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Geoarchaeological insights into ancient ports of the northern Persian Gulf: A vanishing heritage

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ABSTRACT

The Persian Gulf is one of the earliest locations where sailing and maritime navigation originated. The Iranian coasts along the northern side of the Persian Gulf have played a key role in maritime history and its development due to the favorable natural and geographical conditions and access to major historical land routes. However, archaeological evidence of ancient ports and maritime activities in this area is scarce and limited to only a few poorly studied sites. This research aimed to identify several potential ancient ports in this region using ground penetrating radar and surface archaeological survey to verify the historical investigations that suggested them as potential ancient ports. The results confirmed that most of the nine suggested sites we investigated had archaeological evidence of maritime activities, but only four of them had buried structures with the others having only surficial evidence. These sites were also threatened by human activity, looting, and encroaching. This study not only highlights the rich and diverse maritime cultural heritage of the northern coast of the Persian Gulf, but emphasizes that more attention and protection needs to be made of this unique heritage, especially in the context of climate change and the need for Iran's economic diversification.

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Climate change; maritime history; cultural heritage; coastal archaeology; economic diversification

Introduction

The Persian Gulf (PG), a semi-enclosed shallow basin between the Arabian Peninsula and Iran, was a gateway for its inhabitants that connected the Indian Ocean through the Strait of Hormuz. Despite the natural advantages and favorable conditions for the development and prosperity of port cities on the northern coasts of the PG due to a more tolerable climate, availability of freshwater, and trade routes on sea and land (Stein 1934), archaeological evidence of maritime activities is limited to only a few sites (Whitehouse and Williamson 1973). This scarcity of information is attributed to two main reasons. First, Iranian archaeologists are not sufficiently involved in maritime history and their findings, which have been relatively sparse, are rarely published or shared

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internationally. Second, the northern coasts of the PG have complex geographical and geological features that have likely buried evidence under sedimentary deposits over time (Pourkerman 2020).

Nonetheless, it is clear that Iran has a rich and diverse maritime cultural heritage that has received little attention or recognition, leading to significant losses culturally and economically. As Firouzi Pourbadi (2022) demonstrated, most Iranians are in fact unaware of their deep maritime past. The result has been a general disinterest by Iranian youth in sea-related studies and careers that focus instead on other fields. This lack of knowledge has also influenced policymaking, with Iran contributing less to maritime activities as a portion of its GDP than neighboring countries (Firouzi Pourbadi 2022). Moreover, neglecting the coast and related maritime activities has reduced the tourism and economic value of coastal heritage sites. As such, identifying and protecting maritime cultural heritage is not only important from a historical and scientific perspective, but also crucial for the economy.

In recent years, the Ports and Maritime Organization of Iran launched a program called "Fostering Maritime Culture" to enhance the knowledge and appreciation of Iran's maritime heritage. One of the objectives of this program was to investigate ancient ports along the coasts of the PG. A comprehensive review of Iran's maritime history by scholars (Vosooghi and Sefatgol 2016) previously identified several locations along the Iranian coast that had historical indications of being ancient port cities, but still required archaeological confirmation (Table 1). Based on the historical accounts—and comparing them with geographical properties of the coasts—researchers were able to determine the coordinates of nine ancient ports. The Iranian National Institute for Oceanography and Atmospheric Science (INIOAS) was assigned to conduct subsurface surveys of these locations using ground penetrating radar (GPR). Many lines of archaeological evidence, especially pottery, have been found along most of the northern PG coast, indicating that various maritime activities were taking place. However, GPR surveys were not possible in all locations due to various constraints such as occupation of the sites by industries or illegal land grabbing by locals. Below, we discuss archaeological investigations that have taken place in these locations and summarize our findings of these potential ancient ports.

Table 1. Summary of the locations and methods examined in this study.

No	Site's name	Lat	Lon	GPR	Surface Archaeology	Historical accounts
1	Shif	29.075	0.87	✓	✓	al-Istakhri (1961), al-Ḥamawi (1977)
2	Hazār-Mardān	28.855	0.85	✓	✓	Saadat (2012)
3	Najirom	27.845	1.83	✓	✓	Mostowfi (1999), al-Maqdisı (1982), al-Istakhri (1961), Ibn Hawqal (1988)
4	Nāyband	27.405	2.62	–	✓	al-Ḥamawi (1977), Abū al-Fidā, (1970)
5	Apostānā	27.135	2.98	–	✓	Arrian (1959)
6	Hūzū	26.825	3.53	✓	✓	Arrian (1959)
7	Lāft	26.905	5.75	–	✓	al-Mas'udı (2012), (Hodūd al Āalam, 1973), al-Ḥamawi (1977), al-Istakhri (1961)
8	Khūrbass	26.915	6.17	–	✓	Arrian (1959)
9	Old Hormuz	27.155	6.89	✓	✓	Arrian (1959), al-Istakhri (1961), Mostowfi (1999)

Study area

The PG, a shallow sea with an average depth of 35 m and a maximum depth of 160 m, lies between Iran and the Arabian Peninsula (Kämpf and Sadrinasab 2006) and marks the eastern border of the Fertile Crescent. Its rich maritime heritage reveals connections through time to regions across the Eastern Mediterranean to East Asia and beyond (Gregoratti 2018; Whitehouse and Williamson 1973) with interconnected maritime and land routes that linked hinterland farms and markets to port cities (Potter 2009).

Archaeological evidence reveals the rich maritime trade history along the northern coast of the PG. The roots of this trade extend back to at least the Elamites (3200–539 BC) (Peighambari and Makvandi, 2022). Heightened activities were observed during the Achaemenids (559–330 BC), as indicated by Arrian (1959). Subsequent periods, notably during the Parthian (247 BC to AD 224), Sasanian (AD 224–651), and early Islamic eras, manifest the study area as a focal point for robust maritime commercial activities (Gregoratti 2011; Priestman 2013). However, the historical significance of this region witnessed a decline due to insecurities resulting from the Mongol invasion in the thirteenth and fourteenth centuries, followed by European presence in the Indian Ocean (Klein 1994). Since the eighteenth century, as noted by Axworthy (2011), the once thriving maritime role of the northern PG coast has faded.

The intrinsic features of the PG, such as prevailing local winds and the restricted availability of cultivable lands with freshwater sources, necessitated the careful selection of secure, sheltered, and strategically advantageous locations for the establishment and development of ancient ports. Moreover, these locations had to ensure connectivity with inland trade hubs through accessible routes across the rugged hinterland. As Pourkerman (2020) notes, the coastal geomorphology and oceanographic characteristics of the region influenced the establishment and sustainability of the road networks, port locations, and maritime routes.

Geology and geomorphology

The PG is a basin formed by the Arabian and Eurasian tectonic plates colliding (Konyuhov and Maleki 2006). The basin has two main domains along its axis (Purser 2012): the northern part is deep, narrow, steep, and quake-prone, and the southern one is shallow, wide, flat, and contains low sedimentary and structural islands (Bird 2010). The PG coast is isolated by mountains in the north and deserts to the south (Ross, Uchupi, and White 1986). It has four segments: (1) the southern coast with a dry climate, flat mudflats (Sabkha), and sandy islands on the Arabian platform; (2) the northern coast with a wetter climate, rugged topography, and permanent rivers flowing from the Zagros Mountains; (3) the Musandam Peninsula with massive carbonate rocks and drowned wadis forming fjords; and (4) the Mesopotamian coastal area with a swampy delta formed as part of the Mesopotamian river system (Figure 1).

Climate

The region has a subtropical arid to hyper-arid climate (Djamali et al. 2011). Annual precipitation varies between <100 and >250 mm mainly between November and April,

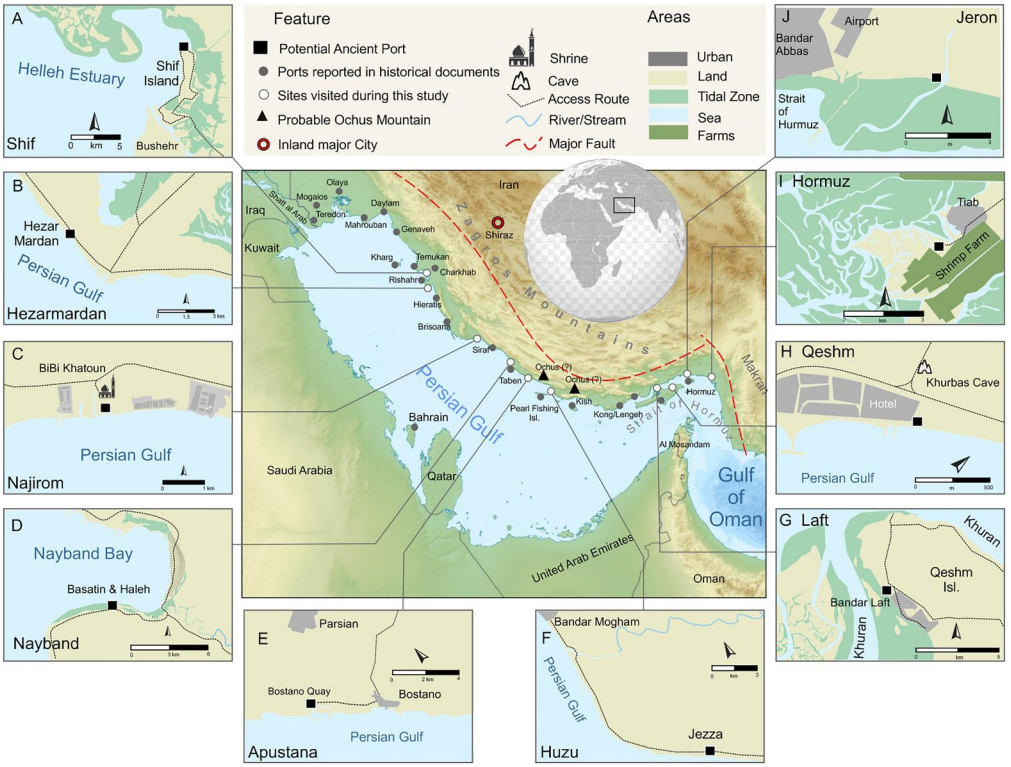

Figure 1. The location of the PG and study sites marked by white circles. The northern coast of the Gulf also shows ancient ports (gray circles) relevant to this paper. The details of the studied sites, the geomorphological features, and the access routes are shown in the boxes labeled A–J around the PG map. The legend on top of the figure explains the patterns and symbols used.

and is higher along the northern coasts. The region's climate is mainly influenced by the Mediterranean Winter Systems, but the eastern parts are also affected by the Indian Ocean Summer Monsoon (IOSM) (Fleitmann et al. 2007). The interplay of the two systems has led to some major climatic events during the Holocene that profoundly affected the history of the region and its maritime activities (Fleitmann et al. 2022). The Shamal winds—northwesterly winds that bring dust into the PG—are the most prominent climatic feature of the PG and are much stronger during autumn and winter.

Oceanography

The PG has a tidal range of >1 m everywhere and up to 4.5 m in some areas. The mesotidal characteristic of this water body enabled ancient ships to enter the estuaries at high tides and load/unload their goods at low tides. Ancient sailors in the Gulf enjoyed the calm conditions of the wave height, which is usually <1 m, especially along the southern and Mesopotamian coasts. In autumn and winter, Shamal winds cause waves to rise up to 4 m high in the PG's central part near the Qatar Peninsula (Kamranzad 2018).

Natural hazards

The PG region faces various hazards from geology, weather, and sea. Storm surge can result from tropical or extratropical storms, or the Shamal wind (Kamranzad 2018). Melville (1984) has reported historical dust storms and storm surges in the PG coast. Earthquakes are common in the northern coast of the Gulf where the Zagros main fault (Figure 1) causes strong earthquakes that can affect the region (Berberian 1995). Some ancient ports like Sirāf (AD 977 and 1008) and Old Hormuz (mid-fourteenth century), for example, were known to have been damaged by earthquakes in the past (Ambraseys and Melville 2005). Tsunamis are rare, but they are possible (Zaré et al. 2012). Historical records report waves from earthquakes that caused damage and deaths (e.g., the AD 1008 event in Sirāf [Ambraseys and Melville 2005] and the AD 1871 "Al-Tabah" event that flooded and destroyed ships along the Kuwaiti coast [Bou-Rabee and VanMarcke 2001]). Thunderstorms often produce heavy rain, lightning, hail, and strong winds and line squalls that can affect trade, travel, infrastructure, and safety in the region (Melville 1984). An illustrative historical instance is the windstorm that swept through Bandar Abbas in December AD 1754, leading to the sinking of ships and causing damage to residential structures (Melville 1984). Flash floods are also known to have frequently damaged ancient ports in the PG's arid region. A similar case occurred in winter AD 1780, marked by intense rainfall and flash floods in Būsheher, resulting in the destruction of numerous buildings (Melville 1984).

Material and methods

As part of this project, government authorities allowed for the use of nondestructive and surface archaeological surveys in some locations along the PG's northern coast (Table 1). Before using GPR, the sites were surveyed for archaeological evidence and random samples of cultural materials, including pottery, were collected. Subsequently, comprehensive archaeological studies were carried out, involving the examination and classification of the collected cultural materials. To establish their chronological context, we compared these findings with known examples from diverse regions and time periods. Our overarching objective was to reconstruct the sequence and nature of trade and exchange activities at these sites. Additionally, our focus extended to determining the age of artifacts, their geographical origins, their diversity, and understanding their potential roles in trade and exchange networks.

For geophysical survey, we used a Mala Geoscience GPR system with an unshielded 200 MHz antenna pair for two-dimensional shallow surveys. The 200 MHz antenna pair balanced depth penetration and resolution for detecting burial structures. Because some sites were inaccessible for GPR measurements, we only collected or photographed surface artifacts. At each accessible site, we established a square grid and aligned the GPR transects within it. The length, direction, and spacing of the lines was kept uniform for subsequent 3D data analysis and processing which was done using ReflexW software and applied different processing steps such as stacking, bandpass filtering, averaging, background removal, static correction, and migration to each transect. We then performed a 3D analysis of the profiles by integrating, interpolating, and normalizing the data using various 3D visualization techniques to display the data optimally.

Results and interpretations

Shif

Geographical background

Shif is a sandy island formed by the riverine sediments of the Helleh River which flows into the PG north of Būshehr Peninsula in the Helleh Bay, an environmentally protected area (Figure 1A). Hosseini et al. (2016) demonstrated that the residual current in this area is mainly controlled by the asymmetric tides that are probably responsible for sediment transportation and deposition. The island's morphology should have changed over time due to an accretional sedimentary environment, as Priestman (2013) noted that the access to the Būshehr Peninsula from the mainland was different in the past.

The island has an average elevation of >1 m above sea level (a.s.l.), with a tidal range that inundates >40% of the island during high tides (Ledari, Saboohi, and Azamian 2021). Currently, desalination plants provide drinking water on Shif Island, but in the past, precipitation was collected in water reservoirs. Farzin et al. (2018) used satellite images to show that the margins of Shif Island have potential submarine freshwater springs. These wells may have also been used to provide water in the past, but we did not observe any evidence of these during our field survey. Another possible mechanism for water delivery to Shif is a canal that transferred water from the river to Būshehr Peninsula through Shif Island (Whitcomb 1987). Fragments of a clay tank were found around Būshehr Peninsula, which might have served as a water conduit from the rivers to the peninsula (Priestman 2013).

Shif has been a favorable anchorage for vessels in the past and still offers a secure shelter for boats needing protection from the prevailing winds. The waters around the peninsula are mostly shallow and at present can be accessed by dredging the inlets for larger ships. In the seventeenth to nineteenth centuries, the Dutch and English East India Companies had to anchor about 3–5 km offshore in the open sea and transport goods by smaller boats. However, traditional shallow draft vessels were able to more easily access the island (Priestman 2013).

Historical and archaeological background

Despite early Islamic sources, modern scholars have overlooked Shif Island's history. The first historical evidence of a settlement there is in al-Istakhri (1961) during the ninth century AD. Rasooli (2019) examined the island's history in the twelfth–fourteenth centuries and argued that the Būshehr Peninsula facilitated maritime communication in the middle of the PG's northern coast through the ports of Lian, Rishahr, and Būshehr before the twelfth century AD. However, between the twelfth and fourteenth centuries, this role shifted to a new port named Khūrshif on northern Shif Island. Shif was a connection between the Būshehr Peninsula and the mainland in the Early Islamic Period, but it gradually evolved into a settlement and the last stop from Shiraz to the PG in the twelfth century because of its safe and easily accessible location (Rasooli 2019). Later in the thirteenth century, Shif emerged as a port city between Sirāf and Mesopotamian ports and served as a supply station for ships (al-Ḥamawi 1977). It also exported textiles and pearls and imported dates and porcelain in the thirteenth–fourteenth centuries AD. Rasooli (2019) claimed that the Persian's rule over the Gulf from

the twelfth to fourteenth century was due to Shif's port, but later declined as a result of the rise of the Hormuz Kingdom and a general lack of secure anchorage and passage.

Our archaeological findings from a damaged site on Shif without architectural stratification show that there was a longer period of settlement beginning in the Sasanian Period. The evidence includes some red pottery with black coating which is similar to that of the Sasanians in Sirāf (Priestman 2013), green glass from the same period, and unidentified copper coins. Carter et al. (2006) suggest that a ship route might have been the primary access to the peninsula. On the west of the Sasanian site, there are signs of the Safavid Period (AD 1501–1736) on a hill ~1.5 m a.s.l. that was destroyed by locals for construction purposes. The few remains observed on the surface included glazed and unglazed pottery from the Islamic Period and Chinese celadon pottery. Field investigation did not indicate any specific structures for either site.

GPR measurements

We defined a 100 m × 20 m quadrangle near the former Sassanid site on the hill's coastal slope for GPR measurements. A challenge was the high water table that attenuated the electromagnetic waves and limited the penetration depth to 1.7 m (Figure 2). However, the results revealed several anomalies from ~70 cm to the end of the GPR record that is around 1.7 m (Figure 2A). A three-dimensional reconstruction of the profiles showed some interconnected rectangular structures at depths of >70 cm. However, the nature of these structures was unclear by manual excavation because of water intrusion. Hence, we are uncertain if these structures belong to the ancient port city or not.

Hazār-Mardān

Geographical background

Hazār-Mardān is located in the southeast portion of the Būshehr Peninsula (Figure 1B) and belongs to the Zagros geological structure. The dominant lithologies are marl and calcareous sandstone from the Āghājāri formation. The area is seismically active and near the Kāzerūn fault zone (Pourkerman et al. 2021). The site is on a rocky shore at ~1.5 m a.s.l., but there are intertidal mudflats east and north of the site behind the headland. A narrow sandstone ridge extends from Hazār-Mardān for a kilometer into the sea. East of the site is Halileh Bay, a tidal estuary where a natural anchorage is present and ancient merchants' vessels could anchor in 5.5 m of water near the shore (Priestman 2013). Hazār-Mardān seems to be an urban area that developed near the anchorage of Halileh and was potentially the optimal source of groundwater. Groundwater is available in the sandstones and this area has potable water unlike the wells in the north and interior of the peninsula (Whitehouse and Williamson 1973). Moreover, there are at least three water conduits at the edge of the gullies that extend from the peninsula's central parts to this region (Whitehouse and Williamson 1973).

The Halileh archaeological site, east of Hazār-Mardān, was obliterated by the construction of the Būshehr nuclear power plant. Its development plans have increased the adjacent land's value and people have engaged in illicit land appropriation, jeopardizing this site's conservation.

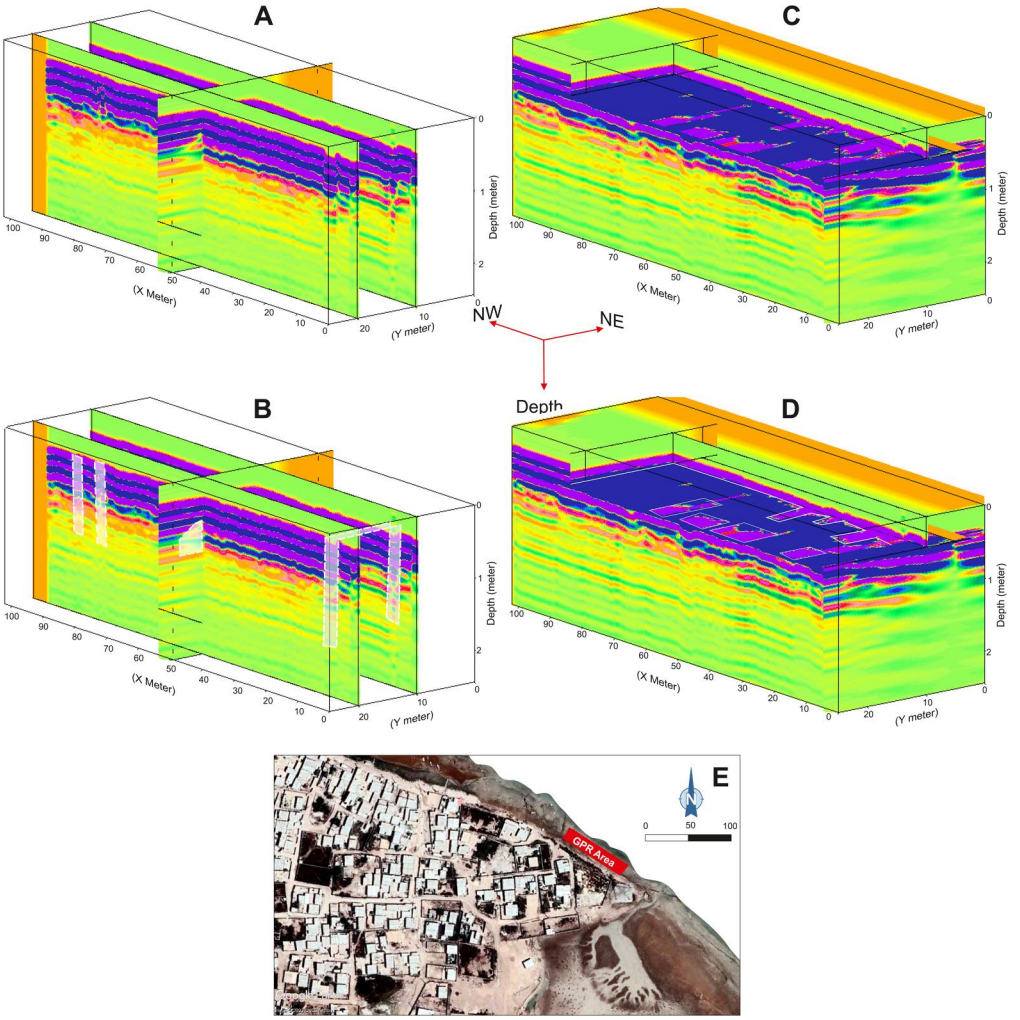

Figure 2. Subsurface anomalies detected by GPR in Shif Island. (A) A cross-section and two parallel 2D GPR profiles in the northern part of the island; (B) interpretation of the GPR profiles of A. The white areas mark major anomalies that reach 1.7 m in depth; (C) 3D GPR anomalies in Shif Island; (D) the interpretation of 3D GPR anomalies that show continuous and interconnected structures between 70 cm and more than 1.5 m in depth; (E) the position of the GPR area on Shif Island.

Historical and archaeological background

Hazār-Mardān's history is obscure and mythical. The Būshehr Peninsula had three main urban centers in the past (Saadat 2012): Būm Ardeshir in the north (Būshehr), Rām Ardeshir in the middle (Rishahr), and Bām Ardeshir in the south (Bishahr), now Hazār-Mardān. Surface archaeological surveys suggest that the Halileh region (6 km north of Halileh on the road to Bushehr) has a longer history dating back to the fifth millennium BC, and the pottery assemblage resembles Iranian and Mesopotamian Ubaid traditions (Carter et al. 2006). They believed that Hazār-Mardān and Halileh formed an ∼160 ha complex. In the 1960s, the complex was >450 ha, with archaeological mounds from the middle–late Sasanian Period (Priestman 2013; Priestman and

Kennet 2002). Cut stone block buildings, fired brick, and pottery fragments are still visible on Hazār-Mardān's surface. We discovered remnants of Sasanian pottery, Indian polished red pottery, and Persian Gulf amphorae during surface survey.

GPR measurements

Some locals who claimed land ownerships and suspected that this measurement aimed to usurp their land threatened the operation team and stopped our field investigation. Therefore, we were only able to measure a small part of the site. We delineated a rectangular area 60 m from the shoreline and 120 m toward the land. We obtained 10 profiles at 1.5 m intervals. The data revealed subsurface structures along all of the profiles. Figure 3 shows several subsurface structures at depths >1 m in the 2D profiles. The 3D reconstruction of profiles also revealed buried structures that had high density and exhibited abrupt variations in the radar wave velocity. The subsurface structures were more abundant at the profile extremities.

Najirom

Geographical background

Pourkerman et al. (2021) documented the geomorphology of Najirom (Botāneh) and identified four areas with archaeological evidence. We examined the Najirom site (Area B) which has four natural geomorphological domains: rocky hills to the north, a small estuary to the west, wadies' flood plains mainly to the east, and a coastal plain to the south (Figure 1C). According to Pourkerman et al. (2021), this site was situated on rocky high ground about 7–11 m a.s.l. However, we observed that archaeological remains were also present in the coastal and flood plain areas. On the northern rocky hills, a calcareous sandstone unit was used to form parts of a mosque dating from the tenth century AD; today, carved stairs and niches are the only remnants of the structure (Tofighian 2015). A cemetery and the holy shrine of Emāmzādeh Abolqāsem sit on the rocky unit north of the site (Figure 1C), while ancient buildings, a furnace, and other unidentified structural ruins are mainly found in the southern and eastern parts of the site. A small estuary borders the site along the west side and is connected to a wadi with a large watershed in marly substrates. Archaeological remains are distributed across an extensive area (ca. 210 ha) with evidence of intensive ancient urbanization, requiring reliable water sources. Apart from the remains of several water reservoirs in the northern rocky hills, Tofighian, Bakhtiari, and Naderi Beni (2023) discovered a complex and integrated system of canals, water reservoirs, and wells, stretching ca. 10 km in the hinterland that would have provided water for this urban area in the ancient past.

Various threats have caused severe damage and loss for the Najirom site. Petrochemical and industrial complexes have encroached from the western and eastern sides, the cemetery has expanded from the northern side, and looting and illegal excavations have also taken a toll on the site. Illicit canals, presumably intended for pipe installation, have inflicted damage to subsurface structures resembling walls on the southern side of the site. Following rainfall, the site becomes a magnet for locals seeking metal objects, contributing to the degradation of its archaeological richness. Moreover, treasure hunters have indiscriminately dug holes throughout the area, causing

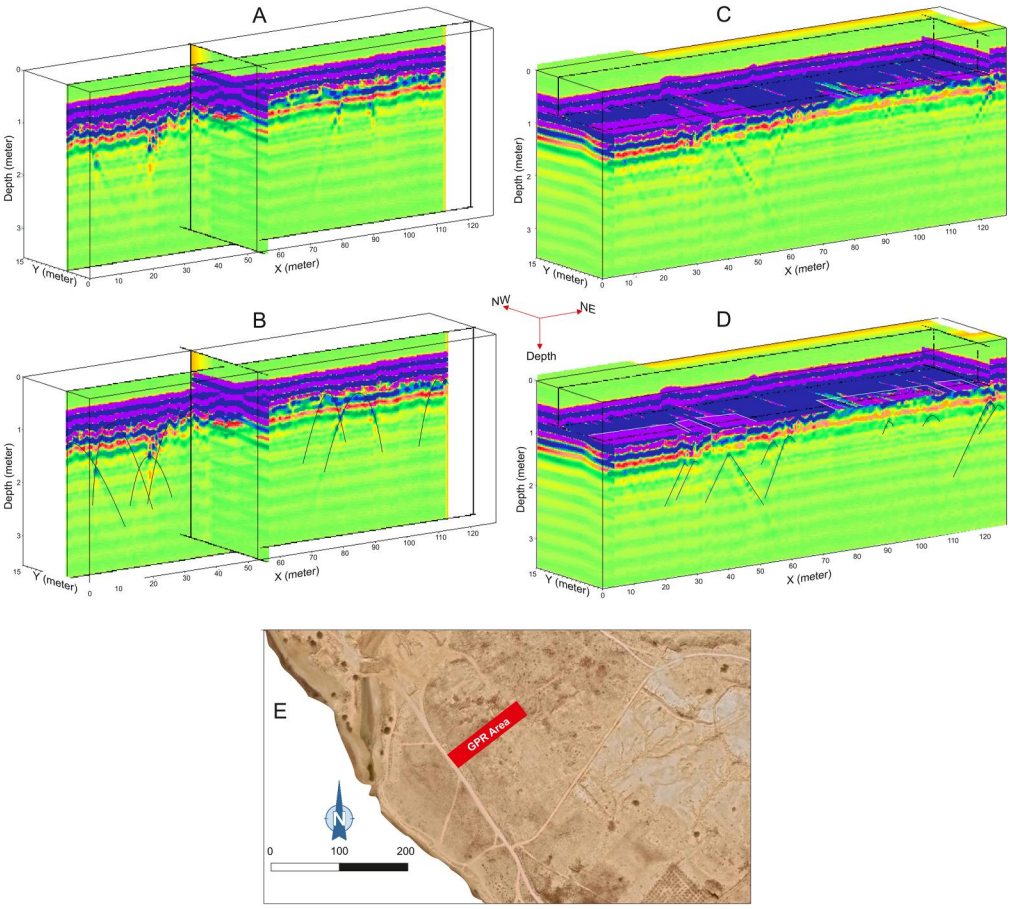

Figure 3. Subsurface anomalies detected by GPR in Hazār-Mardān. (A) A 2D processed image with two cross-sections perpendicular to each other; (B) the interpretation of the GPR measurements. The anomalies are indicated by curve lines; (C) the 3D processing of GPR data in Hazār-Mardān; (D) the interpretation of a 3D image of Hazār-Mardān. The areas with subsurface anomalies are indicated by white lines showing some interconnected subsurface structures; (E) the area of the GPR measurements in Hazār-Mardān in Google Earth image which is indicated by a red rectangle.

widespread damage. The detrimental impact extends to nearby villages where archaeological artifacts, such as plaster pieces with Islamic geometric features, fire-altars, coins, and glass objects, are found in residential dwellings, often available for sale at minimal prices, further perpetuating the illicit trade in historical items.

Historical and archaeological background

Najirom was repeatedly mentioned by Islamic geographers and historians, such as al-Istakhri (1961), al-Maqdisı (1982), Ibn Hawqal (1988), Mostowfi (1999), and many others. According to historical accounts, the prosperity of the port dates from the tenth to thirteenth centuries AD. These historians all suggested that Najirom was located near the Sākān River (Mānd) and west of Sirāf. However, the exact location of Najirom is largely unknown since its decline after the thirteenth century. Based on geospatial

analysis, genealogy of the Emāmzādeh Abolqāsem, historical accounts describing the geographical properties of Najirom, and satellite imagery, Tofighian (2015) concluded that Najirom should be this same study area.

The site had not been systematically excavated until 2023, which was done by Tofighian, Bakhtiari, and Naderi Beni (2023). Prior to this, only surface surveys were conducted (e.g., Tofighian 2015) which suggested that the port was occupied from the late Sassanid Period to the thirteenth century and was contemporary with Sirāf. However, recent excavations along with this study have revealed that the site had a continuous occupation since the Parthian Empire to the Qajar dynasty (AD 1789–1925). The collection of coins and seals indicates that the city had economic and cultural relationships with China, East and North Africa, and India, particularly during the Islamic Period (Tofighian, Bakhtiari, and Naderi Beni 2023).

GPR measurements

This site was a prominent coastal city, probably Najirom, as evidenced by the numerous archaeological findings. We surveyed a network of GPR measurements on a 100 m × 100 m area on the backshore, about 2 m a.s.l., to explore the city's southern boundary. The data showed an abundant and complex series of subsurface structures (Figure 4). While the high groundwater level hindered the detection of hard objects below 1 m depth, 3D images showed thick walls enclosing different areas and various materials (or objects) that strongly attenuated electromagnetic waves. However, it is known that these materials also have the potential to dampen electromagnetic waves, suggesting that structures here may be more pronounced than what is currently visible.

Nāyband

Geographical background

Nāyband Bay, on the eastern coast of Būshehr Province (Figure 1D), is an environmentally protected area due to its unique coral reef and mangrove communities in the western part of the PG. Mangroves stretch along its eastern edge and coral reefs skirt the southern and northern coasts down to 10 m in depth (Fatemi and Shokri 2001). Nāyband is a large and wide bay that provides good shelter from storms (Fatemi and Shokri 2001). Two main historical ports, Basātin (Hāleh) and Nāyband, are close to each other on the bay's southern coast. These archaeological sites, covering 80 ha, are on an exposed raised coral substrate, 5 m a.s.l. The corals were used to build the historical settlement of Nāyband (in ruins during the time of our investigation) and are now collected and reused for new construction. Two pits in the settlement's western side provided coral material for the ancient buildings.

Groundwater supplied water for the area, as the frequency of wells clearly indicated. However, during our visit we also observed evidence of rainwater harvesting in a reservoir on the wadi to the west of the site and on a coral substrate. In addition, some modern water reservoirs are currently in use. The ancient wells morphologically are of two types: (1) circular, deeper, and stone-lined wells further from the shoreline; and (2) smaller and shoreline-proximal wells.

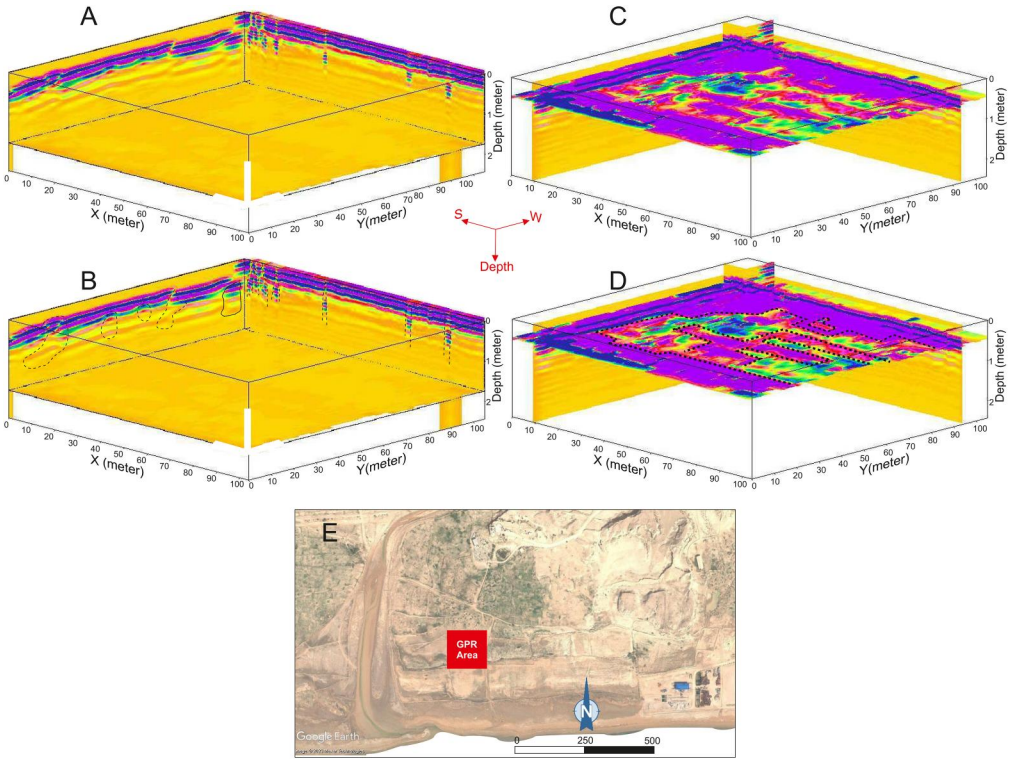

Figure 4. Subsurface anomalies detected by GPR in Najirom. (A) A 2D processed image with two cross-sections perpendicular to each other that shows the outer limit of the surveyed area; (B) the interpretation of the two cross-sections presented in (A). The data show some anomalies indicated by dashed lines resembling the foundation of walls that are extended to depth of ca. 1 m; (C) 3D processes of GPR data in Najirom; (D) interpretation of 3D processing of GPR data. Structures in the form of walls or hard objects are evident in the south–north profiles that are indicated by dashed lines; (E) the location of GPR measurements in Najirom indicated by a red rectangle.

The bay's northern coast is heavily industrialized from ongoing gas and petrochemical activities. Though industrial development increased the land value around Nāyband, this ultimately led to land grabbing by the locals. These groups prevented us from conducting GPR measurements near the mangroves, where we suspected there were some buried structures. When we came back to perform GPR the following year, the area was completely devoid of archaeological evidence (Figure 5).

Historical and archaeological background

al-Ḥamawi (1977) reported that the rich city of Nāyband, with a mosque that had teakwood columns, replaced Sirāf by merchants after a series of devastating earthquakes. Abū al-Fidā, (1970) referred to Nāyband in the early fourteenth century as a city east of Sirāf.

Plaster pieces related to architectural features that had Islamic geometric designs, along with pieces of colored glass, coins, pottery, and metal objects, were among the

Figure 5. Land grabbing by locals and deterioration of the Nāyband archaeological site over a period of three years (2016–2018).

most significant cultural materials found at this site (Tofighian 2015). Buff colored pottery with black and brown motifs was also an important discovery. The site's oldest pottery dates back to the thirteenth and fourteenth centuries AD, as well as the Qajar Period (nineteenth century) (Tofighian 2015).

Toward the east, there was another area near Nāyband with archaeological evidence that extended from the northwest to east of Basātin village for a kilometer and was around 500 m wide; it has now been completely removed by locals. In the area's eastern portion, a historical water reservoir 15 m in diameter was present during our visit but has now disappeared. A relatively large hill containing an architectural layer existed such that on its surface frequent buff colored, gray, black, and orange unglazed and glazed pottery could be found. Some sgraffito with raised or added motifs and a smaller number of celadon were also found. Colored glass, metal pieces, and plaster pieces with Islamic motifs depicting flowers, bushes, rats, and geometrical patterns were also found. The archaeological evidence indicates that this site was active contemporary with Nāyband.

Apostānā

Geographical background

The Zagros Mountain's anticline of marl and calcareous sandstone from the Āghājāri formation forms the Apostānā rocky shore. Behind this shore, differential erosion has created a small, protected embayment in the marly unit near the site. The embayment, enlarged to build a quay, destroyed and buried parts of the historical site. It is the harbor of Bostānū village, east of Apostānā, from which its name may have derived. Unfortunately, the quay constructors prevented us from conducting GPR measurements.

Historical and archaeological background

Arrian (1959) mentions eight rivers on the Persian coast, including Apostānā. Daryaee, Mousavi, and Rezakhani (2014) associated it with the village of Bostānū based on descriptions of a headland west of Qeshm with rugged hills and two small towns situated to the east. Hammond and Atkinson (2013) reported Arrian's account of anchoring near a high mountain (Ochus) and a good harbor 70 km to the west. The Ochus Mountain could be Herang and Jezzeh anticlines, over 670 m high, which meet the sea 70 km east of Bostānū (Figure 1).

Apostānā was an old Achaemenid port near Bostānū (Vosooghi and Sefatgol 2016), was active until the Sassanid Period, and was used by the Portuguese in the sixteenth century AD based on our findings. On the coast, we observed six chambers carved in limestone, linked to the Portuguese, but with older pottery sherds on the surface, especially those that were Parthian and Sassanid. Some chambers had the remains of walls next to them that probably linked to structures extending toward the coast (Figure 6). These walls may have been destroyed during road and quay development.

About 50 m westward, we discovered an ancient thick wall along a steep waterway. It appeared to be rubble and pebbles from the higher escarpment, but after examination they appeared to be arranged deliberately. Behind the site there was a vast area as a repository for dredging and construction waste, forming a large embankment. This area marked the end of the estuary at the tide's edge. We observed brick fragments in the waste, likely from the cleared area for the quay construction.

Hūzū (Ochus)

Geographical background

Hūzū is a small archaeological site less than 10 ha in size between Nokhailū and Jezzeh, two littoral villages. Jezzeh's inhabitants moved to Nokhailū for work. Hūzū is near the Herang and Jezzeh anticlines, conspicuous geological structures that meet the sea and form rocky shores with eye catching features. The Lāvān Island is 8 km offshore from Hūzū. A large ephemeral stream from the anticlines and the salt domes empties its saline water into the Gulf, 10 km north of Hūzū. The site has many peepul trees (*Ficus religiosa*) and date palm (*Phoenix dactylifera* L.), contrasting with the xeric landscape. Frequent shallow wells show groundwater availability, at least in the past. The

Figure 6. Chambers carved in calcareous sandstone in Āghājāri formation on Apostānā beach, northern coast of the Persian Gulf with evidence of Parthian to Sassanid settlement.

archaeological site is bounded by a small estuary and a deep wadi on the east, coastal sand dunes on the west, and sandstone hills in the north.

Historical and archaeological background

Arrian (1959) describes a pearl fishing island and a safe harbor about 7 km away from the island where fishermen lived on its banks, near a tall hill, called Ochus. Hūzū is the most likely location for the harbor near the pearl island (Lāvān) based on Arrian's description. Hūzū is rarely mentioned in historical documents. Vosooghi and Sadeghi (2021) stated that Hūzū was part of Fars Province in the fourteenth and fifteenth centuries AD and identified it as present day Chārak port, east of Hūzū. They stated that Hūzū was a connecting point between Kish Island and Shiraz, the capital of Fars. However, our archaeological findings show a longer continuous settlement for this site.

In the southwest corner, a coastal sand-covered old wall can be seen, about 5 m long and more than 2 m high. The wall's parallel alignment to the coast may indicate that it protected the harbor from waves. In the southeast corner, a walled area can be seen, but whose purpose is unknown, and a shallow well behind it. To the north of this wall, there is an area around 5 ha in size with archaeological evidence, including copper coins, pottery, and porcelain dating back to the Sassanid era, according to preliminary observations. In this area, cisterns, late Islamic artifacts, and pottery or blacksmith furnaces were also recorded. The artifacts from this area indicate that the site prospered from the late Sassanid/early Islamic Period to the modern era. Moreover, areas with fired and partly fired pottery, a uniform metal button, and significant soot and charcoal were observed, probably related to a kiln feature.

GPR measurements

We conducted GPR in a 60 m × 30 m quadrangle that had the most robust archaeological evidence. Measurements were taken along profiles in 1 m intervals. The results indicated anomalous areas up to 1 m deep (Figure 7) with interconnected areas in some

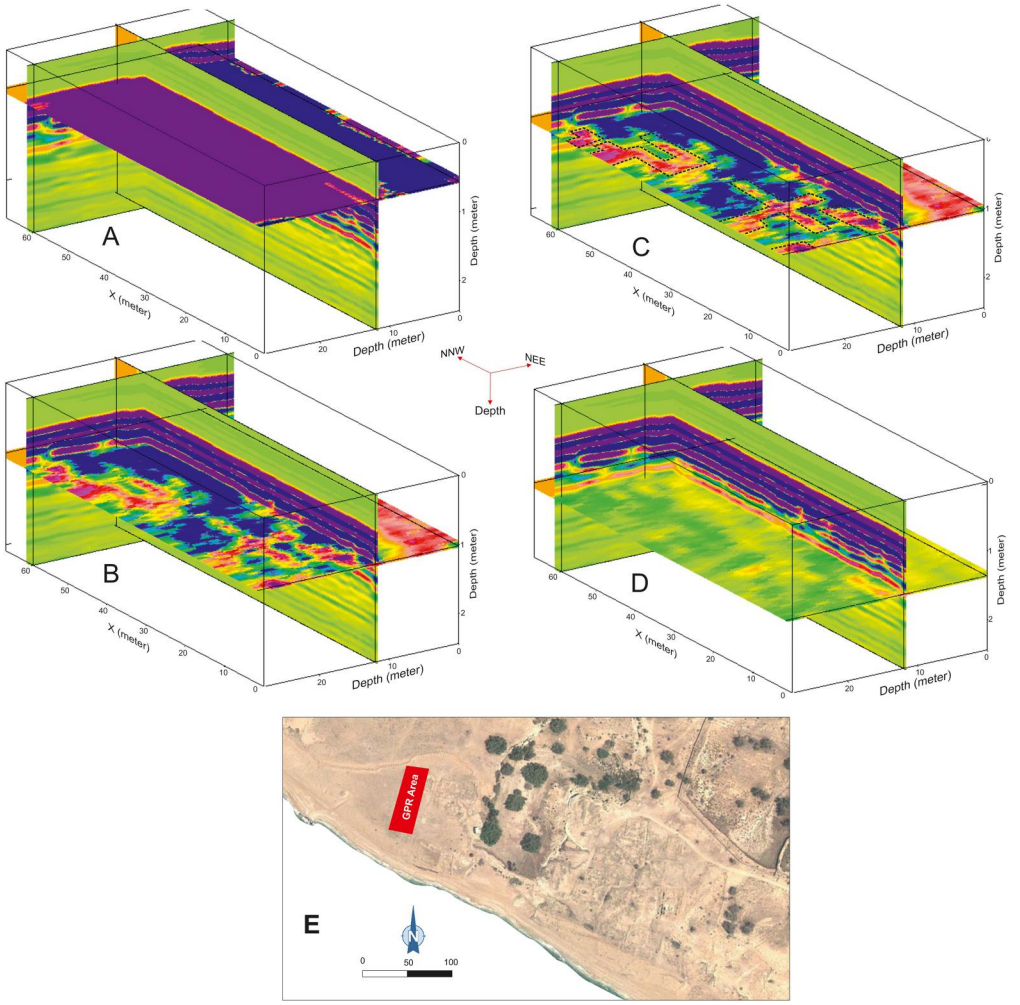

Figure 7. The 3D processing of GPR profiles at the historical site of Hūzū. Most of the anomalies appear at a depth of about 1 m. (A) The 3D processing does not reveal any noticeable subsurface anomaly at a depth of 0.5 m; (B) underground structures are visible at a depth of 1 m; (C) interpretation of the GPR data in depth of a meter that is indicated by a dashed line; (D) underground structures are dimmed at a depth of 1.5, showing relative shallow foundation for the structures; (E) the GPR measurement area in Hūzū is indicated by a red rectangle.

of the 3D images, seaward cross-shaped structures, and a landward U-shaped structure. The many surface cultural materials confirm its importance, but its link to the Achaemenids and its history and archaeology require further investigation.

Lāft

Geographical background

Lāft is on the northern coast of Qeshm Island, closest to the mainland, with the Khūrān natural canal situated between them. The spring tide range in Lāft exceeds 4.5 m and

the average tide range is around 2.5 m, while the wave height rarely reaches 1 m. The environment is suitable habitat for mangrove forest, west of Lāft, which is an environmentally protected area. This situation makes Lāft well sheltered and accessible by both sea and land. The city's main water source has been groundwater and precipitation harvesting using cisterns. The island's main lithologies are marl and sandstone of the Mishan formation and the primary groundwater resources reside in the sandstone units. Due to the city's expansion and numerous buildings, GPR operations were not feasible here.

Historical and archaeological background

The origin of Lāft port is debated. Some scholars trace it to the Sassanids, Achaemenids, or Parthians, but the earliest historical accounts are from Islamic geographers. al-Mas'udı (2012) and the Hodūd al Āalam (1973) described Lāft as both an island and a prosperous city (Bosworth 1997). al-Dimashqi (2007) called Lāft Yāft and considered it a main island in the PG, since the court of Hormuz king was situated there. al-Ḥamawi (1977) and al-Istakhri (1961) also identified Lāft as an island with abundant water and cultivated lands (Shahin, Sepahvand, and Nemati 2018). This port was vital in the premodern era when it was defended by the Portuguese and became a battleground between the Persians and the Portuguese invaders in the eighteenth century (Clulow and Mostert 2018). It also served as a dock for repairing warships and changed the power dynamics of the PG from the Muscatis to the Persians in the mid-eighteenth century (Clulow and Mostert 2018). Walker (1981) notes that Lāft was a major port in the PG in the late nineteenth and early twentieth centuries, connecting India, Makran, Yemen, and Zanzibar. However, Lāft's role declined after the new port of Qeshm was built in the mid-twentieth century.

Lāft is known for its Islamic archaeological evidence, but recent findings by Khosrowzadeh, Aali, and Weeks (2017) have uncovered Bronze Age remains at a coastal site about 4 km east of Lāft. This site on Qeshm Island, along with Khārg Island, are the only Iranian islands with evidence of a Bronze Age settlement (Khosrowzadeh, Aali, and Weeks 2017). Moreover, surficial evidence shows occupation from the Sasanids to Seljuqs (Khosrowzadeh, Aali, and Weeks 2017). This site had been damaged by digging and flattening during our visit. We also observed two jetties more than 80 m long on both sides of Lāft, constructed using igneous and limestone rubble-stones supposedly transported from the mainland or a salt dome, south of the island. The salt dome includes different types of lithic inclusions such as limestone and igneous rocks that were brought to the surface by salt diapirism (Mukherjee 2011). The age of these jetties is unknown and some locals attribute it to the Achaemenids or Sasanids. However, there is no archaeological evidence for this claim and they appear to be modern (Figure 8).

Khūrbass

The Khūrbass heights in Qeshm have traces of rock architecture that some researchers link to a Zoroastrian fire temple. In 2015, we conducted a reconnaissance study along the Khūrbass coast and found a wall buried under coastal sands. We also observed an

Figure 8. Remains of a jetty at the southern end of Lāft city. The age of the jetty is unknown.

Figure 9. Devastation of the Khūrbass archaeological site over three time periods. The photographs show the rapid and severe damage to the site caused by coastal development that disregarded the cultural heritage value of the area. The photos were taken in 2015, 2016, and 2018, respectively.

outcrop with cultural layers containing fish and cattle bones, pottery, and miscellaneous metal objects. However, when we returned in 2016 to collect GPR measurements, this archaeological site had been destroyed to make room for a hotel (Figure 9). As a result,

only some surface materials remained. Preliminary analysis suggested that it likely dated to the Parthian Period.

Old Hormuz

Geographical background

Old Hormuz was on the Mināb River delta (Moghistān Plain), northeast of the Strait of Hormuz. Average annual rainfall is >250 mm which, along with the fertile plain, allows for relatively extensive farming. The river's tributaries come from the Makran Mountains and have good and moderate quality water for drinking and farming. The river is ephemeral and depends on torrential rains, which can cause flooding during the summer due to the IOSM. The main groundwater source in the region is a permeable sand layer sandwiched by non-permeable deposits.

The Mināb River flows into the Tiāb estuary. The estuary is bordered by the sea to the west and by the active Mināb fault to the east. The fault marks the boundary between the Makran and Zagros geological zones and is known to cause deadly earthquakes on land and tsunamigenic earthquakes in the Gulf of Oman (Ambraseys and Melville 2005). The estuary has a rich biodiversity and hosts mangroves near Tiāb village (Figure 1-I). It has a high sedimentation rate from eolian, riverine, and sea sources. However, in recent decades, the area has been transformed for shrimp farming. During our investigation, we found an archaeological site next to an artificial pond with abundant archaeological materials.

Historical and archaeological background

The plain hosts the oldest and most continuous civilization centers in southeast Iran (Mirdadi, Jadidi, and Boushasb Gosheh 2022). Its water resources and strategic position on the land routes (Stein 1934) enabled human settlement and population growth. Frequent historical sites from the Early Paleolithic Period (Dashtizadeh 2012) to historical periods have been documented (Stein 1934). Hormuz, or Harmozeia (Arrian 1959), was the plain's most important hub to connect to maritime routes. However, its location is unknown. The earliest historical reference to Hormuz is by Arrian (1959) who states that Alexander's fleet arrived at the Harmozeia river and pulled their ships to its shore. This river had Old Hormuz on its estuary (Sarlak and Aghili 2013). The city's peak of fame and wealth was in the eleventh–thirteenth centuries as a vassal of the Persian kings (Vosooghi and Sefatgol 2016). Hormuz impressed Islamic geographers with its secure harbor, plentiful resources, and strategic location. However, in the fourteenth century, the Mongols (Vosooghi and Sefatgol 2016) and earthquakes (Ambraseys and Melville 2005) destroyed it, and its inhabitants subsequently moved to Jeron (Hormuz) Island. In AD 1272, Mongols attacked it to exact tribute, though expelling them from the city in AD 1303 did not restore its glory and prosperity because of damage from both the invasion and earthquakes (Vosooghi and Sefatgol 2016). Stein's (1934) quest for traces of old Hormuz found some ruins likely related to the old port's shipping activities about 20 km southwest of Mināb on a flat land prone to flooding, very similar to our site.

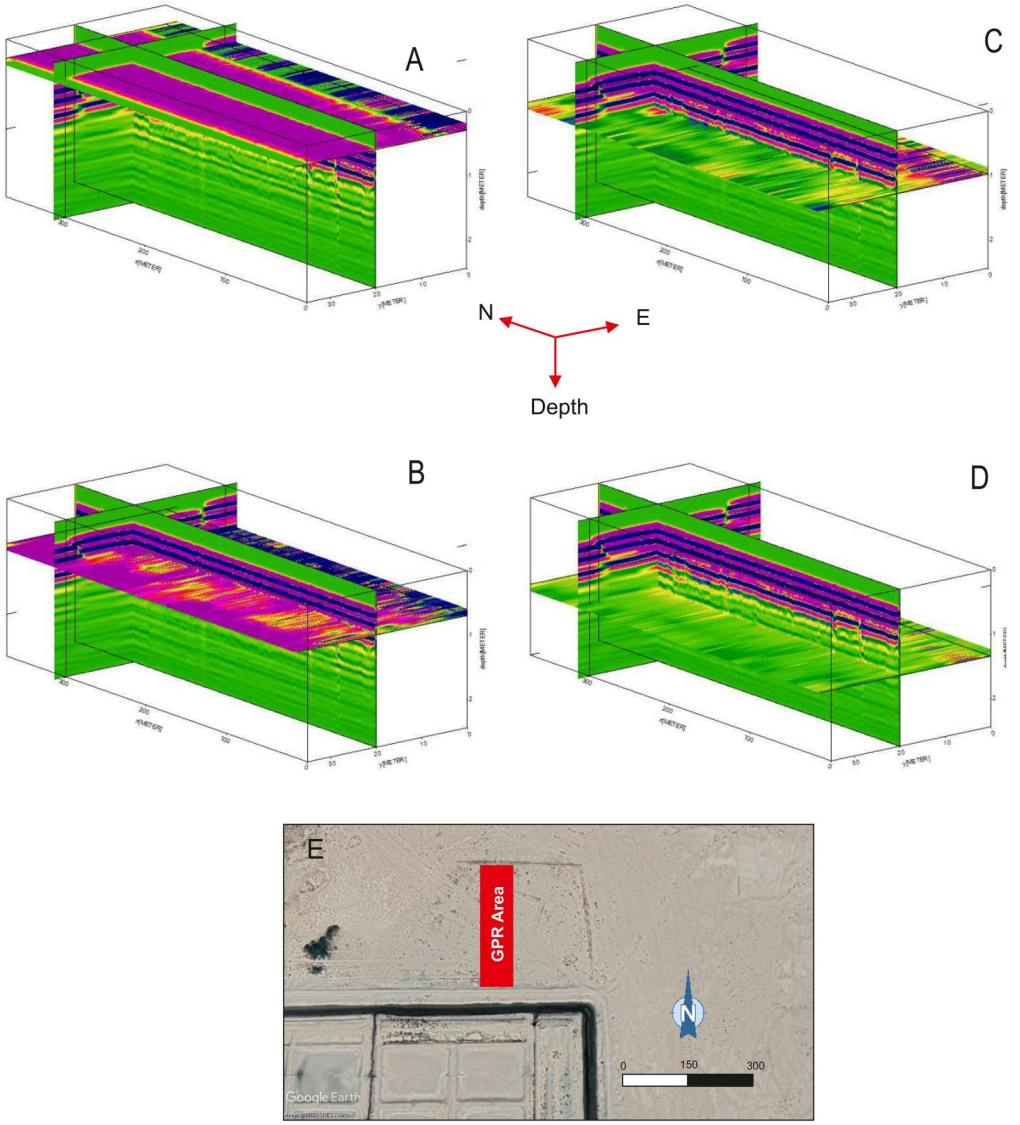

Figure 10. Three-dimensional visualization of GPR measurements at the Tiāb archaeological site (Old Hormuz) at four different depths; (A) the GPR data at a depth of ca. 20 cm; (B) the GPR data at a depth of around 80 cm still does not show evidence of any buried structures; (C) the GPR data at a depth of 1 m. The N–S profile shows some anomalies in the first 100 m as well as around the last 50 m. However, the horizontal surface does not show any extension or interconnectivity between the anomalies; (D) at a depth of >1 m, the data also do not show any evidence of subsurface structures; (E) the location of the measured area at Tiāb, north of the shrimp farms. The limits of the site are evident in the Google Earth image.

GPR measurements

We selected the archaeological site closest to the Tiāb estuary tributaries as the most probable location of Old Hormuz. Though the site was occupied by shrimp farms, an archaeologist named Khosrowzadeh was able to save a small area from damage. We

defined a 350 m × 35 m area and conducted GPR measurements perpendicular to the coast. The profiles showed several anomalies from 70 cm to more than 150 cm deep (Figure 10). However, in 3D format, these anomalies did not show any interconnectivity and we could not identify any subsurface structures at this location.

Discussion

Verifying the ancient ports

The mesotidal sea and flat coasts of the PG let ancient ships approach the coast for loading/unloading goods in estuaries without special infrastructure as might be required in the Mediterranean Sea. Therefore, we do not expect to encounter buried port structures in the PG as might be found elsewhere. That is why we believe that the detected subsurface structures are more likely from coastal cities than port structures and the jetties in Lāft are modern structures.

All of the studied sites are near estuaries with mesotidal ranges. Three of them, Shif, Najirom, and Hūzū, have clear subsurface coastal structures. Two sites, Nāyband and Lāft, have no GPR measurements but enough historical and archaeological evidence to support the presence of maritime activities. Other sites, Bostānū, Khūrbass, and Tiāb estuary (Old Hormuz), have insufficient evidence of coastal city or port use. A coastal road erased Bostānū's evidence and a hotel Khūrbass's. Tiāb estuary's GPR data showed no subsurface structures; its scattered surface evidence may have been reworked by natural processes such as flooding events.

The archaeological sites of Shif, Apostānā, Hūzū, and Khūrbass have been identified as Achaemenid ports by some historians (Vosooghi and Sefatgol 2016), but we found no archaeological evidence to support this claim. Some scholars (e.g., Salles 1996), have argued that the Achaemenids had a weak presence and policy in the PG, and attributed the scarcity or absence of their archaeological remains to their lack of interest in the PG. However, historical accounts indicate great significance of PG for the Achaemenids who engaged in extensive trade with peripheral regions of the Indian Ocean through the PG (Potts 2010). Furthermore, the archaeological traces of Achaemenid are located a few kilometers inland, such as Charkhāb, Susa (Henkelman 2012), and Qal'at al-Bahrain (Potts 2010). Pourkerman (2020) detected marine deposits a few kilometers inland near Charkhāb, as sea level was higher in Achaemenid times. As such, their relics may lie further inland. This is corroborated by Lokier et al. (2015) who suggested that the PG level reached its peak ~5000 years ago and declined to its present level around 1300 years ago. Besides the global sea level changes, local factors such as tectonic movements (Pourkerman et al. 2021) and hydrodynamics of the water body (Pourkerman et al. 2018) should also be considered when locating ancient ports. Historical sources indicate that most of the Achaemenid ports were situated at river mouths (Daryaee, Mousavi, and Rezakhani 2014). Considering the high sedimentation rate of the rivers from the Iranian mountains and the late Holocene hydrological changes (Gharibreza 2017), it is plausible that many traces were buried under fluvial deposits inland and/or removed by floods.

In contrast to the absence of Achaemenid occupation evidence, almost all of the studied sites exhibit traces of Parthian and Sassanian presence. The maritime activities

of the Parthians have been neglected for centuries (Gregoratti 2018). The Parthian Empire lasted for five centuries and had a political presence on both the northern and southern coasts of the PG as well as on the islands, and dominated the trade between Romans, Indians, and Chinese through the PG and its land routes (Gregoratti 2011, 2018; Potts 1996). Their coinage features maritime elements such as crabs, anchors, and ships (Hansman 1990). Archaeological evidence of their maritime trade has been found in South Asia, Arabia, China, and East and North Africa (Gregoratti 2018). The Persian trade in the Indian Ocean peaked during the Sassanid Empire (Whitehouse 1996) which the Arab Muslims inherited and surpassed (Bhacker 2009).

Iran's maritime heritage in decline

The sites we studied have undergone extensive damage. Some, such as Halileh and Nāyband, are completely destroyed. Others, including Shif, Hazār Mardān, Apostānā, and Tiāb, have only remnants left. For example, the area of Halileh-Hazār Mardān was reduced by 65% from 460 ha in the 1960s to 160 ha in 2004, and today, only a few hectares remain, as the land itself has been subject to encroachment. In addition, Hūzū and Najirom are subject to looting and Najirom has been increasingly impacted by the expansion of industrial sites.

Iran's maritime cultural heritage seems to be more affected by conscious destruction rather than ignorance. In fact, the nation's coastal cultural heritage is only minimally mentioned in the Integrated Coastal Zone Management plans (Pak and Farajzadeh 2007). According to Honey and Krantz (2007), two large-scale sets of primary actors drive maritime cultural development: governments at the national or local level and real estate development by financial institutions and other private companies. In Iran, these sectors are not interested in maritime cultural resources when the oil and gas industries—that lie mainly along the PG coasts—are the primary economic drivers.

The Iranian coasts of the PG do have some freshwater sources and wide coastal plains, but they are intermittent and confined to specific areas. All these locations have been used or inhabited for millennia and served as critical port cities and hubs for maritime activity. But today, these areas are also subject to intensive population and industrial growth (Beni et al. 2021). This development has enhanced the value of private land and, as a result, the government resorts to using public lands, including environmentally protected areas and ancient sites, for coastal development (Ansari, Shal, and Fayaz 2007; Naseri, Dizaji, and Poursalimi 2018; Nasrabadi et al. 2023). It should be noted that the Iranian government is legally responsible for protecting the nation's cultural heritage (Mashhadi 2016) and any activity in these areas requires permission from the authorities. However, the economic potential of maritime cultural heritage has often been overlooked in favor of supporting and expanding the oil and gas industries. Cultural heritage resources are rapidly disappearing along almost all the coasts of Iran under the pretext of coastal development. Even in places like Siraf, which has attracted worldwide attention, city expansion has taken priority over the area's cultural heritage; in some parts, these have become landfills for garbage and urban waste.

Iran has a rich maritime heritage, a favorable climate for tourism in wintertime, and various recreational opportunities that could help diversify its economy beyond fossil

fuels (Morakabati 2013). This is crucial in the context of global change that challenges the oil producers of the region to find alternative income sources for the post-oil era (Beni et al. 2021). Despite its appealing tourist destinations, Iran, along with other regional countries, had only a small share of global tourist arrivals (Morakabati 2013). This situation is improving for the Arab countries of the region, as their travel and tourism revenue has increased 30 times since 1995 (Beni et al. 2021). However, this situation is worsening in Iran due to geopolitical tensions and conflicts between Islamic traditions and international coastal tourism (Kovjanić 2014). Due to the mountainous inland areas of the northern PG coast, most of the 8 million people that live in the >2000-km-long coastal zones grapple with higher unemployment than other internal provinces and this has led to domestic migration (Beni et al. 2021). However, policy makers have never looked at coastal cultural heritage as a source of sustainable income to prevent the migration of residents. At the same time, due to the neglect of the cultural heritage, these sources are disappearing.

Coastal cultural heritage sites face multiple threats from human and natural factors (Erlandson and Fitzpatrick 2006; Reeder-Myers 2015). Climate change, particularly sea-level rise, endangers the sites by submerging and/or eroding them (Elliott and Williams 2021; Fitzpatrick et al., 2015). Earthquakes, which are also frequent in the region, can cause further damage to the sites from shaking, leading to displacement and collapse of architectural features (Fitzpatrick et al. 2015; Trakadas 2023). In the PG, the situation is even more critical, as the rate of sea-level rise is estimated to be higher than the global average, exceeding 3.5 mm/year (Beni et al. 2021). The seismicity of the northern coast of the PG also contributes to the considerable destruction of the region's coastal heritage (Berberian and Yeats 2001). Moreover, coastal sites are susceptible to changes in sedimentation regime and erosional processes as seen on a global scale (Fitzpatrick et al. 2015; Westley et al. 2023). While coastal erosion imperils the stability and preservation of some sites in the central part of the northern PG coasts (Pourkerman 2020), high sedimentation rate and river avulsion has led to coastal progradation along the western segment (Gharibreza 2017), posing a threat to coastal monuments. Despite the potential of the coastal and maritime heritage of Iran—along with its stunning landscapes of rocky shores and tidal flats—to offer a sustainable and eco-friendly income source for people through cultural tourism, these resources are deteriorating at an alarming pace.

Conclusions

Our study is one of only a handful of studies carried out along the northern shores of the Persian Gulf that highlight the region's remarkable archaeological record of ancient maritime activities that include pottery, coins, seals, and architecture. In four of the sites, we identified subsurface structures that could be related to ancient ports and in two others, sufficient historical and archaeological evidence that confirm the presence of maritime activities. Other sites, however, have been obliterated as a result of efforts to develop the coast. Overall, it is clear that Iran's maritime cultural heritage along the entire coastline is under threat due to the lack of any comprehensive national policy on the protection, management, authenticity, and integrity of the properties. These ancient

monuments of maritime activities in the Persian Gulf could easily become part of a more regional and global cultural heritage, but for now, the attention and recognition they deserve is limited. In the future, we hope to continue our research and provide scholars, the public, and other stakeholders with information that can hopefully shed further light on these important but rapidly disappearing resources that hold unique clues about ancient maritime movements and behaviors. We also believe that any collaboration with NGOs and local communities to enhance awareness regarding the conservation of the coastal heritage, as well as any effort to draw the attention of policymakers to the economic potential of these monuments, depends on garnering scholarly attention toward these unique heritage sites, nurturing a comprehensive understanding of their value and significance, and formulating optimal preservation strategies.

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