

RESEARCH ARTICLE



Paleoshoreline reconstruction: A proposed method to approach submerged prehistoric landscapes of Espiritu Santo Island, Baja California Sur, Mexico

Mayra C. Robles-Montes¹ | Guillermo Martínez-Flores¹ | Michael K. Faught² | Enrique H. Nava-Sánchez¹

¹Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, Av. Instituto Politécnico Nacional S/N, Col. Playa Palo de Santa Rita, La Paz, México

²School of Anthropology, University of Arizona, Tucson, Arizona, USA

Correspondence

Mayra C. Robles-Montes, Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, Av. Instituto Politécnico Nacional S/N, Col. Playa Palo de Santa Rita, La Paz 23096, México.
Email: mroblems2000@alumno.ipn.mx

Scientific editing by Sarah Sherwood.

Funding information

Instituto Politécnico Nacional

Abstract

When the first Americans inhabited the area now known as Isla Espiritu Santo, around 12.5 and 6 ka, the sea level continuously rose. This resulted in the loss of the coastal territory and the retreat of the human population further inland. Part of the archaeological evidence of this period currently lies over the seafloor and under the seabed. Therefore, reconstructing paleoshorelines is a necessary first step toward submerged precontact archaeology and a broad understanding of the spatial context in which those human populations interacted and how the landscapes changed. Isla Espiritu Santo is of prehistoric importance as it contains numerous Paleocoastal tradition sites as early as ~12,400 Cal B.P. This research aims to reconstruct the changing shoreline positions as sea levels rose around Isla Espiritu Santo between 12.5 and 6.5 ka. We apply numerical modeling to map digital elevation models at 1 ka intervals by estimating the changes in the morphology of the seafloor according to the deposition rates and global sea-level curve. The results show the evolution of coastal morphology and paleoshoreline's position. Three primary geoforms are proposed: (1) coastal plains, (2) tombolo, and (3) a coastal lagoon-island barrier system. This also offers insights into the physical aspect of submerged prehistoric landscapes and the possible resource exploitation options of early societies. In this research, the reconstruction of submerged landscapes seeks to contribute to the long-term goal of locating submerged precontact sites.

KEYWORDS

DEM, modeling, paleoshoreline reconstruction, sea-level rise, submerged paleolandscapes

1 | INTRODUCTION

The effects of climate and sea-level changes during the Late Pleistocene and Early Holocene resulted in the reconfiguration of coastal zones around the world. Prehistoric archaeological sites were submerged because of the loss of coastal territories before ~6 ka when the sea-level stabilized (Benjamin et al., 2011; Lambeck et al., 2014). We seek to understand these events to

obtain a broader view of the spatial context in which the coastal populations of Espiritu Santo interacted. This context lies underwater on the continental shelf and is embedded in the marine-generated sediment cover. Such territory can be referred to as the Aquatarrea, because it is an area that was exposed as part of the coastal zone for thousands of years and was recently (4ka) covered by water (Dobson, 2014). We work from a geoarchaeological perspective, integrating local marine geology to identify

the different variables affecting the submerged landscape's morphology (Bailey & Flemming, 2008; Faught, 2004).

In this research, the landscape is considered the outcome of human-space interaction. Studying this interaction contributes toward understanding human adaptation patterns and cultural processes (Anschuetz et al., 2001). Landscape refers to the inhabited space, its intrinsic characteristics, and the cultural system that we project on these spaces, giving them a coherent sense according to our individual or collective experience. In this case, we seek to understand the changing physical landscape of Isla Espiritu Santo between 12.5 and 6.5 ka to find more submerged archaeological evidence. To achieve a better interpretation of the cognitive map of prehistoric societies, we must complete the record of the spatial context that they inhabited (Gusick et al., 2019; Lemke, 2020). Therefore, reconstruction of relict landscapes is the first step toward finding submerged precontact sites.

Based on these premises, our study area is the southwestern part of Isla Espiritu Santo in Baja California Sur, Mexico (Figure 1). Previous archaeological research on the island has recorded abundant human settlement areas related to the Paleocoastal tradition in the Baja California Peninsula (Fujita, 2010; Fujita & Ainis, 2018; Fujita & Poyatos de Paz, 1998; Gusick & Erlandson, 2019). Our research aims to approach submerged paleolandscapes by reconstructing the position of the coastline and morphological characteristics between a short period of 12.5 and 6.5 ka, which corresponds to the Paleoindian and (early) Archaic archeological periods in the Baja California Peninsula. We have chosen numerical modeling as our primary method. Numerical modeling has become a tool in reconstructing coastlines due to its usefulness in recreating past coastline scenarios and predicting future ones (Faught & Smith, 2021; Fedje & Christensen, 1999; Legg & Anderton, 2010).

Modeling sea levels to study submerged landscapes of relict coastlines provides a broader picture of the spatial context in which prehistoric societies settled on the world's coastlines (Clark et al., 2014; Gautney, 2018; Gusick et al., 2022; Meredith-Williams et al., 2014; Reeder-Myers et al., 2015). Reconstruction of ancient shorelines requires information on sea-level change, bathymetric features, tectonics, and sedimentary history. We worked with sea-level change, bathymetry, and sedimentary variables in this case. The results are contrasted with the archaeological faunal record of the Covacha Babisuri shell-midden site to propose changing coastal environments.

Completing the spatial record of the coastal zone contributes to a new perspective on the interaction of the early human population and their ancient landscapes. It also offers keys to submerged prehistory's final aim: locating submerged prehistoric sites.

2 | REGIONAL SETTING

Isla Espiritu Santo is located northeast of La Paz, at the far southwestern end of the Gulf of California (Figure 1). Together with Isla Partida and the islets La Ballena, El Gallo, La Gallina, and La

Lobera, they make up the Espiritu Santo archipelago, which flanks the Bahía de La Paz at its eastern side, bordering the Gulf of California to the east. The Canal de San Lorenzo separates the island from the Peninsula by ~8 km. The island was connected to Tecolote Beach when the sea level dropped, forming a single paleo-peninsula feature.

The lithology of the region dominates the coastal landscape, and the main component is of volcanic origin. These include tuff layers, conglomerates, volcanic breccia, and lava flows, all of which are exposed due to the desertic biomass of the region.

Bahía de La Paz has a well-defined bathymetric gradient from the north (deeper) to the south (shallower) (Nava et al., 2001). Canal de San Lorenzo is part of the inner continental shelf; its maximum depth in the central part is ~15 m. As is typical of the Pacific coasts, particularly on the western coast of the Gulf of California, this bay is characterized by narrow shelves and steep slopes that can be observed on the Isla Espiritu Santo margin and the northwestern fringe of the bay (Figure 1).

2.1 | Sediments

Halfar et al. (2000, 2001) studied the sedimentary history of our study area, the western portion of Isla Espiritu Santo and Canal de San Lorenzo, by seismic remote sensing and sediment collection by coring. The study area is a region of high production of various nontropical carbonate sediments, indicating high sedimentation rates. These mainly include a rain of fragments of indurated red algae (rhodolith), mollusks, corals, and foraminifera. The abundance and diversity of this biogenic carbonate rain result from a marine environment being a transitional zone between temperate and subtropical waters. In Canal de San Lorenzo, Halfar and collaborators found that the rhodolith bioherm covers an area of 40.5 km². In addition, they reported that the percentages of carbonate material in the sediment composition change according to the depth of the marine environment, resulting in differentiated sedimentation rates. For example, carbonate percentages between the intertidal zone and 30 m depth vary between 90% and 100%.

More profound than 30 m, carbonates are mixed with olive-green terrigenous mud, silt, and sand-sized materials, so the carbonate percentage varies between 50% and 90% depending on the locality (Halfar et al., 2000, 2001). These sediment variations have significant implications for reconstructing the position of ancient coastlines (Braje et al., 2022), which will be explained below.

2.2 | Geology and tectonics

Another aspect of studying how the reconfiguration of ancient coastlines occurs is the tectonic history. The Baja California Peninsula tectonics is complex since it is associated with the rifting of the Gulf of California (~6.5 Ma, Nava-Sánchez et al., 2001). Isla Espiritu Santo is a microplate resulting from separating the Baja California Peninsula from the eastern continental massif. Another feature that is possible

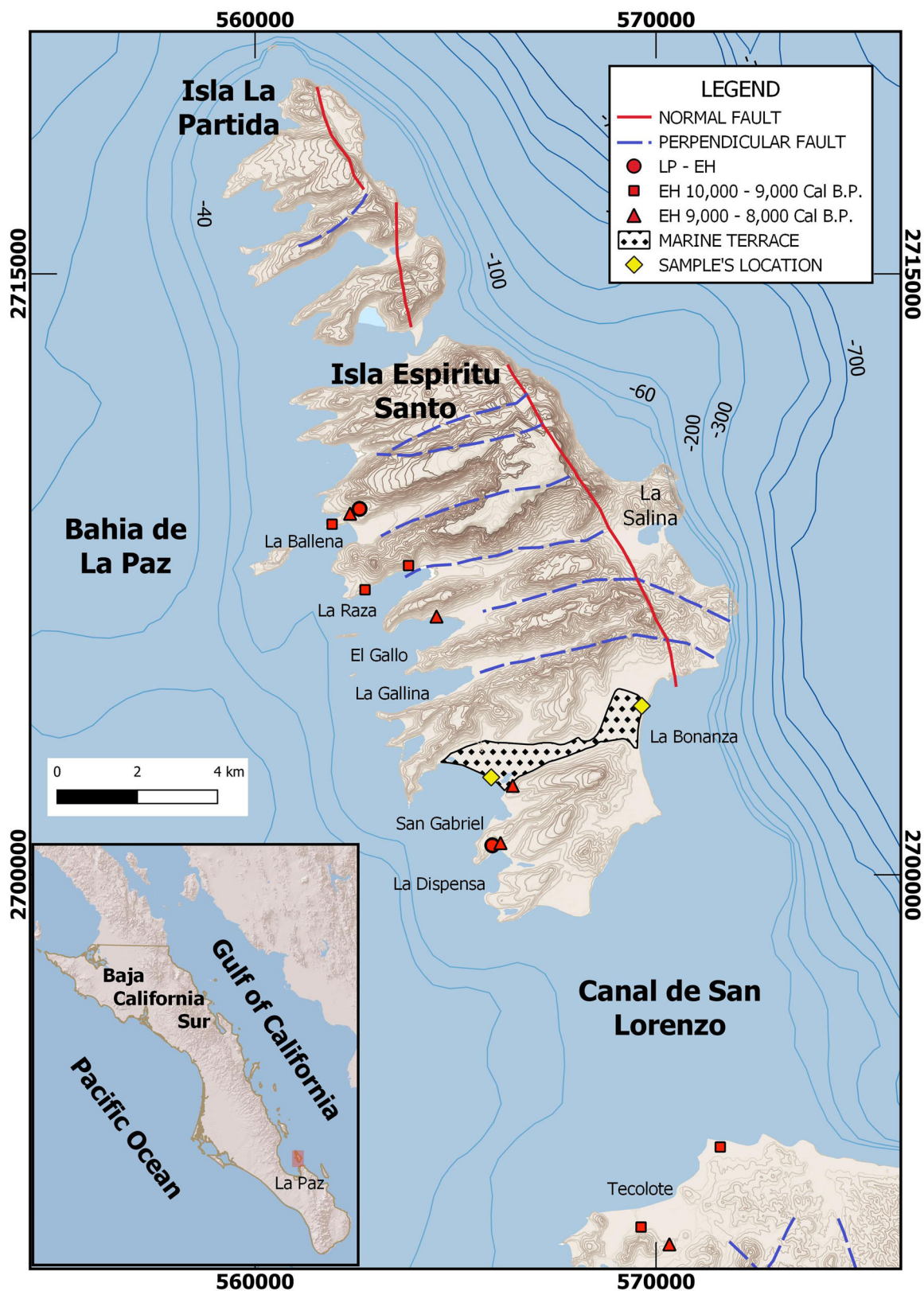


FIGURE 1 Map of Isla Espiritu Santo showing mapped faults, archaeological sites, and named pocket beaches. Coordinate system UTM 12N WGS84. Tectonic features, coverage of the marine terrace, and location of the samples for U/Th dating (Halfar et al., 2001); <https://www.inegi.org.mx> topographic data sets (1:50,000) G17D72, G12D73, G12D62, G12D63; and geologic features data set (1:25,000) G1211lg.

to observe on the island is the La Paz fault and related perpendicular faults, as shown in Figure 1. These are part of the fault system of the western margin of the Gulf of California, one of the three fault systems that generate the Pacific-North American plate motion (Fletcher & Munguía, 2000).

Although the tectonic activity of the La Paz fault has been mostly inactive, the portion lying on the east margin of the island is active today, as evidenced by a 1995 earthquake (Munguía et al., 1997). The fault shows an east-down normal faulting and a west-dipping of $\sim 10^\circ$ of the west block (Aranda-Gómez & Pérez-Venzor, 1986; Fletcher & Munguía, 2000; Hausback, 1984, Figure 2). However, the tectonic activity has been relatively slow in the last 140 ka compared to other areas of the Peninsula, such as at Punta Banda in Ensenada Baja California, where the rates of tectonic uplift generated by the Agua Blanca fault are 180 and 300 mm/ka (Sirkin et al., 1990).

On the other hand, by determining the age and elevation of marine terraces, tectonic uplift and subsidence rates can be obtained. A marine terrace is a low-relief surface of marine origin formed during extended intervals of sea-level stillstand (Yokoyama et al., 2023). Sirkin et al. (1990) dated the marine terraces at El Tecolote Beach, Punta Coyote, La Ventana, and Isla Espiritu Santo (Figure 1) to calculate rates of tectonic uplift in the Gulf of California. Marine terrace deposits between 1.5 and 10 m.a.s.l., dated between 123 and 138 ka, corresponding to the 5e marine isotopic stage. Based on this information, they calculated an average uplift rate for the east margin of Bahía de La Paz of $<70\text{--}40$ mm/ka. A marine terrace lies at the southern end of Isla Espiritu Santo, extending from the east in Bahía de San Gabriel to the west in Playa La Bonanza (Figure 1). Halfar et al. (2001) dated two coral samples from this marine terrace to calculate tectonic uplift and subsidence rates. U/Th dated the sample collected at the east side (9 m.a.s.l.) to an age of 103 ± 2 ka, corresponding to marine isotopic stage 5c when the sea level was at ~ 18 m, from which an uplift rate of 310 mm/ka was calculated. On the other hand, the sample collected on the western side (at 1 m.a.s.l.)

yielded a U/Th age of 142 ± 2 ka assigned to isotopic stage 5e (sea level was <-60 m), from which they calculated a subsidence rate of ~ 15 mm/ka (Figure 1). However, these results are inconclusive because the authors attribute the diachrony of the dates to an abnormal diagenetic history of the sample collected in the eastern part of the island.

These background data indicate no consensus on calculation of tectonic uplift rates for the study region. Therefore, there is a need to collect more data to establish a more reliable subsidence rate. In places, Isla Espiritu Santo is tectonically active on the western margin of the Gulf of California and presents differential uplifting across the island since the Pleistocene through recent times, which contrasts with previous data that establish that the margins of Bahía de La Paz are areas with a slow uplift rate (Halfar et al., 2000; Sirkin et al., 1990). However, in the hypothetical case in which the age of both samples (one at the west and the other one at the east of the marine terrace) corresponds to the marine isotopic stage 5e, the estimate of uplift and subsidence for 12.5 ka would be ~ 56 and ~ 19 cm, respectively, data negligible compared to the sedimentation rates of the area. Therefore, given the lack of reliability of the tectonic data, it is not pertinent to integrate tectonic uplift and subsidence rates into the proposed reconstruction model.

2.3 | Sea level

Past sea levels are measured from present positions with information on land movement (isostatic/tectonic component) and changes estimated in ocean volume (eustatic component, Lambeck et al., 2014). Working with accurate sea-level curves derived from local samples is essential when modeling ancient shorelines. However, glacial-isostatic adjustment and sea-level curves have yet to be estimated for our study area. Therefore, it was decided to use a portion of the sea-level curve modeled by Lambeck et al.

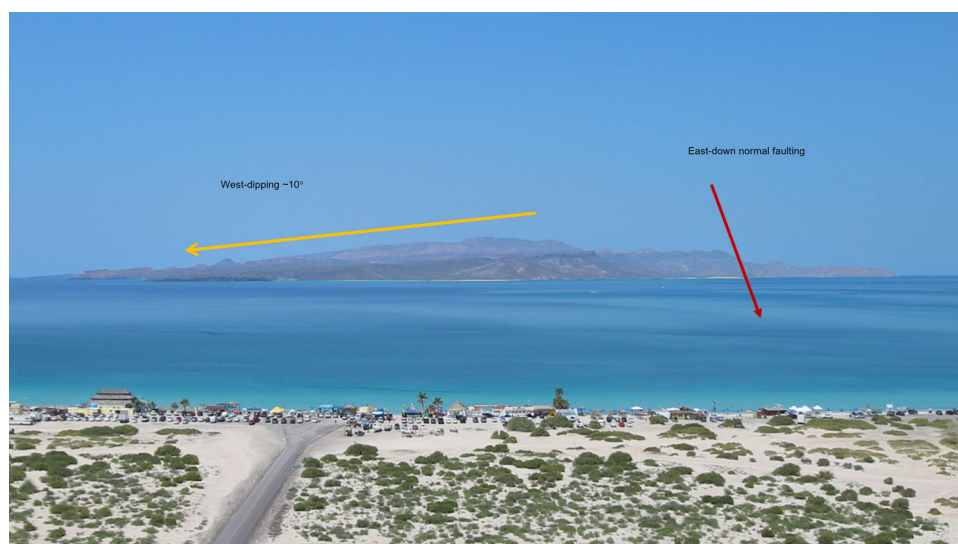


FIGURE 2 View of southern Isla Espiritu Santo from Tecolote Beach.

(2014) between 12.5 and 6 ka. They analyzed the response of the Earth–Ocean system (glacial–isostatic adjustment) to the glacial cycle from ~1000 observations (sediment and coral records) from far-field locations to estimate the variation of ice and ocean water volumes during the last 35,000 years. These locations are underpinned by independent near-field analyses for the individual major ice sheets of the Northern Hemisphere and inferences about past Antarctic ice sheets. Lambeck et al. (2014) used coral records for the last glacial period from Barbados, Tahiti, Huon Peninsula, the western Indian Ocean, and the Great Barrier Reef of Australia (Bard et al., 2010; Camoin et al., 2004; Fairbanks, 1989; Yokoyama et al., 2001). Sediment records came from significant data sources of Sunda Shelf, the Indian Ocean, the Bonaparte Gulf, New Zealand, Singapore, Malaysia, and the South China Sea to the Bohai Sea (Bird et al., 2007; De Deckker & Yokoyama, 2009; Gibb, 1986; Hanebuth et al., 2000).

In paleoenvironmental research, relative sea-level curves (RSL) have been constructed from the analysis of ice, sediment, and coral samples, corrected by regional glacial–isostatic adjustment (GIA). GIA models are generally used to capture crustal deformations associated with the visco-elastic response of the mantle from redistributed ice and water loads that occur over millennia and also to capture the greater rates experienced in the past at high-latitude sites where there has been substantial rebound. However, the models are sensitive to small changes in parameterization, which may result in differences of up to 0.5 mm/year at far-field sites (Murray-Wallace & Woodroffe, 2014). Theoretically, these differences occur because the sea-level response within, or close to, the former ice margins (near field) is primarily a function of the underlying rheology and ice thickness. In contrast, far from the former ice margins (far field), it is mainly a function of earth rheology and the change in total ice volume through time (Lambeck et al., 2014, p. 15297). Therefore, GIA effects are more important in near- and intermediate-field locations than far-field locations.

To show this effect, we compare two RSL curves, one intermediate-field location (Reeder-Myers et al., 2015, Northern Channel Islands) and one far-field location (Lambeck et al., 2014, global data applied to Espiritu Santo area), with two RSL curves of the exact location obtained from the ICE-7G NA model (Roy & Peltier, 2018), which was estimated based on near-field data (East Coast U.S.). The RSL curve obtained from this model presents an over- and underestimation compared to the original RSL curve (Figure 3). Since the ICE-7G Na model is based on near-field data, the RSL curve for the intermediate field does not consider the tectonic parameters of the local area. At the same time, the far field is located in a marginal area, where the application is less accurate.

Based on this comparison, the Lambeck et al. (2014) RSL curve is more accurate and relevant to our research for two reasons. First, the analysis of different sea-level indicators, such as corals (representing lower sea-level limit values) and sediments (representing upper sea-level limit values), is less likely to be biased toward one or the other limit. Second, analysis of a multiplicity of data from far-field localities is more likely to locally average out undetected tectonic effects and any uncertainties in the GIA contributions (Blanchon & Shaw, 1995; Lambeck et al., 2014).

2.4 | Archaeology

Isla Espiritu Santo has cultural and historical importance as it contains numerous precontact sites with long occupation records extending from ~12,400 Cal B.P. when the sea level was ~65 m below the present sea level (Lambeck et al., 2014) up to the European contact and the modern sea level. In the western part of the Isla Espiritu Santo and Tecolote beach (south of the island, Figure 1), 16 early archaeological sites have been recorded and dated between the late Pleistocene and early Holocene (Figure 4). The oldest sites are (1) Bahía La Ballena, dated at ~12,400 Cal B.P., and (2) the Covacha

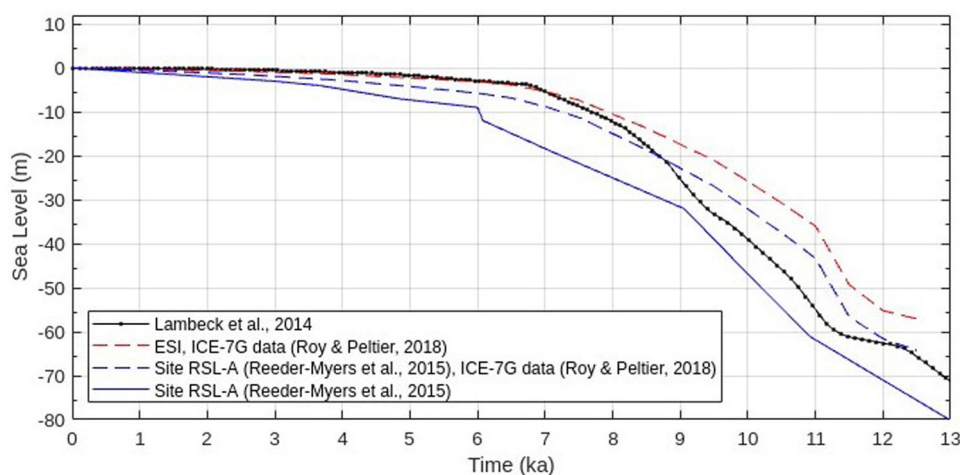


FIGURE 3 Comparison between intermediate- and far-field relative sea-level curves (RSL) obtained from the ICE-7G NA data model (Roy & Peltier, 2018) (dashed lines) for the Isla Espiritu Santo (IES) region and East Coast U.S. Northern Channel Islands (location RSL-A [Reeder-Myers et al., 2015]). Global data (Lambeck et al., 2014) applied to the IES area (black dotted line).

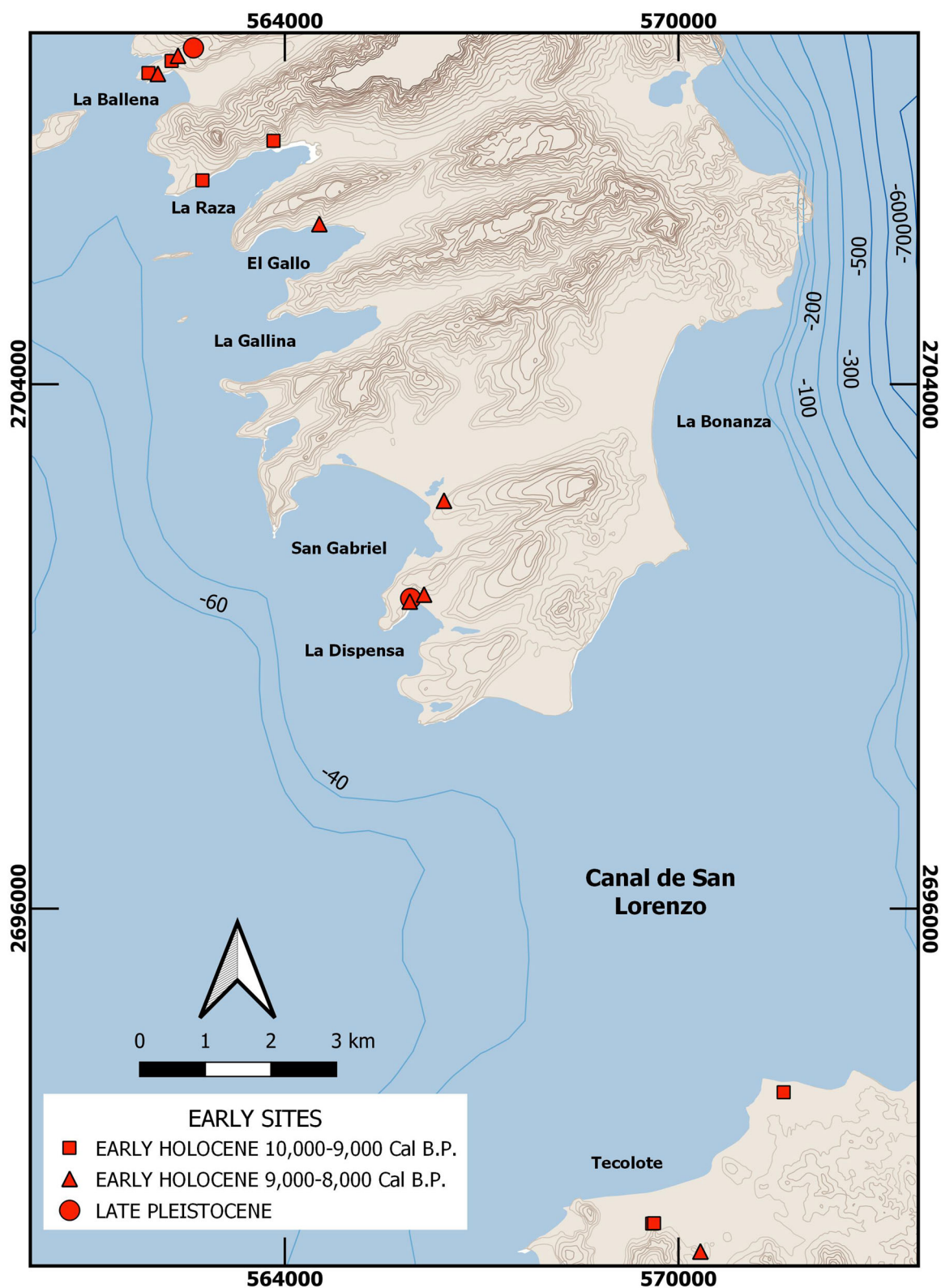


FIGURE 4 Early human settlement areas.

Babisuri site in Bahía la Dispensa, dated at ~12,100 Cal B.P. (Fujita & Ainis, 2018). The archaeological evidence from fauna, domestic tools, and ornamental objects reveals specific cultural practices indicating that Isla Espíritu Santo was a central Cabo region area. Furthermore,

it has been shown that the people of Espíritu Santo belonged to the Paleocoastal tradition (Fujita, 2010; Gusick & Erlandson, 2019).

The concept of a Paleocoastal tradition arose from archeological evidence found on the southern coast of California (Moratto, 1984).

The high density and diversity of marine faunal remains indicated a subsistence economy focused on exploiting marine resources (Braje et al., 2019; Moratto, 1984). Some consider this evidence to support a coastal pathway from Beringia for first Americans (Des Lauriers, 2006; Erlandson et al., 2008, 2009; Fujita & Ainis, 2018; Gusick & Erlandson, 2019; Rick et al., 2013).

In 2010, Gusick conducted the first bottom mapping and underwater exploration at the Isla Espiritu Santo to locate submerged prehistoric sites. The most important contributions of their research were observations on the efficiency of the methods and techniques used (side scan sonar, hand fanning underwater excavation, airlift dredge, and pneumatic corer). From these methods, Gusick obtained bathymetric and geomorphological information about the northern area of the Islote La Ballena, generating a map of the seabed where rock formations, a riverine area, and a sandy beach area were proposed. In addition, they identified a possible ancient human settlement area now submerged to a depth of ~20 m (Gusick & Davis, 2010; Gusick & Faught, 2011). Furthermore, the evidence of morphological features of relict shorelines highlights the need to work on the reconstruction of the submerged landscapes of the Isla Espiritu Santo early prehistory. This will contribute toward understanding the geographic context in which early populations interacted during deglaciation.

In the case of Isla Espiritu Santo, it has been estimated that the island was connected to the Peninsula by a land bridge formed in what is currently the San Lorenzo Channel. In Fujita and Melgar (2014), Paul Porcasi modeled shorelines around Isla Espiritu Santo based on bathymetric data and sea-level curves published by Fairbanks (1990) and Bard et al. (1996). Porcasi's estimation indicates the position of the coastline for 12,000 B.P. (at -61.5 m) and 8000 B.P. (at -16.25 m).

3 | DATA AND METHODS

3.1 | Data sets

3.1.1 | Digital elevation model

The DEM was generated from three data sources covering the quadrant bounded by UTM 12N coordinates N557900 E2690500 and N573850 E2710500 (Figure 3). Mexican topographic data are available at the governmental site <https://www.inegi.org.mx/>, where the following vector data sets were obtained: G12D62, G12D63, G12D72, and G12D73 (1:50,000). The bathymetric data are composed of two databases: a global one and one obtained by the first author. The global database was obtained from the Bathymetric Chart of the Oceans (GEBCO, <https://www.gebco.net/>). Bathymetric surveys were carried out in October 2021 to obtain more precise GEBCO data. The data were collected using a Humminbird 365i echosounder, following parallel and perpendicular transects to the coastline from SW to NE and NW to SE to cover the area surrounding the southwestern portion of Isla Espiritu Santo and Canal de San Lorenzo, between ~2 and ~40 m depth (Figure 5).

Track lines were also run inside the pocket beaches since no bathymetric data were available for these shallow areas. The data were corrected for the effects of the tide using spreadsheet formulae. The tide data were obtained from the UNAM tide gauge at Pichilingue harbor, located 10 km southward of the San Lorenzo Channel. To generate the DEM, a Kriging interpolation was performed using Surfer software to obtain a digital elevation model of the three databases, and then converted as a grid file and later exported to GeoTiff format.

3.1.2 | Sea-level data points

Sea-level data points were obtained between 13 and 6 ka from the RSL curve estimated by Lambeck et al. (2014). During this period, three relevant events happened: (1) between 12.8 and 11.4 ka, there is a minor pause in sea-level rise that coincides with the last low-temperature period known as Younger Dryas for the Northern Hemisphere; (2) between 11.4 and 8.2 ka, there is a continuous and uniform period of global sea-level rise, at a rate of ~15 m/ka; and (3) between 8.2 and 6.7 ka, the sea-level rise slows, consistent with North America's last stage of deglaciation (Figure 6).

3.1.3 | Sediment accumulation rates

Halfar et al. (2001) calculated sediment accumulation rates for the early Holocene and late Pleistocene by analyzing sediment cores (Figure 1) and acoustic reflection profiles from subbottom profiling in San Gabriel Bay. They propose six sedimentation environments: (1) shallow subtidal, (2) deep subtidal, (3) inner shelf, (4) bioherm, (5) west outer shelf, and (6) east outer shelf. The first two categories correspond to the island's western portion, and the fourth and fifth categories correspond to the San Lorenzo Channel area. This categorization indicates marine microenvironments within our study area. Here, we defined three categories that represent in a general way the reported sedimentation rates to generate the prehistoric coastal landscapes that correspond to the western area of the island and the channel since these are the localities where the highest densities of early human settlements are known. Our first zone encompasses categories 1 and 2 described above and refers to the subtidal area between -1.5 and -8 m. The second zone corresponds to the inner shelf, whose depth was established between -8 and -30 m. Finally, the third zone corresponds to the west outer shelf, with a -30 to -100 m depth. The continental shelf boundary is at -100 m in our study area, where a conspicuous change in slope is present. The sediment accumulation rates for the subtidal and inner shelf were obtained by averaging the minimum and maximum values reported by Halfar et al. (2001).

On the other hand, morphological aspects of the Pacific continental shelf were considered to define the appropriate sedimentation rate for the outer shelf. Since a narrow and sloping outer shelf characterizes the Pacific Ocean, sedimentary deposition

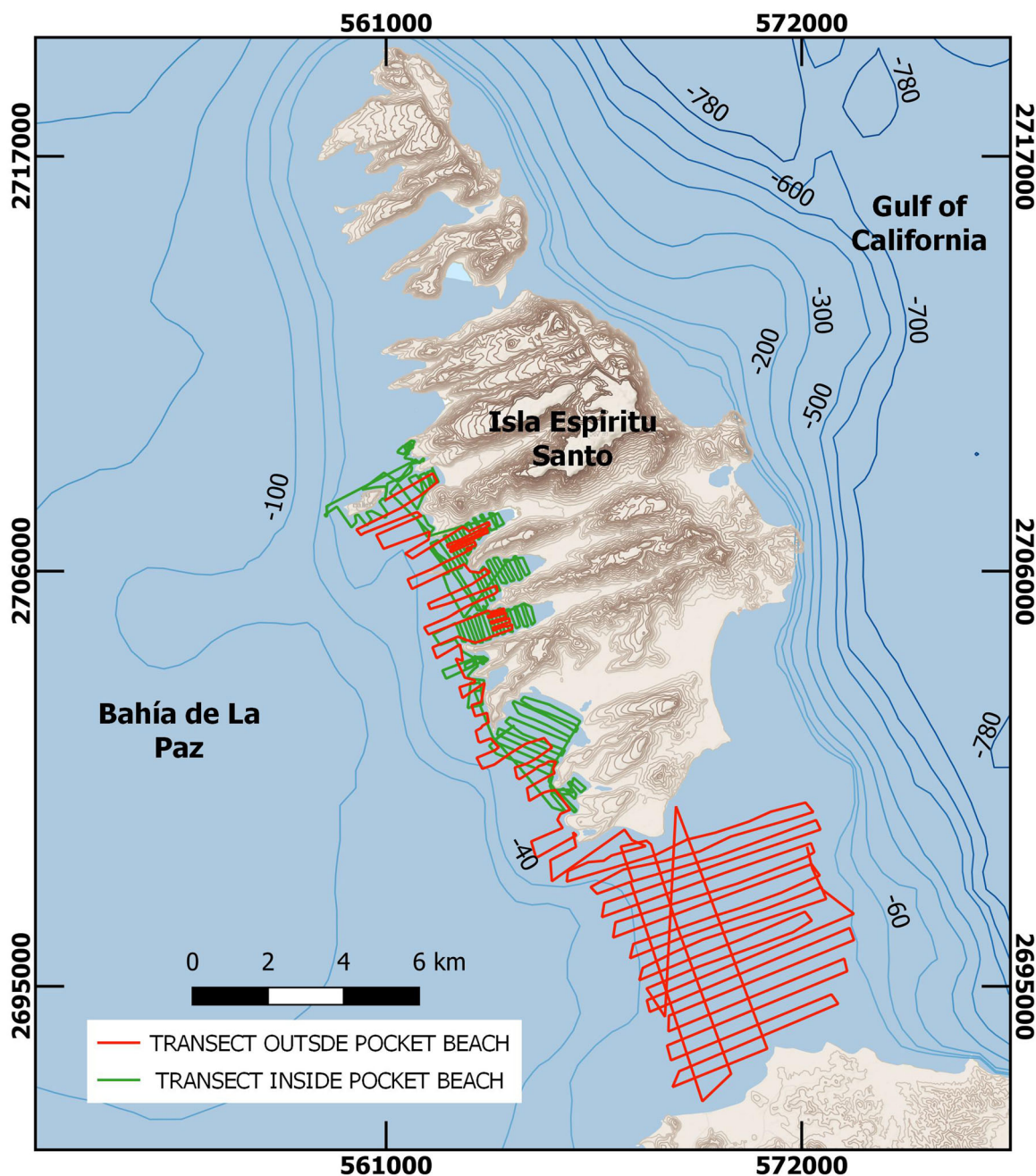


FIGURE 5 Track lines of echosounder data collection to refine the GEBCO bathymetric data set.

on slopes is minimal due to the gravitational effect. Therefore, it has been established to work with the minimum sedimentation value reported for this area. (Table 1).

3.2 | Paleoshoreline reconstruction model

The model used in this study is based on the work of Yao et al. (2009), who consider the sedimentation variable a primary factor in reconstructing past shoreline positions. Their model reconstructs paleo-digital elevation models (DEM) by combining subaerial and

terrestrial data. Thus, the DEM is modified based on sediment thickness generated by deposition estimates.

To implement the model, we use the MATLAB programming platform developed by MathWorks (www.mathworks.com) and the Topo Toolbox plugin (Schwanghart & Scherler, 2014), which provides relief analysis functions.

As an initial condition of the model, we use contemporary bathymetry (characterized by the data described in Section 3.1.1). First, we estimate the evolution of relief in time intervals of 1 ka toward the past, considering the changes in the sea level and the sedimentation rates accumulated between 12.5 and 6.5 ka in each

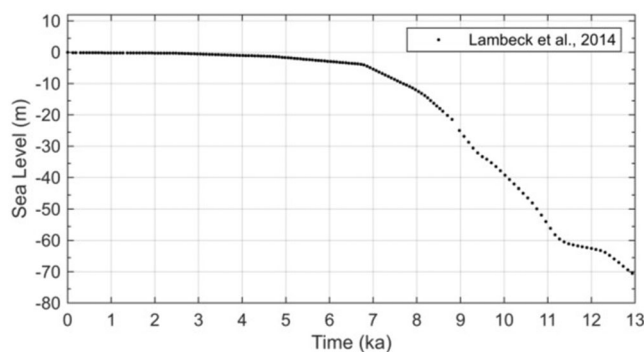


FIGURE 6 Relative sea-level curve from 13 to 0 ka, Lambeck et al. (2014).

TABLE 1 Annual sedimentation rate for the recognized environments in Isla Espiritu Santo.

Environment	Depth (m)	Sedimentation rate (m/ka)
Subtidal	1–8	1.40
Inner shelf	8–30	1.05
Outer shelf	30–100	0.70

time interval. Finally, the DEM was updated using the following formula (Yao et al., 2009):

$$DEM_t = DEM_0 - RSL_t + S_t,$$

where DEM_t is the reconstructed model at time t and DEM_0 is the current elevation model. RSL_t is the difference between the current sea level and the one corresponding to time t and S_t is the difference caused by sedimentation from time t to the present (Yao et al., 2009). This model allows us to estimate the position of changing coastlines and observe potential changes in coastal geomorphology over time.

The Fourier function of MATLAB's Curve fitting tool (The MathWorks, 2022) was applied to estimate and smooth sea-level changes as a function of time (6.5–12.5 ka) based on global sea-level change data estimated by Lambeck et al. (2014) by using the following formula (Supporting Information S1: Appendix A. Figure 1):

$$sl = a_0 + a_1 \cos(w) + b_1 \sin(w) + a_2 \cos(2w) + b_2 \sin(2w) + a_3 \cos(3w) + b_3 \sin(3w) + a_4 \cos(4w) + b_4 \sin(4w) + a_5 \cos(5w) + b_5 \sin(5w) + a_6 \cos(6w) + b_6 \sin(6w),$$

where the vector coefficients $a = (-91.13, -16.41, 81.4, 52.54, 12.21, 14.11, 0.5545)$, $b = (143.3, 47.13, 38.28, -33.46, 0.76, 3.46)$, $w = t \beta$, $\beta = 0.30$, and t is the time (ka) for calculation of the sea level (Supporting Information S1: Appendix A. Figure 2).

To estimate sedimentation rates as a function of bathymetry in the time intervals mentioned above, and once the sea level was established for a particular time, the following formula (exponential fit) was used, taking as a reference the sedimentation rates reported by Halfar et al. (2001) and using the MATLAB Curve Fitting tool (The MathWorks, 2022):

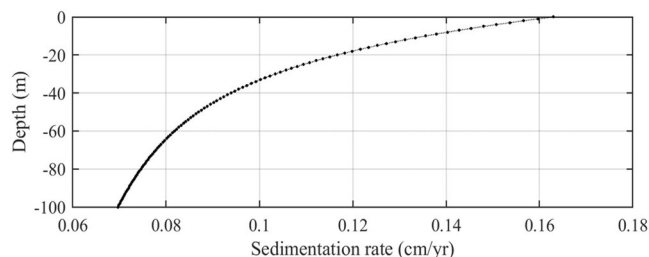


FIGURE 7 Sedimentation rate versus depth.

$$sr = \kappa_1 e^{\kappa_2 \delta} + \kappa_3 e^{\kappa_4 \delta},$$

where sr is the sedimentation rate (cm/year), the vector coefficients $\kappa = (0.085, 0.002, 0.077, 0.039)$, and δ is the depth (m) of the deposition environment (Figure 7). Sedimentation scenarios are presented in Supporting Information S1: Appendix B, Figure 1.

Using these functions and applying them to the contemporary DEM in the time intervals mentioned above allowed us to estimate the ancient coastline positions and reconfigure the DEM surface every millennium.

4 | RESULTS

Model results show the evolution of coastal geomorphology and relative sea-level position every 1000 years between 12.5 and 6.5 ka (Figure 7).

At 12.5 ka, the island was connected to the Peninsula by a tombolo that spanned the entire area of SLC, forming a paleopeninsula. The island remains connected to the Peninsula up to ~7.5 ka. In addition, three lagoons formed: two on the western side of the channel and one on the northeastern coastal plain of the channel. A small peninsula was also formed in the western part of the island between Bahia San Gabriel and La Gallina. This locality might be crucial for pelagic fishing since it is the closest point to the deep part of the Bahia de La Paz. At this time, the littoral zone of the study area extended to ~115,662 km² compared to today. It remained relatively stable for a millennium, which coincides with the pause in sea-level rise due to the last glacial cooling event, the Younger Dryas (Figure 8a). At ~11.5 ka, the peninsula mentioned above was separated, forming an island, and the lagoons on the western side were flooded due to the sea-level rise (Figure 8b). Around ~10.5 ka, the island formed on the western side was also flooded. At ~9.5 ka, the tombolo started to contract, and the lagoon on the eastern side described above was connected to the Gulf of California, forming an islet, which remained until ~6.5 ka, shrinking from ~1 km² (10.5 ka) to ~0.171 km² (Figure 8c). Another islet was formed on the island's western side, in front of the current La Dispensa Bay, which had an extension of ~0.704 km² and was flooded at ~8.5 ka. Finally, a sandy barrier was formed at the northwestern of San Gabriel, becoming an islet at around ~8.5 ka and remaining until 6.5 ka, extending from ~0.856 to ~0.310 km² (Figure 8d). At ~8.5 ka, another Peninsula was formed on the western point of Tecolote Beach and was flooded at ~6.5 ka, while the La Ballena islet was connected to the island by a tombolo until 8 ka (Figure 8e). The sea-level rate rise occurred steadily between circa 11.4 and 8.2 ka.

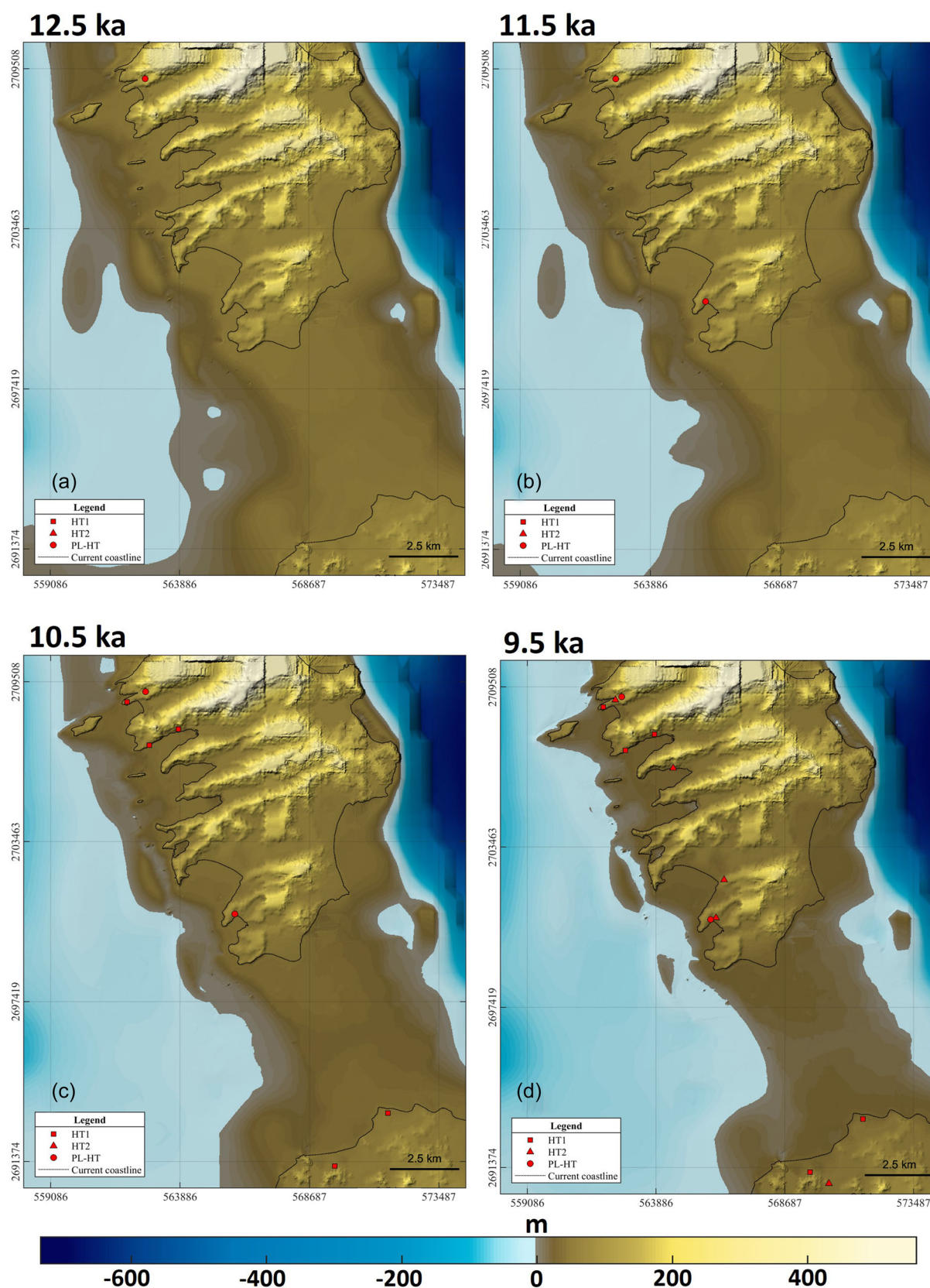


FIGURE 8 Digital elevation model of the reconstructed paleoshoreline position for (a) 12.5 ka, (b) 11.5 ka, (c) 10.5 ka, (d) 9.5 ka, (e) 8.5 ka, (f) 8 ka, (g) 7.5 ka, (h) 6.5 ka. Each map shows the archaeological sites according to their temporality. Circles indicate late Pleistocene sites. Squares indicate early Holocene sites between 10,000 and 9,000 Cal B.P. Triangles indicate early Holocene sites between 9,000 and 8,000 Cal B.P. (see Supporting Information S1: Appendix C for the animation).

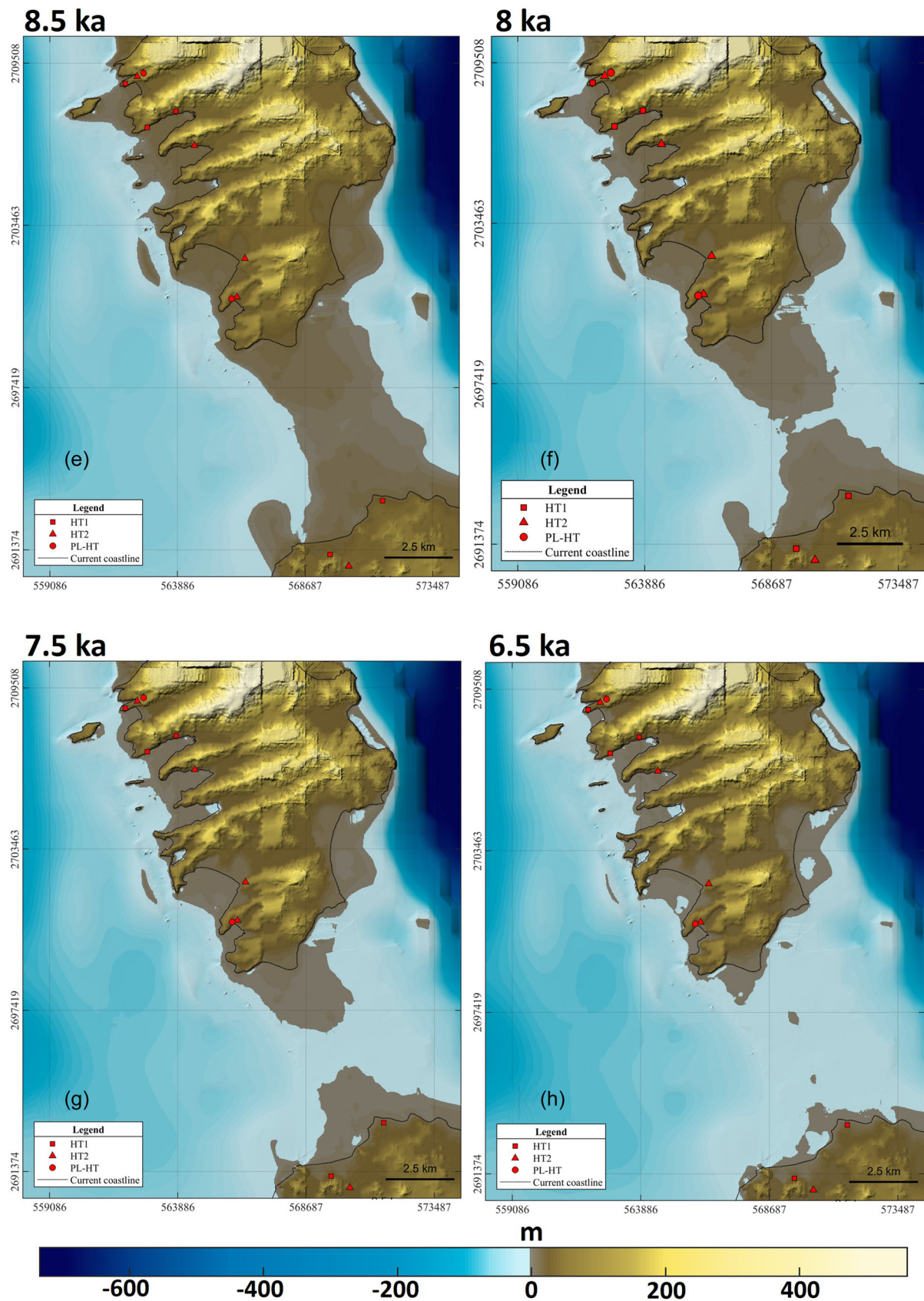


FIGURE 8 (Continued).

Around 8 ka, the Isla Espiritu Santo started to separate from the Peninsula and was completely separated at 7.5 ka (Figure 8f). At 7.5, the El Gallo islet seems to be the remnant of an ancient point, and the La Gallina islet was already separated from the island (Figure 8g). Finally, at 6.5 ka, the coastline of these islets is similar to the present, probably due to the attenuation of the sea-level rise started at ~8.2 ka reported by Lambeck et al. (2014) (Figure 8h).

The paleoshoreline position obtained from this model differs from Fujita and Melgar (2014, Figure 9). These differences are attributed to two aspects. First, the sedimentation variable was considered in our reconstruction model and second, the fact that Lambeck et al. (2014) worked with databases from several far-field locations, and the Fujita and Melgar (2014) reconstruction was generated from one locality database: Barbados.

Since the paleoshoreline position data obtained from our model were calculated based on differentiated deposition rates according to the depositional environment (depth), it is not possible to propose a constant numerical value of the shoreline position. However, the distance between the reconstructed shorelines and the early archaeological sites was estimated. The estimation was made using the QGIS linear measurement tool (Table 2).

TABLE 2 Estimated distance between reconstructed shoreline and early archaeological sites.

Map age	Sites	Site average age (ka)	Distance to the shore (km)
12.5	J69E	12.4	3.5
11.5	J17	12.1	2.5
10.5	J65	10.2	2.4
10.5	J69G	10.0	2.6
10.5	J94	9.9	2.4
10.5	A176	9.9	4.2
10.5	A175	9.9	4.2
10.5	A16	9.9	3.4
9.5	A183b	9.0	3.7
9.5	J69D	9.1	0.9
9.5	J57	8.5	2.7
9.5	J18	8.2	1.1
9.5	J30	8.5	2.3

Note: The site's age is based on Fujita and Ainis (2018).

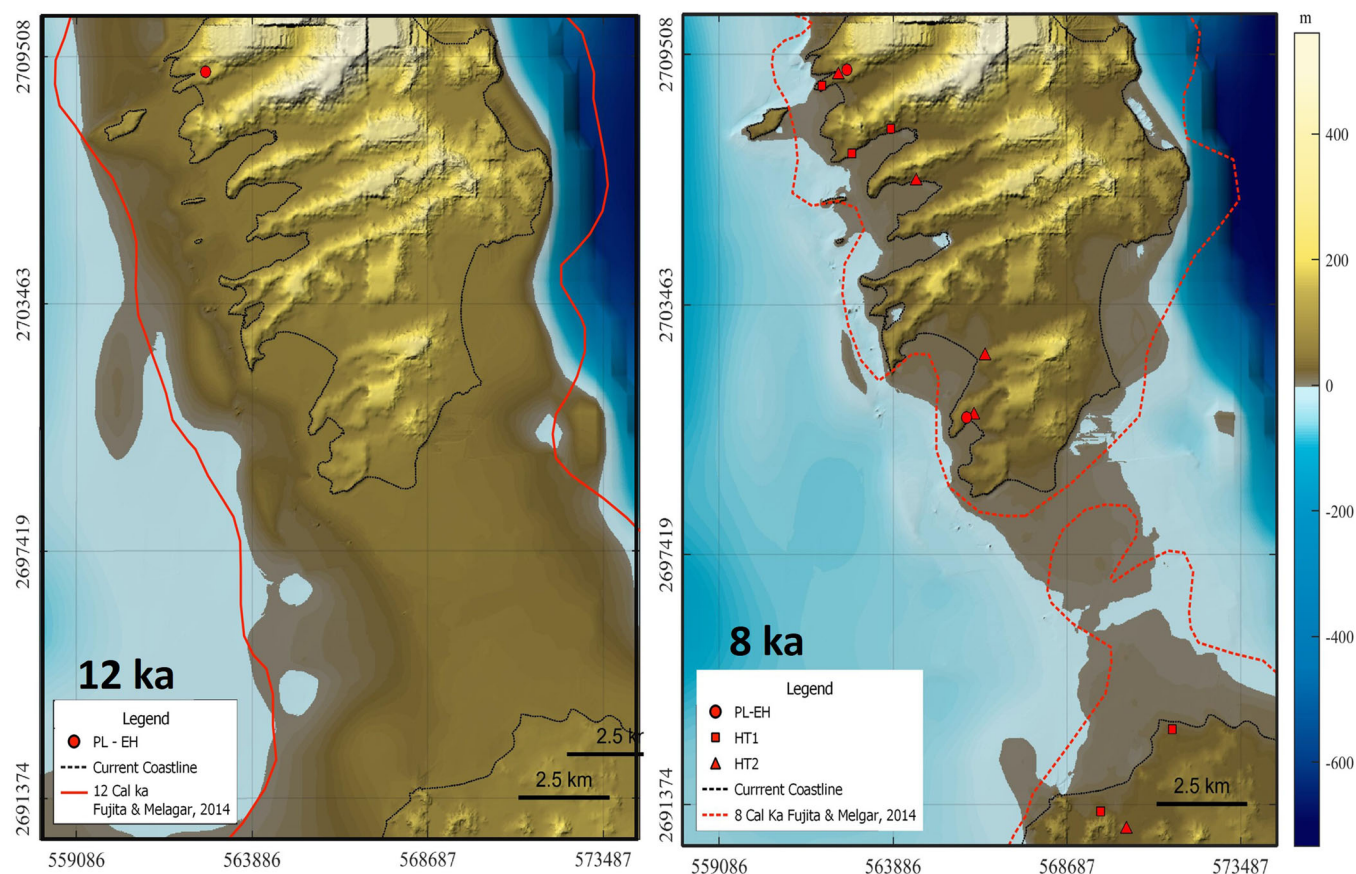


FIGURE 9 Comparison between our shoreline reconstruction and the Fujita and Melgar (2014) reconstruction.

On the other hand, we propose that the contraction of the coastal territory due to the sea-level rise during the Late Pleistocene–Early Holocene caused the formation of three main geoforms: (1) the presence of relatively vast coastal plains and, consequently, the reduction of the continental shelf; (2) tombolo that, when flooded, gave rise to small islets and to the Isla Espiritu Santo itself; and (3) a coastal lagoon–island barrier system.

Currently, the coastal plains in the western part of Isla Espiritu Santo are narrow and mostly floodplains. Assuming that the environmental conditions between 12.5 and 8.5 ka were similar to today, this type of morphology may indicate the presence of marsh and mangrove ecosystems and areas of high evaporation with the potential for sea salt exploitation. However, a reduced continental shelf indicates that deep waters were even closer to the coastline than today, a situation that can be considered a good condition for a potential pelagic fishery as, for example, the Peninsula and later island formed between 12.5 and 11.5 ka and the northern side of the La Ballena islet. The tombolo formed during the sea-level drop, connecting Isla Espiritu Santo to the peninsula, was a vital landscape feature as a land bridge for humans, flora, and fauna transit. Subsequently, land-tide islands were formed, as was the case of the La Ballena islet, at around 7.5 ka (Figure 1, Murray-Wallace & Woodroffe, 2014; Woodroffe, 2003). The separation of Isla Espiritu Santo from the Peninsula resulted in endemic species such as the rabbit *Lepus insularis*, the squirrel *Ammospermophilus insularis*, and the whip snake *Masticophis basouri*.

Finally, in geomorphic general terms, coastal lagoons are relatively shallow bodies of water that may be enclosed or partially open to the adjacent sea and provide an environment conducive to the flourishing of marsh or mangrove vegetation, depending on the sedimentation patterns influencing them (Kjerfve, 1994). In this case, when the sea level rose (8.5 ka), the evolution of this geoform gave rise to a barrier island, which, when flooded, became subject to erosion and covered by sedimentation processes of the region.

5 | DISCUSSION

The results were contrasted with the archaeological fauna record obtained from excavations at the Covacha Babisuri site for the Late Pleistocene and Early Holocene. The presence of certain species indirectly indicates the possible coastal ecosystems that existed during that period. Species recorded between 12 and 10 ka are from different habitat types such as mangrove (*Ostrea pamula*); the intertidal zone with coral reef ecosystem and rhodoliths (*Turbo fluctuosus*); lagoons and channels with sandy bottoms (*Lyropecten subnodosus*); the subtidal area between 2 and 50 m depth of sandy and rocky bottoms (*Spondylus crassisquama*); shallow water-exposed rocks and coral reefs (*Hyotissa Hyotis*); and coral reefs and rocky bottoms (*Pinctada mazatlanica*) (Fischer et al., 1995; Fujita & Melgar, 2014). All the mentioned environments have a high potential for shellfishing, and shell-midden settlements are evidence of this.

The diversity in the malacological sample indicates that the morphological characteristics described above are consistent with the inferred habitats. However, it also shows that several of these species need a rocky substrate to proliferate, and that, together with the archaeological record of other marine fauna such as chitons, crabs, and sea urchins, leads us to believe that the seabed, between the intertidal and subtidal zone, was of a mixed type. These facts can be justified based on the geology of the study area. Even though it has been possible to reconstruct the evolution of the coastline, the erosional rates of the island's lithological component are unknown. Currently, the rocky points delimiting the pocket beaches on the western side of Isla Espiritu Santo are characterized by cliffs of volcanic rocks, mainly tuff, ignimbrite, and conglomerate. These elements are the weakest for erosion by wind and waves, which trigger landslides that become part of the seafloor and provide substrates conducive to the proliferation of rocky reefs. This scenario may have occurred since ancient times. Between 10 and 8 ka, the archaeological sample presents the new species *Chione californiensis*, *Strombus glacior*, and *Chama frondose*. The first two species are of sandy bottom habitat and the last is of rocky bottom habitat (Fischer et al., 1995). Therefore, the presence of *Chione* and *Strombus* might indicate a more extensive area of sandy environments. In addition, in Bahía de San Gabriel, a snail of the genus *Melampus* was documented in one of the cores collected by Halfar et al. (2001), and it was dated to 7.9 ka, indicating a marsh ecosystem with aerobic exposure.

It is essential to point out that the mathematical reconstruction of paleolandscapes is a complex task. Depending on the study's objectives, it may include other variables in addition to those mentioned here. An example of these variables is erosion. In our study area, the cliffs are subject to periodic transformation by landslides and weathering, thus potentially altering the coastal landscape that existed during the first human occupation of the island.

A morphological indicator of this type of erosion, due to waves and the tide's erosion effect, is shoreline notches (Figure 10). These elements are characteristic of current coastal erosion and can be considered indicators of the different sea-level positions. They can even be found underwater, showing lower sea-level positions. However, the sediment cover precludes exposure, and it is not possible to detect them without subbottom profiler remote sensing or excavations (Evelpidou et al., 2012; Murray-Wallace & Woodroffe, 2014).

Another variable is the island's geohydrology, which gives us a better idea of the types of arroyo valleys and water bodies associated with the coastal zone and their role in the configuration of the ancient coastlines. Although, in this case, the study of local geohydrology is a topic that should be carried on, as well as the case of tectonics, new studies should be conducted to complement or validate existing information. Then, the information on these variables could be integrated into a future model to complete the reconstruction of the submerged prehistoric landscapes that we propose here.



FIGURE 10 Local examples of shoreline notches and their associated overhanging rocks: (a, b) notch with an overhanging rock composed of volcanic tuff on Isla Espiritu Santo, (c) large notch and notched stack in volcanic breccia along the wave-exposed northern portion of Balandra beach.

6 | CONCLUSION

The study of relict coastal landscapes is a priority in the discourse of precontact archaeology. The sea, particularly the coastal zone, was a vast and prolific ecological niche that allowed the first human societies that colonized new territories around the world to thrive. Therefore, reconstruction of ancient coastlines is the first task that needs to be completed to gain knowledge of the physical landscape and in coastal areas with high relief, such as Isla Espiritu Santo. The knowledge of lithology, sedimentary history, tectonics, and coastal dynamics allowed a better interpretation of the data obtained and the methods used to reconstruct submerged prehistoric landscapes. The usage of the geoarchaeological perspective is crucial in studying precontact underwater archaeology. This perspective and knowledge of ancient ecosystems and environmental conditions contribute to a broader understanding of landscape reconstruction.

In this case, applying numerical modeling to reconstruct sedimentary scenarios of the seafloor during sea-level rise (12.5–6.5 ka) led us to visualize the evolution of the coastline during the Paleoindian period, the first peopling of Isla Espiritu Santo, and to contrast the results with the archaeological faunal record recovered in previous archaeological excavations. These data offer insight into the physical features of submerged prehistoric landscapes and the options of resources that early societies could have used in the past. Such information also provides clues to identify potential areas of submerged human settlement in the future, the final aim of submerged prehistory.

AUTHOR CONTRIBUTIONS

Mayra C. Robles-Montes: Conceptualization; investigation; writing—original draft; methodology; visualization; software; data curation; formal analysis; writing—review and editing. **Guillermo Martínez-Flores:** Conceptualization; investigation; visualization; writing—review and editing; software; data curation; formal analysis; methodology. **Michael K. Faught:** Conceptualization; writing—review and editing. **Enrique H. Nava-Sánchez:** Conceptualization; funding acquisition; writing—review and editing; project administration; supervision; resources; investigation; methodology.

ACKNOWLEDGMENTS

We acknowledge the Consejo Nacional de Humanidades, Ciencias y Tecnologías (CONAHCTY) for the graduate scholarship and the Instituto Politécnico Nacional (IPN) for financially supporting this work through project number 20211371, “Detección de líneas de costa del Holoceno Temprano inundadas por el ascenso del nivel del mar en Isla Espiritu Santo,” and the use of the facilities at Centro Interdisciplinario de Ciencias Marinas (CICIMAR-IPN). Furthermore, we acknowledge Comisión Nacional de Áreas Naturales Protegidas (CONANP) and Instituto Nacional de Antropología e Historia (INAH) for granting permits to work on the natural protected area and archaeological sites. Finally, we especially acknowledge Harumi Fujita for the scientific legacy that she has built over three decades in Baja California Sur and for introducing us to the earliest human settlement areas at the Isla Espiritu Santo.

ORCID

Mayra C. Robles-Montes  <http://orcid.org/0000-0003-1735-7877>

REFERENCES

- Ansuetz, K. F., Wilshusen, R. H., & Scheick, C. L. (2001). An archaeology of landscapes: Perspectives and directions. *Journal of Archaeological Research*, 9(2), 157–211.
- Aranda-Gómez, J. J., & Pérez-Venzor, J. A. (1986). Estudio Geológico de Punta Coyotes, Baja California Sur. *Rev. Universidad Nacional Autónoma de México, Instituto de Geología*, 7, 1–21.
- Bailey, G., & Flemming, N. (2008). Archaeology of the continental shelf: Marine resources, submerged landscapes, and underwater archaeology. *Quaternary Science Reviews*, 27, 2153–2165.
- Bard, E., Hamelin, B., & Delanghe-Sabatier, D. (2010). Deglacial meltwater pulse 1B and Younger Dryas Sea levels revisited with boreholes at Tahiti. *Science*, 327(5970), 1235–1237.
- Bard, E., Jouannic, C., Hamelin, B., Pirazzoli, P., Arnold, M., Faure, G., & Sumosusastro, P. (1996). Pleistocene sea levels and tectonic uplift based on dating of corals from Sumba Island, Indonesia. *Geophysical Research Letters*, 23(12), 1473–1476.
- Benjamin, J., Bonsall, C., Pickard, C., & Fischer, A. (Eds.). (2011). *Submerged Prehistory*. Oxbow Books. <https://doi.org/10.2307/j.ctvh1dx0v>
- Bird, M. I., Fifield, L. K., Teh, T. S., Chang, C. H., Shirlaw, N., & Lambeck, K. (2007). An inflection in the rate of early mid-Holocene eustatic sea-level rise: A new sea-level curve from Singapore. *Estuarine, Coastal and Shelf Science*, 71, 523–536.
- Blanchon, P., & Shaw, J. (1995). Reef drowning during the last deglaciation: Evidence for catastrophic sea-level rise and ice-sheet collapse. *Geology*, 23(1), 4–8. [https://doi.org/10.1130/0091-7613\(1995\)023<0004:RDTLD>2.3.CO;2](https://doi.org/10.1130/0091-7613(1995)023<0004:RDTLD>2.3.CO;2)
- Braje, T. J., Maloney, J., Gusick, A., Erlandson, J. M., & Klotsko, S. (2022). Re-evaluating terminal Pleistocene and Early Holocene settlement patterns with Chirp subbottom data from around California's Northern Channel Islands. *World Archaeology*, 54(1), 107–121. <https://doi.org/10.1080/00438243.2022.2077825>
- Braje, T. J., Maloney, J. M., Gusick, A. E., Erlandson, J. M., Nyers, A., Davis, L., Gill, K. M., Reeder-Myers, L., & Ball, D. (2019). Working from the known to the unknown: Linking the subaerial archaeology and the submerged landscapes of Santarosae Island, Alta California, USA. *Open Quaternary*, 5(10), 1–15. <https://doi.org/10.5334/oq.66>
- Camoin, G. F., Montaggioni, L. F., & Braithwaite, C. J. R. (2004). Late glacial to post-glacial sea levels in the Western Indian Ocean. *Marine Geology*, 206, 119–146.
- Clark, J., Mitrovica, J. X., & Alder, J. (2014). Coastal paleogeography of the California–Oregon–Washington and Bering Sea continental shelves during the latest Pleistocene and Holocene: Implications for the archaeological record. *Journal of Archaeological Science*, 52, 12–23.
- De Deckker, P., & Yokoyama, Y. (2009). Micropalaeontological evidence for Late Quaternary sea-level changes in Bonaparte Gulf, Australia. *Global and Planetary Change*, 66, 85–92.
- Des Lauriers, M. R. (2006). Terminal pleistocene and early holocene occupations of Isla de Cedros, Baja California, Mexico. *The Journal of Island and Coastal Archaeology*, 1(2), 255–270. <https://doi.org/10.1080/15564890600882955>
- Dobson, J. E. (2014). Aquaterra incognita: Lost land beneath the sea. *Geographical Review*, 104(2), 123–138.
- Erlandson, J., Moss, M., & Des Lauriers, M. (2008). Life on the edge: Early maritime cultures of the Pacific Coast of North America. *Quaternary Science Reviews*, 27(23–24), 2232–2245.
- Erlandson, J. M., Braje, T. J., Rick, T. C., Troy, D., & Southon, J. (2009). A paleocoastal shell midden at seal cave (CA-SMI-604), San Miguel Island, California. Institute for Wildlife Studies.
- Evelpidou, N., Vassilopoulos, A., & Pirazzoli, P. A. (2012). Submerged notches on the coast of Skyros Island (Greece) as evidence for Holocene subsidence. *Geomorphology*, 141–142, 81–87.
- Fairbanks, R. G. (1989). A 17,000-year glacio-eustatic sea level record: Influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature*, 342, 637–642.
- Fairbanks, R. G. (1990). The age and origin of the younger dryas climate event in Greenland ice cores. *Paleoceanography*, 5(6), 937–948.
- Faught, M. K. (2004). The underwater archaeology of paleolandscapes, Apalachee Bay, Florida. *American Antiquity*, 69(2), 275–289. <https://doi.org/10.2307/4128420>
- Faught, M. K., & Smith, M. F. (2021). The magnificent seven: Marine submerged pre-contact sites found by systematic geoarchaeology in the Americas. *The Journal of Island and Coastal Archaeology*, 16, 86–102. <https://doi.org/10.1080/15564894.2020.1868632>
- Fedje, D. W., & Christensen, T. (1999). Modeling paleoshorelines and locating early Holocene coastal sites in Haida Gwaii. *American Antiquity*, 64(4), 635–652. <https://doi.org/10.2307/2694209>
- Fischer, W. F., Schenelder, K., Soomer, C., Carpenter, K. E., & Niem, V. H. (1995). *Guía Fao para la identificación de especies para los fines de la pesca, Pacífico Central-Oriental*. Organización de Las Naciones Unidas para la agricultura y la alimentación.
- Fletcher, J. M., & Munguía, L. (2000). Active continental rifting in southern Baja California, Mexico: Implications for plate motion partitioning and the transition to seafloor spreading in the Gulf of California. *Tectonics*, 19(6), 1107–1123.
- Fujita, H. (2010). Prehistoric occupation of Espiritu Santo Island, Baja California Sur, Mexico: Update and synthesis. *Journal of California and Great Basin Anthropology*, 30(1), 17–33.
- Fujita, H., & Ainis, A. F. (2018). Traditions of early human groups in Baja California and possible routes for the peopling of the Peninsula. *Western North American Naturalist*, 78(3), 285–301.
- Fujita, H., & Melgar, E. (2014). Early holocene use of pleistocene fossil shells for hide-working at Covacha Babisuri on Espiritu Santo Island, Baja California Sur, Mexico. *The Journal of Island and Coastal Archaeology*, 9(1), 111–129.
- Fujita, H., & Poyatos de Paz, G. (1998). Settlement patterns on Espiritu Santo Island, Baja California Sur. *Pacific Coast Archaeological Society Quarterly*, 34, 67–105.
- Gautney, J. R. (2018). New world paleoenvironments during the last glacial maximum: Implications for habitable land area and human dispersal. *Journal of Archaeological Science: Reports*, 19, 166–176. <https://doi.org/10.1016/j.jasrep.2018.02.043>
- Gibb, J. G. (1986). A New Zealand regional Holocene eustatic sea-level curve and its application for determination of vertical tectonic movements. *Royal Society of New Zealand, Bulletin*, 24, 377–395.
- Gusick, A. E., & Davis, L. G. (2010). Exploring baja California's submerged landscapes. *Journal of California and Great Basin Anthropology*, 30(1), 35–49. <http://www.jstor.org/stable/23215634>
- Gusick, A. E., Dodds, T., Jaffke, D., Meniketti, M., & Ball, D. (2019). Defining maritime cultural landscapes in California. *California Archaeology*, 11(2), 139–164.
- Gusick, A. E., & Erlandson, J. M. (2019). Paleocoastal landscapes, marginality, and early human settlement of the California Islands. In K. M. Gill, M. Fauvelle, & J. M. Erlandson (Eds.), *An archaeology of abundance: Reevaluating the marginality of California's Island* (pp. 59–97). University Press of Florida. <https://doi.org/10.5744/florida/9780813056166.003.0003>
- Gusick, A. E., & Faught, M. K. (2011). Prehistoric underwater archaeology: A nascent subdiscipline critical to understanding early coastal occupations and migration routes. In N. F. Bicho, J. A. Haws, & L. Davis (Eds.), *Trekking the shore: Changing coastlines and the antiquity of coastal settlement* (pp. 27–50). Springer.

- Gusick, A. E., Maloney, J., Braje, T. J., Retallack, G. J., Johnson, L., Klotsko, S., Ainis, A., & Erlandson, J. M. (2022). Soils and terrestrial sediments on the seafloor: Refining archaeological paleoshoreline estimates and paleoenvironmental reconstruction off the California coast. *Frontiers in Earth Science*, 10:941911. <https://doi.org/10.3389/feart.2022.941911>
- Halfar, J., Godínez-Orta, L., Goodfriend, G. A., Mucciarone, D. A., Ingle, Jr. J. C., & Holden, P. (2001). Holocene–Late Pleistocene non-tropical carbonate sediments and tectonic history of the western rift basin margin of the Southern Gulf of California. *Sedimentary Geology*, 144, 149–178.
- Halfar, J., Godínez-Orta, L., & Ingle, Jr. J. C. (2000). Microfacies analysis of recent carbonate environments in the Southern Gulf of California, Mexico—A model for warm–Temperate to subtropical carbonate formation. *Palaios*, 15(4), 323–342.
- Hanebuth, T., Stattegger, K., & Grootes, P. M. (2000). Rapid flooding of the Sunda Shelf: A late-glacial sea-level record. *Science*, 288(5468), 1033–1035.
- Hausback, B. P. (1984). Cenozoic volcanic and tectonic evolution of Baja California Sur. In I. A. Frizell (Ed.), *Geology of the Baja California Peninsula* (pp. 219–236).
- Kjerfve, B. (1994). *Coastal lagoon processes*, Elsevier Oceanography Series, University of South California.
- Lambeck, K., Rouby, H., Purcell, A., Sun, Y., & Sambridge, M. (2014). Sea level and global ice volumes from the last glacial maximum to the Holocene. *Proceedings of the National Academy of Sciences United States of America*, 111(43), 15296–15303.
- Legg, R. J., & Anderton, J. B. (2010). Using paleoshoreline and site location modeling in the northern great lakes: Geoarchaeological approaches to prehistoric archaeological survey in the Pictured Rocks National Lakeshore. *Geoarchaeology*, 25, 772–783.
- Lemke, A. (2020). Submerged prehistory and anthropological archaeology: Do underwater studies contribute to theory? *The Journal of Island and Coastal Archaeology*, 16, 5–26. <https://doi.org/10.1080/15564894.2020.1782540>
- Meredith-Williams, M. G., Hausmann, N., Bailey, G. N., King, G. C. P., Alsharekh, A., Al Ghamdi, S., & Inglis, R. H. (2014). Mapping, modelling and predicting prehistoric coastal archaeology in the southern Red Sea using new applications of digital-imaging techniques. *World Archaeology*, 46(1), 10–24. <https://doi.org/10.1080/00438243.2014.890913>
- Moratto, M. J. (1984). *California archaeology*, Coyote Press.
- Munguía-Orozco, L., Valdéz-López, T., Navarro-Sánchez, M., Cruz-Falcón, A., & Mayr-Geraldo, S. (1997). Red sísmica temporal de La Paz. *GEOS Unión Geofísica Mexicana, Boletín informativo*, 17(1), 23–28.
- Murray-Wallace, C. V., & Woodroffe, C. D. (2014). *Quaternary sea-level changes: A global perspective*. Cambridge University Press.
- Nava-Sánchez, E. H., Gorsline, D. S., & Molina-Cruz, A. (2001). The Baja California peninsula borderland: Structural and sedimentological characteristics. *Sedimentary Geology*, 144(1–2), 63–82. [https://doi.org/10.1016/S0037-0738\(01\)00135-X](https://doi.org/10.1016/S0037-0738(01)00135-X)
- Reeder-Myers, L., Erlandson, J. M., Muhs, D. R., & Rick, T. C. (2015). Sea level, paleogeography, and archeology on California's Northern Channel Islands. *Quaternary Research*, 83(2), 263–272. <https://doi.org/10.1016/j.yqres.2015.01.002>
- Rick, T. C., Erlandson, J. M., Jew, N. P., & Reeder-Myers, L. A. (2013). Archaeological survey, paleogeography, and the search for late pleistocene paleocoastal peoples of Santa Rosa Island, California. *Journal of Field Archaeology*, 38(4), 324–331. <https://doi.org/10.1179/0093469013Z.00000000065>
- Roy, K., & Peltier, W. R. (2018). Relative sea level in the Western Mediterranean basin: A regional test of the ICE-7G_NA (VM7) model and a constraint on late Holocene Antarctic deglaciation. *Quaternary Science Reviews*, 183, 76–87.
- Schwanghart, W., & Scherler, D. (2014). Short communication: TopoToolbox 2—MATLAB-based software for topographic analysis and modeling in earth surface sciences. *Earth Surface Dynamics*, 2, 1–7. <https://doi.org/10.5194/esurf-2-1-2014>
- Sirkin, L., Szabo, B. J., Padilla, G. A., Pedrin, S. A., & Diaz, E. R. (1990). Uranium-series ages of marine terraces, La Paz Peninsula, Baja California Sur, Mexico. *Coral Reefs*, 9, 25–30.
- The MathWorks. (2022). *Curve fitting toolbox for use with MATLAB®: User's guide*. Natick.
- Woodroffe, C. (2003). *Coast form, process, and evolution*. Cambridge University Press.
- Yao, Y., Harff, J., Meyer, M., & Zhan, W. (2009). Reconstruction of paleocoastlines for the northwestern South China Sea since the last glacial maximum. *Science in China Series D: Earth Sciences*, 52(8), 1127–1136. <https://doi.org/10.1007/s11430-009-0098-8>
- Yokoyama, Y., Esat, T. M., & Lambeck, K. (2001). Coupled climate and sea-level changes deduced from Huon Peninsula coral terraces of the last ice age. *Earth and Planetary Science Letters*, 193, 579–587.
- Yokoyama, Y., Nagano, G., Nakamura, A., & Miyairi, H. Y. (2023). *Uplift rates of the marine terraces in the south coast of Japan deduced from in situ cosmogenic Be and Al*. <https://www.science.gov/topicpages/u/uplifted+marine+terraces>

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Robles-Montes, M. C., Martínez-Flores, G., Faught, M. K., & Nava-Sánchez, E. H. (2023). Paleoshoreline reconstruction: A proposed method to approach submerged prehistoric landscapes of Espiritu Santo Island, Baja California Sur, Mexico. *Geoarchaeology*, 1–16. <https://doi.org/10.1002/gea.21983>