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## 8th century coastal uplift in Peninsular India – The Shore Temple at Mahabalipuram, Tamil Nadu

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## ABSTRACT

The Shore Temple in Mahabalipuram (Tamil Nadu, Southern India) exists since the late 7th century. Historical sources suggest that it was built on an island in honour of the gods Vishnu and Shiva. A former bridge over the canal, which separated the island from the mainland, and a seawall, which protected the shore from the waves are dysfunctional now, as they are located too high above the present day sea level. A holy well, part of the temple complex, reaches down to the modern freshwater lens. We suggest that about 1 m uplift occurred after the construction of the temple, the canal and the seawall, but before the construction of the well. This event during the reign of King Rajasimhan in the early 8th century most likely was caused by an earthquake of magnitude  $M > 6.5$  that led to the uplift of the island. There are thick walls of a ruined masonry building in the former, sand-filled canal, tilted in various directions. These are evidence for liquefaction of subsoil, caused by a second earthquake of intensity IX-X. The east coast of India has remained prone to destructive earthquakes: archaeoseismology proves to be useful tool which can help to identify these areas.

### 1. Introduction

The Indian Peninsula is traditionally considered to be a stable continental block, surrounded by the tectonically active Himalayan orogen on three sides in the north (Fig. 1) An increasing number of observations, including those on the strong intraplate earthquakes in Kachchh (e.g. Shaikh et al., 2020) and in Maharashtra (Copley et al., 2014) in the west and in various, not yet well understood sites put the question whether there is active tectonics within (Roy and Purohit, 2018). Seismic (Nath et al., 2017) and coastal studies (Selvakumar and Rajasamy, 2014) are the best way to understand whether there is any contemporary tectonic activity; however, the number of available data is particularly low, considering the enormous area of the Peninsula. Therefore it is of prime importance to find and describe sites which prove rapid uplift and/or subsidence along the coast.

Historical and instrumental seismic data show that there were very few earthquakes within Tamil Nadu, not exceeding magnitude  $M 5.0$  (Rao, 2000; Bilham, 2004). Marine coasts are sensitive indicators of active tectonics, due to the stability of sea level on the short term scale. It is relatively easy to determine sea level before and after a tectonic event by identifying various natural sea-level markers (Van de Plassche, 1986;

Shennan et al., 2015). Besides natural features there are various archaeological sea-level markers available (Auriemma and Solinas, 2009). Objects along Mediterranean coasts are particularly well studied in this respect: harbours (Marriner and Morhange, 2007; Riddick et al., 2021), fish tanks (Morhange et al., 2013), coastal wells (Sivan et al., 2004; Vunsh et al., 2018), salt pans (Bechor et al., 2020), to name a few. There are a multitude of potentially significant archaeological sites along the Indian Ocean coastline, too. Rao (1987) already indicated various submerged ports all around the Peninsula. Gaur and team in Gujarat and Sundaresh in Tamil Nadu put the most efforts into discovering and interpreting archaeological records of coastal change (Gaur and Vora, 1999; Sundaresh et al., 2017). The first effort into determining coastal change using the functional elevation of a fish tank was made in Diu in western India, indicating  $\sim 0.5$  m of uplift of the coast in Diu within the past 500 years (Kázmér et al., 2016).

The southern Indian shoreline hosts several ancient monuments, which may be suitable for reconstructing tectonic/eustatic changes witnessed by the shoreline, but however have been ignored so far in this context. Here we use archaeological evidence to recognize and describe relative sea level change, providing interpretation in a framework of active coastal tectonics.

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1.1. Study area – The Shore Temple at Mahabalipuram

Mahabalipuram (Mamallapuram) is an UNESCO World Heritage archaeological site 50 km south of Chennai (former Madras, Tamil Nadu, India) (Fig. 1). Hindu temples and wall reliefs were carved in Precambrian charnockite rock (Sreejith et al., 2021) during the reign of the Pallava dynasty in the 7-8th centuries (Francis, 2021). A few stone masonry temples add to the variety of surviving constructions.

There is a peninsula extending into the Indian Ocean today, on which the masonry Shore Temple complex stands. There was an ancient sculpture of Jalasayana Vishnu carved in bedrock probably since the time of king Narasimhavarman I Mamalla (ruled 630-668 AD). Dandin, a Sanskrit poet and prose writer in the court of Rajasimha, in his *Avantisundarikathasara*, reported his visit to Jalasayana Vishnu, mentioning that the sculpture is on an island, encircled by the sea (Krishnarao, 1941). The site was developed into a magnificent temple complex during the early years of king Narasimhavarman II Rajasimha (ruled 700-729 AD). A surrounding enclosure was probably left unfinished (Fig. 2). In a second phase of construction an apsidal shrine was built, strangely below the floor level of the temple complex (Sivaramamurti, 2006).



Fig. 2. The shore temple of Mahabalipuram, as seen from the southeast. View towards the Indian Ocean. The canal on Fig. 3 is between the lawn and the wall made of simple masonry. Archaeological DataBase photo #2155.

2. Methods

We measured the elevation of functional height of various parts of the temple complex (Table 1). Functional height is the elevation of an

archaeological object relative to sea level to allow its use according to the purpose or function it was designed and built for (Auriemma and Solinas, 2009). For example, bottom of a canal must be under water,

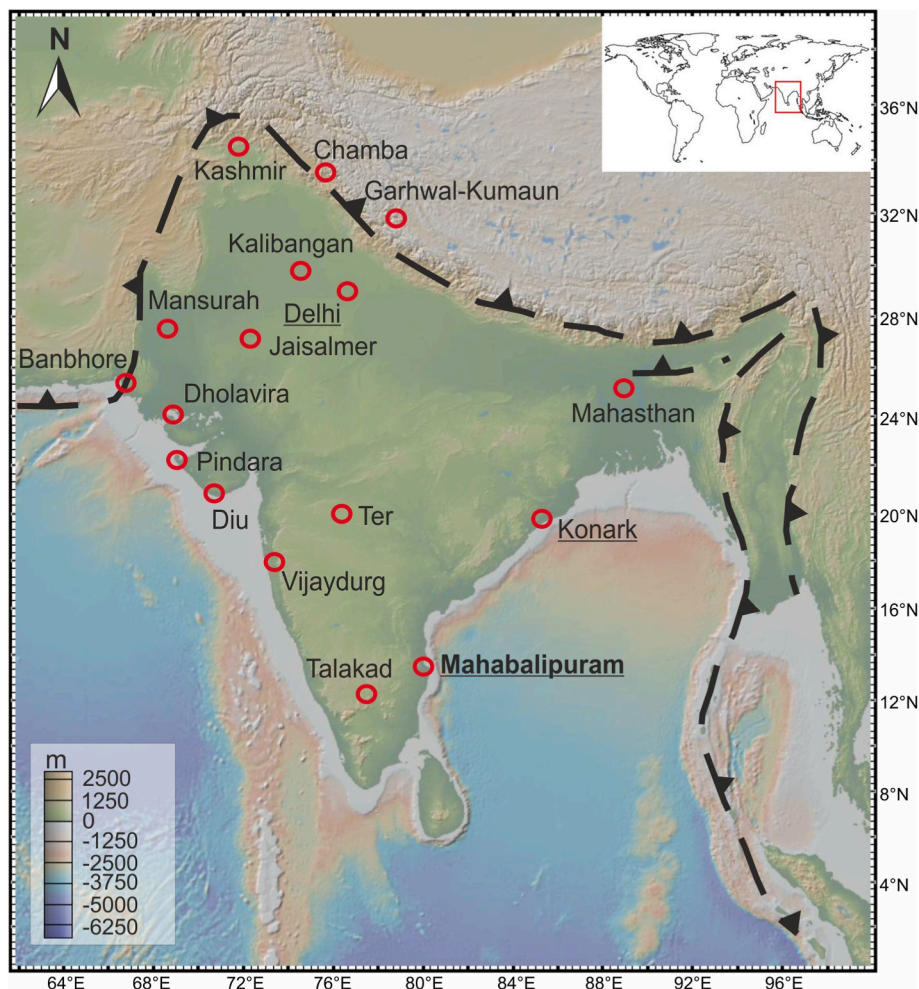


Fig. 1. Sites of archaeoseismological studies in the Indian subcontinent (after Kázmér et al., 2020, modified). Damaged ancient buildings there are witnesses to tectonic activity both along the Himalayan front (dashed line with triangles on the upthrust side) and within the Peninsula. Mahabalipuram (bold, underlined) is on the east coast.

**Table 1**

Elevation of man-made construction and water table relative to tidal datum at Mahabalipuram Shore Temple. See Fig. 11 for geometry.

Elevation	Feature
4.3 m	Paved walkway above seawall
4.2 m	Bottom of former bridge beams
~3.8 m	Temple floor
~2.2 m	Sandy walkway in canal
1.7 m	Water table in apsidal shrine well
1.6 m	Water table in marsh
<1.6 m	Lowest part of stepped seawall
1.2 m	Calculated highest high tide spring
0.7 m	Tide at time of measurement
0.1 m	Calculated lowest low tide spring

while the bridge above the canal must be above high water. Bottom of a well must reach groundwater level, while the pavement surrounding the well must be above groundwater level. If these simple requirements are not met, an explanation is needed. We measured the elevation of water in the temple well, elevation of the freshwater lake on the peninsula, and elevation of the canal, seawall and bridge, all relative to sea level (Table 1). A Leica Disto D8 laser range finder was used for surveying horizontal and vertical distances with centimetre precision up to 30 m distance. A TruPulse 360 laser range finder, with 10 cm precision was used to measure elevation up to a few hundred m distance. Position of the tide at the time of survey and tidal range were calculated by Tide-Comp software, version 9.0 (Kázmér, 2019).

### 3. Results and discussion

We studied the masonry temples in the complex, the surrounding structures (remnants of a former bridge and a seawall), and various tilted walls seeking evidence for active tectonics.

#### 3.1. Evidence for earthquake

Archaeoseismological evidence for earthquakes are deformed walls and floors (Marco, 2008; Kázmér, 2014). These are stronger where the buildings were built on soft soil, and less visible where the edifice is standing on hard rock. This is the case of the Shore Temple (Subramanyan and Vetriselvi, 2019, p. 304). The temple is built of various granite types, as shown by distinct categories of weathering (Kumar and Singh, 2019). This layered structure might indicate rebuilding, following the original plans. Excellent modern restoration of the shrine covered most fractures, and restored shifted blocks, if there were any. Fortunately, vintage photos preserve the 19th century looks of the shrine: topmost elements of each Shiva temple have been slightly displaced towards the ocean (Fig. 3). A casual remark of Subramanyan and Vetriselvi (2019, p. 305) says: „the see-through joints of the masonry were pressure grouted in 1905-06 during the restoration of Alexander Rea.” See-through joints are created when masonry blocks are displaced, shifted, either parallel with the wall (in-plane displacement) or perpendicular (out-of-place displacement). These shifts unequivocally indicate seismic shaking (Marco, 2008). Vertical and horizontal vibration, acting simultaneously, makes a block ‘wander’ off its original location, potentially rotating in the meantime (see e.g. Kázmér, 2021 for shifted columns in Tunisia). Another, still visible evidence for past seismic loading comes from a broken lintel above the gate to the lingam in the Shiva temple (Fig. 4). Shifted blocks record severe earthquake of intensity IX or higher (Rodríguez-Pascua et al., 2013). Description of further seismic damage elsewhere on the mainland in Mahabalipuram is in progress.

The sediment-filled canal, which separated the Shore Temple island from the mainland, is bordered by two stone walls. Heavily restored portions partly underlie and partly overlie various stone-and-brick masonry constructions. These walls and floors deviate from the vertical and



Fig. 3. Shifted blocks on top of shore temple: both are shifted towards the left, in the direction of the ocean, probably due to seismic shaking. Photographed in 1885. Intensity I = IX. [https://www.reddit.com/r/HistoryPorn/comments/85i2hs/the\\_shore\\_temple\\_8th\\_century\\_shiv\\_temple\\_built/](https://www.reddit.com/r/HistoryPorn/comments/85i2hs/the_shore_temple_8th_century_shiv_temple_built/) Accessed 20 July 2020.



Fig. 4. Broken lintel on the west gate of the Shore Temple. ADB #2226. Penetrative fracture in masonry block. Intensity I = VII or higher. (Rodríguez-Pascua et al., 2013).

the horizontal, respectively (Fig. 5). This deviation, yielding up to 80° westward tilt for a former floor (Fig. 6), is a feature of subsoil liquefaction. It can happen during seismic shaking: increasing pore pressure separates grains in water-saturated sand, making it behave like fluid. Walls, heavier than water, tilt, overturn, and sink in the fluidized sediment (Khan-Mozahedy, 2015). This happened to the building(s) built on



**Fig. 5.** Remnants of a construction postdating the Shore Temple. These were built while the sea canal was already uplifted to become part of land. Blocks are visible in various degree of tilting due to liquefaction of enclosing and underlying sand by seismic shaking. Much of masonry armour is modern restoration, overlapping the tilted walls. ADB #2166.



**Fig. 6.** Vertical layers of brick masonry wall, result of liquefaction of sandy soil due to seismic shaking. ADB #2173.

the canal-filling sand.

Since the 2004 Indian Ocean tsunami there are frequent studies on tsunami and its effects on Indian shoreline. Studies on Mahabalipuram concluded that although the temples suffered high inundation, there are no marked effects on the shrine. This is probably true for preceding

tsunamis as well (Rajendran et al., 2006; Srivastava et al., 2012; Nair et al., 2011).

### 3.2. Evidence for coastal uplift

The canal which separates the Shore Temple island from the mainland is bordered by two walls: a modern, simple stone wall on the eastern, island side, and a complex, unusual, ancient wall on the landward side (Fig. 7). The latter rises to a height of up to 3.5 m. It was exposed in 20–25 m length, now extended by modern restoration. Further 150–200 m extensions southward and 150 m extension northward almost parallel to the seashore are known. Opinions on its purpose vary (summarized here after Sivaramamurti, 2006, pp. 81–83). Some say it was a wharf. We think that it would be impractical to be used in a port: a stepped wall rather hinders than facilitates easy loading and unloading of boats. Others say it was a bathing-ghat. However, it is too steep of easy and safe access to the sea by masses of pilgrims. Another idea is that it was a wall protecting the shrine from blowing sand. As dominant winds are from the northeast and southeast, sand is rather blown from the beach towards the land than in opposite direction.

Each hypothesis neglects the curious form of masonry blocks in the wall (Fig. 8). Blocks are rectangular, set vertically and horizontally to form a stepped surface. There are specially formed horizontal connecting blocks, extending beyond the vertical faces. Having lateral grooves on both sides (a kind of mortise-and-tenon joint) these fix the vertical blocks in the desired position, preventing any displacement out of the wall. This pattern of stones made the structure resistant to wave action, esp. to the suction of returning waves. We suggest that this was a seawall, erected to protect the coast from wave-induced retreat.

Curiously, this seawall – which is inherently a rough sea-level marker – does not protect anything today: it is located well above sea level. Both the floor of the former canal and its border walls are beyond the reach of calm or stormy seas. The reason might be that the coast have been uplifted since the Shore Temple was constructed in the early 8th century. Whether this uplift was rapid, of seismic origin, or slow, due to accumulating tectonic stress, we can tell if other sea-level markers are examined.

There are remnants of a former bridge, connecting the island to the mainland visible in the middle of the seawall. Two nests to hold former stone beams which connected two bridgeheads across the canal (Fig. 9) mark a sea level functionally at the same place as indicated by the elevation of the seawall. A bridge is a very rough sea-level marker.

There is another archaeological sea-level marker in the Shore Temple: there is an apsidal temple, including a holy well, adjacent to the main shrine (Fig. 10). Its floor is about 2 m below the temple floor. Water table was 20 cm deeper than the apsidal temple floor at the time of visit on 25 December 2018. Wells are water-level markers, both at the seaside (Vunsh et al., 2018) and at rivers (Mészáros and Serlegi, 2011). This Varaha well was built by King Rajasimha, attested by his inscribed name on the small shrine (Saxena, 2016). As this well is reaching the modern groundwater table, and the floor of the enclosing apsidal temple is only 20 cm higher, it means that both the apsidal temple and the well were built after the uplift, subsequent to the construction of the Shiva temples (Fig. 11). We disagree with the remark of Sivaramamurti (2006) that the Shiva temples were built in the last phase of construction. There would have been no need for a well in the absence of the adjacent temple.

Both the Shiva temples, built first, and the apsidal temple, built later, were constructed by King Rajasimha. His rule lasted from 700 to 728 AD, therefore the uplift event happened between the two construction periods during his reign. An uplift event of ~1 m within a period of less than three decades suggests that an earthquake was responsible.

### 3.3. Uplift or subsidence? Results of underwater archaeology

Following mythological records of submerged temples at



Fig. 7. Seawall protecting the shore (left). Bridgeheads of the ruined bridge (right) are above the canal surrounding the Shore Temple island. View to northwest. ADB #2212.



Fig. 8. Detail of masonry armour protecting the soft coast. Intricately carved blocks are tied together to resist suction force of retreating waves. ADB #2274.



Fig. 9. Western bridgehead. Nests for two, massive stone beams are visible. The canal is never filled by the sea today. ADB #2271.

Mahabalipuram, underwater archaeological surveys reported several masonry blocks, walls, stepped construction on solid foundations, chisel marks and quarries, between low tide and 6 m depth (Vora and Sundaresh, 2003; Sundaresh et al., 2004, 2006, 2017; Sundaresh and Gaur, 2011). Unfortunately, meagre published documentation makes it hard for the reader to assess the importance of this discovery (We note that Rajani and Kasturirangan, 2013, suggested that each ‘submerged temple’ is still standing on land.). It is suggested that about half a metre of measured annual retreat of the coast is sufficient to erode 800 m of land since the temple was built, scattering masonry below sea level (Sundaresh et al., 2014). Additionally, tsunamis returning every five centuries and typhoons also contribute to coastal change by erosion (Rajendran et al., 2006). We cannot exclude that some of the underwater masonry was washed away from its original location by retreating waves, as suggested by Gaur et al. (2021).

There is an increasing number of publications providing data on recent uplift along the coasts of Peninsular India. Dynamic loss and accretion of northern Tamil Nadu coast was observed by Jayakumar and Malarvannan (2016), where Mahabalipuram is dominated by erosion.

Uplift of marine terraces in southern Tamil Nadu was recorded by Sahayam et al. (2015). A similarly constrained coastal uplift was described in Diu (Gujarat) for the past five centuries by Kázmér et al. (2016). A particularly valuable study of Mörner (2017) used a combination of geomorphological, sedimentary and historical sources to describe coastal change in Goa during the past 500 years.

### 3.4. Earthquake parameters

#### 3.4.1. Dating

The dysfunctional elements of the Shore Temple complex (seawall and bridge) were built before an earthquake-caused uplift event. The functional apsidal temple holding the well was built after uplift. As both groups were constructed during the reign of King Rajasimhan, a first earthquake occurred between 700 and 728 AD. Following uplift, the canal, which previously separated the temple island from the mainland was silted up. After an undetermined interval buildings were erected there. Later, these buildings suffered catastrophic collapse and sinking during a liquefaction event. Dating of the buildings by



**Fig. 10.** Varaha well within the apsidal temple to the north of the shrine. Overlapping row of stairs indicate that the apsidal temple was built later than the shrine, after coastal uplift. Depth of the platform is 2.2 m below the shrine floor. ADB #2258.

thermochronology of the bricks or radiocarbon analysis of the mortar would give a *terminus post quem* date for the second earthquake. We note that liquefaction-prone sediments enable the subsidence of coastal buildings.

**3.4.2. Intensity**

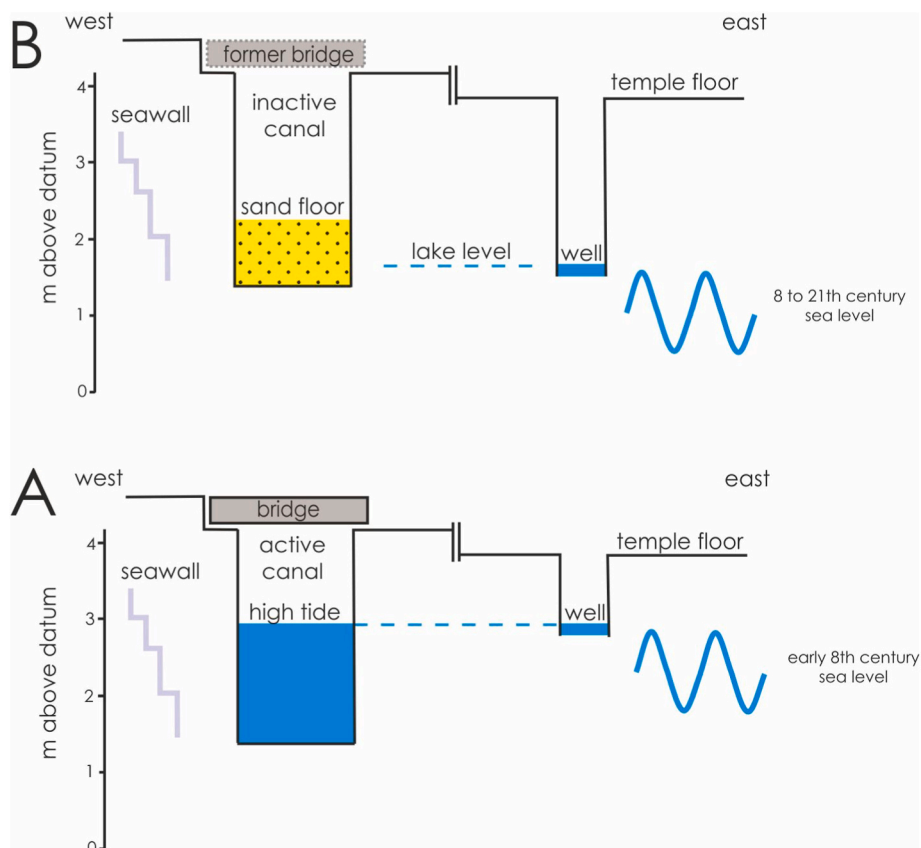
Coastal uplift in the range of a few decimetres to a few metres marks

an intensity IX-X earthquake (Michetti et al., 2007). Shifted, displaced, rotated masonry blocks in temples yield intensity IX or higher (Rodríguez-Pascua et al., 2013). An earthquake of this intensity certainly caused major damage, which were repaired promptly, leaving behind a layered stratigraphy of the pyramidal parts made of different rows of stone (Kumar and Singh, 2019).

It is hard to assess intensity from liquefaction which made one or more major buildings to collapse. There is no established scale of damage for this kind of deformation. We can approximate the severity of the situation for intensity assessment by the Environmental Intensity Scale ES07 (Michetti et al., 2007). During liquefaction, sand boils up to 3 m diameter are formed, and soil settles more than 30 cm. This is intensity IX – destructive. Liquefaction with soil compaction and subsidence more than 1 m and sand volcanoes more than 6 m diameter yield intensity X – very destructive. To sum up, an intensity value IX-X is suggested for Mahabalipuram for the second earthquake event.

**3.4.3. Magnitude**

An earthquake causing >1 m vertical displacement is at least M 6.5+ in magnitude (Wells and Coppersmith, 1994). As the uplift was in the 1–2 m range, the assumed magnitude was M 6.5–7, well beyond anything instrumentally recorded in the Peninsula. Earthquakes of M 4.6–5.5 were recorded in the south of India (Nath et al., 2017). There were historical earthquakes up to magnitude 4.9 in Madras and Pondicherry region during the past three hundred years (Ramalingeswara Rao, 2000). The catastrophic Bhuj earthquake in 2010 was of M 7.8 (Institute of Seismological Research catalogue).



**Fig. 11.** Indicators of coastal uplift at the Shore Temple in Mahabalipuram. (A) In early 8th century sea level (marked by wavy line indicating tidal range) was between ~2.0–3.0 m above datum. Seawall and canal were functional. The well reached down to freshwater groundwater level, ca. 1 m below shrine floor. (B) Uplift in 8th century made seawall and canal dysfunctional. Well was built deeper, to reach groundwater at 2.2 m below shrine floor.

#### 4. Conclusions

Studies on active tectonics in the Indian Peninsula got an impetus recently (e.g. Ramkumar et al., 2019). Archaeoseismology offers a new and useful approach to estimate seismic hazard in the Peninsula (Kázmér et al., 2020). We surveyed the Shore Temple of Mahabalipuram (Tamil Nadu, India) for eventual evidence for seismic events. Displaced (shifted, rotated) blocks in the temples were observed and a broken lintel identified, suggesting an earthquake of intensity IX or higher. A possibly contemporaneous uplift raised the island and the adjacent coast by more than 1 m. The canal, the bridge above, and the adjacent seawall protecting the land from wave erosion became suddenly dysfunctional. A holy well was made after the uplift to reach down to the water table. Construction date of the temple and of the holy well bracket the uplift in time to the period of the reign of king Rajasimha (700–729 AD). As time passed, the disused canal was filled by sand and a massive building erected. A second earthquake caused liquefaction, causing the walls collapse, tilt, and sink into the sand behaving like fluid. Both archaeological and environmental data indicate earthquakes of intensity IX–X. >1 m coastal uplift was made by a  $M > 6.5$  earthquake, never recorded by instruments in the Peninsula.

#### Data availability

Data used are published within the main body of the text and in the figures.

#### Author contributions

Miklós Kázmér: Conceptualization, Methodology, Investigation, Writing – Original Draft, Visualization. Siddharth Prizomwala: Validation, Writing – Reviewing and Editing. Krzysztof Gaidzik: Reviewing, Editing, Visualization.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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