Archaeological Evidence for Modern Coastal Uplift at Diu, Saurashtra Peninsula, India

Miklós Kázmér,[1,*] Nilesh Bhatt,[2] Vishal Ukey,[2] Siddharth Prizomwala,[3] Danko Taboroši,[4] and Balázs Székely[5,6]

[1]Department of Palaeontology, Eötvös University, Budapest, Hungary
[2]Department of Geology, The M.S. University of Baroda, Vadodara, India
[3]Institute of Seismological Research, Raisan, Gandhinagar, India
[4]Island Research and Education Initiative, Palikir, Pohnpei, Federated States of Micronesia
[5]Department of Geophysics and Space Science, Eötvös University, Budapest, Hungary
[6]Interdisziplinäres Ökologisches Zentrum, TU Bergakademie Freiberg, Germany

Correspondence
*Corresponding author; E-mail: mkazmer@gmail.com

Received
20 August 2014
Revised
20 September 2015
Accepted
23 September 2015

Scientific editing by Jamie Woodward

Published online in Wiley Online Library (wileyonlinelibrary.com).

doi 10.1002/gea.21575

There is a tank hewn into coastal Pleistocene limestone near Diu city on the Saurashtra Peninsula of western India. Site survey and a review of similar structures worldwide provide evidence that this tank could have been used for holding fish or *Murex* snails. The approximately 5 × 5 m tank is connected to the sea by a 1-m-deep canal; today it would be impossible to use the tank, given that not even the high spring tides can fill it. It is suggested that the Diu coast was uplifted by ~0.5 m after the tank was hewn in the coastal platform. Since that time, the carved surfaces have been modified by coastal karst dissolution and have developed deep gouge marks. Uplift of the Diu coast raises the possibility of a major seismic event in Diu during the latter part of the last millennium. © 2016 Wiley Periodicals, Inc.

INTRODUCTION

Indicators of past sea levels have excellent records effectively preserved in rocky coasts (Pirazzoli, 1986; Rust & Kershaw, 2000; Stiros et al., 2000; Kershaw & Guo, 2001; Furlani et al., 2011). Relative sea-level changes—caused either by eustatic or tectonic movements—leave traces in geomorphology, bioerosion, and even in human-made features (Flemming & Webb, 1986; Papageorgiou et al., 1993; Stiros, 1998; Faivre, Bakran-Petricioli, & Horvatinčić, 2010; Evelpidou et al., 2012; Mourtzas, 2012a; Özdaş & Kızıldağ, 2013; Seeliger et al., 2014; Kázmér et al., 2015). The respective methodologies applied in these studies have been developed mostly on sites within the environs of the Mediterranean Sea and applied worldwide (Pirazzoli, 1996; Morhange & Marriner, 2015). During a systematic survey of the coastal morphology near the city of Diu on the Saurashtra Peninsula, in the west of India, a human-made, rock-hewn tank-like structure was found. This paper provides a detailed description and interpretation of this structure with reference to tectonically induced coastal uplift along the coastal region near Diu.

Archaeological Sea-Level Markers

Archaeological objects can serve as indicators of coastal change. Buildings—originally constructed on land—are sometimes discovered underwater, thus indicating subsidence after construction (e.g., Flemming & Webb, 1986; Faivre, Bakran-Petricioli, & Horvatinčić, 2010; and many others). There are also structures originally built on the coast, such as ports, which have subsequently been elevated above their functional level, indicating coastal uplift (e.g., Papageorgiou et al., 1993; Stiros, 1998). There are locations that suggest a history of both subsidence and uplift in repeated episodes, such as the iconic columns of the Serapeum in Pozzuoli, Italy (see a range of studies from Lyell, 1837 to Morhange et al., 2006). Archaeological sea-level markers—if studied in conjunction with biological sea-level markers—can also be very reliable in the

 Copyright © 2016 Wiley Periodicals, Inc.

description of relative sea-level change. For recent studies with further references, see Morhange et al. (2013) and Morhange and Marriner (2015).

STUDY AREA

The Saurashtra Peninsula was still considered to be an integral part of the Indian Shield up until quite recently (Rao, 2000), and it was assumed that it belonged to the stable continental interior of western peninsular India (Singh et al., 2014). It is covered by deeply weathered, lateritised Upper Cretaceous-Palaeocene Deccan trap basalts. Along the southwestern and southeastern coasts, late Quaternary Miliolite limestone forms coastal cliffs, beach ridges, and eolianites (Bhatt, 2003).

Recent intensive surveys related to hydrocarbon exploration, as well as seismological studies, have provided a picture of tectonic mobility. Saurashtra is bound by the N–S trending Cambay Basin in the east, the Narmada fracture in the south, the Kachchh rift in the north, and a major WNW-ESE fault in the west (Bhattachariya et al., 2004; Figure 1). Diu is just north of the NE–SW Narmada Son Fault; this fault lies offshore and south of some onland faults, namely the Chachhar and Rupen faults (Bhatt et al., 2006). Recently, a few faults have been mapped on land (Gandhi et al., 2015), along with conspicuous joint sets in the late Quaternary limestone, and these manifest the effects of stress (Bhonde & Bhatt, 2009).

The Kachchh district of Gujarat is the only region outside the Himalaya–Andaman belt that has a high seismic hazard of magnitude 8; this corresponds to zone V in the seismic zoning map of India. The other parts of Gujarat have respective seismic hazard magnitudes of 6 or less. While potential earthquake source zones in Kachchh have already been recognized (Chopra et al., 2013: Figure 2), those in Saurashtra are practically unknown; this is due to the lower magnitude of seismicity that has so far been observed. Earthquakes up to M_w 5.7 occur infrequently along the poorly defined faults of the area (Rastogi, Kumar, & Aggrawal, 2013). Furthermore, the Cambay Basin faults in the east have shown only moderate seismic activity in the last 200 years, while the Narmada–Son trend and the SW-West Coast trend of faults have shown very moderate seismic activity (Rastogi, Kumar, & Aggrawal, 2013a).

Nevertheless, since these earlier assumptions were made, late Quaternary coastal changes have been extensively studied along the southern Saurashtra coast. As a result of this research, there is now ample evidence for sustained uplift. For example, since the last interglacial, it appears there has been uplift of up to 15 m above mean sea level, and this can be observed in the form of Holocene marine terraces and notches (Gupta, 1972; Bhatt & Bhonde, 2006).

These conclusions with respect to uplift follow in the light of widespread underwater and onshore archaeological surveys carried out in the western part of Saurashtra (Rao, 1996, 1996; Gaur & Vora, 1999; Gaur & Tripati, 2006; Gaur, Tripati, & Tripati, 2007). The archaeological surveys found submerged living quarters and ports, and even a submerged Hindu temple in the northwestern part of Saurashtra (Gaur, Tripati, & Tripati, 2007). Such discoveries are further evidence for active coastal change.

Along the southern coast of Saurashtra, on Diu Island, a rectangular tank-like structure was found, and it had clearly been hewn into the local Miliolite limestone. The research recorded in this paper shows that during high tides the tank was only partly filled by the sea through a canal, and fully emptied during low tides. This tank was examined and special emphasis was placed on its position relative to sea level, with the aim of being better able to quantify the Holocene vertical displacement of the coast.

METHODS

The location was surveyed between September 18 and 22, 2012, using a compass, tape measure, and a laser distance meter. These measures routinely provide ±1 cm accuracy. Unfortunately, the rough rock surface prevented precise fitting of the laser distance meter and because of this the estimated accuracy of measurement was ±3 cm. Elevations were related to current sea level and calibrated to the nearest tide gauge; that is located approximately 50 km to the east, at Nava Bandar (20°4′09″ N, 71°05′30″ E). The tidal table was provided by *http://tides4fishing.com* (for September 2012).

THE TANK

West of Diu, the rocky coastline is, in most of its sections, bordered by a tidal platform tens of metres wide. In a few places the remnants of older, uplifted platforms have been preserved. The tank was cut into one of these older platforms, near a place called Chakratirtheshwar (Figure 1). A detailed description and interpretation of the tank is given below.

The rectangular tank or basin found on the small promontory north of Chakratirtheshwar sanctuary (20°42′19″ N, 70°58′45″ E) is entirely carved in the bedrock. This bedrock is indurated Middle-to-Late Pleistocene Miliolite limestone that forms the island of Diu (Figure 2). The tank has a rectangular plan, being approximately 3 × 3 m at the bottom, >5 × 5 m at the top,

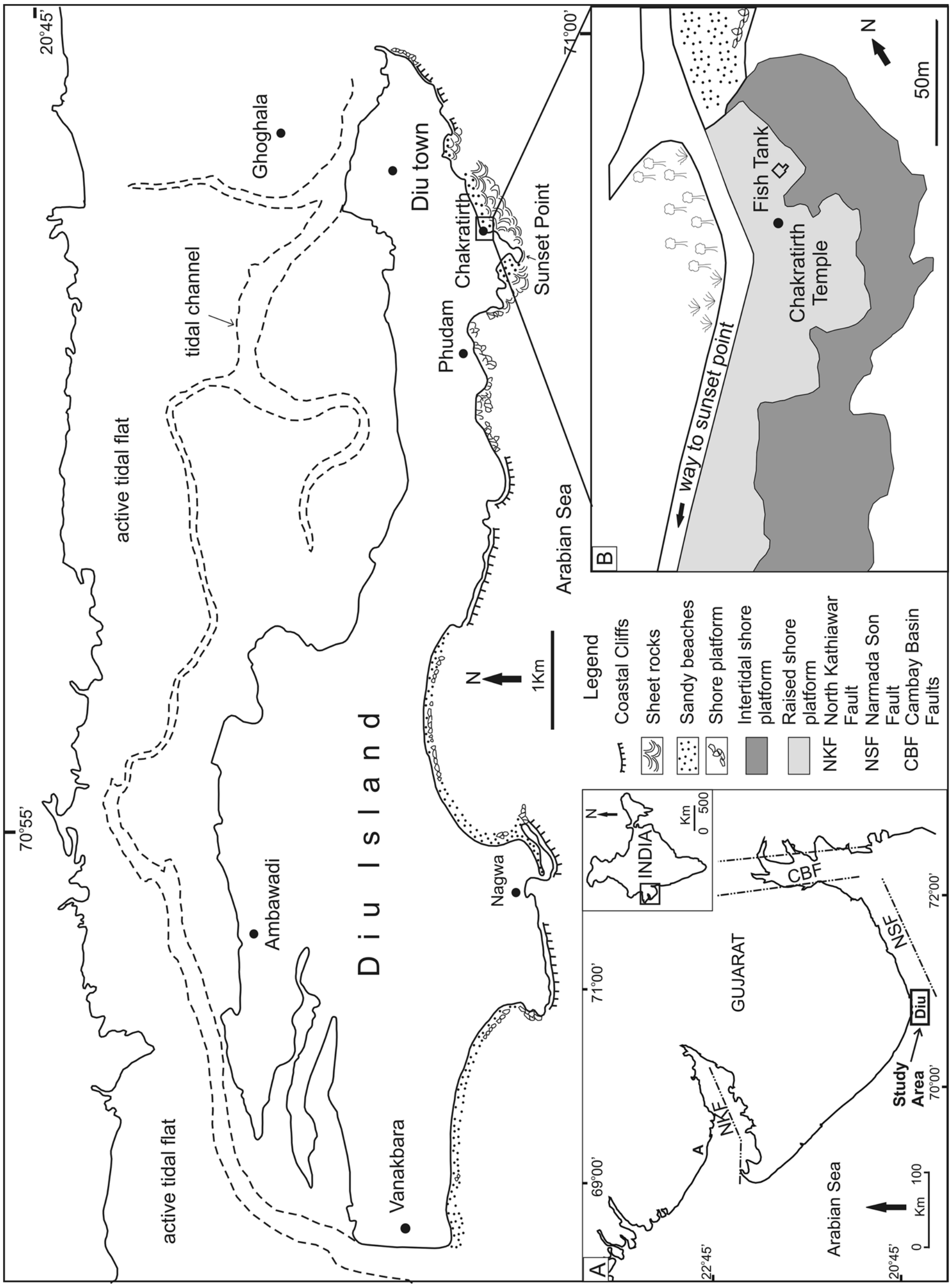

Figure 1 Map showing the geomorphological setting of the Diu island. (A) Location of Diu in India and Gujarat state along with bounding faults of the Saurashtra Peninsula. (B) Location of the fish tank near Chakratirtheshwar temple.

Figure 2 Fish tank and inlet canal after high tide. View toward the east. Conspicuous bedding of the Miliolite limestone (Pleistocene calcareous sand dunes) is tilted toward the east. Steps surround the tank. The person in the photograph is standing on the lowest step. A further three steps (equivalent of Roman *crepidini*), leading to the loading platform, are visible to the right of the person. The cross section of Figure 7 is a representation drawn along the axis of the canal. Tide at 225 cm, ~5 cm above the canal bottom at time of photographing. The highest astronomical spring tide at 270 cm is 45 cm above tide level as shown on the photograph, barely covering the step where the person is standing. Photo: M. Kázmér, #P9220375.

and widening upward in a stepwise fashion. Its sides are oriented N–S and E–W and the survey indicated that it was ~1 m deep at the time of construction. All sides of the tank are stepped; however, now only the southeastern half is fully preserved.

An entrance for sea water was cut on the eastern side of the tank. The canal of this entrance is 0.5 m wide, 1.0 m deep, and about 5 m long. It is horizontal near the tank, and slopes distally toward the sea. A vertical, semicircular groove of 50 cm diameter was cut in the northern wall of the canal. There are three holes of 5–10 cm diameter at the bottom of this site and these probably held the poles of some kind of a barrier (perhaps a movable "gate"). This barrier would have retained the water in the tank during low tide.

All around the tank, there are stepped walkways that are 25 to 55 cm wide and 20 to 25 cm high. Stairs (20 cm high) were inserted in the lowermost walkway on each side to facilitate access to the bottom of the tank.

It appears that the promontory bearing the tank was modified at some time on the eastern and the southern sides. There are visible remnants of rock-hewn steps and these are 3 m long along the eastern side, and 5 m long along the southern side; the steps are 26 cm high and 30 cm wide. A flight of six steps leads down to the level of the coastal platform (Figure 3). There are similar steps along the southern rock of the small embayment. The steps along the eastern side of the promontory display peculiar, inclined edges. These surfaces are the products of fracturing along the eastward-facing, foreset beds of the eolian Pleistocene limestone that forms the promontory. The same weakness along the bedding planes caused the fracture of the step-cut of the lowermost step on the western side of the tank.

There are conspicuous holes on top of what appears to have been a loading platform, as well as on the uppermost steps along the eastern and southern sides of the promontory (Figure 4). Steep walls and a mostly flat floor down to a depth of 16 cm indicate that these are solution features of the supratidal spray zone (*kamenitza*, Taboroši & Kázmér, 2013). The evidence of bioerosion caused by grazing littorinid snails in the supratidal zone and by grazing limpets in the upper intertidal zone (Kázmér & Taboroši,

Figure 3 Irregular steps (26 to 51 cm high) along the southern side of the promontory holding the fish tank, as seen at low tide. The irregular corners are products of extreme karstic dissolution in the spray zone. The biological mean sea level (BMSL) is along the top of the pink crust of corallinacean algae, at knee elevation of the person in the photograph. Photo: V. Ukey, #DSCF1459.

2012) explains the irregular pitting and lowering of the originally flat, rock-hewn surfaces of the steps. There is a conspicuous pink crust of corallinacean red algae covering the rock surface in the lower part of the intertidal zone (Figure 3). Along its irregular upper boundary is the Biological Mean Sea Level (BMSL), as defined by Laborel and Laborel-Deguen (1994, 1996).

Figure 2 was photographed at 16.33 local time on September 22, 2012, 1 hour before a high tide of 2.3 m. The maximum astronomical high tide reaches 2.7 m. The top of the platform in which the tank was cut is at a level of 330 cm. The photograph shows clearly that the high tide is unable to fill the tank to any reasonable level and Figure 3 shows that low tide leaves the coastal platform dry.

DATING

The dating of (fish) tanks derives indirectly from the age of the settlements they served (Mourtzas, 2012b). Diu was a rich merchant settlement during the reign of the Cambay sultan in the late Middle Ages. The town was captured by the Portuguese in 1531 and a major fort was built in 1537. The town and the fort controlled Portuguese interests on the west coast of India throughout the 16th and 17th centuries (Shokoohy & Shokoohy, 2003, 2010). The supposition of the present study is that the small port and tank at Chakratirtheshwar were constructed during the period of Portuguese rule; this is based on the analogous structure of the tank with Roman-age fish tanks in the Mediterranean (Table I).

The deep solution pits on the carved top of the platform and on the steps are the result of the constant spraying of seawater (Taboroši & Kázmér, 2013). The depth of these pits has increased proportionally with time. In order to assess the magnitude of change the present study considered the erosion rate of about 10–35 μm/yr, which was measured at an analogous site in the Ryukyu Islands of Japan. There the lithology and the environment are similar to those discussed in this paper: namely, moderately indurated, highly porous Pleistocene limestone that has been dissolved by spraying seawater in tropical conditions (Aoki, 2009). The conditions outlined in this paper suggest that the 16-cm-deep pits on the stairs needed several centuries to develop under subaerial conditions—that is, the tank and its associated stairs are at least a few hundred years old. This is supported by the

 Copyright © 2016 Wiley Periodicals, Inc.

Figure 4 Actively growing solution pits on the southern flight of steps in the spray zone. The higher the elevation of the step, the deeper is the pit. Those on the uppermost step are up to 16 cm deep. The rough and irregular surface of the stairs is the result of a combined action of wave splash, sea spray, and grazing by littornid snails (Kázmér & Taboroši, 2012). Photo: M. Kázmér, #P9220384.

historical sketch of a tank of the kind being discussed here (Figure 5).

DISCUSSION

The Tank

Observations on the tank at Chakratirtheshwar leave little doubt about its function. Entirely carved from bedrock, there is no need for a detailed hypothetical reconstruction of its lost portions. Its purpose was certainly to hold sea water and allow a direct connection to the sea at certain times, while blocking this connection at others. The Diu tank is surprisingly small compared with similar Roman structures described as fish tanks. However, the exact kind of animal kept in the tank is a matter of speculation. Fish are most likely to be, but it should be taken into account that fish could easily have jumped out of the tank and escaped to the sea, a mere 1–2 m away. Turtles, or rather *Murex* snails, are both significantly less mobile than fish; furthermore, records show that these species were certainly expensive enough at the time to justify the costs of carving a tank to hold them (Mourtzas, pers. comm., 2014).

It will probably never be known exactly what was held and cultivated in the coastal tank at Diu. The following discussion is about a rich variety of analogous structures around the Mediterranean Sea considered as "fish tanks" and that have been described in detail. In the 1st–2nd century A.D. fish tanks were built by the Romans (Higginbotham, 1997; Lambeck et al., 2004a,b; Mourtzas, 2012b). Most of these were built into or on top of nearshore platforms, exhibiting various designs with hydraulic features related to the local geomorphology (Mourtzas, 2012a; Evelpidou et al., 2012). The basins of these tanks were connected to the sea by canals constructed to allow sea water into the tank. Movable gates regulated the water level in the basins. Step-like walks around and within the basin allowed maintenance to be carried out as summarized by Evelpidou et al. (2012).

In the Mediterranean, in Antiquity, purple dye was manufactured by processing the hypobranchial gland of muricid gastropods. After oxidation, the normally translucent mucus of this gland turns to various shades of red, purple, or blue (Higginbotham, 1997; Forstenpointner et al., 2007). Fishermen collected the live snails, and kept them in a tank (the *vivarium*) until a sufficient number had been gathered to start the dye extraction (Leadbetter, 2003). Rock-hewn tanks, not dissimilar to that at Diu, are also known from ancient Greece (Kardara, 1961). Although related mollusc species are abundant along the coast around Saurashtra (Radwin & D'Attilio, 1986), historically *Murex* dyeing is unknown in India, where plant dyes have been preferred (Siva, 2007). However, it is possible that Portuguese merchants started a purple dye business in Diu, and the Chakratirtheshwar tank belonged to this industry.

Elements of construction that relate to former sea levels are as follows:

- the bottom of the inlet canal, which should be below high neap tides in order to allow the passage of sea water into the basin at least daily;
- the top of the inlet canal, and the sluice gate within it, should be above the high spring tide level to prevent the loss of fish (Evelpidou et al., 2012: 275).

Coastal tanks, derived from Antiquity, are considered to be the most reliable class of archaeological monument for studying relative sea level variations (Auriemma & Solinas, 2009). A direct provenance of the technology from the Roman-age Mediterranean (of which the territory of present-day Portugal was an integral part) to Portuguese-dominated Diu in the 16th century is quite

Table I Comparison of Mediterranean fish tanks with the Diu tank of this study.

	Mediterranean Sea	Diu
Fish tank/pond *(piscina)*	Fish tanks (Latin *piscinae*) were either entirely carved from bedrock (e.g., Mourtzas, 2012b) or built from hewn blocks (e.g., Evelpidou et al., 2012).	The Diu tank is carved from bedrock. Although only the southeastern half has been preserved, it is suggested in this study that it was a fully rock-hewn basin, the missing portions having been quarried away since the tank came into disuse.
Sidewalk *(crepido, crepidini)*	The sidewalks—called *crepidini* in Roman architecture—enabled maintenance. These were used to walk around the pools without getting wet (Auriemma & Solinas, 2009; Anzidei et al., 2012). In a few fishponds, several levels of *crepidini* were found.	Having a set of three at Diu, with an additional fourth as a small step cut into the lowermost one, means that water level changed frequently in the tank. The uppermost sidewalk always had to be in an elevated position to allow maintenance.
Canal	Canals refilled fishponds with seawater. Their bottom had to be always submerged for a permanent water supply, even during low tide. This applies to the microtidal Mediterranean Sea.	The canal is horizontal between the basin and the margin of the coastal platform, and then slopes seaward. A tidal range exceeding 2 m does not allow the canal bottom to be permanently submerged.
Closing gate *(cataracta)*	Closing gates *(cataractae)* prevented fish leaving the ponds. The top of the gates was slightly above high tide to prevent loss of fish. Cataractae were either narrowly spaced grills or stone/lead plates with a large number of holes allowing water circulation.	A vertical groove in the northern canal wall and three subcircular holes in the canal bottom are the sole remains of the former closing gate. A barrier prevented fish escaping during high tide, while allowing an inflow of fresh seawater. A second, water-tight gate prevented loss of water during low tide.
Date	1st century B.C.–1st century A.D.	Unknown (possibly 16–17th century)

possible. However, this needs further extensive archaeological, historical, and ethnographical research.

Certain Roman building traditions in Antiquity can be recognized that survived well into the Middle Ages and even later, and were applied very far from the territory of the former Roman Empire. For example, builders of the Crusader castle of al-Marqab in Syria, built in the late 12th century, applied Roman concrete technology (Kázmér & Major, 2010). Up to the 18th century at least, Spanish military engineers used the very same technology when constructing fortifications for military outposts in the Philippines (Cabigas, 2008).

The use of permanent seashore tanks in Diu is visible on an early engraved panoramic view from 1572 (Bruin, Novellanus, & Hogenbergius, 1572–1618; Figure 5) and on a mid-18th-century map (Salmon, 1752–1753; Figure 6). Although their purpose is not stated expressly, the word "tank or pond" on the latter do not leave much doubt that the keeping of live catches from the sea in coastal tanks was a common practice throughout the centuries of Portuguese rule. For a detailed comparison of the architectural details of the Diu tank with counterparts in the Mediterranean, see Table I.

Consideration must be given to the possibility that coastal tanks developed independently in various areas and periods, both in the Roman-age Mediterranean and in Medieval India. Analogous examples are the *qanats* or underground water transportation systems that developed and expanded from central Asia and Iran. These engineering constructions were independently developed in, for example, pre-Roman Italy and the Americas (Stiros, 2006).

Tides and the Diu Tank

The maximum tidal range in the Tyrrhenian Sea—where the best-studied Roman fish tanks are found—is 45 cm; this happens to be equal to the depth of the fish pond canals that can be found there. This indicates that the flow of water into the tanks was tidally controlled (Lambeck et al., 2004b). At Diu (measured on the Nava Bandar mareograph nearby) the spring tide range is ~2 m, and the neap tide range is ~1 m; these ranges are far too large to have let the inflow and outflow be regulated by tides only. A control gate would have been essential to keep water in the tank during low tides. The 0.5-m-wide, 1-m-deep inlet canal provided an ample supply of fresh sea water to the tank, even during high neap tides. This is an important consideration given the year-round high temperatures at 20°N tropical latitude. During low tide, a water-tight barrier prevented the water level in the tank from falling to a level insufficient for the animals to survive.

Today the Diu tank is dysfunctional with respect to its original purpose, given that even the highest spring tide cannot fill it completely, and a high neap tide is barely enough to supply water to cover the basin bottom. However, if the fish tank was positioned just 0.5 m lower, it could function effectively. Therefore, the suggestion being made here is that the tank, the promontory, and the

 Copyright © 2016 Wiley Periodicals, Inc.

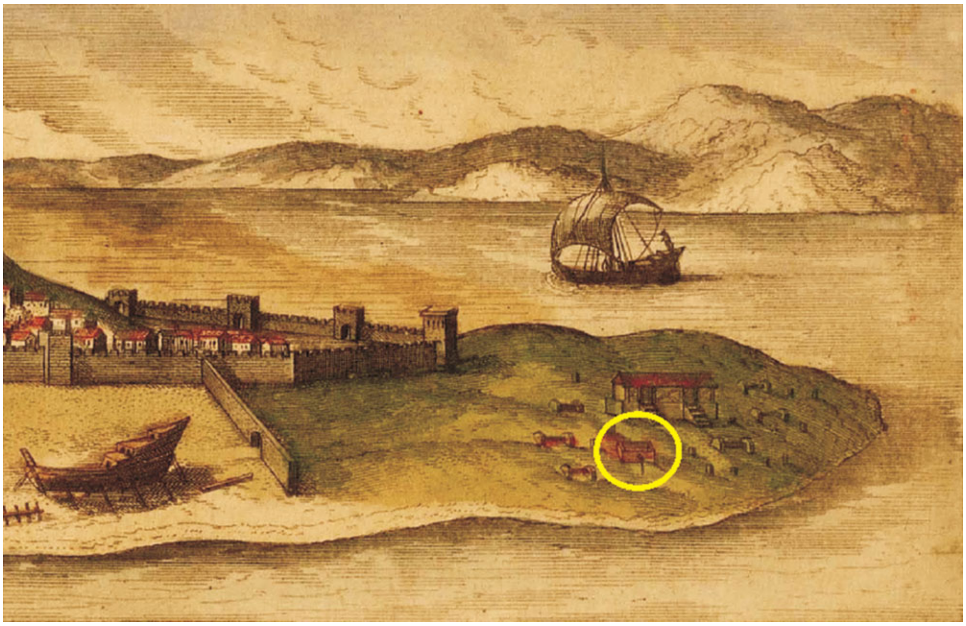

Figure 5 Tank (encircled) out of the city walls of Diu. Flowing water suggests the tank is at the top of the intertidal zone: detail of a panoramic view in Bruin et al. (1572-1618). Source: http://www.columbia.edu/itc/mealac/pritchett/00routesdata/1700_1799/malabar/diu/diu.html.

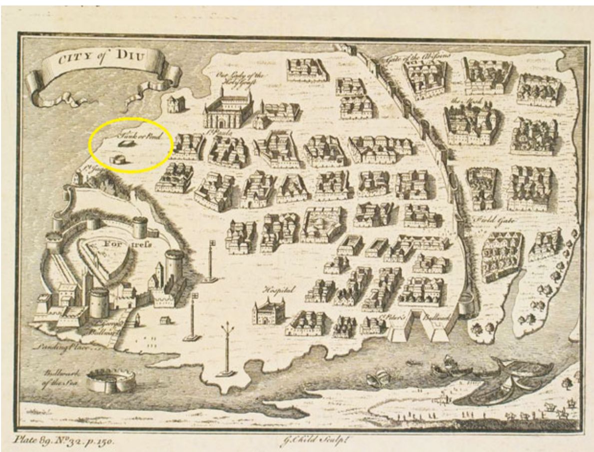

Figure 6 Map of Diu, mid-18th century. Note the "tank or pond" just above the fortress. It is evidence for the ongoing practice of keeping live catches from the sea in tanks near the shore. Engraved by G. Child. Size of engraved area 200 × 140 mm. Source: Salmon (1752–1753), http://en.wikipedia.org/wiki/File:Diu_map1729.jpg.

Chakratirtheshwar portion of Diu Island have been uplifted by at least 0.5 m since its construction. This uplift probably occurred at some time during the latter part of the last millennium (Figure 7).

There is a rich literature on displaced maritime archaeological structures, indicating either coastal uplift or subsidence some time after the construction of these structures. The functionality of fish tanks, jetties, ports, and watchtowers (recently Anzidei et al., 2011, 2012; Mastronuzzi & Sansò, 2014; for a review see Evelpidou et al., 2012) is very closely related to the local sea level. This is why they are excellent markers of relative sea level change, whether in the Mediterranean or elsewhere. There is an increasing number of papers offering considerations on the tectonic and seismic background of the cause of such displacements (e.g., Stiros, 1998; Kontogianni, Tsoulos, & Stiros, 2002; Mastronuzzi & Sansò, 2014).

With regard to the site that is the subject of this study, modeling of eustatic sea level changes has shown that the present-day relative sea level is stable along the coasts of Saurasthra (Peltier, 2002). Therefore occurrences of both uplifted and submerged archaeological features in Saurashtra (Rao, 1996, 1996; Gaur & Vora, 1999; Gaur & Tripati, 2006; Gaur, Tripati, & Tripati, 2007) invite a tectonic explanation.

Implications for Seismicity

As mentioned before, Diu is close to the intersection of the fault sets bordering Saurashtra in the southeast and southwest. It is possible that the activity of these faults was responsible for the uplift of the Diu coast. Historical data on earthquakes date from the present back to 1668 only (Rastogi, Kumar, & Aggrawal, 2013a). Major earthquakes, having a recurrence interval of several centuries,

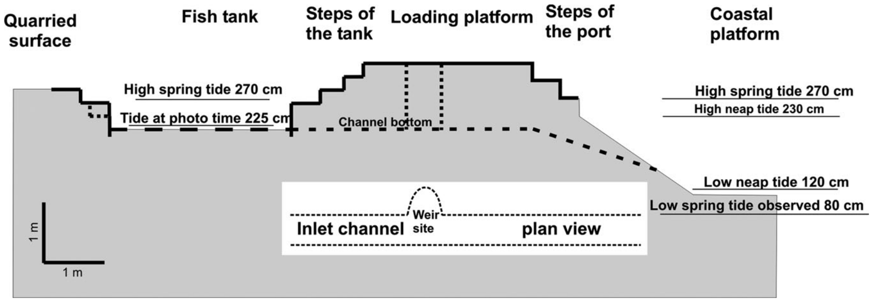

Figure 7 Cross section of the fish tank along the axis of the inlet canal (for location see Figure 2). Ranges of spring and neap tides are indicated on the right. An approximately 60-cm-higher spring tide is needed to fill the tank completely with seawater (leaving 10 cm of the loading platform above sea level to prevent loss of the catch). The coastal platform is above the low spring tide level, and was uplifted together with the tank. BMSL, biological mean sea level.

even millennia, are unknown in Saurashtra—this study is the first to suggest the possibility of their occurrence in historical times.

The Narmada rift zone experienced shocks of a magnitude of *M* 5.4 at Bharuch in 1970. However, even this moderate earthquake is ranked as having been severely damaging due to poor construction practices (Rastogi et al., 2013b). The 2010 Talala earthquake (M_w 5.1) was 100 km to the NW (Yadav et al., 2011). Another $M < 5$ seismic event was a mere 50 km to the north (Rastogi et al., 2013b). An $M_w \sim 7$ earthquake in 1705 near the Cambay Basin raises the suspicion that boundary faults of Saurashtra are capable of causing major, damaging earthquakes (Bhattachariya et al., 2004).

Whether there was a single, major uplift, or several minor uplift (i.e., seismic) events at Diu cannot be ascertained at the moment. In a worst-case scenario, if a 0.5 m uplift occurred during a single earthquake, it may have been the result of a *M* 6.8 earthquake (Wells & Coppersmith, 1994)—this is greater than anything instrumentally recorded in Saurashtra. Considering the proximity of the city of Diu a few kilometres away, as well as other port cities in Saurashtra, and the proximity of the offshore oil industry in the Cambay Bay, significant human and material loss would result if there was an earthquake of this magnitude. A consequent tsunami, generated by displacement along offshore faults, would, in turn, endanger Mumbai (Bombay), the most important port city of India, and further settlements along the west coast of India.

CONCLUSION

This study suggests that a fish tank was hewn into coastal limestone during the latter part of the last millennium near Diu, Saurashtra, India. It was connected to the ocean via a 0.5-m-wide canal that enabled the free flow of seawater. The tank is now dysfunctional because it is elevated beyond sufficient reach of the high tide necessary to fill it with water. This occurred as a result of coastal uplift of about 0.5 m after construction. The uplift occurred at least a few centuries ago, as indicated by well-developed karst dissolutional features on the human-made features. This degree of coastal uplift raises the possibility of an M_w 6.8 earthquake in Saurashtra during the later part of the last millennium.

The authors are very grateful to Marco Anzidei (INGV, Rome) and Nikos Mourtzas (Athens, Greece) for their valuable suggestions concerning the purpose of the tank. This study was supported by INCOIS, a Government of India sponsored research project to Nilesh Bhatt, and by the Hungarian Science Foundation grant K67.683 to Miklós Kázmér. The funding sources had no involvement in the design of the study; in the collection, analysis, and intepretation of data; in the writing of the paper; and in the decision to submit the manuscript for publication. We thank Stathis Stiros (Patras, Greece), Niki Evelpidou (Athens, Greece), an anonymous reviewer, and editor Jamie Woodward for their detailed, constructive comments on the manuscript. Thanks are due to Philip Rawlinson for improving the English of the manuscript. Miklos Kazmer is grateful to Judit and István Dunkl for their hospitality in Göttingen, Germany, while writing this paper. This article is a contribution to the International Geoscience Programme IGCP Project 588, "Preparing for Coastal Change." Siddharth Prizomwala thanks the Director General, ISR, for encouragement and permission to publish this work.

REFERENCES

Anzidei, M., Antonioli F., Lambeck K., Benini A., Soussa M., & Lakhdar R. (2011). New insights on the relative sea level change during Holocene along the coasts of Tunisia and western Libya from archaeological and geomorphological markers. Quaternary International, 232, 5–12.

Anzidei, M., Antonioli, F., Benini, A., Gervasi, A., & Guerra, I. (2012). Evidence of vertical tectonic uplift at Briatico

 Copyright © 2016 Wiley Periodicals, Inc.

(Calabria, Italy) inferred from Roman age maritime archaeological indicators. Quaternary International, 288, 158–167.

Aoki, H. (2009). Growth rates of kamenitzas on raised Holocene limestone terraces in coastal environments in the Ryukyus, Japan. Transactions, Japanese Geomorphological Union, 30, 317–329.

Auriemma, R., & Solinas, E. (2009). Archaeological remains as sea level change markers: A review. Quaternary International, 206, 134–146.

Bhatt, N. (2003). Quaternary carbonate deposits of Saurashtra and Kachchh, Gujarat, Western India: A review. Proceedings of the Indian National Science Academy, 69, 137–150.

Bhatt, N., & Bhonde U. (2006). Geomorphic expression of late Quaternary sea level changes along the southern Saurahstra coast, western India. Journal of Earth System Science, 115, 395–402.

Bhatt, N., Patidar, A.K., Maurya, D.M. & Chamyal, L.S. (2006). Delineation of three shallow subsurface faults using GPR in south Saurashtra, western India. 11th International Conference on GPR, Columbus, OH.

Bhattachariya, S.N., Karanth, R.V., Dattatrayam, R.S., & Sohoni, P.S. (2004). Earthquake sequence in and around Bhavnagar, Saurashtra, western India during August-December 2000 and associated tectonic features. Current Science, 86(8), 1165–1170.

Bhonde, U., & Bhatt, N. (2009). Joints as fingerprints of stress in the quaternary carbonate deposits along coastal Saurashtra, Western India. Journal of the Geological Society India, 74, 703–710.

Bruin, G., Novellanus, S., & Hogenbergius, F. (1572–1617). Civitates orbis terrarum. Amstelodami. Novellani & Francisci Hogenbergii.

Cabigas, E. (2008). Fortified settlement ruins of Daanglungsod, Oslob. http://simbahan.net/2008/09/20/fortified-settlement-ruins-of-daanglungsod-oslob/ (Accessed August 24, 2015).

Chopra, S., Kumar, D., Rastogi, B.K., Choudhury, P., & Yadav, R.B.S. (2013). Estimation of seismic hazard in Gujarat region, India. Natural Hazards, 65, 1157–1178.

Evelpidou, N., Pirazzoli, P., Vassilopoulos, A., Spada, G., Ruggieri, G., & Tomasin, A. (2012). Late Holocene sea level reconstructions based on observations of Roman fish tanks, Tyrrhenian coast of Italy. Geoarchaeology, 27, 259–277.

Faivre, S., Bakran-Petricioli, T., & Horvatinčić, N. (2010). Relative sea-level change during the Late Holocene in the island of Vis (Croatia) – Issa harbour archaeological site. Geodinamica Acta, 23, 209–223,

Flemming, N.C., & Webb, C. (1986). Tectonic and eustatic coastal changes during the last 10,000 years derived from archaeological data. Zeitschrift für Geomorphologie, 62, l–29.

Forstenpointner, G., Quatember, U., Galik, A., Weissengruber, G., & Konecny, A. (2007). Purple-dye production in Lycia – Results of an archaeozoological field survey in Andriake (south-west Turkey). Oxford Journal of Archaeology, 26, 201–214.

Furlani, S., Biolchi, S., Cucchi, F., Antonioli, F., Busetti, M., & Melis, R. (2011). Tectonic effects on Late Holocene sea level changes in the Gulf of Trieste (NE Adriatic Sea, Italy). Quaternary International, 232, 144–157.

Gandhi, D., Prajapati, P., Prizomwala, S.P., Bhatt, N., & Rastogi, B.K. (2015). Delineating the spatial variability in neotectonic activity along the southwestern Saurashtra, Western India. Zeitschrift für Geomorphologie, 59(1), 21–36.

Gaur, A.S., & Tripati, S. (2006). Marine archaeological explorations on the southwestern coast of Saurashtra, India. Journal of Indian Ocean Archaeology, 2006(3), 81–89.

Gaur, A.S., & Vora, K.H. (1999). Ancient shorelines of Gujarat, India, during the Indus civilization (Late-Mid-Holocene): A study based on archaeological evidences. Current Science, 77, 180–185.

Gaur, A.S., Tripati, S., & Tripati, S. (2007). A submerged temple complex off Pindara, on the northwestern coast of Saurashtra. Man and Environment, 32(2), 37–40.

Gupta, S.K., (1972). Chronology of the raised beaches and inland coral reefs of the Saurashtra coast. Journal of Geology, 80, 357–361.

Higginbotham, J.A. (1997). Piscinae: Artificial fishponds in Roman Italy. University of North Carolina Press. Chapel Hill, NC.

Kardara, C. (1961). Dyeing and weaving works at Isthmia. American Journal of Archeology, 65(3), 261–266.

Kázmér, M., & B. (2010). Distinguishing damages of two earthquakes – Archeoseismology of a Crusader castle (al-Marqab citadel, Syria). In M. Sintubin, I. Stewart, T. Niemi, & E. Altunel (Eds.), Ancient earthquakes (pp. 186–199). Special Paper 471. Boulder, CO: Geological Society of America.

Kázmér, M., & Taboroši, D. (2012). Bioerosion on the small scale – Examples from the tropical and subtropical littoral. Hantkeniana, 7, 37–94.

Kázmér, M., Leman, M.S., Mohamed, K.R., Ali, C.A., & Taborosi, D. (2015) Features of intertidal bioerosion and bioconstruction on limestone coasts at Langkawi Islands, Malaysia. Sains Malaysiana, 44, 921–929.

Kershaw, S., & Guo, L. (2001). Marine notches in coastal cliffs: Indicators of relative sea level change, Perachora Peninsula, central Greece. Marine Geology, 179, 213–228.

Kontogianni, V., Tsoulos, N., & Stiros, S. (2002). Coastal uplift, earthquakes and active faulting of Rhodes Island (Aegean Arc): Modeling based on geodetic inversion. Marine Geology, 186, 299–317.

Laborel, J., & Laborel-Deguen, F. (1994). Biological indicators of relative sea-level variation and of co-seismic displacements in the Mediterranean area. Journal of Coastal Research, 10, 395–415.

Laborel, J., & Laborel-Deguen, F. (1996). Biological indicators of Holocene sea-level and climatic variations on rocky coasts of tropical and subtropical regions. Quaternary International, 31, 53–60.

Lambeck, K., Anzidei, M., Antonioli, F., Benini, A., & Esposito, A. (2004a). Sea level in Roman time in the Central Mediterranean and implications for recent change. Earth and Planetary Science Letters, 224, 563–575.

Lambeck, K., Antonioli, F., Purcell, A., & Silenzi, S. (2004b). Sea-level change along the Italian coast for the past 10,000 yr. Quaternary Science Reviews, 23, 1567–1598.

Leadbetter, B. (2003). Diocletian and the purple mile of Aperlae. Epigraphica Anatolica, 36, 127–136.

Lyell, C. (1837). Principles of geology. London: Murray.

Mastronuzzi, G., & Sansò, P. (2014). Coastal towers and historical sea level change along the Salento coast (southern Apulia, Italy). Quaternary International, 332, 61–72.

Morhange, C.H., & Marriner, N. (2015). Archeological and biological relative sea-level indicators. In I. Shennan, A.J. Long, & B.P. Horton (Eds.), Handbook of sea-level research (pp. 146–156). Chichester: Wiley.

Morhange, C.H., Marriner, N., Laborel, J., Todesco, M., & Oberlin, C.H. (2006). Rapid sea level movements and noneruptive crustal deformations in the Phlegrean Fields caldera, Italy. Geology, 34, 93–96.

Morhange, C.H., Marriner, N., Excoffon, P., Bonnet, S., Flaux, C., Zibrowius, H., Goiran, J.-P., & El Amouri, M. (2013). Relative sea-level changes during Roman times in the northwest Mediterranean: The 1st century A.D. fish tank of Forum Julii, Frejus, France. Geoarchaeology, 28, 363–372.

Mourtzas, N.D. (2012a). Archaeological indicators for sea level change and coastal neotectonic deformation: The submerged Roman fish tanks of the Gulf od Matala, Crete, Greece. Journal of Archaeological Science, 39, 884–895.

Mourtzas, N.D. (2012b). Fish tanks of eastern Crete (Greece) as indicators of the Roman sea level. Journal of Archaeological Science, 39, 2392–2408.

Özdaş, H., & Kızıldağ, N. (2013). Archaeological and geophysical investigation of submerged coastal structures in Kekova, southern coast of Turkey. Geoarchaeology, 28, 504–516

Papageorgiou, S., Arnold, M., Laborel, J., & Stiros, S.C. (1993). Seismic uplift of the harbour of ancient Aigeira, Central Greece. International Journal of Nautical Archaeology, 22, 275–281.

Peltier, W.R. (2002). On eustatic sea-level history: Last glacial maximum to Holocene. Quaternary Science Reviews, 21, 377–396.

Pirazzoli, P.A. (1986). Marine notches. In O. van de Plassche (Ed.), Sea-level research: A manual for the collection and evaluation of data (pp. 361–400). Norwich: Geo Books.

Pirazzoli, P.A. (1996). Sea-level changes – The last 20,000 years. Chichester: Wiley.

Radwin, G. E., & D'Attilio, A. (1986). Murex shells of the world. An illustrated guide to the Muricidae. Stanford: Stanford University Press.

Rao, S.R. (1996). Further excavations of the submerged city of Dwarka. In Rao, S.R. (ed.): Recent advances in marine archaeology. Proceedings of the Second Indian Conference on Marine Archaeology of Indian Ocean Countries. National Institute of Oceanography, Goa (pp. 51–59).

Rao, S.K. (1996). From Dvaraka to Kurukshetra. Journal of Marine Archaeology, 5–6, 61–71.

Rao, B.P. (2000). Historical seismicity and deformation rates in the Indian peninsular shield. Journal of Seismology, 4, 247–258.

Rastogi, B.K., Kumar, S., & Aggrawal, S.K. (2013a). Seismicity of Gujarat. Natural Hazards, 65, 1027–1044.

Rastogi, B.K., Kumar, S., Aggrawal, S.K., Mohan, K., Rao, N., Rao, P., & Kothyari, G.C.H. (2013b). The October 20, 2011 M_w 5.1 Talala earthquake in the stable continental region of India. Natural Hazards, 65, 1197–1216.

Rust, D., & Kershaw, S. (2000). Holocene tectonic uplift patterns in northeastern Sicily: Evidence from marine notches in coastal outcrops. Marine Geology, 167, 105–126.

Salmon, T. (1752–1753). The universal traveller: or, a compleat description of several nations of the world, I–II. London: Richard Baldwin.

Seeliger, M., Brill, D., Feuser, S., Bartz, M., Erkul, E., Kelterbaum, D., Vött, A., Klein, C., Pirson, F., & Brückner, H. (2014). The purpose and age of underwater walls in the Bay of Elaia of western Turkey: A multidisciplinary approach. Geoarchaeology, 29, 138–155.

Shokoohy, M., & Shokoohy, N.H. (2003). The Portuguese fort of Diu. South Asian Studies, 19, 169–203.

Shokoohy, M., & Shokoohy, N.H. (2010). The island of Diu, its architecture and historic remains. South Asian Studies, 26, 161–191.

Singh, A.P., Roy, I.G., Kumar, S., & Kayal, J.R. (2014). Seismic source characteristics in Kachchh and Saurashtra regions of Western India: *b*-Value and fractal dimension mapping of aftershock sequences. Natural Hazards. doi 10.1007/s11069-013-1005-3.

Siva, R. (2007). Status of natural dyes and dye-yielding plants in India. Current Science, 92(7), 916–925.

Stiros, S. (1998). Archaeological evidence for unusually rapid Holocene uplift rates in an active normal faulting terrain: Roman harbor of Aigeira, Gulf Of Corinth, Greece. Geoarchaeology, 13, 731–741.

Stiros, S. (2006). Accurate measurements with primitive instruments: The "paradox" in the qanat design. Journal of Archaeological Science, 33, 1058–1064.

Stiros, S.C., Laborel, J., Laborel-Deguen, F., Papageorgiou, S., Evin, J., & Pirazzoli, P.A. (2000). Seismic coastal uplift in a region of subsidence: Holocene raised shorelines of Samos Island, Aegean Sea, Greece. Marine Geology, 170, 41–58.

 Copyright © 2016 Wiley Periodicals, Inc.

Taboroši, D., & Kázmér, M. (2013). Erosional and depositional textures and structures in coastal karst landscapes. In M.J. Lace & J.E. Mylroie (Eds.), Coastal karst landforms (pp. 15–57). Coastal Research Library 5. Dordrecht: Springer.

Yadav, R.B.S., Papadimitriou, E.E., Karakostas, V.G., Shanker, D., Rastogi, B.K., Chopra, S., Singh, A.P., & Kumar, S. (2011). The 2007 Talala, Saurashtra, western India earthquake sequence: Tectonic implication and seismicity triggering. Journal of Asian Earth Sciences, 40, 303–314.

Wells, D.L., & Coppersmith, K.J. (1994). New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. Bulletin of the Seismological Society of America, 84(4), 974–1002.

 Copyright © 2016 Wiley Periodicals, Inc.