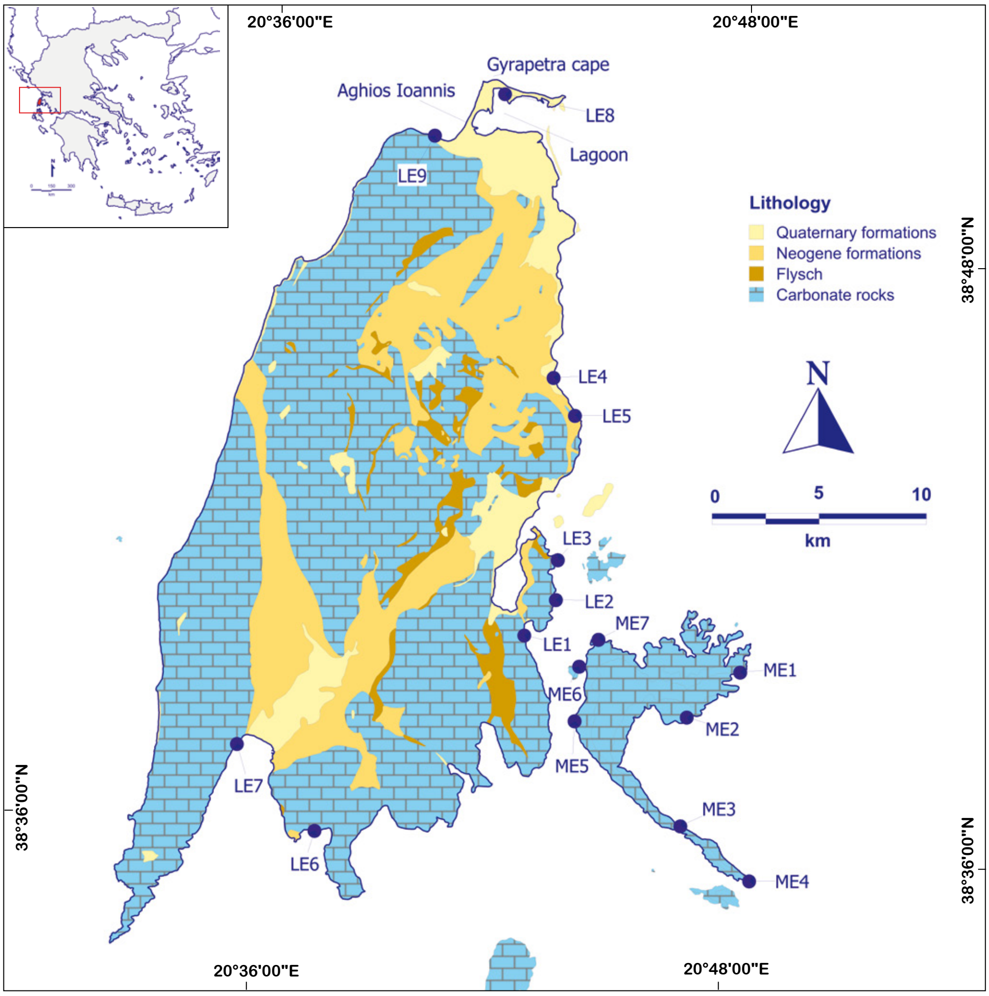

FIGURE 2. Location of tidal notches in Leukas and Meganisi islands, discussed in the paper.

Former sea-level positions were deduced from sea-level indicators, such as emerged and submerged tidal notches. Notch geometry *i.e.* height, inward depth and vertex depth from present mean sea level were measured according to Pirazzoli (1986) and Evelpidou and Pirazzoli (2014). The rocky shoreline was investigated through snorkeling and all indications suggesting relative sea level changes were recorded. We report here only the measurements of tidal notches that were continuous. Considering that the factors affecting the erosion of the tidal zone are various (*e.g.* Trenhaile, 2015), only the sites where the tidal notch profiles provided clear information were taken into account (*e.g.* with no irregularities on the rock, wave-protected sites, continuity). For each site, measurements were taken along extended outcrops of continuous notches. The final values correspond to the average of 10 measurements for each morphological characteristic of the notches (notch height, vertex depth, inward depth). In particular, the vertex depth measurements in relation to the present sea level were accomplished during favorable weather conditions. Depth measurements were subsequently corrected for tide and atmospheric pressure during the fieldwork period. In addition, the error estimations for the depth measurements were applied by taking into consideration the wave conditions and the measuring method. Atmospheric pressure and tidal records at the time of measurements were provided by the Hellenic Navy Hydrographical Service (HNHS) at the station of Leukas. The tidal range in the investigated area is 0.17 m and the mean sea level (MSL) is situated at 0.510m based on 21 years of statistical data (1990–2011) of HNHS.

An interpretation of the relative sea level change was made based on the profiles of the notches. Figure 3 depicts the different types of profiles identified in the study area. Given the difficulties in obtaining a chronology for the submerged erosion features, either by direct dating (all submerged fossils contemporary with the time of deposition or having grown on the

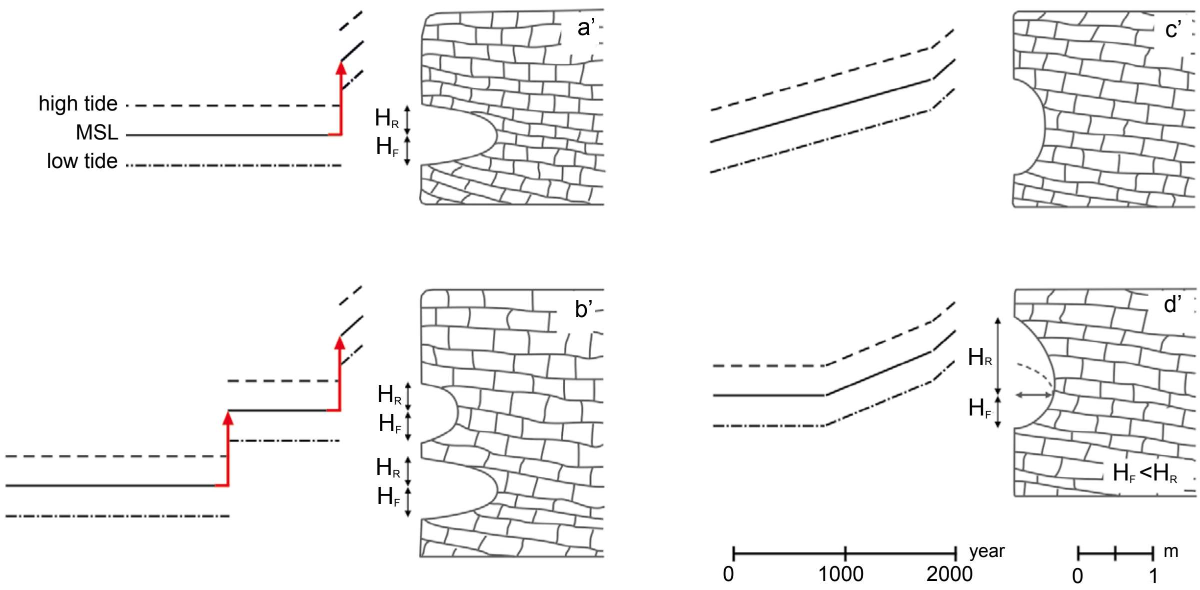

FIGURE 3. Different types of tidal notch profiles identified in the study area (MSL is mean sea level, HF is the height of the notch floor and HR is the height of the notch roof).

notch profile are rapidly destroyed by bioerosion), or by comparison with already dated levels of assumed global significance, we have limited our study to the following:

i) The Late Holocene, *i.e.* about the last 5–6ka during which global sea level is generally considered to have remained almost stable;

ii) an area of the eastern Mediterranean where the tectonic influence on relative sea level change can be identified and isolated (*e.g.* Nixon *et al.*, 2009; Evelpidou *et al.* 2012a, 2013a, b). Accurate underwater measurements of appropriate sea-level indicators (*i.e.* tidal notches) were used to identify changes in relative sea-level and to distinguish the speed (slow or rapid) of observed vertical displacements (*e.g.* Anzidei *et al.*, 2011);

iii) an estimation of the time required for tidal notch formation based on local rates of intertidal erosion (a range between maximum and minimum possible values) (Furlani *et al.*, 2010, 2014; Evelpidou and Pirazzoli, 2016b). This technique is useful in areas lacking archaeological remains or stratigraphical data from coastal boreholes;

iv) a determination of sequences of vertical movements, in the case of several tidal notches existing in the same area, and quantification of coseismic subsidences and estimation of their return time.

RESULTS

Leukas Island

Leukas Island appears to present evidence of repeated subsidence (6 events have been identified) with the exception of the northwestern edge. In particular, near the northwestern tip of the island, the coasts of Aghios Ioannis are undercut by a notch, which is indicative of a former sea level several decimetres higher than at present (Fig. 4). Near Aghios Ioannis, at the edge of the island until Cape Gurapetra, where the area is a low-lying coastal area of a few meters elevation enclosing the Leukas lagoon, there are uplifted beachrocks on the sea side.

Table I (Electronic Appendix, available at www.geologica-acta.com) summarizes the main characteristics of the six submerged tidal notches observed in Leukas. No tidal notch exists at present sea level (the notch in Aghios Ioannis is above present sea level), however a notch that can be considered modern (*sensu* Evelpidou *et al.*, 2012c) has been observed (shoreline A) at two sites (LE6, LE7) at a depth of about -25±6cm. Its average inward depth is 11.5cm (Table II), suggesting that the MSL remained almost stable at the level of its vertex, prior to the 19th century, over a period between 1.1 century (corresponding to an assumed maximum intertidal erosion rate of 1mm/yr) and 5.7 centuries (corresponding to an assumed minimum erosion rate of 0.2mm/yr) (Pirazzoli *et al.*, 1982; Pirazzoli, 1986; Laborel *et al.*, 1999; Evelpidou *et al.*, 2012b, 2016b;

FIGURE 4. Slightly elevated notch near Aghios Ioannis, Leukas.

Furlani and Cucchi, 2013). According to recent studies (*e.g.* Jevrejeva *et al.*, 2008, Church *et al.*, 2010; Kemp *et al.*, 2011), the rate of sea level rise has increased since the 19th century, reaching an average rate of 2.1mm/yr. The profile of shoreline A is of the a' type (Fig. 3) and it was developed at sea level that has been submerged by the global sea-level rise that is known to have occurred since the 19th century (*e.g.* Jevrejeva *et al.*, 2008, Kemp *et al.*, 2011) at a rate faster than local intertidal erosion (that seems to be of the order of 0.64mm/yr in nearby Cephalonia Island; Evelpidou and Pirazzoli, 2016b). The next submerged shoreline (B) at -45±6cm was measured at three sites (LE2, LE3 and LE7). Its average inward depth of 21cm suggests that MSL remained almost stable at the level of its vertex for 210 to 1050 years. The type b' profile of the notches of shoreline B indicates that the passage of sea level from shoreline B to shoreline A was due to a coseismic subsidence of 20±6cm. According to Ambraseys and Jackson (1990) when vertical displacements are of co-seismic origin, they generally occur at the time of earthquakes with magnitude larger than 6.0, commonly associated with morphogenic faults, and thus producing direct surface faulting. According to Wells and Coppersmith (1994) the surface rupture length is typically equal to 75% of the subsurface rupture length and the average surface displacement is typically equal to one-half of the maximum surface displacement. For earthquakes with a magnitude less than 5.6–5.7, vertical displacements may be limited to 1–2cm, therefore often not distinguishable from other features of ground deformation (Pavlides and Caputo, 2004). In this case a series of earthquakes may produce an apparent trend of aseismic vertical deformation. The aforementioned are in accordance with field observations by Anzidei *et al.* (2009) and previous studies in central Apennines (Italy) showing that normal faults are able to produce surface faulting for earthquakes with Ms>5.5, generating measurable landscape signatures (*e.g.* Roberts and Michetti, 2004; Roberts, 2006). In the same way it may be deduced that the submergence of shorelines C, D, E and F can be ascribed to previous coseismic subsidences of 15±6cm, 20±6cm, 20±6 and 40±6cm, respectively.

In summary, submerged tidal notches on Leukas Island provide evidence of five coseismic subsidences during the last few millennia. Their cumulative effect was total subsidence of 140±6cm over a period of 1130 to 5670 years. The average coseismic subsidence was 23±6cm (Table II), with a return time between 1.7 and 8.3 centuries. Assuming an average bioerosion rate of 0.6mm/yr (medium value between 0.2 and 1mm/yr), an average return time of 310 years would be obtained.

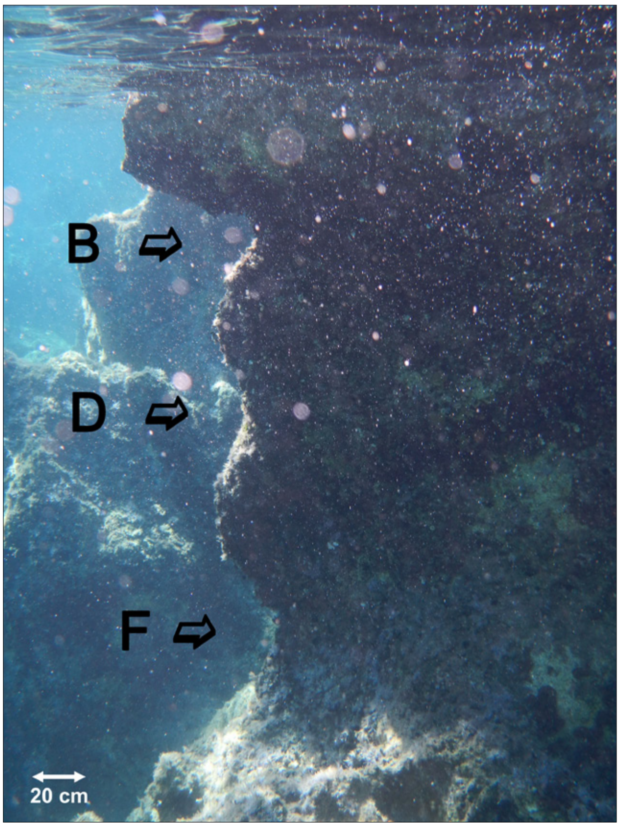

FIGURE 5. Shoreline A, B and D in Meganisi, Site ME1. It should be noted that it is common for notches to vanish laterally, even in the same rock (Pirazzoli and Evelpidou, 2013).

Meganisi Island

Table III summarizes the main characteristics of the four submerged tidal notches observed in Meganisi. No tidal notch exists at present sea level and also a modern notch (*sensu* Evelpidou *et al*., 2012c) at a depth of about -20cm is absent. The first submerged shoreline (B) at -40±6cm has an average inward depth of 17cm, suggesting that MSL remained almost stable at the level of its vertex for 170 years (corresponding to an assumed maximum intertidal bioerosion rate of 1mm/yr) to 850 years (corresponding to an assumed minimum bioerosion rate of 0.2mm/yr generally accepted for the Mediterranean) (Pirazzoli *et al*., 1982; Pirazzoli, 1986; Laborel *et al*., 1999; Evelpidou *et al*., 2012b, 2016b; Furlani and Cucchi, 2013). According to its a' type profile (Fig. 3; 5), shoreline B was submerged by a coseismic subsidence of 20 to 40cm, probably less than 2 centuries ago (Table IV). The submergence of shorelines D (Fig. 5), E and F can be ascribed to previous coseismic subsidences of 40±6cm, 20±6cm, and 35±6cm, respectively.

As shown in Table IV, submerged tidal notches from Meganisi Island provide evidence of four coseismic subsidences. Their cumulative effect was total subsidence of 135±6cm over a period of 7.8 to 38.7 centuries. Average co-seismic subsidence was between 29±6 and 34±6cm with a return time between 2 and 10 centuries. Assuming a mean value of 0.6mm/yr for the bioerosion rate, the return time decreases to 3.2 centuries.

DISCUSSION

Vött *et al*. (2007) interpreted the northern border of Leukas as representing remnants of a former mid-Holocene strandline made of beachrock that was subsequently partly dislocated by tsunami. Near Cape Gurapetra some *in situ* slightly elevated beachrock was reported by Pirazzoli *et al*. (1994) from which two shell samples, collected at an estimated palaeo - MSL of +1m, provided radiocarbon ages between 4.2 and 5.3ka BP, thus possibly dating the formation of the elevated notch of Aghios Ioannis. This uplift was probably originated the seismo-tectonic activity related to the Cephalonia Transform Fault and the Leukas Fault (Louvari *et al*., 1999). The seismicity, following the western coast of Leukas Island, shows the continuation of the Cephalonia Transform Fault to the north and defines the Leukas segment. The maximum magnitude for this fault segment, according to its length, is 6.8 (Papazachos and Papazachou, 1997). Historical reports of earthquakes that caused damage to Leukas Island cited in Papazachos and Papazachou (1997) clearly indicate that this is the maximum magnitude ever observed in the island (Table V). Vött *et al*. (2007, p. 52) assume that the beachrocks dated by Pirazzoli *et al*. (1994) "are not *in situ* but probably relocated and uplifted by tsunamigenic influence". The size of beachrock (it extends almost continuously parallel to the coast for more than 2km) and the condition of the beachrock slabs (undisturbed, in-situ slabs, maintaining their morphological characteristics, such as their inclination parallel to the coast) makes difficult to adopt this assumption. This mid-Holocene uplift seems to have been local and limited to the northernmost border of Leukas Island. Tectonic movements during the next centuries, as shown below, consist of a sequence of coseismic subsidences, deduced from submerged tidal notches, which affected not only most of Leukas Island, but also the nearby Meganisi Island.

A comparison between the two islands may now be attempted (Table VI). If the total observed subsidence (about 140cm) and the range of possible return times of coseismic subsidence (especially for a medium bioerosion rate) are similar in the two islands, several differences appear:

i) number of coseismic events: 5 in Leukas against 4 in Meganisi;

ii) absence of modern notches in Meganisi;

iii) and the type of certain tidal notch profiles, *e.g.* for the -100±6cm shoreline, which is of b'-type in Leukas, while it is of d'-type in Meganisi.

The aforementioned suggest that although the area was affected by a similar tectonic strain, certain coseismic events were only recorded in one of the two islands and, furthermore, some events may have affected only part of one island.

CONCLUSIONS

Five coseismic subsidences have been identified from submerged notches in Leukas Island in the last few millennia. Their cumulative effect was a total subsidence of 140±6cm in a period of 1.1 to 5.7kyr. Four submerged fossil shorelines were found in Meganisi Island. The cumulative effect was a total subsidence of 135±6cm during a period lasting between 0.9 and 3 kyr. The average coseismic subsidence was between 29±6 and 34±6cm with a return time between 0.2 and 1kyr respectively.

Although the observed subsidences are similar in Leukas Island and the nearby Meganisi Island, several differences appear indicating that certain coseismic events have a local effect and in some cases have affected only part of the study area.

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REFERENCES

Ambraseys, N.N., Jackson, J.A., 1990. Seismicity and associated strain of central Greece between 1890 and 1988. Geophysical Journal International, 101, 663-708.

Anzidei, M., Baldi, P., Casula, G., Crespi, M., Riguzzi, F., 1996. Repeated GPS surveys across the Ionian Sea: evidence of crustal deformations. Geophysical Journal International, 127, 257-267.

Anzidei, M., Boschi, E., Cannelli, V., Devoti, R., Esposito, A., Galvani, A., Melini, D., Pietrantonio, G., Riguzzi, F., Sepe, V., Serpelloni, E., 2009. Coseismic deformation of the destructive April 6, 2009 L'Aquila earthquake (central Italy) from GPS data. Geophysical Research Letters, 36, 3-7. DOI: http://doi.org/10.1029/2009GL039145

Anzidei, M., Antonioli, F., Benini, A., Lambeck, K., Sivan, D., Serpelloni, E., Stocchi, P., 2011. Sea level change and vertical land movements since the last two millennia along the coasts of southwestern Turkey and Israel. Quaternary International, 232(1-2), 13-20. DOI: http://doi.org/10.1016/j.quaint.2010.05.005

Anzidei, M., Lambeck, K., Antonioli, F., Furlani, S., Mastronuzzi, G., Serpelloni, E.,Vannucci, G., 2014. Coastal structure, sea-level changes and vertical motion of the land in the Mediterranean. The Geological Society of London, 388 (Special Publications), 453-479. DOI: http://dx.doi.org/10.1144/SP388.20

British Petroleum Co. Ltd, 1971. The Geological Results of Petroleum Exploration in Western Greece. Athens Institute of Geology and Subsurface Research, 10.

Church, J., Woodworth, P.L., Aarup, T., Wilson, W.S., (eds.), 2010. Understanding Sea-Level Rise and Variability. Oxford, Blackwell Publishing Ltd, 421pp.

Cocard, M., Kahle, H.G., Peter, Y., Geigera, A., Veisb, G., Felekis, S., Paradissis, D., Billiris, H., 1999. New constraints on the rapid crustal motion of the Aegean region: recent results inferred from GPS measurements (1993–1998) across the West Hellenic Arc, Greece. Earth and Planetary Science Letters, 172(1-2), 39-47.

Evelpidou, N., Pirazzoli, P.A., 2014. Underwater geomorphological survey revealing past temporary standstills of the relative sea level in carbonate rock areas: A methodological approach. Quaternaire, 25(4), 383-390.

Evelpidou, N., Pirazzoli, P., 2016a. Comment on «Tidal notches in the Mediterranean Sea: A comprehensive analysis» by Fabrizio Antonioli, Valeria Lo Presti, Alessio Rovere, Luigi Ferranti, Marco Anzidei, Stefano Furlani, Giuseppe Mastronuzzi, Paolo E. Orru, Giovanni Scicchitano, Gianmaria Sa. Quaternary Science Reviews, 131, 237-238. DOI: http://doi.org/10.1016/j.quascirev.2015.08.023

Evelpidou, N., Pirazzoli, P.A., 2016b. Estimation of the intertidal bioerosion rate from a well-dated fossil tidal notch in Greece. Marine Geology. DOI: http://doi.org/10.1016/j.margeo.2016.04.017

Evelpidou, N., Melini, D., Pirazzoli, P., Vassilopoulos, A., 2012a. Evidence of a recent rapid subsidence in the S-E Cyclades (Greece): an effect of the 1956 Amorgos earthquake? Continental Shelf Research, 39-40, 27-40. DOI: http://dx.doi.org/10.1016/j.csr.2012.03.011

Evelpidou, N., Vassilopoulos, A., Pirazzoli, P.A., 2012b. Submerged notches on the coast of Skyros Island (Greece) as evidence for Holocene subsidence. Geomorphology, 141-142, 81-87. DOI: http://dx.doi.org/10.1016/j.geomorph.2011.12.025

Evelpidou, N., Kampolis, I., Pirazzoli, P., Vassilopoulos, A., 2012c. Global sea-level rise and the disappearance of tidal notches. Global and Planetary Change, 92-93, 248-256. DOI: http://dx.doi.org/10.1016/j.gloplacha.2012.05.013

Evelpidou, N., Koutsomichou I., Pirazzoli, P.A., 2013a. Evidence of Late Holocene events in Sporades Islands: Skopelos and Alonnisos. Continental Shelf Research, 69, 31-37. DOI: http://dx.doi.org/10.1016/j.csr.2013.09.017

Evelpidou, N., Melini, D., Pirazzoli, P.A., Vassilopoulos, A., 2013b. Evidence of repeated late Holocene rapid subsidence in the SE Cyclades (Greece) deduced from submerged notches. International Journal of Earth Sciences, 101(1), 381-395. DOI: http://dx.doi.org/10.1007/s00531-013-0942-0

Fokaefs, A., Papadopoulos, G.A., 2004. Historical earthquakes in the region of Lefkada island, Ionian Sea - estimation of magnitudes from epicentral intensities. Bulletin of the Geological Society of Greece, XXXVI, 1389-1395.

Furlani, S., Cucchi, F., 2013. Downwearing rates of vertical limestone surfaces in the intertidal zone (Gulf of Trieste, Italy). Marine Geology, 343, 92-98. DOI: http://doi.org/10.1016/j.margeo.2013.06.005

Furlani, S., Cucchi, F., Odorico, R., 2010. A new method to study microtopographical changes in the intertidal zone: one year of TMEM measurements on a limestone removable rock slab (RRS). Zeitschrift Für Geomorphologie, 54(2, Supplementary Issues), 137-151.

Furlani, S., Ninfo, A., Zavagno, E., Paganini, P., Zini, L., Biolchi, S., Antonioli, F., Coren, F., Cucchi, F., 2014. Submerged notches in Istria and the Gulf of Trieste: Results from the Geoswim project. Quaternary International, 332, 37-47. DOI: http://doi.org/10.1016/j.quaint.2014.01.018

Hollenstein, C., Geiger, A., Kahle, H.-G., Veis, G., 2006. CGPS time-series and trajectories of crustal motion along the West Hellenic Arc. Geophysical Journal International, 164(1), 182-191. DOI: http://doi.org/10.1111/j.1365-246X.2005.02804.x

Jevrejeva, S., Moore, J.C., Grinsted, A., Woodworth, P.L., 2008. Recent global sea level acceleration started over 200 years ago? Geophysical Research Letters, 35(8), L08715. DOI: http://doi.org/10.1029/2008GL033611

Kahle, H.G., Müller, M.V., Geiger, A., Danuser, G., Mueller, S., Veis, G., Billiris, H., Paradissis, D., 1995. The strain field in northwestern Greece and the Ionian islands: results inferred from GPS measurements. Tectonophysics, 249, 41-52.

Kemp, A.C., Horton, B.P., Donnelly, J.P., Mann, M.E., Vermeer, M., Rahmstorf, S., 2011. Climate related sea-level variations over the past two millennia. Proceedings of the National Academy of Sciences, 108, 11017-11022.

Laborel, J., Morhange, C., Collina-Girard, J., Laborel-Deguen, F., 1999. Littoral bioerosion, a tool for the study of sea level variations during the Holocene. Bulletin of the Geological Society of Denmark, 45, 164-168.

Louvari, E., Kiratzi, A.A., Papazachos, B.C., 1999. The Cephalonia Transform Fault and its extension to western Lefkada Island (Greece). Tectonophysics, 308, 223-236. DOI: http://dx.doi.org/10.1016/S0040-1951(99)00078-5

Nixon, F.C., Reinhardt, *E.g*., Rothaus, R., 2009. Foraminifera and tidal notches: Dating neotectonic events at Korphos, Greece. Marine Geology, 257(1-4), 41-53. DOI: http://doi.org/10.1016/j.margeo.2008.10.011

Papathanassiou, G., Pavlides, S., Ganas, A., 2005. The 2003 Lefkada earthquake: Field observations and preliminary microzonation map based on liquefaction potential index for the town of Lefkada. Engineering Geology, 82, 12-31.

Papazachos, B.C., 1990. Seismicity of the Aegean and surrounding area. Tectonophysics, 178, 287-308.

Papazachos, B., Papazachou, C., 1997. The Earthquakes of Greece (in Greek). Thessaloniki, Greece, Ziti and Co, 304pp.

Pavlides, S., Caputo, R., 2004. Magnitude versus faults' surface parameters: quantitative relationships from the Aegean. Tectonophysics, 380(3-4), 159-188.

Peter, Y., Kahle, H.G., Cocard, M., Veis, G., Felekis, S., Paradissis, D., 1998. Establishment of a continuous GPS network across the Kephalonia Fault Zone, Ionian islands, Greece. Tectonophysics, 294 (3-4), 253-260.

Pirazzoli, P.A., 1986. Marine notches. In: Van de Plassche, O. (ed.), Sea –Level Research: a Manual for the collection and Evaluation of Data. Norwich, Geo Books, 361-400.

Pirazzoli, P., Evelpidou, N. 2013. Tidal notches: A sea-level indicator of uncertain archival trustworthiness. Palaeogeography, Palaeoclimatology, Palaeoecology, 369, 377-384. DOI: http://dx.doi.org/10.1016/j.palaeo.2012.11.004

Pirazzoli, P.A., Thommeret, J., Thommeret, Y., Laborel, J., Montaggioni, L.F., 1982. Crustal block movements from Holocene shorelines: Crete and Antikythira (Greece). Tectonophysics, 86, 27-43.

Pirazzoli, P.A., Stiros, S.C., Laborel, J., Laborel-Deguen, F., Arnold, M., Papageorgiou, S., Morhange, C., 1994. Late-Holocene shoreline changes related to palaeoseismic events in the Ionian Islands, Greece. The Holocene, 4, 397-405. DOI: http://dx.doi.org/10.1177/095968369400400407

Roberts, G.P., 2006. Multi-seismic cycle velocity and strain fields for an active normal fault system, central Italy. Earth and Planetary Science Letters, 251, 44-51. DOI: 10.1016/j.epsl.2005.11.066

Roberts, G.P., Michetti, A.M., 2004. Spatial and temporal variations in growth rates along active normal fault systems: An example from the Lazio-Abruzzo Apennines, central Italy. Journal of Structural Geology, 26, 339-376. DOI: 10.1016/S0191-8141(03)00103-2

Serpelloni, E., Vannucci, G., Pondrelli, S., Argnani, A., Casula, G., Anzidei, M., Gasperini, P., 2007. Kinematics of the Western Africa-Eurasia plate boundary from focal mechanisms and GPS data. Geophysical Journal International, 169(3), 1180-1200. DOI: http://doi.org/10.1111/j.1365-246X.2007.03367.x

Serpelloni, E., Faccenna, C., Spada, G., Dong, D., Williams, S.D.P., 2013. Vertical GPS ground motion rates in the Euro-Mediterranean region: New evidence of velocity gradients at different spatial scales along the Nubia-Eurasia plate boundary. Journal of Geophysical Research: Solid Earth, 118(11), 6003-6024. DOI: http://doi.org/10.1002/2013JB010102

Sorel, D., 1989. L'évolution structurale de la Grèce nord-occidentale depuis le Miocène, dans le cadre géodynamique de l'Arc Egéen. PhD Thesis. Orsay, Université de Paris 11, 306pp.

Trenhaile, A.S., 2015. Coastal notches: Their morphology, formation, and function. Earth-Science Reviews, 150, 285-304. DOI: http://doi.org/10.1016/j.earscirev.2015.08.003

Underhill, J., 1988. Triassic evaporites and Plio-Quaternary diapirism in western Greece. Journal of the Geological Society, 145, 269-282.

Valkaniotis, S., Ganas, A., Papathanassiou, G., Papanikolaou, M., 2014. Field observations and geological effects triggered by the January-February 2014 Cephalonia Ionian Sea, Greece) earthquakes. Tectonophysics, 630, 150-157. DOI: http://dx.doi.org/10.1016/j.tecto.2014.05.012

Vött, A., Brückner, H., May, M., Lang, F., Brockmüller, S., 2007. Late Holocene tsunami imprint at the entrance of the Ambrakian gulf (NW Greece). Méditerranée, 108, 43-57.

Wells, D., Coppersmith, K., 1994. New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement. Bulletin of the Seismological Society of America, 84(4), 974-1002.

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ELECTRONIC APPENDIX I

TABLE I. Location and significant sizes of submerged tidal notches in Leukas Island

Locality				Tidal notches									
Location	Site (Fig. 1)	Long. E	Lat. N	Notch name	measured Vertex depth from SL (cm)	corrected Vertex depth from MSL (cm)	Height (cm)	Inward depth (cm)	Possible duration of development (centuries)	Genesis (Fig. 2)	Shoreline	Regional sea-level correlation (cm below present SL)
Leukas	LE1	20º42'45.1188''	38º40'11.3988''	LE1.1	-63	-58	50	20	2-10	b'	C	-60±6
	LE2	20º43'31.5012''	38º40'55.2612''	LE2.1	-50	-46	31	18	1.8-9	b'	B	-45±6
	LE3	20º43'32.2212''	38º41'43.0188''	LE3.1	-47	-43	33	20	2-10	b'	B	-45±6
				LE3.2	-60	-56	23	20	2-10	b'	C	-60±6
	LE5	20º 43' 50.4588''	38º 44' 36.6''	LE5.1	-82	-81	21	12	1.2-6	e''	D	-80±6
				LE5.2	-97	-96	42	25	2.5-12.5	b'	E	-100±6
	LE6	20º 37' 35.5188''	38º 36' 8.5212''	LE6.1	-27	-27	17	10	1-5	a'	A	-25±6
				LE6.2	-143	-143	78	30	3-15	d'	F	-140±6
	LE7	20º 35'32.1''	38º37'48.9612''	LE7.1	-20	-19	32	13	1.3-6.5	a'	A	-25±6
				LE7.2	-50	-49	25	5	0.5-2.5	b'	B	-45±6
				LE7.3	-105	-104	18	13	1.3-6.5	b'	E	-100±6

TABLE II. Number of tidal notches mesurated, depth below MSL, average inward depth, number of coseismic submergences and possible duration of development for the submerged tidal notches in Leukas Island

Shoreline	Number of tidal notches measured	Depth below the present MSL (cm)	Average inward depth (cm)	Amount of coseismic submergence (cm)	Possible average duration of development related to certain bioerosion rates (centuries)		
					1.0 mm/a	0.2 mm/a	0.6 mm/a
A	2	-25±6	11.5	-	1.1	5.7	1.8
B	3	-45±6	21	20±6	2.1	10.5	3.5
C	2	-60±6	20	15±6	2	10	3.3
D	1	-80±6	12	20±6	1.2	6	2
E	2	-100±6	19	20±6	1.9	9.5	3.2
F	1	-140±6	30	40±6	3	15	5
Total	11	140±6			11.3	56.7	18.8
Average			18.9	23±6	1.7	8.3	3.1

TABLE III. Location and significant sizes of submerged tidal notches in Meganisi Island

Locality				Tidal notches										
Location	Site (Fig. a)	Long. E	Lat. N	Notch name	Measured Vertex depth from SL (cm)	corrected Vertex depth from MSL (cm)	Height (cm)	Inward depth (cm)	Possible duration of development (centuries)	Genesis (Fig. 2)	Shoreline	Figures	Regional sea-level correlation (cm below present SL)
Meganisi	ME1	20°48'16.74''	38°39'32.22''	ME1.1	-33	-45	18	20	2-10	a'	B	Fig. 3	-40±6
		20°48'16.74''	38°39'32.22''	ME1.2	-74	-86	41	11	1.1-5.5	d'	D	Fig. 3	-80±6
		20°48'16.74''	38°39'32.22''	ME1.3	-123	-135	42	17	1.7-8.5	d'	F	Fig. 3	-135±6
	ME2	20°46'55.0812''	38°38'36.6''	ME2.1	-125	-137	58	22	2.2-11	d'	F		-135±6
	ME4	20°48'39.96''	38°35'26.2212''	ME4.1	-87	-101	74	30	3-15	d'	E		-100±6
	ME7	20°44'34.1988''	38°40'6.1212''	ME7.1	-27	-41	20	14	1.4-7	a'	B		-40±6

TABLE IV. Number of tidal notches measured, depth below MSL, average inward depth, number of coseismic submergences and possible duration of development for the submerged tidal notches observed in Meganisi Island

Shoreline	Number of tidal notches measured	Depth below the present MSL (cm)	Average inward depth (cm)	Amount of coseismic submergence (cm)	Possible average duration of development assumed for certain bioerosion rates (centuries)		
					1.0 mm/a	0.2 mm/a	0.6 mm/a
B	2	-40±6	17	20±6 to 40±6	1.7	8.5	2.8
D	1	-80±6	11	40±6	1.1	5.5	1.8
E	1	-100±6	30	20±6	3	15	5
F	2	-135±6	19.5	35±6	2	9.7	3.2
Total	6	-135±6		115±6 to 135±6	7.8	38.7	12.8
Average			19.4	29±6 to 34±6	1.95	9.7	3.2

TABLE V. List of Historical earthquakes that caused damage in Leukas Island (Papazachos and Papazachou, 1997; Louvari *et al.*, 1999)

Date	Magnitude (M)
26/5/1612	6.5
12/10/1613	6.4
28/6/1625	6.6
2/7/1630	6.7
22/11/1704	6.3
5/6/1722	6.4
22/2/1723	6.7
12/10/1769	6.7
23/3/1783	6.7
1815	6.3
21/2/1820	6.4
19/1/1825	6.5
28/12/1869	6.4
27/11/1914	6.3
22/4/1948	6.5

TABLE VI. Comparison between the sequences of coseismic subsidences deduced from submerged tidal notches at Leukas and Meganisi Island

Island	Total subsidence observed (cm below the present MSL)	Number of coseismic events	Range of possible return times of coseismic subsidences (centuries)	Average coseismic return time corresponding to a medium bioerosion rate of 0.6 mm/a (centuries)
Leukas	140±6	5	8.3 to 41.7	3.1
Meganisi	135±6	4	7.8 to 38.7	3.2