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Contents

Relative Sea-Level Changes in the Central Aegean from the Late Roman/Early Byzantine Period Onwards

Eleni Kolaiti, Nilhan Kızıldağ, Harun Özdaş, and Nikos Mourtzas

Abstract

Geoarchaeological data from the central and northern Cycladic plateau coasts, Peloponnese and Crete, and the western coast of Turkey shed light on the Late Roman/Early Byzantine period, for which little is known about the relative sea-level (RSL) changes. This study focuses mainly on ancient maritime installations and coastal structures (e.g., quays, breakwaters, fish tanks, protective rockfills, and buildings), all falling in the same chronological frame. A total of 34 locations throughout the central Aegean (eastern Peloponnese: 5 locations, Cycladic plateau: 6 sites, Crete: 10 locations, western coast of Turkey: 13 locations) were evaluated. Data suggest an RSL rise of 2.40 ± 0.20 m in the eastern Peloponnese and central/northern Cyclades, 1.25 ± 0.05 m in Crete, and a variable RSL rise from 1.50 ± 0.40 m to 4.20 ± 0.30 m on the coast of western Turkey since at least the sixth century AD onwards. The spatial distribution of the above sites in the backarc area of the Hellenic subduction zone implies that the complex tectonic regime of the central Aegean Sea reflects the differential rates of RSL rise over the reference period of about 1400 years.

Keywords

Aegean sea · Greek coast · Turkish coast · Relative sea-level rise · Late Roman/Early Byzantine period

1 Introduction

Recent geoarchaeological studies of relative sea-level (RSL) changes on both the Greek and Turkish coasts of the central Aegean Sea, mainly based on archaeological markers (ancient remains related to a former sea level) and geomorphological indicators (marine tidal notches, marine terraces, and beach rock generations), show a remarkable subsidence trend during the Late Holocene.

Since the early nineteenth century onwards, numerous studies have dealt with the Late Holocene RSL changes of the Aegean, covering a broad period of the last six millennia (e.g., Kolaiti & Mourtzas, 2020 and related references therein). Nevertheless, a few studies have focused on the RSL changes that happened in Late Antiquity, after the fourth century AD onwards, a period for which little is known to date (e.g., Bechor et al., 2019; Kolaiti, 2020; Kızıldağ & Özdaş, 2021; Kolaiti & Mourtzas, 2023). Therefore, to establish the rates of RSL changes in the central Aegean since the Late Roman/Early Byzantine period, we collected and evaluated geoarchaeological data from the Greek and the western Turkish coasts.

This study focuses on submerged ancient maritime installations and coastal structures (e.g., quays, breakwaters, fish tanks, protective rockfills, and buildings), all falling chronologically within the reference period. A total of 34 locations throughout the central Aegean area was evaluated: 5 sites on the eastern coast of the Peloponnese (Kolaiti, 2019), 6 spots on the islands of the central and northern Cycladic plateau (Kolaiti & Mourtzas, 2020; Kolaiti & Mourtzas, 2023), 10 locations on the coast of Crete (Mourtzas et al., 2016), and 13 locations on the coast of western Turkey (Kızıldağ, 2019; Kızıldağ & Özdaş, 2021) (Fig. 1).

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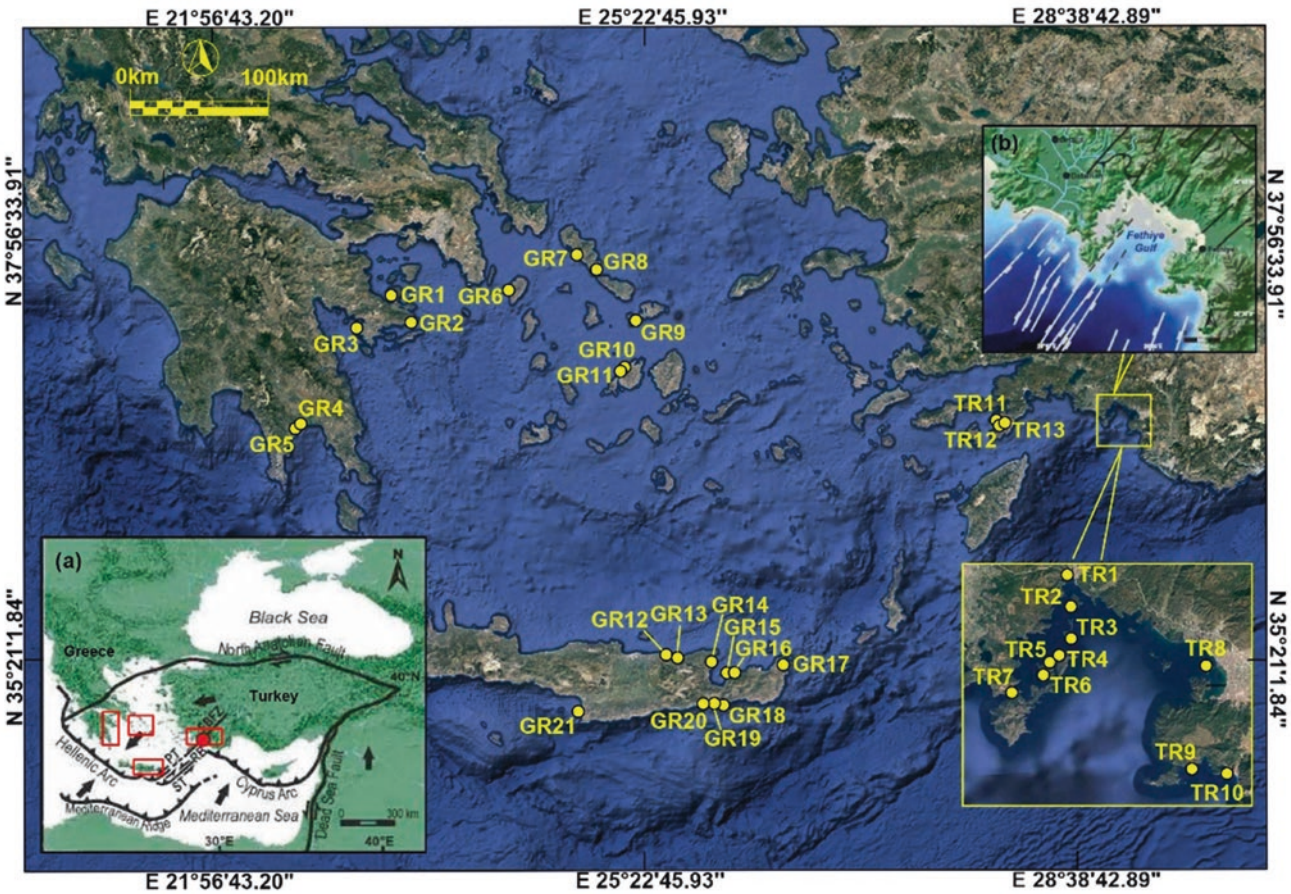

Fig. 1 Location map of the study areas along the Greek and Turkish coasts. Locations are indicated in yellow and are reported in Table 1 (columns A and B). **a** Geotectonic features of the Eastern Mediterranean Sea. FBFZ: Fethiye-Burdur Fault Zone, PT: Pliny Trench, ST: Strabo Trench, RB: Rhodes Basin. Red squares indicate the study areas. **b** Major faults around the Fethiye Gulf (from Kızıldağ and Özdaş (2021))

2 Seismotectonic Setting of the Central and South Aegean

The Aegean Sea and its surrounding coastal areas of Greece and western Turkey is one of the most seismically active and rapidly deforming regions (see Fig. 1a). The convergence rate between the Aegean region and the Nubian (African) plate (~35 mm/yr) is attributed to the rapid southwestward motion of the Aegean region (e.g., Reilinger et al., 2010). The northward subduction of the African plate beneath west Turkey and the Aegean region is causing the extension of the continental crust and volcanism in the overlying Aegean extensional province (e.g., Taymaz et al., 2007). Normal faulting predominates in the Greek mainland, along the eastern Aegean islands, and the western coast of Turkey, while thrust faulting predominates in the Hellenic Arc. As a result, the central Aegean appears aseismic, while E-W structures offshore the west Anatolia are delineated by seismic activity. The most significant part of seismicity is crustal, concentrated along major active seismic zones at less than 30 km focal depths. Focal mechanisms indicate transpressional tectonics along the Hellenic Arc and transtensional tectonics across the overriding Aegean plate (Kassaras et al., 2020).

3 Materials and Methods

All depths reported herein are corrected for tide and atmospheric pressure and correspond to depths below mean sea level (bmsl). The functional elevation of the operational features of the ancient coastal remains, directly related to a former sea level when they were in use and now submerged, with respect to mean sea level, provides not only a reasonable estimate of the RSL rise since the time they were in use, but also the dating of the sea-level stand during their use and a terminus *post quem* for the time that the sea-level change may have occurred. In this study, a mean elevation of the top surface of a quay or breakwater of 0.60 ± 0.30 m above mean sea level (amsl) during the period it was in use, 0.10 m amsl for a slipway, 0.30–0.50 m amsl for a protective rockfill, sea wall, and coastal building, and $\pm$ 0.05 m for a fish tank, which is the most precise sea-level marker, are assumed (e.g., Mourtzas et al., 2016; Kızıldağ, 2019 and related references therein).

4 Results

The location and archaeological age of the ancient maritime and coastal structures and the measured mean depths of their functional features for the 34 study areas are presented in Table 1 (columns A÷E). The submerged ancient remains along the Greek coastline are located between 1.60 and 2.20 m bmsl in the eastern Peloponnese, 1.10 and 2.60 m bmsl in the central/northern Cyclades, and 0.70 and 1.40 m bmsl in Crete. On the Turkish coastline, the submerged ancient remains were measured between 0.70 and 1.20 m bmsl at Bozburun Peninsula and 1.60 and 3.60 m bmsl in Fethiye Gulf.

5 Discussion

Based on the measured mean depths of the ancient coastal remains in reference to their functionality, and comparing these with the depths of available geomorphological sea-level indicators, the related sea-level stands when the ancient structures were in use can be inferred (Table 1, column F). To summarize, the results point to an RSL rise of 2.40 ± 0.20 m to 2.60 ± 0.30 m in the eastern Peloponnese, 2.40 ± 0.20 m in the central/northern Cyclades, 1.25 ± 0.05 m in Crete and an RSL rise ranging from 1.50 ± 0.40 m to 4.20 ± 0.30 m in the western coast of Turkey since at least the sixth century AD onwards.

The spatial distribution of the above sites in the backarc area of the Hellenic subduction zone implies that the complex tectonic regime of the central Aegean Sea reflects on the differential rates of the RSL rise during the reference period (about the last 1400 years): from 1.70–1.90 mm/yr in areas of seismic quiescence (Cyclades) or moderate seismicity (eastern Peloponnese) to 0.90–2.90 mm/yr in regions of intense seismotectonic deformation (Crete, western coast of Turkey). Furthermore, the comparative study of the submerged ancient remains from Greece and Turkey, all falling within the same historical period, has confirmed that the RSL rise varies in different geotectonic contexts due to the differential vertical tectonic movements of the crust and is locally affected by fault activations (see Fig. 1b). Further data processing will enable assessing the amount of vertical tectonic movements and the resulting subsidence rates of that period.

Table 1 Archaeological sea-level indicators along the coast of Greece and western Turkey evaluated in this study. **Column A**: Number of site as shown on Fig. 1. **Column B**: Location, P: Peloponnese, C: Cyclades, Cr: Crete, F: Fethiye Gulf, Bz: Bozburun Peninsula. **Column C**: Type of archaeological indicator, pr.w./w: protective wall/wall, rf: rockfill, br: breakwater, b/b.c.: building/building complex, sl: slipway, s.d.: sea defensive works, q: quay, f.t.: fish tank, c/ch: cistern/channel, m: masonry, ws: workshop, p: pavement. **Column D**: Archaeological age, R: Roman, LR: Late Roman, EB/LB/PB/: Early/Late/Post-Byzantine, u.s.: as above. V: Venetian. **Column E**: Measured mean depth (m, bmsl), **Column F**: Related sea-level stand at the time of use (m, bmsl)

A	B	C	D	E	F
GR1	Palaiokastro, Methana (P)	pr.w./rf	PB	1.65–2.20	2.40 ± 0.20
GR2	Agios Athanassios (P)	br	LB or PB	2.00	2.60 ± 0.30
GR3	Thini (P)	br	LR (end 6c. AD)	2.05	2.65 ± 0.30
GR4	Valtaki (P)	w	u.s.	1.60 ± 0.10	2.40 ± 0.20
GR5	Mandilou Bay (P)	b.c.	LR-EB (6c. AD)	1.60 ± 0.10	2.40 ± 0.20
GR6	Poises (Keos, C)	sl	R	2.55–2.60	2.40 ± 0.20
GR7	Palaiopolis (Andros, C)	br/rf	R/EB (41AD-5c.)	2.00–2.40	2.40 ± 0.20
GR8	Exo Steno (Andros, C)	w/rf	R/LR	1.10/2.45	2.40 ± 0.20
GR9	Ancient Delos (C)	s.d.	LR	2.00–2.50	2.40 ± 0.20
GR10	Krotiri (Paros, C)	br	R/LR	1.60	2.40 ± 0.20
GR11	Paroikia (Paros, C)	b.c./rf	u.s.	1.75–2.35	2.40 ± 0.20
GR12	Chersonissos (Cr)	q f.t.	R (67 BC-395 AD)	1.00 1.20	1.25 ± 0.05

Table 1 (continued)

A	B	C	D	E	F
GR13	Mylos bay (Cr)	c/ch	B or V (961 AD - 1669)	0.70	1.25 ± 0.05
GR14	Poros Eloundas (Cr)	br/b	EB (395–824 AD)	1.00–1.30	1.25 ± 0.05
GR15	Psira island (Cr)	m	R/LR (67 BC-395 AD)	1.00	1.25 ± 0.05
GR16	Mochlos (Cr)	w f.t.	R or B (67–824 AD) R (1–200 AD)	~1.00 1.10–1.40	1.25 ± 0.05
GR17	Kouremenos (Cr)	br	R/LR (69 BC-400 AD)	1.20 ± 0.10	1.25 ± 0.05
GR18	Ferma (Cr)	f.t.	R (1–200 AD)	1.30	1.25 ± 0.05
GR19	Ierapetra (Cr)	br	R/LR (67 BC-395 AD)	0.30–1.30	1.25 ± 0.05
GR20	Stomio Ierapetra (Cr)	b/ws	R (1–200 AD)	1.20	1.25 ± 0.05
GR21	Matala Bay (Cr)	11 f.t.	u.s.	1.25 ± 0.05	1.25 ± 0.05
TR1	Göcek Bay (F)	b.c	LR/EB (5–7 c.)	2.10 ± 0.20	2.70 ± 0.50
TR2	Göcek Isl. (F)	q	u.s.	2.50 ± 0.10	3.10 ± 0.30
TR3	Zeytinli-Şeytan Isl. (F)	q	u.s.	2.40 ± 0.10	3.00 ± 0.30
TR4	Tersane Isl. (F)	p	u.s.	2.40 ± 0.10	3.00 ± 0.30
TR5	Domuz Isl., N (F)	q	u.s.	3.40 ± 0.10	4.00 ± 0.30
TR6	Domuz Isl., W (F)	q	u.s.	3.60 ± 0.10	4.20 ± 0.30
TR7	Hamam Bay (F)	b	u.s.	3.40 ± 0.20	4.00 ± 0.30
TR8	Şövalye Isl. (F)	q	u.s.	1.60 ± 0.10	2.20 ± 0.30
TR9	Gemiler Isl. (F)	q	u.s.	2.30 ± 0.10	2.90 ± 0.30
TR10	Ölüdeniz Lagoon (F)	b.c.	LR/EB (6–7 c.)	2.50 ± 0.20	3.10 ± 0.50
TR11	Bozburun Bay (Bz)	br	LR/EB (5–7c.)	1.00 ± 0.20	1.80 ± 0.40
TR12	Söğüt Isl. (Bz)	b/ws	u.s.	1.20 ± 0.20	1.80 ± 0.50
TR13	Söğüt Bay (Bz)	br	u.s.	0.70 ± 0.20	1.50 ± 0.40

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