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Evolution of Sea Level at Tyre During Antiquity

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Abstract—Former studies of sea level rise (RSLR) at Tyre during the antiquity provide seemingly discrepant results. To reconcile previous observations we have inventoried markers of sea level along the peninsula of Tyre. Roman/Byzantine breakwaters and fish tanks have only experienced limited submersion. Sea level stability allowed the formation of well-developed notches and shore platforms on natural and anthropogenic substrates. In contrast, Phoenician quarries and breakwaters, document ~2 m of relative sea level rise, with no markers of former shoreline stability. The observed +40 cm of rise in sea level since the late Antiquity is consistent with the previously documented 50± 10 cm regional amount of sea level rise in the Eastern Mediterranean, We document an earlier~2 m RSLR, which implies the paradoxical foundering of the bedrock of Tyre, within the regional context of a Lebanese coast mostly affected by tectonic uplift over the past millennia. We review the potential contribution of local tectonics to the foundering of Tyre.

Keywords: Tyre, Phoenician, Roman, sea level, breakwater, fault, notches, tectonics, harbour.

Introduction

Several lines of evidence indicate that sea level has risen relative to the city of Tyre (**fig. 1**) since early Phoenician settling times. First, the top of a Phoenician breakwater (Noureddine and Mior 2018) protecting the northern, 'Sidonian', harbour of Tyre (**fig. 1: 1**) currently lies ~2.5 m b.s.l. (below sea level). If the top of the breakwater is not missing, then the depth of the top of the breakwater implies that RSL has risen at least ~3.5 m relative to the breakwater since antiquity, if one assumes that the top of the breakwater stood at least a meter above sea level. Such a large amount of submergence has been ascribed to land foundering after the late Antiquity (Marriner, Goiran and Morhange 2008). Second, it has been observed that the floors of quarries located within the 'southern harbour' of Tyre lie ~2–3 m b.s.l. (el-Amouri, el-Hélou, Marquet *et al.* 2005) documenting a similar amount of relative sea level rise. However, more recently, the levelling of Roman/Byzantine fish tanks located near the north-west and south-west capes of the peninsula (**fig. 1: 2** and **3**) has revealed a much more modest sea level rise of 40–50 cm since the late Antiquity (Goiran, Chapanski, Régagnon *et al.* 2019). This later value is more consistent with the amount of sea level rise found along the coasts of the Eastern Mediterranean Sea (Anzidei, Antonioli, Benini *et al.* 2011, Dean, Horton, Evelpidou *et al.* 2019).

These observations can be reconciled if sea level rose by at least two meters between the early Phoenician and the late Roman/Byzantine antiquity. Such a large amount of RSLR certainly had a sizeable influence on the development of the city of Tyre and its ports. A substantial part of the northern, submerged part of the 'Sidonian' port has been surveyed (Noureddine and Mior 2018) while its extension inland has been assessed by coring (Marriner, Goiran and Morhange 2008). The location of the southern, 'Egyptian' port of Tyre remains elusive. Ernest Renan (1864) envisions it as an immense harbour that spread over the entire southern bay of Tyre, bound to the west by a man-made breakwater running along the southern islets (**fig. 1: 4**). Antoine Poidebard (1939) after conducting pioneering submarine observations

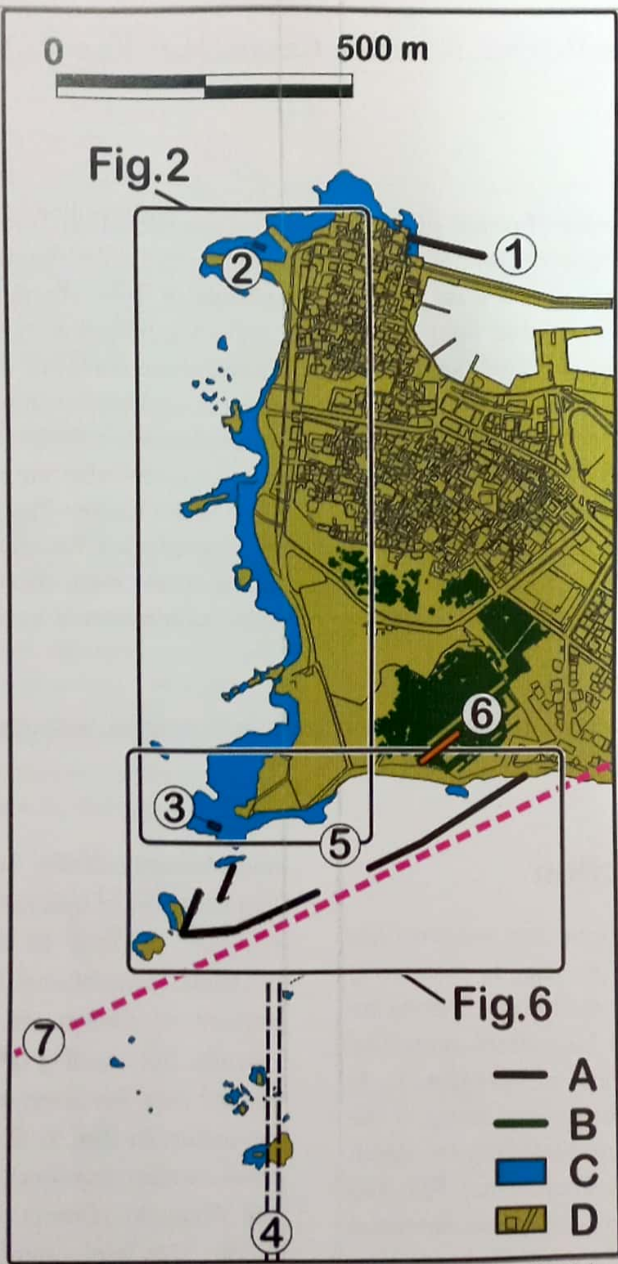

Fig. 1- Map of the study area; A) ancient breakwaters; B) onshore archaeological excavations; C) tidal zone: natural platforms and submerged quarry floors; D) emerged land with modern buildings and infrastructures (DAO: G. Brocard). Structures mentioned in the text: 1) Phoenician breakwater of the northern harbour; 2) northern fish tank; 3) southern fish tank; 4) southern harbour breakwater (Renan 1864); 5) southern harbour; 6) Phoenician city wall (red line); 7) projected trace of the fault of Tyre.

of the southern harbour, concluded that the conspicuous protective structures currently submersed within 150 m of the current coastline (**fig. 1: 5**) are the breakwaters of the Egyptian harbour. In his view, the harbour possessed two entrances, servicing two separate basins. Honor Frost (1971) and el-Amouri, el-Hélou, Marquet *et al.* (2005) conducted diving campaigns along the south coast. They found that the string of tiny islets that forms a north-south-oriented alignment off the south coast is a natural structure (**fig. 1: 4**). They also concluded that the breakwaters of Poidebard (1939) are sea walls that protected a landfilled urban district.

The comprehensive diving campaigns of el-Amouri, el-Hélou, Marquet *et al.* (2005) provide the most detailed available mapping of the southern harbour. The amount of work conducted in this harbour and the abundance of natural and anthropogenic sea level indicators preserved along the southern and west coasts make this coast ideal for a study of sea level relative change with light equipment (walking and snorkelling). Indicators include fish tanks, breakwaters, and quarry floors submersed in shallow waters (less than 4 m deep).

In this paper we first review the types of structures found along the rocky shorelines of Tyre and evaluate whether their elevation meshes with that of natural indicators of past sea levels. We then combine these observations and discuss the age and origin of RSL during antiquity.

Methods: Field Inventory of Sea Level Indicators

We walked and snorkelled the rocky shoreline of Tyre, from the submerged Phoenician mole of the northern harbour (**fig. 1: 1**) in the north, down to the eastern termination of the southern harbour in the south. An unmanned aerial vehicle (UAV or drone) was used to inspect the transition between on-land and offshore structures during a survey of the monumental Roman-Byzantine baths. We inventoried indicators of past sea level, with a particular attention to man-made structures such as breakwaters, quays, coastal quarries and fish tanks, and natural erosional landforms such as sea notches, intertidal strath, *infratidal* shore platforms and bioconstructions. We report uncharted structures by expanding the numbering scheme implemented by el-Amouri, el-Hélou, Marquet *et al.* (2005). We calculate sea level rise as the difference in elevation between the current low tide sea level and the current depth of inventoried level indicators (**fig. 2**).

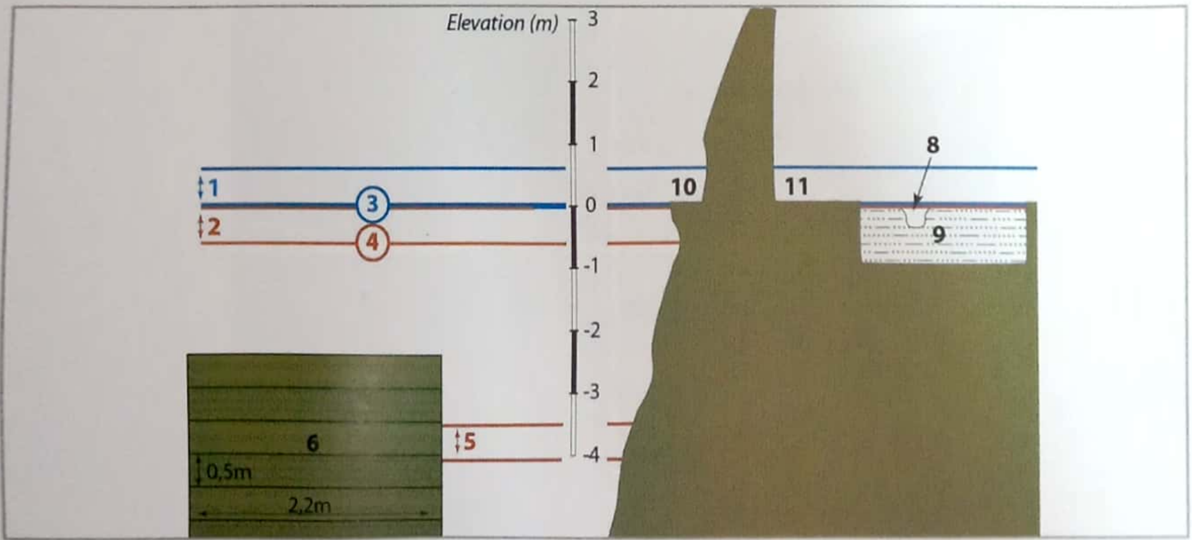

Fig. 2- Elevation relationships between the current sea level, the operational sea level of Roman-Byzantine fish tanks, and the operational sea level of the northern Phoenician breakwater. 1) Present-day tidal range; 2) tidal range during fish tank construction; 3) present low tide; 4) Roman low tide; 5) tidal range during Phoenician breakwater construction; 6) Phoenician breakwaters; 7) fish tank sea wall; 8) fish tank feeding channel; 9) fish tank; 10) natural intertidal platform; 11) quarry floor (DAO: S. Chapkanski).

Results

Sea level indicators along the west coast

The festooned west coast is strongly exposed to sea waves and therefore does not offer natural shelters for seafaring. Few port structures are therefore observed there. The west coast seems to have been used chiefly for the quarrying of *ramleh* or *kurkar* (Badawi 2016), a cemented biocalcarenitic sandy eolianite. Stones were quarried behind sea walls that have since been eroded away.

Fish tanks are located at the northern and southern terminations of this stretch of coast (St 2010; **fig. 3** and **fig. 4: F**), and St 1012, see *infra*. They were built most probably during Roman or Byzantine time (Goiran, Chapanski, Régagnon *et al.* 2019). They communicate with the sea through channels cut in the bedrock. These channels lie at their operational

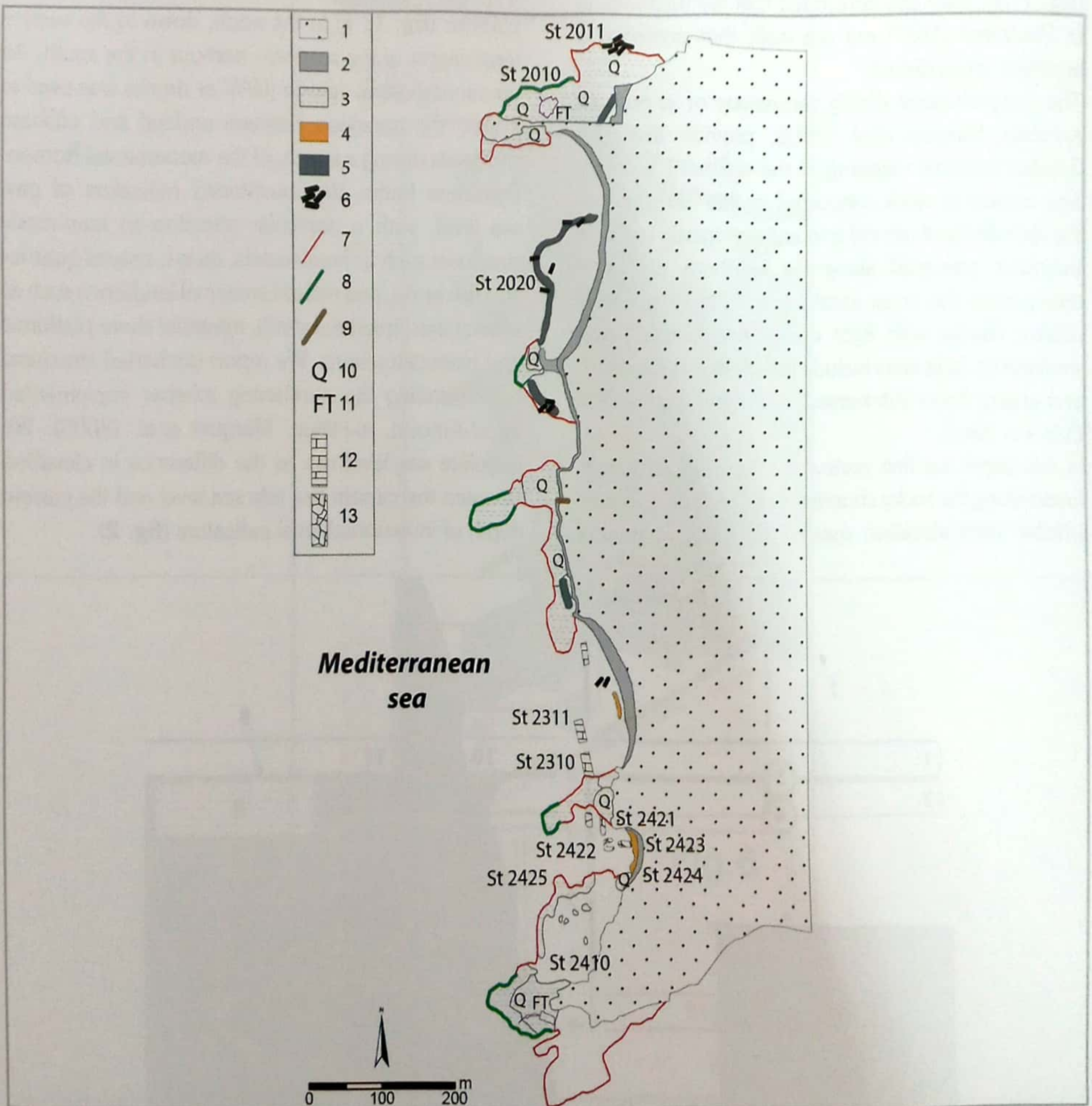

Fig. 3- Map of the west coast of Tyre showing the distribution of the main natural and man-made submerged features. 1) emerged land; 2) sandy/pebbly beach; 3) intertidal platform (natural or man-made); 4) beachrock; 5) post-Byzantine breakwater; 6) column drums; 7) erosive underwater cliff; 8) bioconstructed underwater cliff; 9) old drain; 10) quarry; 11) fish tank; 12) Phoenician breakwater; 13) submersed rubble/cobble piles (DAO: S. Chapkanski).

elevation during low tide, indicating a limited rise of the mean sea level of at most 40 cm since their construction. This is consistent with the amount of sea level rise measured along the tectonically most stable stretches of coast of the Mediterranean Sea (Morhange 2014).

The rocks at many capes as well as the sea walls of many coastal quarries have been levelled landward by the sea, leading to the formation of well-developed intertidal notches. These notches are, on average, several tens of centimetres wide. In addition, breakwaters, sea walls, and immerged cliffs are commonly fringed by bioconstructed rims that are several decimetres thick (**fig. 4: D**). They are found from the current sea level, down to depths of 1.0–1.5 m. Their most extensive development occurs just below the current sea level, which is consistent with a very slow rise in the sea surface since Roman times. No clustering of bioconstructions and of erosive features is found deeper, suggesting that sea level was more variable before Roman times.

Several man-made structures bear indications of past sea level. Structure St 2020 is a long, curvy sea wall made of *ramleh* blocks 80–120 cm wide on average. Toward the top of the structure, these blocks are held together by *opus caementicium*, indicating a Roman age, with a late addition of column drums. The sea wall was likely emergent in Roman times and has since been extensively levelled by the development of a natural intertidal platform.

Other man-made sea level indicators are found at greater depth. Quarry floors along the west coast St 2010 (Badawi 2016) and St 2410 (**fig. 4: C**) lie on average 1.7 ± 0.3 m b.s.l. A mole made of large

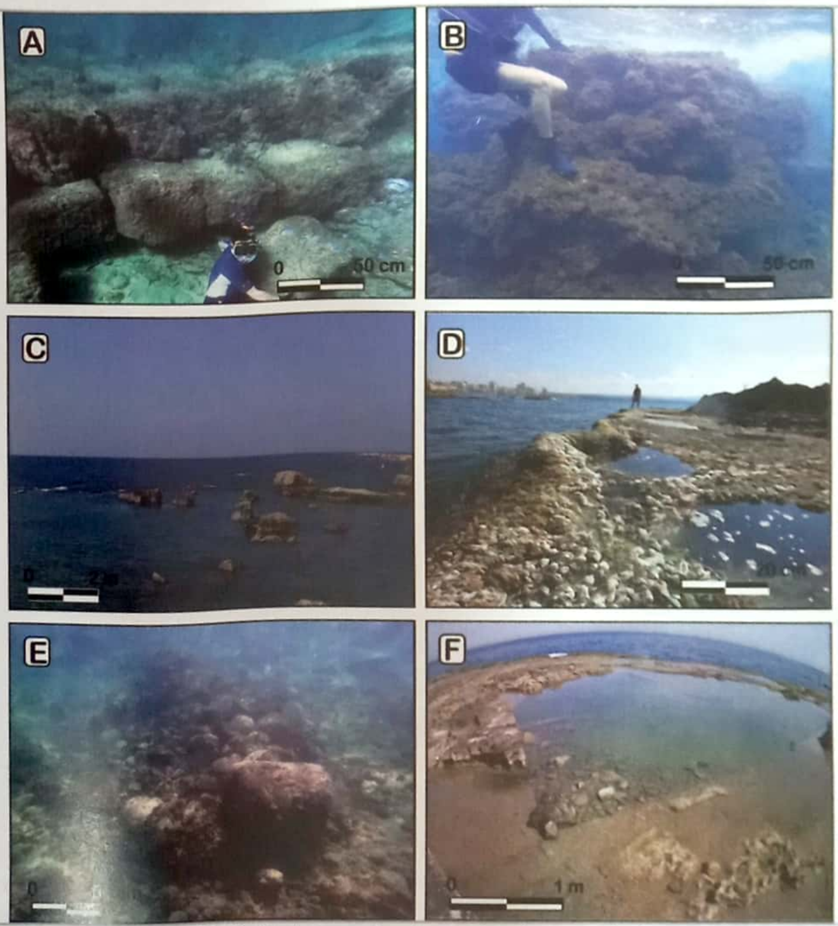

Fig. 4- Underwater (A, B, E) and subaerial (C, D, F) photographs of natural and man-made features along the west coast; A) Phoenician mole (St 2310) on eolianite substrate (photo: J.-P. Goiran); B) Roman sea wall St 2020 (photo: G. Brocard); C) quarry wall St 2410 (photo: G. Brocard), D) Vermetus rim *J.-P. Goiran); E) medieval rubble mound St 2423 (photo: G. Brocard); F) northern fish tank St 2010 (photo: J.-P. Goiran).*

stone headers (St 2310, St 2311; **fig. 3** and **fig. 4: A**) culminates at ~2 m b.s.l. The layout of its building blocks, as well as its depth, is comparable to that of the Phoenician mole of the northern harbour, suggesting that this mole was also built during Phoenician times. Column drums reworked from Roman monuments, made of granite, cipolin, and breccia, sprinkle submersed coastal structures all around Tyre. It is likely that they have been laid down in the sea in late Byzantine or Middle Ages times to reinforce pre-existing breakwaters. An alignment of such drums stretches parallel to the Phoenician mole of the northern harbour, a few metres landward. Other drums are found on the top of Roman structure St 2020 (**fig. 4: B**), on the floor of quarry St 2410, and as foundation in a series of rubble mounds (St 2421-2422-2423, **fig. 4: E**) which functionality remains unclear. These later might represent poorly designed, partially dispersed breakwaters, the top of which remains 1.5 to 2.5 m below the current sea level.

Sea level indicators along the south coast

We extended the inventory of el-Amouri, el-Hélou, Marquet *et al.* (2005) in the southern harbour, and inspected previously mapped structures. We classified man-made indicators according to their most likely function and age (**fig. 5**). Structure St 1012 (**fig. 5: A**), interpreted as a tower by Poidebard (1939), has recently been reinterpreted as a Roman or Byzantine fish tank, slightly submerged by 40 cm of sea level rise (Goiran, Chapanski, Régagon *et al.* 2019). Structures St 1015 and St 1016 are well-built breakwaters, clad on both sides with *ramleh* headers (**fig. 6: A** and **B**), and filled with rubble (Poidebard 1939, el-Amouri, el-Hélou, Marquet *et al.* 2005). Over the top-meter, St 1016 is held together by *opus caementicium*. These two breakwaters define a harbour area (**fig. 5: A**), slightly smaller than the 'west basin' of Poidebard (1939). Other structures containing *opus caementicium*, but without similar protective headers occur further east (St 1104; **fig. 5: B** and **fig. 6: C**). They could represent a sea wall that protected a landfill projecting from the Roman bath area. All these structures (St 1015-1016-1104) are partially emerged and are cut by natural erosional platforms (**fig. 6: A**).

Submerged quarries were found at several locations (**fig. 5: 16** and **fig. 6: D**) including the quarries already reported in el-Amouri, el-Hélou, Marquet *et al.* (2005) at depths of 2.5 ± 0.5 m (St 1002-1004-1005). Thick walls (**fig. 5: A** and **B**) typically composed of a rubble several metres thick, enclosed by two parallel header walls were found within the east basin of Poidebard (1939). The widest of these newly observed walls (St 1101) is 20 m-thick and contains three parallel lines of headers (**fig. 5: B**). The headers are 1.5–2 m long, with a ca 0.5 × 0.5 m square section (**fig. 6: F**). Only the top course of these headers is exposed, because the seafloor has been filled with gravel, cobble, and man-made debris up to the top of the structures. These thick walls are built in the same way as Phoenician city walls found nearby under the Roman baths (**fig. 5: B**). They are also similar to the northern Phoenician harbour breakwater (Noureddine and Mior 2018) and to Phoenician walls found in Athlit, Tabbat al-Hammam (Syria), and Amathonte, in Cyprus (Noureddine and Mior 2018). The top of these walls lie at a depth (2.2 ± 0.5 m) similar to the depth of the top of the northern Phoenician breakwater. Some of these walls (St 1019-1021, **fig. 5: A**) have been interpreted as parts of an inner-city district (el-Amouri, el-Hélou, Marquet *et al.* 2005). However, they are extremely thick, and therefore better interpreted as breakwaters.
Some of the newly described structures (St 1101 on **fig. 5: B** and on **fig. 6: F**), together with formerly mapped ones (St 1019-1021), define an east-west Phoenician mole, that likely protects a harbour basin that would be located farther north, below the Roman baths. The bedrock of eolianite, which crops out extensively over the seafloor at shallow depth, south of the mole, plunges northward below the coastline, disappearing below a thick sediment fill. The mole almost connects two shallow sills made of eolianite. The one in the west was previously interpreted by Poidebard (1939) as the southern entrance to the Egyptian harbour, while the one in the east is still partly emerged (St 1102), forming a small islet east of Poidebard (1939)'s 'Quay of the spring' (St 1027-1028, **fig. 5: A** and **fig. 6: H**). The basin area hosts a thinner structure, St 1023, made of a single wall of headers. We tentatively interpret St 1023 as a quay wall, located inside the Phoenician harbour.

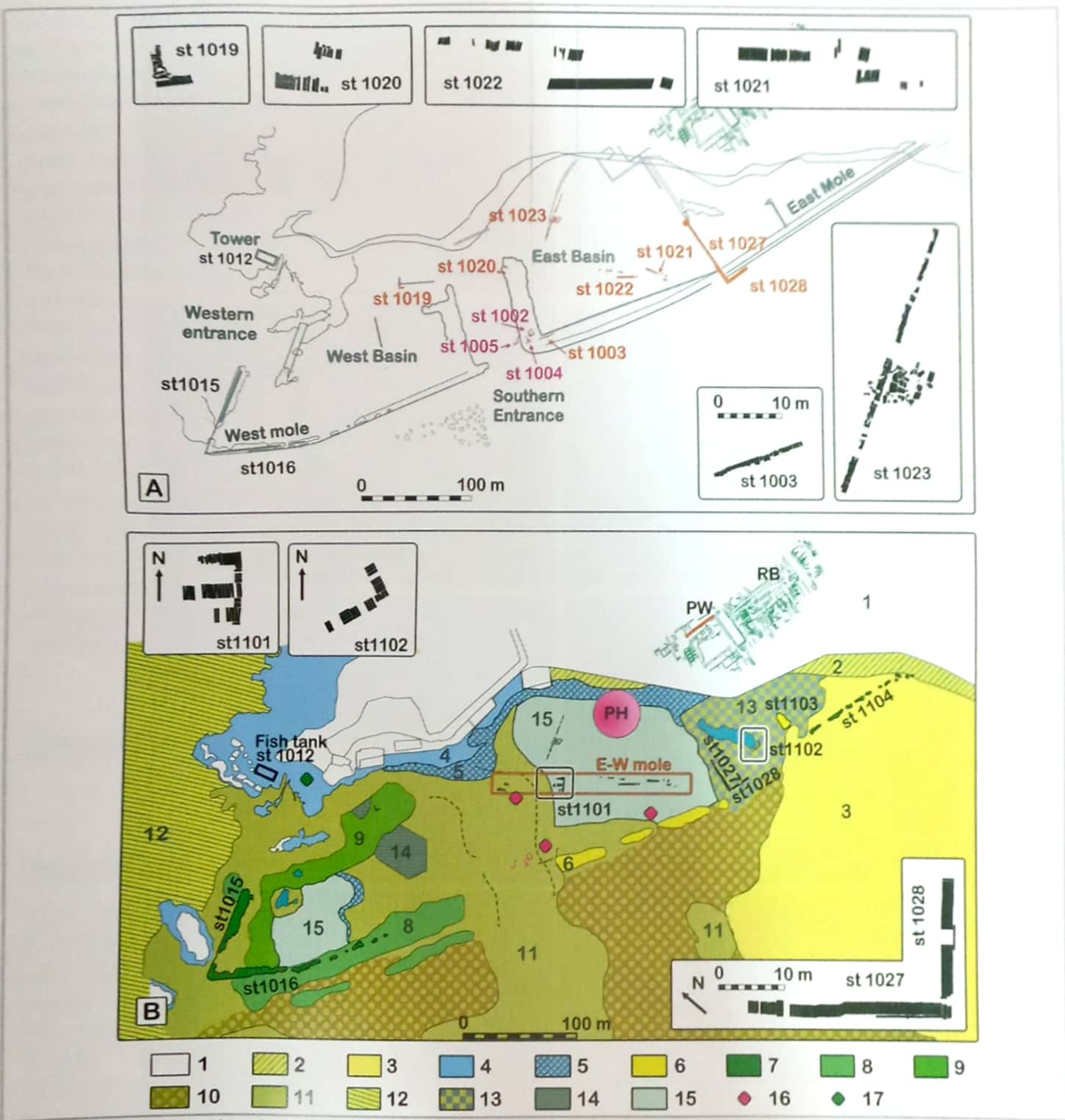

Fig. 5- Maps of the southern harbour; A) map of former interpretations. Grey lines: structures of Poidebard (1939); red lines: structures of el-Amouri, el-Hélou, Marquet et al. 2005; green lines: on-land excavated structures (Roman baths area). Insets: enlargements at same scale of red structures mapped by el-Amouri, el-Hélou, Marquet et al. 2005. B) map of new interpretations, with the spatial distribution of natural features and man-made structures, grouped by type, age, and purpose. Insets: enlargements at the same scale of the newly-mapped structures, including previously uncharted structures (St 1101 and St 1102). RH: Roman harbour, PH: Phoenician harbour. Legend 1: emerged land; 2) sandy beach; 3) infratidal sand; 4) intertidal rocky platform (natural or man-made); 5) partially cemented gravel and cobble; 6) post-Roman breakwaters; 7) Roman-Byzantine breakwaters; 8) dispersed elements of Roman breakwaters; 9) mixed anthropogenic and natural blocks and rubble; 10) coarse sand and gravel in deep water (3–6 m); 11) barren eolianite substrate; 12) biota-covered eolianite; 13) rubble and eolianite substrate; 14) clay and rubble; 15) rubble, gravel, and sand; 16) deeply submersed (2–3 m) quarries; 17) shallowly submersed (0.5 m) quarries (DAO: Gilles Brocard).

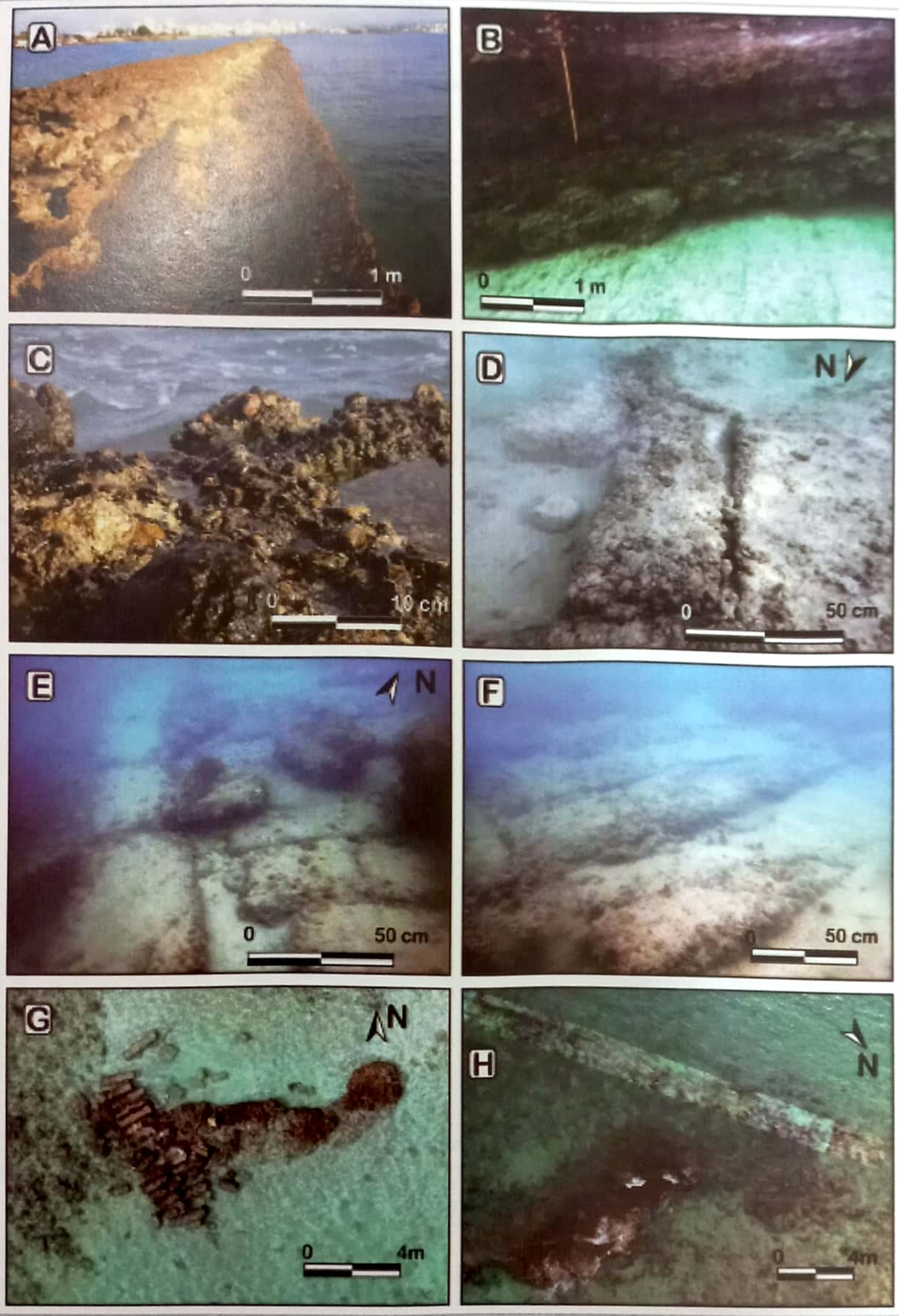

Fig. 6- Underwater (B, D, E, F), subaerial (A, C) and aerial (G, H) photographs of structures immersed along the southern coast; A) intertidal platform cut into ramleh headers St 1016 (photo: G. Brocard); B) ramleh courses resting on barren eolianite substrate St 1016 (photo: J.-P. Goiran); C) opus caementicium on St 1104 (photo: G. Brocard); D) quarry floor with header half cut in eolianite substrate, depth 2.5 m near St 1021 (photo: G. Brocard); E) top pavement and outside cladding on Poidebard (1939)'s Dock of the Spring St 1027 (photo: G. Brocard); F) wall made of long ramleh headers, typical of the E-W mole St 1019 (photo: G. Brocard); G) UAV view of a post-Byzantine pile of column drums (St 1103) on a natural reef of cemented eolianite (photo: H. Kahwagi-Janho); H) drown view with the dock of the spring (St 1027) highlighted, along the islet of cemented eolianite (photo: H. Kahwagi-Janho).

Structure St 1003 is another thin wall, enigmatically located in an unsheltered location, outside the breakwaters, next to a shallow eolianite ridge.

Poidebard's 'quay of the spring', together with a newly mapped structure (St 1103, **fig. 5: B**) have retained their top pavement (**fig. 6: E**). They lie at depths comparable to that of the east-west mole (St 1019-1021), suggesting that the mole has not been stripped of its uppermost courses. All these structures, as well as the submersed quarries, were able to operate under a relative sea level 2–3 m lower than today.

The southern harbour underwent later additions, in particular the dumping of piles of column drums and rubble (e.g. St 1103, **fig. 6: G**). Some of these piles connect older structures, while others obstruct the western entrance to the west basin. They seem to have been laid out to reinforce decaying harbour structures, or to repurpose harbour basins into urban districts. They are currently almost entirely submerged, and do not reach the elevation of earlier Roman structures. They might have never reached the sea level, or were damaged by sea waves more rapidly than earlier, better-built structures.

Discussion: Age and Origin of Sea Level Rise

Age of sea level rise

The surveyed structures can be grouped into three main age categories: pre-Roman, Roman-Byzantine, and Middle Ages. Medieval breakwaters have little value for reconstructing sea level variations because they are poorly built, and widely dispersed by the waves. The better-built Roman structures are all emerged, and cut by natural intertidal platforms. Fish tanks (Goiran, Chapanski, Régagnon *et al.* 2019) indicate that sea level has risen 40–50 cm over the past 1,500–2,000 years. Such slow rise in sea level has allowed the development of extensive erosive and bioconstructed landforms over natural and Roman-made substrates. The pre-Roman group consists of well-built breakwaters, coated with *ramleh* (bioclastic aeolian calcarenite) headers, extracted from the bedrock of the island of Tyre, from close islets, and from coastal quarries (Badawi 2016). The breakwater of the northern harbour, which is Phoenician (Noureddine and Mior 2018) culminates at a depth of 2.5 ± 0.5 m. The newly identified east-west breakwater in the southern harbour was built in the same way, and similarly lies at a depth of 2.2 ± 0.5 m. It is therefore suspected of being Phoenician in age. They have been similarly buried in sediments up to their top row of headers. A third mole of similar crafting is located along the west coast (St 2310-2311; **fig. 3**). The high energy of waves along the west coast has prevented sediment accumulation such that it is exposed over its full height. It also culminates at a depth of 2–3 m. Preservation of the top pavement on the Quay of the Spring (St 1027-1028), and on the newly mapped St 1102, combined to quarry floors found at depths of 2.5 m b.s.l. provide the strongest evidence of a relative rise in sea level between the building of the Phoenician breakwaters and the building of the Roman-Byzantine sea walls.

The Phoenician structures do not appear to have been refitted to the Roman sea level after their submergence, a common practice in ancient harbours (Stiros and Blackman 2014). It is nonetheless possible that the structures were indeed refitted, but that the materials used to refit them was eroded or quarried away. Alternately, such refitting may have not been deemed worth the investment, either because the structures had lost their importance, or because they were already buried under later structures. Differences in the orientation of Phoenician and Roman structures in the southern harbour suggest that some of the Roman sea walls overlap the Phoenician breakwaters. The overlap suggests a repurposing of the southern harbour, whereby older harbour structures would have been buried below a landfill over which the Roman baths were built. The repurposing may predate ground subsidence, such that no attempt was made to regrade them to sea level following their flooding. Alternately, the repurposing itself may be a response to their flooding.

Rate of sea level rise

The island of Tyre has been exposed to two superposed trends in RSLR: a continuous and slow trend, driven by global eustatic sea level rise, spreading over thousands of years, and a shorter-lived phase of ground subsidence, that took place between Phoenician and Roman-Byzantine times. This short-lived phase separates two periods of slower sea level rise which are not identical. The post-Roman period has been long enough, with the sea rising slowly enough to allow the formation of natural erosional platforms as wide as 0.5–2 m, while conspicuous bioconstructions grew around them. No erosional platforms or bioconstructions are found between 2 and 4 m b.s.l., at the depth of the flooded Phoenician structures, suggesting either that the Phoenician phase of slow RSLR was faster than the post-Roman one, or that its duration was much shorter.

The episode of fast subsidence has an amplitude (2.0 ± 0.6 m) much larger than the 50 ± 10 cm of sea level rise that can be attributed to global sea level rise from Phoenician to Roman times (Morhange, Pirazzoli, Marriner *et al.* 2006; Anzidei, Antonioli, Benini *et al.* 2011; Morhange 2014, Dean, Horton, Evelpidou *et al.* 2019). This episode of fast relative sea level rise requires some foundering of the bedrock of Tyre into the sea. The bedrock is made of Pleistocene (<2 millions of years) cemented eolianite resting on Pleistocene clays. The island could have undergone some slow seaward creep over the clay layer. The intermittent nature of the ground subsidence, however, rather suggests that it was triggered by incremental slip on a regional tectonic fault. The coarse temporal resolution of the data does not allow us to address whether subsidence involved a series of successive small increments, spreading over several centuries, or occurred all at once during a single, large, possibly seismogenic slip event.

Origin of sea level rise

Most of the relief of Lebanon results from contractional uplift, generated along a broad restraining bend that developed during Plio-Quaternary times along the Levantine fault (Morhange, Pirazzoli, Marriner *et al.* 2006; Elias, Tapponnier, Singh *et al.* 2007; Carton, Singh, Tapponnier *et al.* 2009). Large offshore thrusts, located at the base of the continental margin, accommodate the uplift of the Lebanese mountains (Carton, Singh, Tapponnier *et al.* 2009). Recurring slip events on these thrusts have generated an incremental uplift of the coastline (Morhange, Pirazzoli, Marriner *et al.* 2006; Elias, Tapponnier, Singh *et al.* 2007). The region most affected by coastal uplift is located north of Tyre (Morhange, Pirazzoli, Marriner *et al.* 2006; Elias, Tapponnier, Singh *et al.* 2007). Within 14 km of Tyre to the north, the coastline has been stable over the past 1,200 years (Morhange, Pirazzoli, Marriner *et al.* 2006) and over the past 4,000 years farther south (Dean, Horton, Evelpidou *et al.* 2019). Nonetheless, several north-east/south-west striking faults with reverse motion crosscut this relatively stable part of the Lebanese coastline. They generate vertical ground displacements that can significantly impact the coastline within a few kilometres to a few tens of kilometres of the fault traces.

The fault of Tyre, in particular, is relevant to the area of study (**fig. 7**). It formed as a normal fault during the Cretaceous opening of the Eastern Mediterranean Sea (Carton, Singh, Tapponnier *et al.* 2009). It was reactivated as a reverse fault in Eocene time, and then again over the past few million years, accompanying the growth of Mount Lebanon (Carton, Singh, Tapponnier *et al.* 2009). It has also been depicted as a left-lateral fault (Morhange, Pirazzoli, Marriner *et al.* 2006), but the rivers that cross the fault are not offset by the fault (**fig. 7 : 7**). By contrast, vertical displacements across the fault have generated a N60-striking, 16 km-long southeast-facing fault scarp up to 50–70 m high. Two imbricate uplifted Pleistocene marine terraces currently lie between 50 and 250 m above sea level (**fig. 7: A** and **B**). They exhibit the same amount of tectonic separation across the fault, implying that fault scarp growth postdates the formation of both terraces. Scarp growth forced some rivers to abandon their course over the rising northern side of the fault, leaving perched dry valleys (**fig. 7: 2**). Upon reaching the coastal plain, the scarp of the fault of Tyre veers east-west. Dip-slip, steep east-west reverse faults are observed in Cretaceous limestones north of the fault in this area (**fig. 7: 1**). No clear scarp disrupts the modern coastal plain of Tyre, suggesting a transfer of the vertical displacement elsewhere. The fault seems to splay into two strands, along which the lateral and vertical components of slip are fully partitioned. The N60-striking trace could stretch as far as Tyre as a purely lateral fault, passing next to the southern harbour (**fig. 1: 7**), while

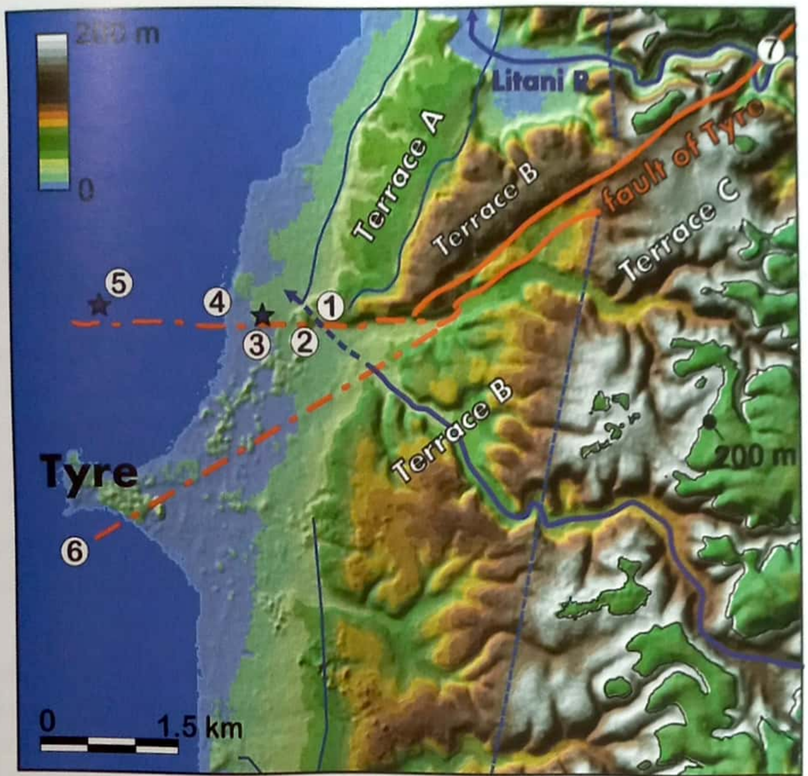

Fig. 7- Spatial relationships between the city of Tyre and the fault of Tyre, on a shaded relief of the coast of Tyre. Red line: observed (solid) and putative (dashed) fault trace. Blue arrowed lines: rivers. Legend 1) observed dip-slip normal fault; 2) abandoned valley; 3) freshwater spring; 4) transition from a rocky shoreline in the north, to a sandy shoreline in the south; 5) submarine freshwater spring of Boroghlieh; 6) projection of the N60 trace of the fault of Tyre; 7) no lateral offset of the Litani River (DAO: Gilles Brocard).

the vertical component would be accommodated along an east-west splay farther north. We could not evidence any offset of the Roman causeway by the fault across the isthmus, or across the rocky substrate exposed in the sea, between the southern harbour and the southern islets. It is highly likely, therefore, that if a strand of the fault passes there, it has not been active in historical times. The east-west oriented strand, on the other hand, separates a stable, rocky coastline in the north, from a subsiding, sandy coastline farther south (**fig. 7: 4**). This strand of the fault may also funnel the outflow of artesian aquifers known to discharge at sea, forming deep, submarine freshwater springs along the projected trace of the east-west splay (**fig. 7: 3** and **5**), such as the Boroghlieh spring (Saad, Kazpard, Slim *et al.*2005). Slip along this splay of the fault might be responsible for the foundering of the island of Tyre. The exposed length of the fault of Tyre does not allow it to produce a foundering of the island in excess of 0.8 m during a single elastic slip event (Wells and Coppersmith 1994). For the fault to be responsible for the observed 2.5 ± 0.5 m of foundering within a single slip event, it must extend farther at sea, over at least several tens of kilometres, and branch onto the offshore thrusts (Carton, Singh, Tapponnier *et al.* 2009). Alternately, it may define a left lateral releasing bend, within which enhanced subsidence would occur.

Conclusions

Markers of sea level, such as notches, intertidal platforms and bioconstructions (red algi and *vermetidae*) have developed extensively over natural and man-made substrates since Roman times, confirming recent findings on fish tanks that the sea level has risen only 40–50 cm since the late Antiquity. The consistent depth of *ramleh* layers on early harbour structures, of quarry floors, and pavements together point to a lower relative sea level (up to 3.5 m b.s.l.) earlier during antiquity. The constructional style of many of these earlier structures is similar to that of the Phoenician mole of the northern harbour, and of Phoenician walls exposed south of the Roman baths. They are therefore likely Phoenician in age. They suggest that relative sea level rose 2.5 ± 0.5 m between Phoenician and Roman times. The absence of visible attempts to refit Phoenician breakwaters to the higher sea level of Roman times further suggests that the Phoenician structures were in disuse by the time the episode of fast subsidence occurred, before the construction of the Roman breakwaters and Roman baths.

This event of relative sea level is larger than eustatic reported sea level rise. Relative sea level rise, therefore, seems to have been caused by an episode of foundering of potential tectonic origin. We tentatively relate this episode of foundering to a slip event on the fault of Tyre. It would have occurred south of a strand of the fault located north of the peninsula of Tyre.

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