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# Relative sea-level changes along the Fethiye coast (SW Turkey) based on recent archaeological data

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## Abstract

We investigated three coastal archaeological sites along the coast of Fethiye (south-western Turkey, eastern Mediterranean) to reveal relative sea-level changes that have occurred since early Byzantine times. Focusing on this little known period, the most recent archaeological data are presented here, providing new data for the history of sea-level changes. Current elevations of submerged archaeological remains relative to present sea level were measured, and relative sea-level change was determined, based on an approximation of the original elevation. The contemporary archaeological structures revealed three different sea levels in adjacent areas. Taking into account the time of the last use of the structures, instead of their time of construction, we suggest a relative sea-level rise at a minimum rate of 1.6 ± 0.3 mm/year for Şövalye Island, 2.1 ± 0.3 mm/year for Gemiler Island, and 2.2 ± 0.6 mm/year for Ölüdeniz Lagoon for the last 1400 years. A comparison of the study results and geoarchaeological data from nearby sites on the western coasts of Fethiye Gulf revealed the degree of sea-level change impact upon coastal archaeological sites. Results demonstrate that the seismically active Fethiye coast has been strongly influenced by the vertical tectonic movement since early Byzantine times.

**KEYWORDS**

Fethiye, sea-level changes, sea-level indicators, submerged archaeological sites, vertical tectonic movement

## 1 | INTRODUCTION

The coastal areas of the tectonically active Mediterranean Sea have been inhabited for thousands of years (Blake & Knapp, 2005; Walsh, 2014). The evidence of ongoing seismicity upon the maritime constructions of ancient coastal settlements is remarkable. These sites are commonly used as an indicator of sea-level change; however, the interpretation of the function of the archaeological marker is an important factor in providing reliable data on the amount of sea-level change (Benjamin et al., 2017; Evelpidou & Karkani, 2018; Morhange & Marriner, 2015).

The submerged archaeological sites located along the coast of south-western Turkey provide important data for relative sea-level changes. Several studies were carried out in recent years on sea-level changes and landscape evolution in this region (Desruelles et al., 2009; Öner & Vardar, 2018; Stock et al., 2020). Geoarchaeological investigations indicate that vertical land movement caused the submergence of coastal sites located along the coast of south-western Turkey during the Late Holocene (Blackman, 1973; Flemming, 1978; Özdaş & Kızıldağ, 2019). Fethiye, which is situated in the region of ancient Lycia, is remarkable for its coastal settlements that offer important sea-level data. The Lycian coast was populated with urban settlements, the harbors of which were active through the 6th century AD. Lycian prosperity continued until the Arab invasion of the 7th century AD (Tsuji, 1995). Following Clive Foss, who visited the Fethiye coast and published his archaeological observations for the first time in 1988 and 1994, in 1991, an archaeological project was begun in this region by a team from Japan and the Fethiye Museum (Malkoç & Tsuji, 2005). However, no geoarchaeological study of the region has yet been undertaken.

  

Comprehensive and large-scale sea-level studies from the Aegean Sea were published by Pavlopoulos et al. (2012) and Vacchi et al. (2014). Based on the previously published geological and archaeological data, Vacchi et al. (2014) presented a relative sea-level database for the NE Aegean Sea and identified the fastest rising rate at 0.9 ± 0.1 mm/year in the last 4.0 ka. Poulos et al. (2009) have constructed a sea-level curve for the past 5000 years for the tectonically stable Attico–Cycladic Massif (central Aegean Sea), with a rising rate of 0.9 mm/year, which is attributed to eustatic factors. However, the most recent sea-level study was published by Karkani et al. (2019), suggesting an average tectonic subsidence rate close to 1 ± 0.4 mm/year since 5500 cal BP for the Cyclades.

There is much information concerning relative sea-level change, but only a little data from the 7th century AD. Based on submerged harbor installations in the Saronic Gulf (in the western Aegean Sea), Kolaiti and Mourtzas (2016) identified the sea-level stability at −0.90 ± 0.15 m at the end of the 4th century AD, possibly even into the 6th century AD. Fouache et al. (2005) suggested that the relative sea level was about −1 ± 0.5 m in AD 1000, which was derived from submerged beach rocks in the Cyclades Islands (in the center of the Aegean Sea). Evelpidou et al. (2018) proposed a former sea-level position at −1.70 m, based upon a submerged tidal notch in Naxos Island, which corresponds to the stratum of tsunami dates in the middle of the 2nd century AD. Geoarchaeological study results from the city of Elaia (eastern Aegean Sea) have revealed that sea level was 0.4–0.6 m lower than today in AD 500, while the silting of the ancient harbors contributed to the decline of the city in late Roman times and its eventual abandonment after that time (Seeliger et al., 2017, 2019). The researchers detected submerged walls in Elaia, dated to 4th and 6th centuries AD, and interpreted them to be the remains of salt works, with the central portion located about 0.8 m below the present sea level (Seeliger et al., 2014). As for Fethiye, the sea-level evolution of the western coasts was recently investigated, and three rates of relative sea-level rise of 2.18 ± 0.3 mm/year; 2.96 ± 0.3 mm/year; and 3,29 ± 0.5 mm/year were presented for the last 1400 years (Kızıldağ, 2019).

This article aims to evaluate the relative sea-level changes that have occurred since early Byzantine times at Fethiye based on geoarchaeological data from three submerged archaeological sites: Şövalye Island (recently discovered), Gemiler Island, and Ölüdeniz Lagoon (both previously known but new insight is presented here; Figure 1d). Three different sets of sea-level data from these contemporary and adjacent sites are presented at Fethiye, focusing on little-known sea-level history since the 7th century AD.

# 2 | REGIONAL SETTINGS

## 2.1 | Tectonic framework

The study area is located between the Fethiye outer harbor and the Ölüdeniz lagoon in the eastern Mediterranean Sea (Figure 1). This region is under the influence of an active tectonic framework, which is controlled by the collision of the Arab-African and Eurasian plates (Dewey & Şengör, 1979) (Figure 1a). The study area is located between the south-western end of the Fethiye–Burdur Fault Zone (FBFZ) and the eastern part of the Pliny and Strabo Trenches (PST), which have caused numerous earthquakes during both historical and instrumental periods (Hall et al., 2009; Figure 1b). NE–SW trending faults run parallel to the PST, extending to Fethiye Gulf and connecting with FBFZ (Barka & Reilinger, 1997; Hall et al., 2014; Taymaz & Price, 1992; Figure 1c). Seismic data indicate that the Fethiye Canyon (off Fethiye Gulf) forms the northeastern extension of the Pliny Trench (PT), linking this basin to FBFZ (Ocakoğlu, 2012).

During historical times, active tectonism gave rise to a large number of destructive earthquakes, which affected the many archaeological sites located on FBFZ (Erel & Adatepe, 2007; Guidoboni et al., 1994; Yolsal et al., 2007; Table 1). The earthquakes that occurred at the beginning of the 6th century and the middle of the second half of the 7th century damaged the ancient city of Sagalassos (Similox-Tohon et al., 2005). The destructive earthquakes (6.1 ≤ Ms ≤ 7.1) between 1957 and 1959 indicate active tectonism in the region (Akyüz & Altunel, 2001; Görgün et al., 2014; Figure 1b). The most recent earthquake activity occurred off Fethiye Bay on June 10, 2012, which had a mainshock of Mw = 6 due to activation of NW–SE trending left-lateral strike-slip fault (Görgün et al., 2014). On the other hand, Doğan et al. (2016) suggested that oblique faulting connected with NW–SE extension, which forms the area between Fethiye Bay and the Rhodes Basin, is dominant.

## 2.2 | Archaeological framework

The city of *Telmessus* (modern Fethiye) was a major settlement of the Lycian region of Asia Minor dating back to the 4th century BC (Bean, 1978). Prosperity from agricultural activity due to the advantageous geographical location of Lycia gave rise to an expansion of coastal trade and settlements, which, in turn, created an increase in architectural construction (Tsuji, 1995). The Lycian coastline also has numerous inlets and promontories that provide sheltered anchoring spots for ships. As a result, beginning in the Hellenistic period and continuing through the early Byzantine period, Lycian cities played an important role in maritime trade (Harrison, 1963).

Archaeological remains clearly indicate that during the early Byzantine period, the number of settlements increased, and sea peoples settled in previously unoccupied regions (Bean, 1978; Elton, 2019, Foss, 1994). Several Lycian islands (e.g., Domuz Island, Tersane Island, and Gemiler Island) provide remarkable examples of such expansion, for which the primary characteristics are the presence of churches, the absence of earlier constructions, and discontinuity in settlement occupation (Elton, 2019; Kızıldağ, 2019). With the arrival of Christianity, a remarkable change in the politics, culture, and economy of the region began in the 4th century AD. Numerous churches were constructed in almost every rural settlement from this period onwards, associated with prosperity (Tsuji, 1995; Table 1). These churches generally conform to early Christian and early Byzantine basilica-type church construction with three aisles, commonly found on the Mediterranean coasts of Asia Minor and Greece (Harrison, 1963; Malkoç & Tsuji, 2005).

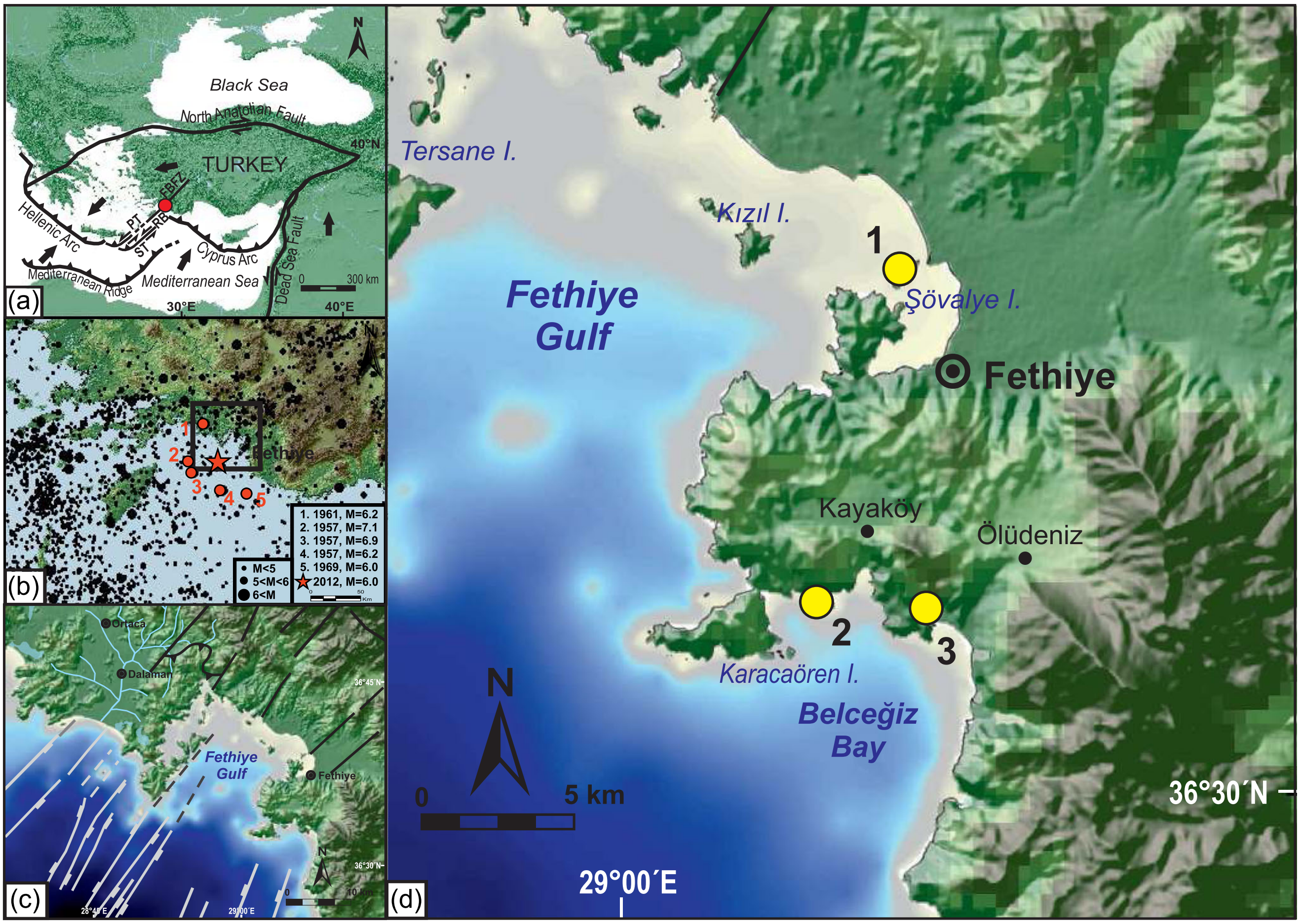


**FIGURE 1** Location maps. (a) Main tectonic features of the eastern Mediterranean Sea (modified from Barka & Reilinger, 1997), FBFZ: Fethiye-Burdur Fault Zone, PT: Pliny Trench, ST: Strabo Trench, RB: Rhodes Basin, thick arrows indicate plate motion direction, half arrows indicate strike-slip faults, triangles indicate subduction zones, red symbol indicates study area; (b) seismicity of the study area and its surroundings (data from AFAD, USGS, and NCEDC), rectangle indicates Figure (c) major faults around the Fethiye Gulf (modified from Bozcu et al., 2007; Hall et al., 2014; Ocakoğlu, 2012); (d) the location of the investigated sites: (1) Şövalye Island; (2) Gemiler Island; and (3) Ölüdeniz Lagoon [Color figure can be viewed at wileyonlinelibrary.com]

During the following two centuries, the size of the settlements increased, especially in the coastal areas, until they were affected by ongoing earthquakes, plague, and the Arab invasions during the 6–7th centuries AD (Atik et al., 2012; Erel & Adatepe, 2007; Zampaki, 2012; Table 1). While the Justinianic plague of AD 542 was a significant factor for urban decline, the Arab invasions in the mid-7th century AD were a major factor in the abandonment of the coastal sites (Elton, 2019; Zampaki, 2012). Coins found on Gemiler island confirm that the occupation ended in the 7th century AD (Foss, 1994).

## 3 | MATERIALS AND METHODS

As part of a long-term project of documenting underwater cultural heritage along the Turkish coast, three submerged archaeological sites were investigated to estimate the relative sea-level change on the coast of Fethiye. Our study was primarily focused on taking aerial photos, measurements of the current elevations of structures, recording minimum original elevations, and developing a dating approach for submergence.

The first step involved taking aerial photos and creating photomosaic images for each of the sites to provide preliminary plans and therefore determine the distribution of the submerged remains (Figure 2). Aerial photos were taken with a DJI Inspire 1 Pro with a Zenmuse X5 16MP 30 s camera, and photomosaics were generated by using Agisoft Metashape software (Agisoft LLC.).

The current elevations of the remains with respect to the present mean sea level were measured through scuba dives, and the finds were located using a JRC model differential global positioning system receiver. All measurements were taken during favorable weather in good sea-surface conditions and corrected for tidal range (the average amplitude is ~0.3 m; http://www.psmsl.org/data/obtaining/rlr.monthly.data/1243.rlrdata). Nevertheless, some error estimation for the elevation measurements of the archaeological remains was added, which could be derived from the accuracy of measurements (Vacchi et al., 2016); and the condition of the measured surface (e.g., visible or

**TABLE 1** Important historical events that occurred in the study area and its surroundings

| Date | Event | Period | Location | References |
|---|---|---|---|---|
| 4th century AD | Arrival of Christianity | Prosperity | Lycia | Foss (1994), Tsuji (1995) |
| 344 | Earthquake (I = IX) | Prosperity | Rhodes | Erel and Adatepe (2007) |
| 365 | Earthquake (I = X–XI) | Prosperity | Crete, E. Mediterranean | Altınok et al. (2011) |
| 417 | Earthquake (Io = IX) | Prosperity | Cibyra | Akyüz & Altunel (2001) |
| 528 | Earthquake (I = IX) | Prosperity | Fethiye, Meis | Erel and Adatepe (2007) |
| Mid-6th century AD | Justinianic plague | Decline | Entire Mediterranean | Elton (2019) |
| 554 | Earthquake (I = X) | Decline | SW Anatolia, Kos | Altınok et al. (2011) |
| 6th–7th century AD | Earthquake activity | Abandonment | Sagalassos | Similox-Tohon et al. (2005) |
| Mid-7th century AD | Arab invasions | Abandonment | Asia Minor | Elton, (2019), Zampaki (2012) |
| 1851–1870 | Earthquake (VII ≤ I ≤ IX) | Modern occupation | Fethiye | Erel & Adatepe (2007) |
| 1957–1959 | Earthquake (6.1 ≤ Ms ≤ 7.1) | Modern occupation | Fethiye Gulf | Görgün et al. (2014) |
| 2012 | Earthquake (Mw = 6) | Modern occupation | Fethiye Gulf | Görgün et al. (2014) |

*Note*: Earthquakes in the historical and instrumental periods were compiled from the literature and various catalogs (I = seismic intensity in MM (I–XII), M = magnitude (2–8)).

buried, protected or damaged) was taken into consideration. Although harbor installations are good indicators for sea-level change, they have some limitations when determining whether the current position of the upper surface of the installations represents the original surface at the time of construction (Benjamin et al., 2017). However, we decided that the original surface should be measured, taking into consideration the uncollapsed regular surfaces, both of them extending for meters at nearly the same level and also those underlying the building foundations. We assumed that the buildings must have been constructed above the upper surface of the quay platform. No later reparation or other construction activity was observed on the surface. Due to the fact that each site is located in a well-protected area, no measurement difficulties were encountered due to wave effects. Thus, we added a vertical error of ± 0.1 m to the measurements taken from the preserved and clear surfaces (e.g. on distinctive stone blocks of quays), ± 0.2 m for the surfaces covered by rubble stones (e.g., the foundation levels of buildings at Şövalye and Gemiler sites), and ± 0.3 m for the unpreserved and unclear surfaces covered by both rubble stones and sedimentation (e.g., the base level of buildings at the Ölüdeniz site).

To estimate the amount of relative sea-level change, we defined a minimum original elevation for the structures with respect to the mean sea level at the time of their use. Identifying the function of the remains is a critical factor in defining an original elevation (Evelpidou & Pirazzoli, 2015; Morhange & Marriner, 2015). In this case, it was important to determine the relationship with the former sea level to reconstruct sea-level changes and define archaeological zonation considering three categories: submerged zone, interface structures zone, and emerged structures zone, which affect the degree of reliability of the archaeological indicators (Morhange & Marriner, 2015). Interface structures of harbors (e.g., quays and docks) and fish tanks are accepted as reliable indicators when compared to emerged structures that are not directly related to the former sea level (e.g., buildings and roads; Evelpidou & Karkani, 2018; Morhange & Marriner, 2015; Vacchi et al., 2016). For the estimation of relative sea-level change, we took into account quay structures among the submerged remains at the Şövalye and Ölüdeniz sites, since their function is directly related to sea level. A minimum original elevation of 0.6 m was assigned for the upper surface of the quays, taking into consideration (i) protection against wave action, (ii) small tidal range, and (iii) the draft for the landing of small boats (e.g., the Ravenna ship from 5th century AD had a draft about 0.5 m; while Yenikapı merchant ship from 7th century AD had a draft of 1 m at full load; Aucelli et al., 2016; Ingram, 2018; Medas, 2003). An error of ± 0.2 m was added for the uncertainty of the original elevation approximation for the quays, which was assumed on the basis of different interpretations presented by various sea-level studies.

Due to the possibility of an absence of harbor structures (e.g., Ölüdeniz site), we used building foundations as indicators. Vacchi et al. (2016) used these archaeological markers as terrestrial limiting points, arguing for their importance in constraining the relative sea level above or below the terrestrial or limiting point. Due to the lack of evidence for an accurate position in relation to the past shoreline, our original elevation assumption was based on the fact that the buildings were constructed upon the quay platform at adjacent sites at the Şövalye and Gemiler sites, and therefore the original elevation of the building foundation would have been at least as high as the upper surface of quay (i.e., 0.6 m). Hence, for the Ölüdeniz site, we assigned the same original elevation with a minimum error of ± 0.3 m for the uncertainty of the function, based on sea-level studies (e.g., Scicchitano et al., 2008).

After determining the position of the past sea level based on archaeological indicators and bathymetric data, the maximum shoreline transgressions were mapped for each site. The bathymetric data were obtained from a single-beam echosounder survey for the Şövalye and Gemiler sites and from the Office of Navigation,

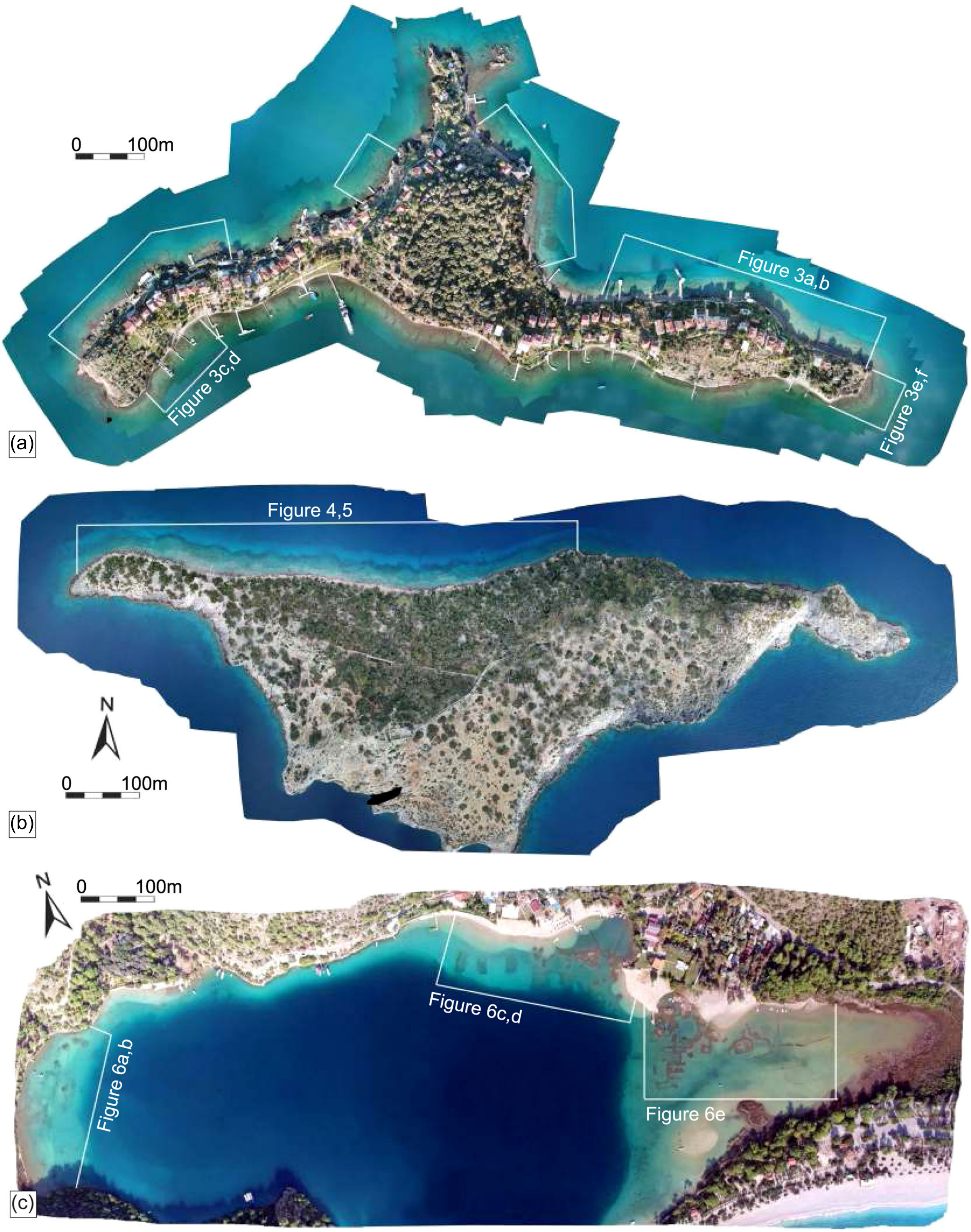


**FIGURE 2** The photomosaic images created from aerial photos. (a) Şövalye Island; (b) Gemiler Island; and (c) Ölüdeniz Lagoon. White lines indicate the investigated areas covered with submerged archaeological remains, where the measured structures are located [Color figure can be viewed at wileyonlinelibrary.com]

Hydrography, and Oceanography of Turkey for the Ölüdeniz site. In the final stage, instead of using construction time for our calculations, we determined the rate of relative sea-level change based on the time of the last use of the constructions when the structures were still functional. Considering the fact that the sites were never used after abandonment, we assessed the time of the last usage based on archaeological data and literature regarding the abandonment date (Kızıldağ, 2019). This provides a more precise estimation and data about the earliest period of submergence.

## 4 | RESULTS

### 4.1 | Şövalye Island site

The entrance to the harbor of Fethiye (called the gulf of *Macre* or *Makri* after the 10th century) is protected by Şövalye Island (also called *Palaio Makri* or Cavalier Island; Figure 1d, No. 1). Şövalye Island was inhabited in early Byzantine times and had churches, private buildings, and three fortresses that were likely to control the harbor (Foss, 1994). Today, the site is heavily damaged by modern construction. The entire coastline of the island is full of submerged architectural remains, which provide useful indicators for sea-level changes (Figure 2).

A large number of foundations belonging to rectangular buildings on the quay platforms are currently submerged (Figure 3a). The foundations of buildings constructed with mortared rubble are located 1.55 ± 0.2 m below the present sea level (Figure 3b). Some parts of the walls are buried among the rubble stones. The remains of a partly submerged church were found on the south-western coast of the island (Figure 3c,d). A building complex, for which the function is unclear, was observed on the north-east coast (Figure 3e,f).

The quays consist of rough-cut stone blocks mixed with mortar. The most well-preserved and visible upper surface of the quays lies at a maximum depth of 1.63 ± 0.1 m below present sea level, while the bottom level lies at −2.40 ± 0.2 m (Table 2). The width of the largest monolithic quay reaches 50 m, the seaward end of which is located 30 m away from the modern shoreline. The quay constructions can be observed on the north-western coast of the island, which is open to the wind.

The concreted remains are covered with a dense plant layer. In addition, modern anchorage and construction activities have contributed to increasing damage to the archaeological structures. Several modern wharves have been built upon the submerged walls (Figure 3c). Construction debris was deposited upon the remains, and original stones have been removed, most probably for reuse. This damage makes it hard to understand the function of the buildings and the original site plan.

To determine the relative sea-level change for the Şövalye site, we considered the upper surfaces of the quay structures, which provide more accurate data. Considering that the minimum original elevation of the quays was defined as 0.6 ± 0.2 m, we suggest that the sea level must have risen by at least 2.2 ± 0.3 m.

### 4.2 | Gemiler Island site

Gemiler Island (*Lebissos*, or St. Nicholas Island) is located in Belceğiz Bay, about 20 nautical miles south of Fethiye (Figure 1, No. 2). The northern coast of the island is well-protected from winds, extending for about 1.2 km, east to west. The island was densely populated in the 6th century AD but was not occupied before this time (Foss, 1994; Tsuji, 1995). It is completely covered with the remains of churches, cisterns, private buildings, and storage buildings, mostly mortared rubble and rock-cut coastal constructions. Foss (1994) suggested that occupation at *Lebissos* continued into the early 7th century AD, inferred from the discovery of Heraclius coins. In addition, Arabic graffiti show that the site was occupied during an invasion. Based on ceramic finds, Tsuji (1995) reported that human activity on the island stopped abruptly at the end of the early Byzantine period. The site was never reoccupied after it was abandoned.

This intensive habitation on such an isolated island must have required extensive use of harbor facilities. Indeed, the coastal remains extend for about 600 m along the northern shore, which provides safe anchorage, protected from winds that blow from the south. The partially or totally submerged remains consist of quays, building foundations, rock-cut building floors, cisterns, rock-cut stairways, and water channels that are clearly visible (Figures 2b and 4). The foundations of rectangular buildings overlie the quay platform at a maximum depth of 2.25 ± 0.2 m (Figure 5a,b). The platform is covered by cemented materials, rubble stones, and a partial plant layer.

Two or three rows of rough-cut stone blocks that are mixed with mortar (approximately 1.0 m × 1.5 m and 1.5 m × 2.5 m in size) form the quay constructions (Figure 5b,c). The most deeply submerged upper surface of the quay lies at −2.32 ± 0.1 m (Table 2). The water depth reaches 3.54 m at its base.

Taking into account the fact that the building foundations are located directly upon the quay platform, and the quay blocks are preserved and uncollapsed, the uppermost surface of the quay blocks is considered to represent the original surface. The longest monolithic quay platform extends about 25 m, and its seaward end is located about 20 m from the modern coastline (Figure 4a). A submerged platform, which lies beneath the remains, can be distinguished in echosounder data (Figure 5d). A flat surface lying between the modern coastline and the seaward end of the quay installations, corresponding to a paleo-terrace, indicates a approximately 20 m shoreline transgression. Taking into account the assumed original elevation for the quay, we suggest a relative sea-level rise of 2.9 ± 0.3 m for the Gemiler site.

### 4.3 | Ölüdeniz Lagoon site

The Ölüdeniz site, located about 2 nautical miles eastward from Gemiler Island, is a well-sheltered lagoon, unlike the other sites (Figure 1, No. 3). A remarkable sand bar created by a high rate of

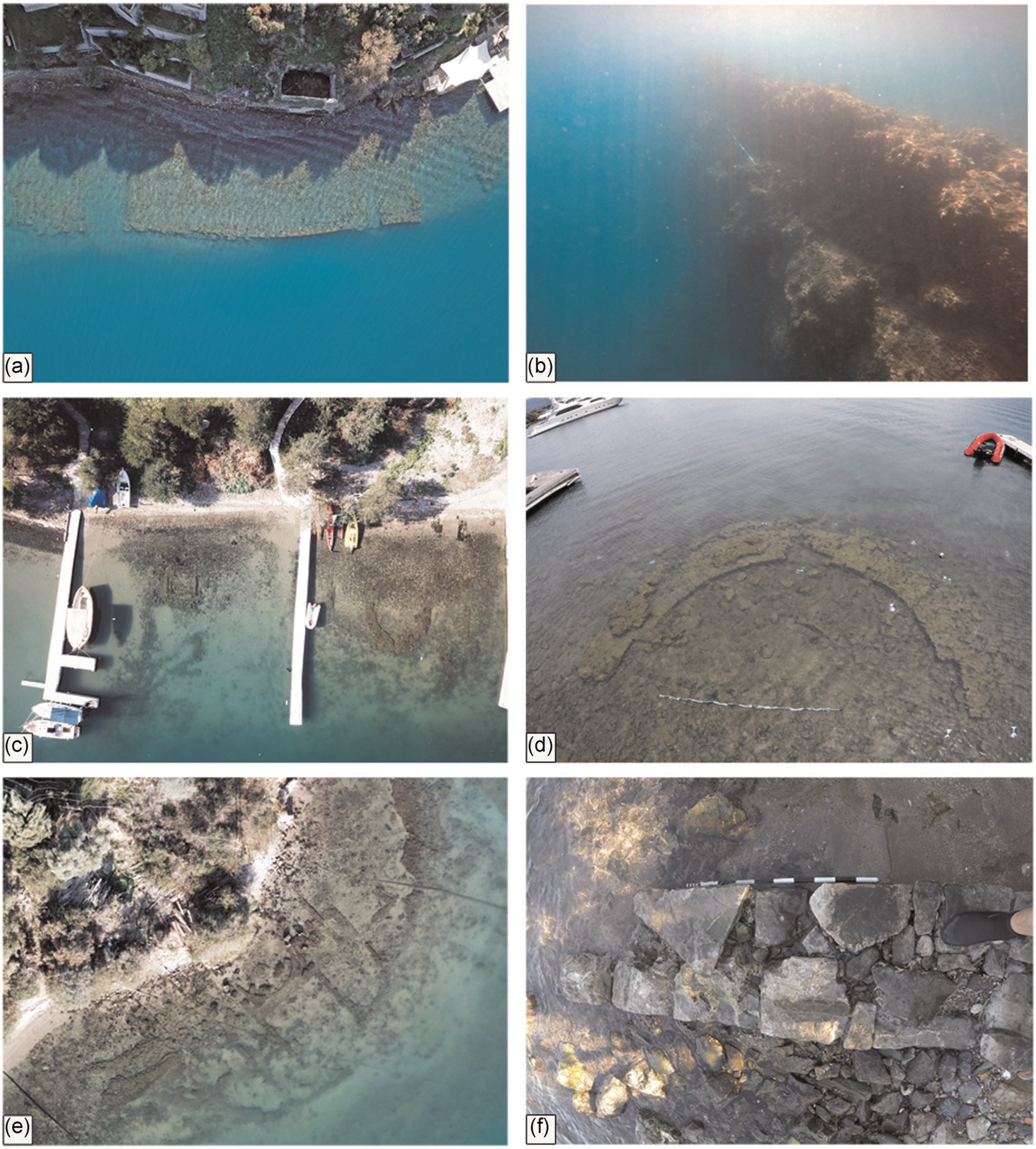


**FIGURE 3** The main submerged remains at Şövalye Island: (a) a monolithic quay platform and the building foundations at its top; (b) the foundations of a rectangular structure, covered with a plant layer; (c) a rectangular structure (left) and a church (right); (d) the apse of the church; (e) a partly submerged building complex; (f) landward wall remains of the building complex [Color figure can be viewed at wileyonlinelibrary.com]

sediment input narrows the entrance of the lagoon. Three churches on land confirm religious activity in this region in the 6th and 7th centuries AD (Malkoç & Tsuji, 2005; Tsuji, 1995). Between Karacaören and the modern village of Ölüdeniz, 11 early Byzantine churches are located along the length of a 14 km coast, demonstrating that this region was a center for religion. A little known site here has been identified based on topographical studies and remarks by Spratt (1811–1888; Tsuji, 1995) as the ancient port of the *Symbolon* or *Symbola* settlement.

**TABLE 2** Current elevations of contemporary submerged archaeological remains with measurement errors

| Site no. | Site name | Time of the last use | Type of indicator | Upper level (m) | Bottom level (m) |
|---|---|---|---|---|---|
| 1 | Şövalye Island | 7th century AD | Building foundation | | −1.55 ± 0.2 |
| | | | Quay | −1.63 ± 0.1 | −2.40 ± 0.2 |
| 2 | Gemiler Island | Early 7th century AD | Building foundation | | −2.25 ± 0.2 |
| | | | Quay | −2.32 ± 0.1 | −3.54 ± 0.2 |
| | | | Water channel | | −2.10 ± 0.2 |
| 3 | Ölüdeniz Lagoon | 7th century AD | Building foundation | | −2.47 ± 0.3 |

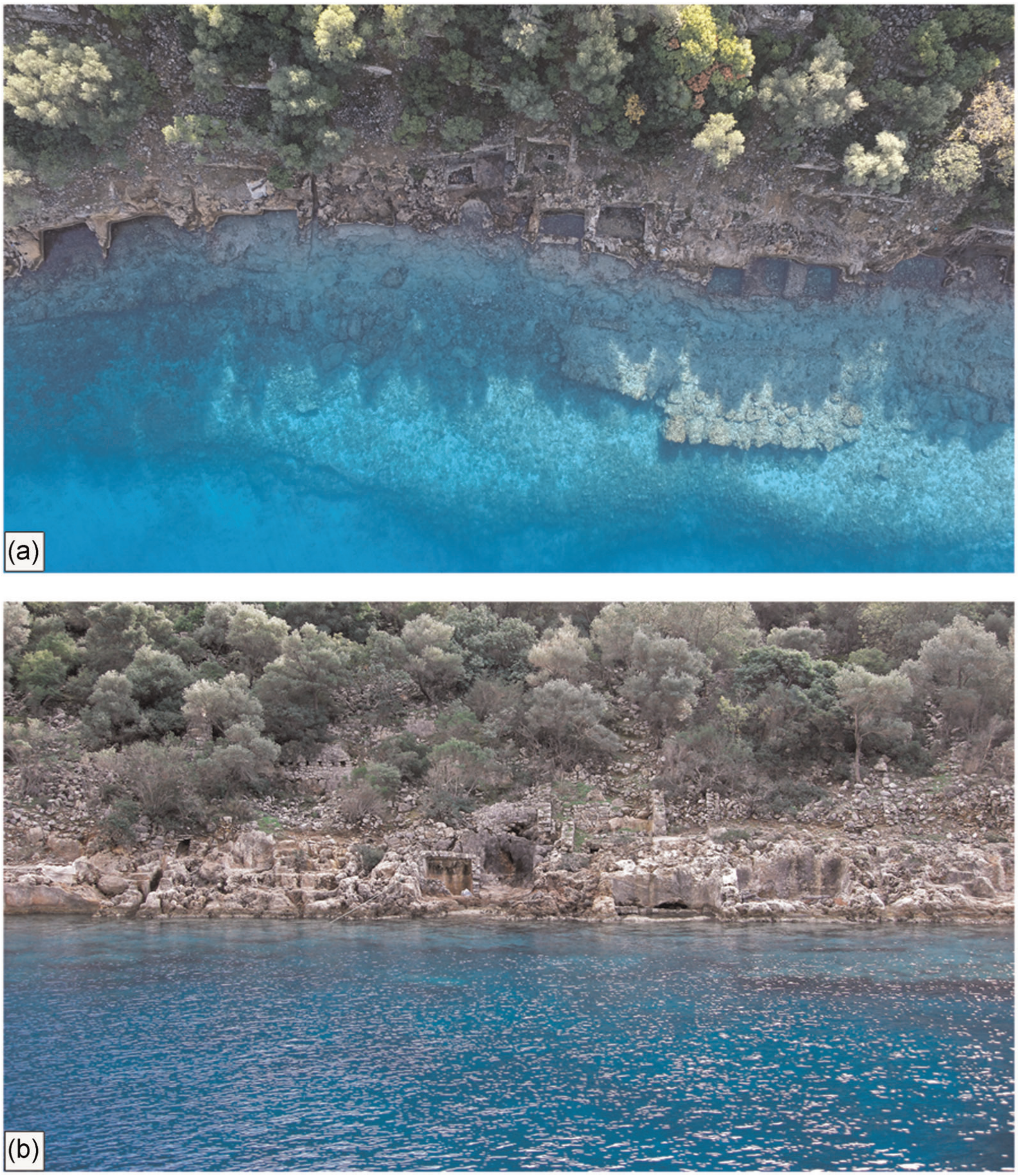


**FIGURE 4** Partially or totally submerged remains of Gemiler Island. (a) aerial image of the quay and rock-cut building remains; (b) land extensions of the submerged remains [Color figure can be viewed at wileyonlinelibrary.com]

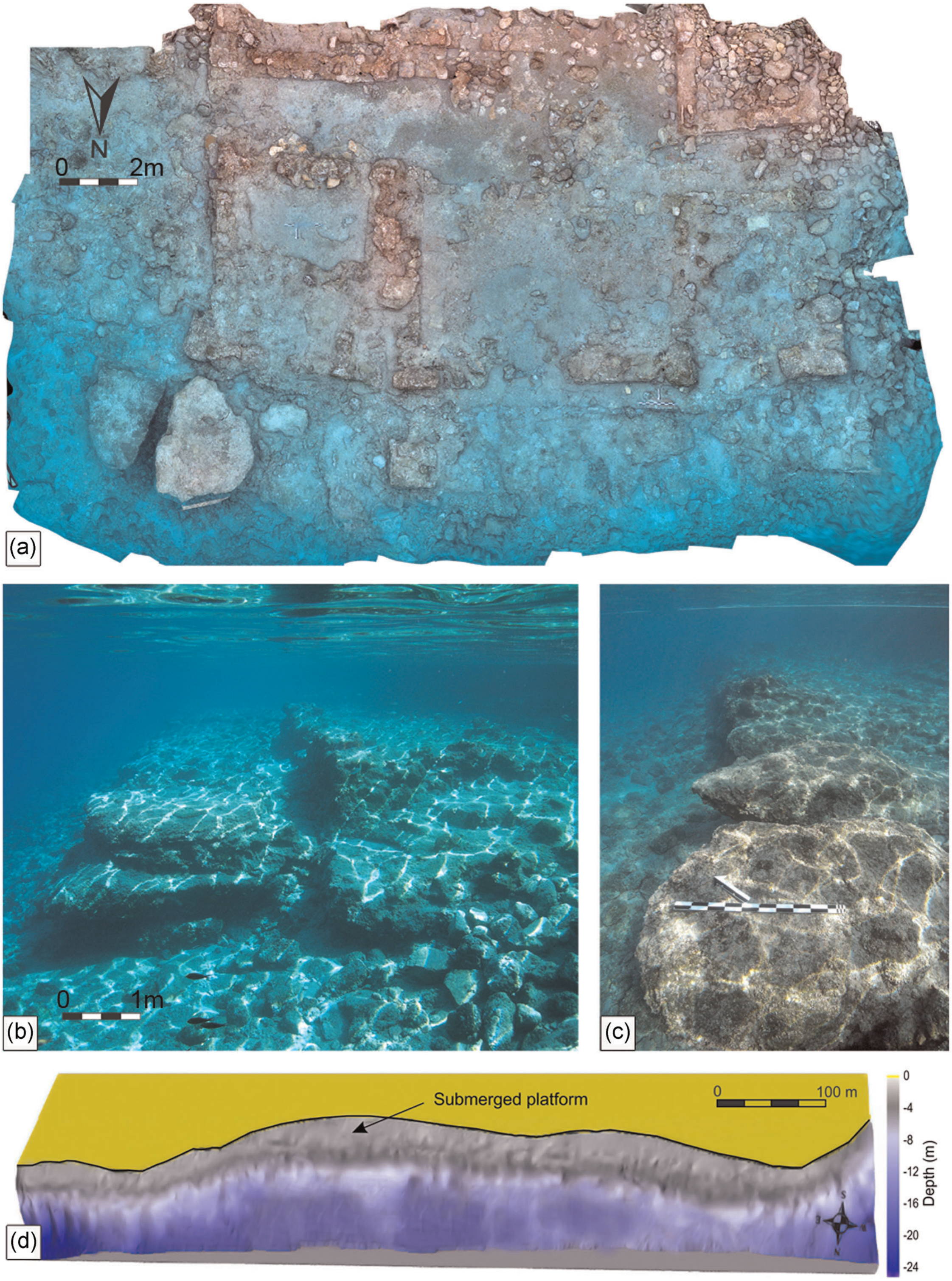


**FIGURE 5** Gemiler Island: (a) photomosaic image of the submerged building structure; (b) building the foundation upon the quay platform; (c) preserved quay blocks; (d) seafloor morphology inferred from echosounder data [Color figure can be viewed at wileyonlinelibrary.com]

Submerged and also partly buried, poorly preserved building-complex structures were found in the lagoon (Figure 2c). Due to high sedimentation and reclamation, only a few foundation blocks of the buildings survived, which makes it challenging to identify the function of the installations. No quay remains were observed, probably due to the well-protected location.

The most visible rectangular structure, 4.7 m × 8.8 m in size, is situated in the eastern part of the lagoon (Figures 2c and 6a,b). The seafloor at the base lies at a depth of 2.1 ± 0.3 m. A large rectangular structure with two rooms (25 m × 45 m) is located to the south at the same depth. Three rectangular building foundations are located on the northern shore (Figures 2c and 6c,d).

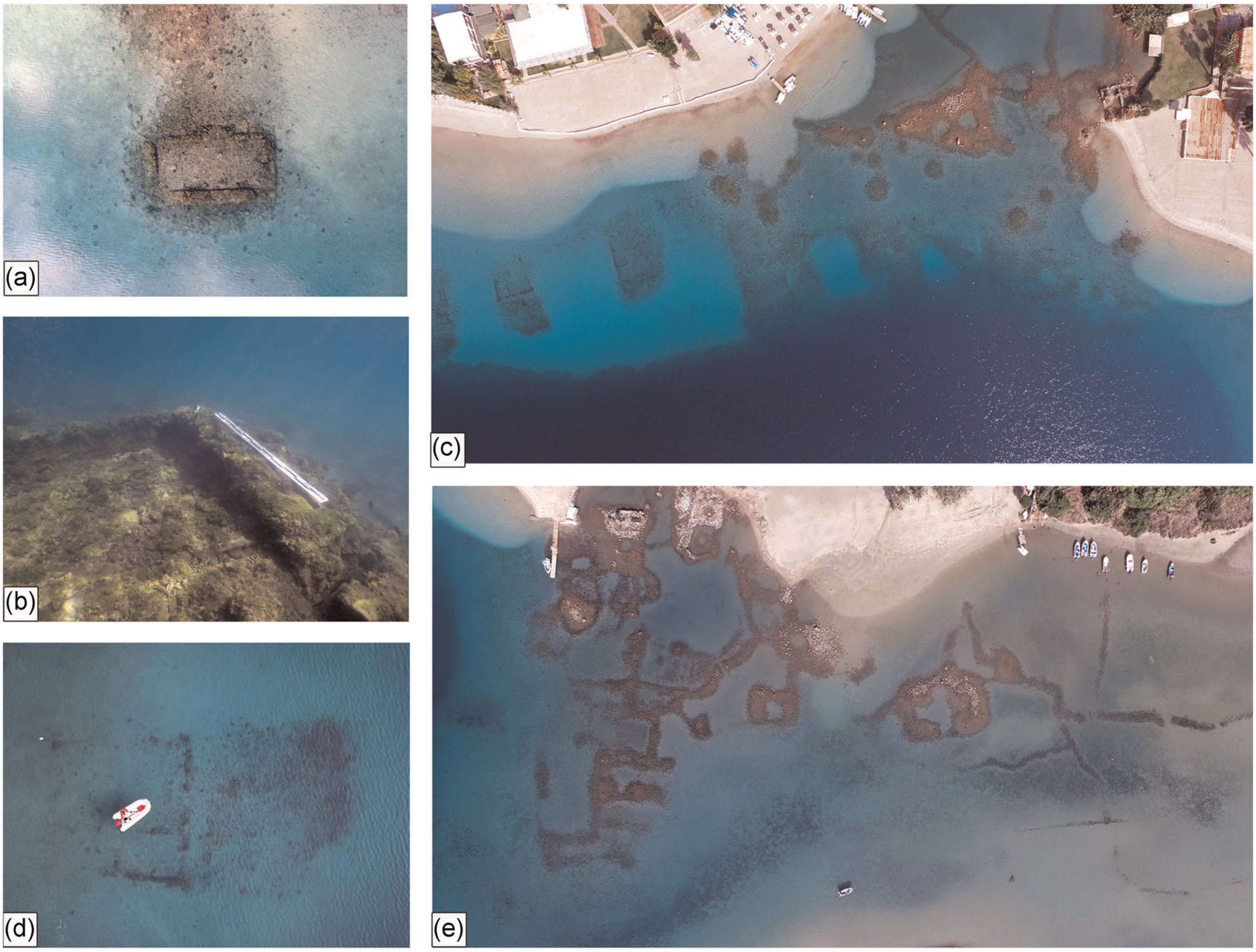


**FIGURE 6** Submerged remains in Ölüdeniz Lagoon: (a) aerial photo of a rectangular building in the western section; (b) underwater image of the same structure; (c) partially and totally submerged building foundations in the northern section; (d) a detailed image of a building in this part; (e) partially and totally submerged building complex and beach rocks in the eastern section [Color figure can be viewed at wileyonlinelibrary.com]

The dimensions of visible parts are about 12 m × 40 m in size (the landward extensions cannot be confirmed). The deepest foundation was measured at −2.47 ± 0.3 m (Table 2). The eastern side forms the deepest part of the lagoon. Here, an area of 140 m × 160 m is covered by a building complex of rectangular composite structures and connection walls, which may constitute the remains of bath or church installations (Figure 6e).

The width of walls built by mortared rubble ranges from 0.4 m to 0.8 m. Very small fragments of roof tiles are the only ceramic findings, and they are unfortunately not useful for dating. In addition to the building techniques of the poorly preserved remains, archaeological constructions on the adjoining mainland provide data for dating. It is clear that the lagoon only began to be occupied in the early Byzantine period. Taking into account the deepest measurement of 2.47 ± 0.3 m, and assuming that the base level would have been at least 0.6 ± 0.3 m above mean sea level, we propose that the relative sea level has risen by minimum 3.1 ± 0.6 m at the Ölüdeniz site. Since early Byzantine times, approximately 120 m, 80 m, and 500 m of shoreline transgression have occurred in the western, northern, and eastern portions of the lagoon, respectively.

## 5 | DISCUSSION

The accuracy of estimating the degree of relative sea-level change depends on defining the original elevation for the architectural constructions with respect to the mean sea level at the time of their use. The primary concern is describing the function of the archaeological sea-level indicator to determine an original elevation (Evelpidou & Pirazzoli, 2015; Morhange & Marriner, 2015). Although harbor structures provide more reliable sea-level data (Evelpidou & Karkani, 2018; Morhange & Marriner, 2015; Vacchi et al., 2016), building installations could be a reasonable indicator in some locations. For instance, the Lycians, who were a maritime society, preferred to establish settlements in sheltered regions, directly using the coastline where the geographical conditions were quite suitable for such occupation. In this case, the environment is

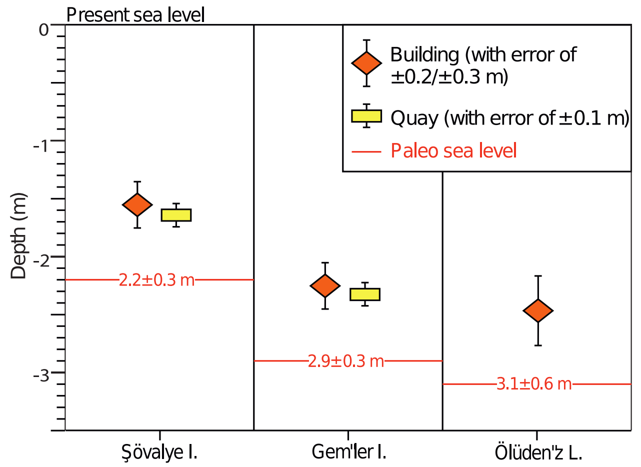


**FIGURE 7** Current elevations of archaeological indicators, which were still functional in the 7th century AD. Symbols include vertical error for measurement [Color figure can be viewed at wileyonlinelibrary.com]

the key factor. It is clear that since the Ölüdeniz site is a well-protected lagoon, the buildings have been directly constructed upon a coastal plain (Figure 2c) very close to the coastline, without the need of a quay. As for Gemiler Island, the sheltered side was used for coastal constructions (Figure 2a,b). It is notable that the buildings have been constructed on a platform of 2–3 rows of the same rough-cut stone blocks seen in the quays at the Şövalye and Gemiler sites. This indicates that buildings were located at the same level as the quay platform, which shows similarities to other Lycian sites (Kızıldağ, 2019; Özdaş & Kızıldağ, 2013). This supports the argument that the foundations of buildings may be used as a sea-level index point for the Lycian coasts by assigning a minimum original elevation with a more significant error margin than that determined for the quays. Such structures are directly related to the former sea level in the well-protected Lycia region. Although the operational function of the installations in the Ölüdeniz lagoon is undefined, it is clear that the structures built directly on the shore must have been related to maritime activity in this protected lagoon.

In addition, most of the remains were buried by sedimentation as well as damaged by modern construction activities at the Ölüdeniz site, which makes the function of the installations unclear. There is a necessity for further excavation-based studies to overcome these difficulties of interpretation. Due to the permit restrictions of this survey, we could only evaluate findings from surface remains. The structures might be church or bath complexes, residential buildings, or they might be used as storage or salt tanks, even snail or fish tanks, which would support the idea of building directly on the coastline. Therefore, we assigned a minimum original elevation based on the assumption that they must be directly related to sea level; however, we assigned a more significant error compatible with previously published sea-level studies (e.g., Scicchitano et al., 2008).

Besides defining the original elevation and the function of the remains, the accuracy of the dating is an important factor in providing a more precise estimation of the rate of relative sea-level rise. Some errors may arise when determining the dating of an archaeological structure due to long-term use. In this paper, we propose a minimum rate of sea-level rise based on the minimum original elevation and earliest date of the last operation, instead of their time of construction. Archaeological data, historical documents, and the literature indicate that early Byzantine construction activities at the coastal and island settlements of the Fethiye began in the 4th century AD and continued into the 7th century AD (Foss, 1994; Tsuji, 1995). The constructions by the sea, especially on the islands, must have been in use during this period, preserving their function. The region was abandoned after this period, mostly due to Arab invasions in mid-7th century AD, which were accompanied by destructive seismic events. The presence of LR1- and LR2-type amphora sherds (dated between 5th and 7th century AD) among the submerged archaeological remains at nearby sites verifies that the sites were in use in the 7th century AD and that the submersion occurred in the last 1400 years (Kızıldağ, 2019).

The main similarities across the three sites include the presence of early Byzantine era churches on the coastline and the adjacent land, the lack of public buildings (e.g., theater, gymnasium, and agora), and the artifacts or architectural remains from earlier occupation (Foss, 1994). All sites are notable for their maritime and religious activities. Three churches on the Ölüdeniz coastline confirm activity in this region in the 6th and 7th centuries AD (Malkoç & Tsuji, 2005; Tsuji, 1995). Likewise, the ceramic finds reveal that human activity on Gemiler Island stopped suddenly at the end of the early Byzantine period (Tsuji, 1995). Foss (1994) suggested that occupation on Gemiler Island continued into the 7th century AD. The author inferred this from finds of Heraclius coins and the fact that the site was never reoccupied and the buildings were never rebuilt after abandonment. The churches and buildings on Şövalye Island are similarly dated to the same period.

The submersion of contemporary coastal archaeological structures led to the identification of three different sea levels along the Fethiye coast (Figure 7). Taking into account the original elevation and the last time of use for the constructions, the relative sea-level changes were determined to be at least 2.2 ± 0.3 m for the Şövalye site, 2.9 ± 0.3 m for the Gemiler site, and 3.1 ± 0.6 m for the Ölüdeniz site since the 7th century AD (Figure 8). We propose that a maximum shoreline transgression of 30 m, 20 m, and 500 m, respectively, for Şövalye Island, Gemiler Island, and Ölüdeniz Lagoon has occurred since early Byzantine times (Figure 9).

Sea-level studies carried out in the Aegean Sea suggest different sea-level positions after the Late Roman period. Kolaiti and Mourtzas (2016) identified sea-level stability at −0.90 ± 0.15 m at the end of the 4th century AD in the Saronic Gulf, while Fouache et al. (2005) suggested that the relative sea level was about −1 ± 0.5 m in AD 1000 in the Cyclades Islands. A former sea level was found at −1.70 m in the 2nd century AD on Naxos Island (Evelpidou et al., 2018). A comparison of this previously recorded data from the Aegean Sea to the estimates of the present survey reveals substantial differences, which are mostly due to vertical land movement. As for Gemiler Island, sea-level data proposed by Anzidei et al. (2011) can be considered consistent with our results, although the dating and the measurement are not coherent, mostly due to the approach used

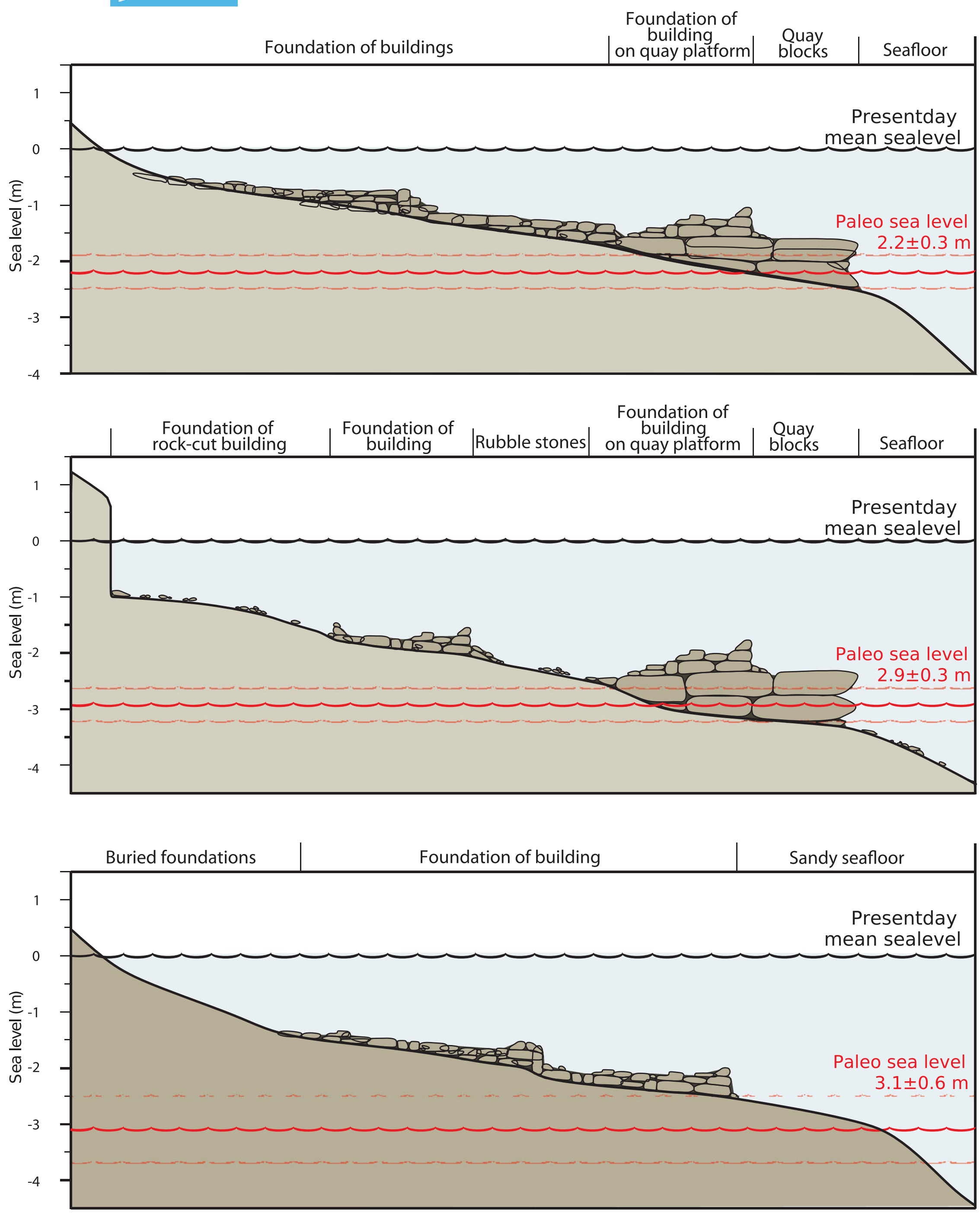


**FIGURE 8** Representative cross-sections of submerged remains in (a) Şövalye Island; (b) Gemiler Island; and (c) Ölüdeniz Lagoon, showing the minimum position of paleo sea level in the 7th century AD [Color figure can be viewed at wileyonlinelibrary.com]

in dating (the time of the structures' last use vs. construction time). A geoarchaeological study from the Turkish Mediterranean coast proposed a relative sea level of at least 2.8 m deeper than today during the late 6th to early 7th century AD (Özdaş & Kızıldağ, 2013).

Sea-level indicators suggest that the eustatic component of relative sea-level change has been negligible in the Mediterranean since the Roman period, and sea-level variations are primarily related to vertical land movements, resulting from tectonic movement and glacial isostatic adjustment (Stocchi & Spada, 2009). Evelpidou et al. (2012), Flemming and Webb (1986), and Lambeck and Purcell (2005) suggested that eustatic-isostatic contribution did not exceed 0.5 m during the last 2000 years on the Mediterranean coasts. Studies performed in tectonically stable regions in the Mediterranean have indicated a relative sea-level rise of 0.4 ± 0.1 m at Fréjus and approximately 0.7 m at Corsica since Roman times (Morhange et al., 2013; Vacchi et al., 2017). Lambeck (1995) proposed that glacio-

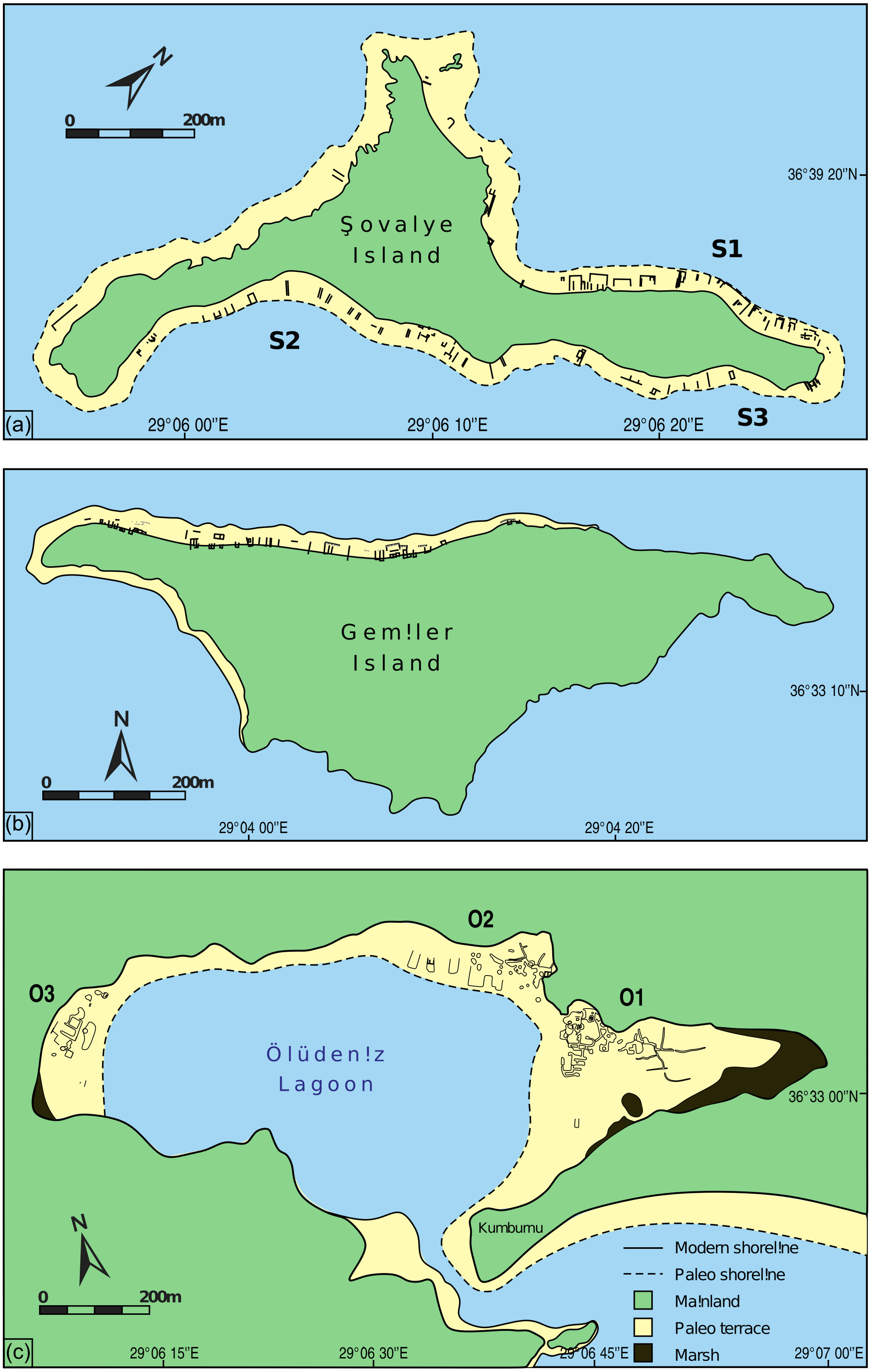


**FIGURE 9** Paleogeographical reconstruction of the coastline after 7th century AD (a) Şövalye Island; (b) Gemiler Island; and (c) Ölüdeniz Lagoon [Color figure can be viewed at wileyonlinelibrary.com]

hydro-isostatic factors make a considerable contribution to Holocene relative sea-level changes around Greece and western Turkey, with a rate of 1 mm/year over the last 6000 years. The comparison between the observed data and Lambeck's predicted GIA model demonstrated that the sea-level rise on the Fethiye coast primarily resulted from local tectonic movement, and only a minor part of the sea-level fluctuation should be attributed to the eustatic-isostatic contribution of the last 1400 years.

Based on the structures' last usage period, we suggest a relative sea-level rise at a rate of 1.6 ± 0.3 mm/year at Şövalye Island, 2.1 ± 0.3 mm/year at Gemiler Island, and 2.2 ± 0.6 mm/year at Ölüdeniz Lagoon over the last 1400 years. However, a recent geoarchaeological study from adjacent sites along the western coast of Fethiye Gulf suggests the greater rates of relative sea-level rise of 2.18 ± 0.3 mm/year, 2.96 ± 0.3 mm/year, and 3.29 ± 0.5 mm/year (Kızıldağ, 2019). This remarkable difference between two adjacent locations can be attributed to the local scale tectonic processes. The tectonic features associated with the western limit of FBFZ and PST confirm that the western coast of Fethiye is more active than the study area (Figure 1c).

## 6 | CONCLUSIONS

This new data set for relative sea-level changes along the coast of Fethiye that have taken place since early Byzantine times provided three different relative sea levels. Based on assumptions of original elevation and last usage for archaeological structures, which were supported by archaeological data, historical sources, and the literature, the rates of sea-level rise were presented in this paper. Although the function of submerged structures at the Ölüdeniz site is still a question requiring further investigation, local similarities support the argument that buildings can be used as a sea-level indicator for this region. A comparison between the observed data and predicted sea-level change demonstrated that the coastline of Fethiye has been under the influence of tectonic movement, sharing the same fate as other coastal settlements in the region. The recent earthquake activity in 2012 supports the conclusion that there is an ongoing movement. Data from newly surveyed sites contribute to our understanding of the evolution of sea level along the Fethiye coasts, filling in a gap for this region. Although numerous sea-level studies have been performed in the Mediterranean, most of them presented data on sea-level changes during the late Holocene, especially in the Roman period; few of these studies presented data from the early Byzantine period. This paper indicates that the Lycian coasts provide remarkable examples of human-nature interaction in that period. These results can also provide insight into future coastal changes.

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### CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions.

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